ALLIANCE FOR pe pipe

Engineer's Package 2020

A Comprehensive and Useful Resource for Understanding, Designing, Specifying, Installing and Operating Polyethylene Pipe Systems for Municipal Engineers

Revision 05/2020

Engineer's Package 2020

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The Alliance for PE Pipe
Insider's Guide to PE Pipe

The purpose of this document is to establish a functioning glossary that provides insight into how a word or phrase is used in addition to providing a straight definition. Note, there are two parts to every definition, the basic definition (basic) and then the insider's guide statement.

Abrasion and Scratch Resistance

Basic: The ability of the pipe to resist minor blemishes such as scratches and grooves.

Insider tip: PE is incredibly tough. It can withstand up to a 10% cut or abrasion to its outside diameter before it must be repaired or de-rated. "*When in doubt, cut it out"* is the saying many contractors use if they come upon a gouge or deep scratch in a pipe. PE pipe is also abrasion resistant and is well suited for the solids environment in mining applications.

Ref: *https://plasticpipe.org/pdf/chapter-7_durability_service_life.pdf*

Apparent Tensile Strength

Basic: A measurement of tensile strength taken by testing pipe rings under ASTM D 2290 in which a bending moment is induced in the pipe's shape. Where tensile strength is measured as the amount of force an object can withstand without breaking, *apparent tensile strength* measures the yield of the pipe's shape, its breakage or both.

Insider tip: When designing with HDPE understanding *apparent tensile strength* will help when planning on bending or straining a pipe during the when conducting actions such as a pipe bursting installations, prepping a line for installation and having to bend the pipe around a cul-de-sac or conducting an HDD installation project.

Ref: *https://plasticpipe.org/pdf/chapter03.pdf*

ANSI

Basic: As the voice of the U.S. standards and conformity assessment system, the American National Standards Institute (ANSI) empowers its members and constituents to strengthen the U.S. marketplace position in the global economy while helping to assure the safety and health of consumers and the protection of the environment. ANSI oversees the creation, promulgation and use of thousands of norms and guidelines that directly impact businesses, including the HDPE industry. ANSI is also actively engaged in accreditation - assessing the competence of organizations determining conformance to standards.

Insider tip: ANSI recently approved the process by which AWWA acknowledged and approved HDPE pipe (4710 resin) for potable water applications from 4" to 65". The standard is known as C906-15.

ASTM

Basic: The American Society of Testing and Materials is an international standards organization that collects and publishes information on technical standards of materials, products, systems and services in terms of their characteristics and performance.

Insider tip: ASTM establishes procedures for many things in the HDPE industry including the manufacturer of pipe and fittings, performance of fusion and test procedures. Please see the *"List of Applicable Standards"* document included in the Engineer Package 2020.

Bead, The

Basic: The heating process begins with a "heater plate" that is heated and melted at a heater plate temperature between 400 – 450° Fahrenheit ambient or outdoor conditions do not negatively affect these conditions (wind, cold, dust, etc). When the pipe comes in contact with the heater plate, the HDPE pipe clamped ends are melted in a controlled state to create two surfaces that will be able to fuse together. After the prescribed "heat soak" the heater is removed, the ends are inspected quickly and the ends are pushed together under prescribed fusion pressure. The result is the double rollback bead is formed on both the outer wall and inner wall of the pipe due to the displacement of molten material that creates the fusion interface.

HDPE Pipe OD	Min Melt Bead Size
< 2.37"	1/32"
≥2.37 to < 3.5"	1/16"
> 3.5 to < 8.62"	3/16"
> 8.62 to < 12.75"	1/4"
> 12.75 to ≤ 24"	3/8"
>24 to < 36"	7/16"
> 36 to≤65"	9/16"

Insider tip: Operators need to know the recommended melt bead dimensions for each size of pipe they are fusion in conjunction with the specified heating time, so they know when to remove the heater plate and initiate fusion. The chart above is a reminder to those trained in butt fusion.

Bead, The Internal

Basic: The internal bead is a raised profile on the interior flow path. It should be noted that the pipes C factor of 150 takes into account the bead so engineers do not need to reduce flow rates during the design process because of the bead. This bead does not need to be removed but may be removed if necessary within the specified cooling cycle of the fusion process Bead removal requires proper training and tools due to the fact reaching the fusion bead internally is a significant distance.

Ref: *https://plasticpipe.org/pdf/chapter09.pdf*

Insider tip: Questions arise about the bead on regular occasions. In pressure applications the bead presence is inconsequential and it does not harm flow. For those who are curious on the topic, it is more expensive (contractor time) to remove the bead so most do not. However, common practice on the west coast is to remove the bead in both pressure and non-pressure applications. In the case of gravity wastewater applications, a build-up may occur at 1% grade or less. The build-up usually is pushed along when velocities increase. It a gravity system when diameters become larger it must be noted that the bead size becomes larger as well. Higher flow rates will wash anything built up behind the bead and nothing can adhere to the HDPE so it is easily washed away. Typically, the bead is not a flow concern. However, it can be removed if necessary using proper protocols.

Bead, External and Internal

Basic: The external bead is an indicator of the butt fusion process and it is used as one indicator of proper alignment, heating and pressure of the pipe ends. An even external bead appearance with good roll back contact on the surface of the pipe.

Ref: *https://plasticpipe.org/pdf/mid-pe-field-manual-municipal-water-applications.pdf*

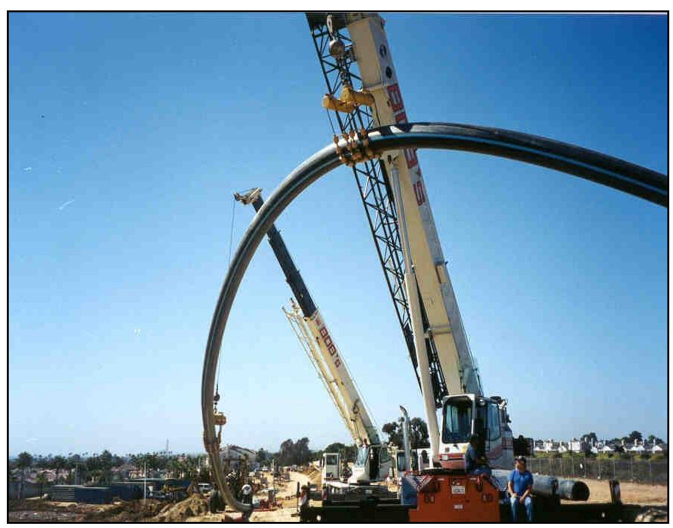
Insider tip: The external bead serves as evidence of butt fusion. Although it is not recommended to remove the external bead, it may be removed once the pipe has been adequately cooled. Removing the bead after the pipe adequately cools using the appropriately designed tools and procedures is critically important to avoid gouging the pipe in anyway. A pipe gouge can potentially cause the pipe to fail adding a stress riser or impeding minimum wall requirements. The internal bead will not restrict flow unless the pipe is in a gravity situation and grade is 1% or less.

Ref: *https://isco-ahmcelroy.com/products-and-services/?amp%3Bcategory_id=3*

Bead Removal

Basic: It is uncommon to remove internal beads, as they have little or no effect on flow, and removal is time consuming. The C factor remains constant at 150 with the bead intact. To reiterate, beads must be removed at ambient temperature as when the pipe is warm, it would be easy to penetrate beyond the pipe wall, thus damaging the pipe.

Insider tip: Internal beads may be removed from pipes after each fusion with a cutter fitted to a long pole. Since the fusion must be completely cooled before bead removal, assembly time is increased.



Bending Radius

Basic: The minimum radius a contractor can bend HDPE without damaging or kinking it.

Insider tip: The tight bend radius of HDPE makes it the preferred HDD, bursting and lining product. If the pipe DR is ≤9 the bending radius is 20x the pipe OD. If the pipe DR is ≥ 21 the bending radius is 30x the pipe OD.

Brittle Failure

Basic: A pipe failure with no visible deformation, such as stretching or necking down, where the pipe broke. Brittle failures any also be represented as a slow crack growth (SCG) failure or "slit" failure as demonstrated as the "Knee" in a high density polyethylene regression curve. With newer bimodal or PE4710 products today the Knee as being pushed beyond 10,000 hours on the regression curve to meet pressure requirements of these materials. The polyethylene industry understands the failure mechanisms of HDPE pipe. Understanding these failures help us better understand the performance of these pipes and more importantly the limitations.

Ref: https://plasticpipe.org/pdf/tr-3-2012.pdf

Insider tip: HDPE pipe is ductile at a prescribed temperature and not brittle. Brittle failure is a primary failure mechanism of other materials, but HDPE is not brittle until it reaches -130° F. Interestingly, HDPE pipe can freeze with a full water load at -20° F and not crack, break or fail. Brittle failure is not a failure mode of HDPE in common practice.

Butt Fusion – see Fusion

Bypass

Basic: A temporary pipeline created to accommodate pipe flow around a system that is not working or has been shut off.

Insider tip: HDPE is the preferred pipe material for bypass projects. Bypasses are frequently used during replacement and rehabilitation projects when water or sewer services must be stopped for both short and long periods of time. HDPE is a common candidate to keep the line running during replacement or repair because it can be run above grade for miles in rights of way and not leak. Contractors who do sewer bypass work, fuse the pipe for a job, use it, then cut it into lengths again and bring it back to the storage yard for subsequent use on the next job.

C Factor

Basic: The classic Hazen-Williams roughness constant is known as the CM factor. It is a constant in the calculation used to determine the head loss for a given pipe flow. The C-Factor for HDPE pipe is 150.

Ref: http://hdpeapp.com/#/terms

Table 7 Hazen-Williams Friction Factor, C

Pipe Material	Values for C		
	Range High / Low	Average Value	Typical Design Value
Polyethylene pipe or tubing	160 / 150	150-155[A]	150
Cement or mastic lined iron or steel pipe	160 / 130	148	140
Copper, brass, lead, tin or glass pipe or tubing	150 / 120	140	130
Wood stave	145 / 110	120	110
Welded and seamless steel	150 / 80	130	100
Cast and ductile iron	150 / 80	130	100
Concrete	152 / 85	120	100
Corrugated steel	–	60	60

[A] Determined on butt fused pipe with internal beads in place.

Insider tip: When designing with HDPE the engineer is not required to lower the C factor for the life time of the pipe like they are for other pipe materials given tuberculation and build up issues. The 150 C factor remains constant for the over 100-year life of PE pipe.

Carbon Black

Basic: A black pigment created when natural gas or oil is not burned completely. The pigment provides highly effective protection against ultraviolet rays. Carbon Black is manufactured and tested within the formulation matrix of polyethylene pipe. It tested for optimal UV protection within the grade formulation but also ensures the additive does not affect other cell classification or and pressure requirements.

Insider tip: A common question during roadshows is why are there two different colors of resin going into the pipe manufacturing process. The black resin is an additive that permits the pipe to last indefinitely in an above ground situation. It also means it does not have a shelf life in a pipe yard. Black pipe will last indefinitely outdoors even when exposed to the sun.

Ref: *https://plasticpipe.org/pdf/chapter-8_quality_control_quality_assurance.pdf*

Ref: *https://plasticpipe.org/pdf/tr-18_weatherability_thermo_pipe_systems.pdf*

Cathodic Corrosion

Basic: Corrosion of a pipeline accelerated by cathodic reactions that create corrosive alkaline conditions. Leads to accelerated deterioration of ductile iron pipe (DIP.)

Insider tip: Does not apply to HDPE as HDPE pipe is a thermoplastic and thermoplastics do not corrode. Key distinguishing feature of HDPE vs DIP. In fact, DIP people recommend wrapping their pipe in HDPE for cathodic protection. Why not just use HDPE?

Ref: *https://plasticpipe.org/pdf/tr-19_thermoplastic_pipe_for_transport_of_chemical.pdf*

Cathodic Protection

Basic: Cathodic protection is a technique used to control the corrosion of a DIP using special cathodes and anodes to avoid corrosion of a pipeline by an electric current.

Insider tip: HDPE is often considered as a pipe option when with the typical incumbent material, DIP. To properly consider the cost of a DIP, the evaluator may consider cathodic protection in the evaluation. HDPE pipe does not require cathodic protection. In fact, the Ductile Iron Pipe Research Association (DIPRA) recommends the use of HDPE wrap to protect DIP.

Ref: *https://plasticpipe.org/pdf/hdpe_corrosion_resistance_dc_answer.pdf*

Cell Classification

Basic: Criteria for distinguishing thermoplastic materials that include density, melt index, flexural modulus, tensile strength at yield, environmental stress crack resistance, and hydrostatic design basis.

Insider tip: The cell classification is not typically a design issue for the design engineer. However, it is an important classification to understand and compare polyethylene materials. It is important for the engineer who is designing process piping and transporting water or chemicals throughout a water plant. Each PE material property is assigned into a "Cell Range" and each cell range consists of a number of "Classes." ASTM D3350 is the standard that classifies these PE piping materials. In addition, the ASTM D3350 also categorizes chorine resistance (see Chlorine, Chloramines below).

Chemical Resistance

Basic: The ability of a pipe to transport a chemical up to a certain concentration and temperature without degrading.

Insider tip: Process piping design and civil engineers who design with HDPE may choose to understand the chemical resistance of HDPE Pipe. The failure mechanism of incumbent materials are well known. PE pipe solves all of them with its fused joint, flexibility and lack of tuberculation. The only significant cause of HDPE failure could be chemical attack. However, the chemical concentrations, fluid temperature and system pressure commonly found in PE pipe will not cause failure for well over 250 years according to laboratory tests. It is well understood which chemicals affect PE and these can be found in the following link.

Ref: *https://plasticpipe.org/pdf/tr-19_thermoplastic_pipe_for_transport_of_chemical.pdf*

Chlorine, Chloramines

Basic: HDPE Pipe made from the 4710 resins is designed and produced to withstand the presence of chlorine/chloramines under normal operating conditions. These oxidizers affect any and all materials, knowing at what degree is the question. The PE industry has studied, developed prediction models and classified polyethylene pipe products and they understand how these oxidizers affect the product. Design engineers need to understand these mechanism of oxidation for all products and compare the best product for use in their system designs. Newer polyethylene (PE 4710) is categorized for the design engineer’s benefit.

Insider tip: Understanding the concentrations, temperatures and pressures in our nation’s water systems is critically important in design. They vary greatly and pipe resistance to such oxidizers will vary based upon those factors. However, if an agency is operating within federally mandated guidelines, the PE 4710 HDPE pipe system life is projected to exceed 100 years.

Ref: *https://plasticpipe.org/pdf/evaluating-disinfectants-on-pe-pipe-nana-awwa.pdf*

DataLogging

Basic: Datalogging technology exists for both butt fusion and electro fusion. The methods for harvesting the data differs by manufacturer. ASTM F3124 covers datalogging for Butt Fusion. The technology allows stakeholders (inspectors, design engineers, owners) to monitor and/or review a record of fusion details. Given the fusion process is operator centric, datalogging permits those not present to review, maintain and refer to a record of individual fusions.

Datalogging technology brings accountability to a new level as owners and inspectors can monitor operator performance in real time from down the block or from across the continent.

Insider tip: In order to assure accountability in the PE fusion process, the industry developed datalogging technology and the ASTM Standard 3124. The implementation of this technology means that owners and their engineers can monitor fusion quality remotely either in real time, hourly or in daily uploads.

Ref: *https://www.mcelroy.com/en/fusion/datalogger.htm*

Dimension Ratio (DR)

Basic: The Standard Dimension Ratio is the outer diameter of the pipe divided by the minimum wall thickness. Pipe is purchased in lengths or coils by Outer Diameter and Dimension ratio.

$$DR = \frac{OD}{t_{MIN}}$$

Insider tip: The lower the DR number the more pressure the pipe will take. If a contractor buys a 6" DR 11 pipe, he is buying a six-inch 200 working pressure class pipe. The market is moving toward a pressure class system which makes it easier for designers who typically work with other materials to select the appropriate pipe. That way they can talk in terms of pressure class versus DR which requires more product knowledge.

Ductile Failure

Basic: A pipe failure term that consists of some form of material distortion along a breakage spot, such as stretching, elongating or necking down.

Insider tip: Ductile failures can occur in HDPE during testing and/or over pressurization. Failure looks like a "duck bill" and is caused by 4x - 5x over pressurization or less if pipe temperature exceeds 73° F.

Ref: *https://plasticpipe.org/pdf/chapter06.pdf*

Environmental Stress Cracking Resistance

Basic: Environmental stress cracking resistance (ESCR) in HDPE means the failure due to continuously acting external and/or internal stresses in the presence of a surface active substances (known as reagents) such as alcohols, soaps, dyes and chemicals. It is measured but the PENT test (Pennsylvania Notch Test - Dr. Norman Brown ASTM F1473) of historically by the Bent Strip ESCR ASTM D1693. This failure mechanism is commonly stated as Slow Crack Growth (SCG), which does not necessarily require a reagent.

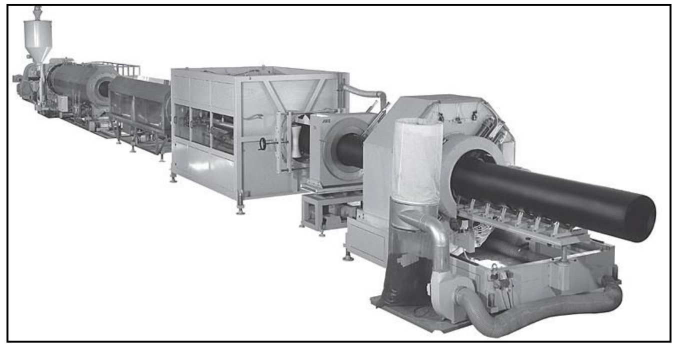
Insider tip: The most common area where ESCR concerns the design engineer is in the presence of contaminated soils. The engineer must know what chemicals are present as chemicals can have a deleterious effect on HDPE pipe and cause ESCR. It is important to know that with the development of improved resin quality to resist reagents to form brittle type failure or the slow crack growth (SCG) failure the BENT Stripe method does not accurately define the products but the PENT does. This failure mechanism is well understood in the polyethylene industry and has many references and publications.

Ref: *https://plasticpipe.org/pdf/chapter-1_history_physical_chemistry_hdpe.pdf*

Ref: *https://www.ineos.com/globalassets/ineos-group/businesses/ineos-olefins-and-polymers-usa/products/technical-information--patents/environmental-stress-crack-resistance-of-pe1.pdf*

Extrusion

Basic: The process of blending, melting, mixing, extruding, shaping and re-cooling plastic through an extrusion system to make it into a specified pipe size under controlled and regulated requirements. Extrusion is the process used to make HDPE, a smooth or corrugated walled pipe profile.



Ref: *https://plasticpipe.org/pdf/chapter-8_quality_control_quality_assurance.pdf*

Insider tip: The extrusion process is immaterial to the user of pipe. However, when specifying certain pipe types, sizes, pressure ratings, applications or striping patterns it helps to understand the exact need and what of how the pipe is expected to perform and be identified, and in most cases how it is to be located. Manufacturers understand how the pipe is to be manufactured, quality controlled, inspected, and the specifications required to be followed.

Fittings

Basic: HDPE pipeline systems require fittings as do all pipeline systems. PE fittings are either molded or fabricated.

Insider tip: Molded fittings are generally available up to 12" in standard sizes and relatively inexpensive. Molded fittings are usually in stock at the distributor. The larger fabricated fittings are custom and made by Alliance members with a week or two lead time.

Flow Capacity

Basic: Flow Capacity Equation as provided in the PPI Handbook:

$$Q = \frac{1.49}{n} A(r_H)^{2/3}\sqrt{S}$$

Insider tip: For comparison purposes the following table illustrates different flows through various pipelines.

Nominal Diameter	Pipe Material	Inside Diameter	Hazen6Williams C Factor	Flow, Q GPM
8" DIPS DR17	HDPE	7.92 in	150	367
8" CL50	Ductile Iron Cement lined	8.39 in	130	370
8" C900 DR18	PVC	7.98 in	150	374

Fusion, Butt

Basic: HDPE pipe is butt fused utilizing a specific procedure and equipment with trained technicians by applying heat to prepared pipe ends and then pushing the pipe ends together with a pre-determined force to make a permanent butt fusion joint. It is a process utilizing a properly sized butt fusion machine for the pipe size to be joined. The pipe is installed, clamped, and cleaned of contamination and debris in the fusion machine. With pipe supports on both ends of the machine to support the pipes on the machine center line the pipe is ready for the fusion process to begin. The PE pipe ends are then faced (machined) to mechanical stops to ensure clean, parallel pipe ends prior to the heat soak phase. The ends are then aligned using clamps on the fusion machine. A temperature controlled heater is checked to ensure it has balanced and appropriate heating and heat then placed in the machine and the pipe ends are heated according to ASTMF2620 (important for details of heating process). Once the heating criteria is met, the heater is removed and the pipe ends are brought together at the pre-determined force. This force is held on the joint for the appropriate time required by the standard. At this point, the pipe can be removed from the machine without affecting the newly fused joint.

Insider tip: Butt fusion is the primary joining method in the US, Canada and all over the world. Operators must be trained properly if they are to work on any job. The fusion technician should have "proper documentation" qualifying that they are capable of conducting the fusions and which demonstrates his/her credentials. A "card" is usually presented and is good for 24 months after last qualification. Fusion is a skill taught by experts to operators who develop the skill over time through experience. These skills and training not only help them understand the process and equipment but also the materials they are working with.

Fusion, Electro

Basic: Electro-fusion (EF) is a method of joining HDPE pipe by using special fittings that have built- in electric wire which is used to melt the resin then join the pipe together. The pipes to be joined are cleaned, inserted into the electrofusion fitting (with a temporary clamp if required) and a current is applied for a fixed time depending on the fitting in use. The built in heater coils then melt the inside of the fitting and the outside of the pipe wall, which weld together producing a very strong connection that is fully pressure rated.

Insider tip: As with butt fusion, the operator must be trained in electro-fusion for the owner to have confidence in the integrity of EF joints. Electro-fusion is not a complicated process, but operators who are trained in it, know that it is a skill that is learned and one which is taught by experts. Owners must require operators to receive EF training. Fusion is a skill taught by experts to operators who develop the skill over time through experience.

Fusion, Sidewall

Basic: Sidewall fusion is similar to butt fusion in that a heater plate is used to melt two sides of the pipe in preparation for fusion. Only in this instance the fusion process is performed on the side of the pipe rather than in line with the pipe. Sidewall fusion is typically employed for installation of lateral lines with saddle fittings.

Insider tip: PPI TR-41 covers sidewall fusion as does ASTM F2620. Only trained operators should perform sidewall fusion. Fusion is a skill taught by experts to operators who develop the skill over time through experience.
Ref: https://plasticpipe.org/pdf/tr-41.pdf

HDPE
Basic: High Density Polyethylene Pipe (PE or HDPE) is a thermoplastic pipe known for being leak free joints, resistance to corrosion, flexibility, low maintenance, seismic resistance, and outstanding durability. High density polyethylene pipe is made from a plastic resin derived from oils and gases extracted from the ground which during the "cracking" process of raw fossil fuels generates an ethylene by product (2 double bonded carbons and four hydrogens). The ethylene is then processed into polyethylene by various reaction processes and techniques. Please keep in mind these processes are well understood and the science and engineering behind this process is complicated and well documented. HDPE for piping products are well controlled and formulations are specific for generating and meeting the cell class and specification requirements (ASTM PPI, TR3, AWWA, API, CSA ANSI, etc). Pressure class polyethylene have been in existence for over 50 years.

Insider tip: HDPE has long been in use in the natural gas industry because of its leak free joints, and it is growing in the water and sewer markets and is an excellent choice for these applications. What makes HDPE stand out from other pipes is its resistance to corrosion, toughness, flexibility, less maintenance, seismic resistance and trenchless installation. Sections of HDPE are connected by butt fusion or electrofusion, which provide HDPE with its leak-free, continuous length. Once fused together aboveground, HDPE can be installed by pipe bursting, sliplining, horizontal directional drilling, or open cut. The life costs of HDPE are significantly lower than other pipe materials.

The key with HDPE is to understand how different it is from all of the other pipe materials. It is a fundamentally different, yet superior material with its own unique set of features, benefits and considerations which inherently save in installation, repair and life expectancy costs.

Hoop Stress
Basic: Hoop stress is the circumferential force per unit area internal pressure exerts on a pipe wall (measured in PSI).

Horizontal Directional Drilling
Basic: Horizontal directional drilling (HDD) is a trenchless method of installing HDPE pipes. It is used when traditional methods are not appropriate. HDPE is prepared above grade in a long string so a single bore can be made. HDD is useful for minimizing surface disruption and dealing with grade and sub-grade challenges such as roads, railroads, wetlands and river crossings.

Insider tip: There are many experienced HDD operators in the US and this is a method where a good prequalification list makes sense for the design engineer. This is a method that places a premium on experience as three significant areas of expertise come into play: fusion experience, boring and traditional underground utility construction. See ASTM F1962 for Use of Maxi- Horizontal Directional

Drilling HDD for Placement of HDPE pipe and *Handbook of PE Pipe*, Chapter 12, PPI-TR 46 for Mini-HDD applications.

Ref: https://plasticpipe.org/pdf/tr-46-hdd-guidelines.pdf

Hydrostatic Design Basis (HDB)

Basic: A series of set stress values for plastic pipe that categorizes the long-term hydrostatic strength in the hoop direction for a given tested pressure and temperature conditions. HDB is used when determining the pressure rating of HDPE pipe.

Insider tip: The design engineer may find it helpful to understand these concepts as full appreciation will convince even the most cynical of users that the science behind HDPE pipe is solid and defensible. For further information consult the *Handbook of PE Pipe.*

Ref: https://plasticpipe.org/publications/pe-handbook.html

Hydrostatic Design Stress MRS (HDSMRS)

Basic: The maximum tensile stress (PSI) that can be sustained in a pipe's wall from hydrostatic pressure with a high degree of certainty that the pipe will not fail.

Insider tip: The design engineer may find it helpful to understand these concepts as full appreciation will convince even the most cynical of users that the science behind HDPE pipe is solid and defensible. For further information consult the Handbook of PE Pipe published by PPI.

Inside Diameter (ID)

Basic: The inner diameter of a pipe. HDPE pipe is outer diameter controlled meaning the OD remains constant as pressure class (DR) varies. Thus, the ID varies based upon the pressure class, DR and/or wall thickness.

Insider tip: HDPE comes in IPS and DIPS with the OD for each varying slightly. So if the nominal pipe diameter is 8" and 8" DIPS pipe has an OD of 9.05" and an 8" IPS pipe has an OD of 8.625". The ID of an 8" DIPS PC 100 pipe is 8.14" and an 8" PC 100 IPS pipe has an ID of 7.76". The industry offers two different pipe sizes to accommodate the needs of its customers. See the pipe manufacturer's sizing charts for a complete table of pipe offering. So remember, inside diameter changes as pressure class (DR) changes and this will affect your flow calculation. But, given HDPE's constant C factor, often times HDPE will carry more fluid than other materials even with a smaller ID.

Impact Strength

Basic: The ability of HDPE pipe to withstand shock loading or sudden strikes by equipment.

Insider tip: HDPE is a ductile material and has exceptional impact strength. HDPE's superior impact strength provides a piping system that is near impervious to impact damage and to damage from improper tapping. Experienced design engineers and contractors understand that PE pipe is proven to be impact tough.

Injection Molding

Basic: When a material is melted and forced into the cavity of a closed mold to take shape. Injection molded fittings and elbows are commonly injected molded to 12" in diameter.

Insider tip: More and more injected molded fittings have entered the market dramatically increasing product availability. Injection molded fittings are generally available up to 12" diameter.

Insert Stiffener

Basic: A metal (usually stainless) still ring that is inserted into HDPE to reinforce the outer diameter from compressive forces seen from mechanical fittings.

Insider tip: Always specify insert stiffeners when using mechanical fittings that clamp or apply compressive forces to an outer HDPE wall. HDPE's flexibility makes this method imperative as if it is not used, the mechanical joint may fail. Flexibility is the feature that makes HDPE the trenchless pipe, but that flexibility also causes issues when forces are applied to HDPE. It "flexes" and "gives" so proper care must be taken when using mechanical connections.

Inspector

Basic: An authorized engineering representative who inspects and observes construction and project work and reports it back to the engineer.

Insider tip: Inspectors who are tasked to work on HDPE jobs must be trained in butt fusion and electrofusion as this is the area where expertise is critical. An untrained eye will not be able to pick up procedural errors made by an experienced, but improperly trained fusion operator. Inspector specific training classes are offered by the industry and strongly recommended.

IPS (Iron Pipe Size)

Basic: Iron Pipe Size (IPS) is the most common size for HDPE pipe. It was developed by the industry so it would be a good OD match for existing cast iron pipe systems.

Insider tip: IPS is a preferred size for many municipalities, as it is generally more available than DIPS sizes as other industries use IPS vs DIPS. IPS features a smaller ID and OD than DIPS.

Joint, Butt Fused

Basic: A joint made by applying heat and pressure to the ends of pipe to form a seamless, leak free bond. See Fusion, joint.

Insider tip: Butt fusion is the primary method that HDPE fusion occurs in North America. Two male pipe ends are clamped in a fusion machine and heated and quickly brought together under "fusion pressure." This process creates a homogenous bond. Joints connected by butt fusion are in fact stronger than the pipe itself. Many argue that they joint, once fused is no longer a joint. However, for purposes of clarity more often than not, it is referred to as a joint even after fusion. This fusion process allows for HDPE to be installed in continuous lengths to ensure a leak free system. Butt fusion can be performed above ground at a jobsite and only needs a short amount of time to fuse and cool the pipe before it can be installed. Follow the ASTM F2620 standard to ensure a properly fused joint.

Joint, Electrofused

Basic: A joint made by inserting ends of pipe into an electrofusion fitting and heating and fusing them within the fitting.

Insider tip: Electrofusion joins lengths of HDPE pipe using heat and pressure to create a strong joint. Electrofusion is unique in that the two ends of pipe are inserted into a fitting and then heated and fused within the fitting, which remains on after the fusion process is completed. Like with butt fusion, electrofusion also creates tough, leak free joints. Electrofusion can be performed aboveground at a jobsite and only needs a short amount of time to fuse and cool and pipe before it can be installed. The pipe must be round in order for electrofusion to work. Fusion operators must be trained to a standard.

Joint, Mechanical

Basic: A mechanical connection between two pieces of HDPE pipe.

Insider tip: Mechanical connections to PE pipe are great ways to make temporary fixes when a failure occurs or when laterals need to be connected. However, as the system is no longer fully HDPE, the weakest part of the system will be at that mechanical connection. The offering of mechanical fittings and connections has grown tremendously over the last few years.

Joint, Saddle-Fused

Basic: A joint made by fusing together a pipe and the base of the saddle fitting with heat according to F2620.

Lateral

Basic: Any connection to a mainline. Typically a connection running to a residential address.

Insider tip: In the HDPE world, laterals should be connected using both butt fusion and electrofusion. Mechanical connections are permitted and sometimes preferred however, they become the weakest part of the system.

Long Term Hydrostatic Strength (LTHS)

Basic: The long-term stress that causes a pipe to fail at 100,000 hours when continuously applied.

Insider tip: Understanding LTHS will provide insight into the test that demonstrates the 250-year life of HDPE pipe.

Manning's Formula

Basic: An equation used to calculate flows in gravity channels and conduits. The formula can be used to calculate the value of c in Chézy Formula using the hydraulic radius and coefficient of roughness values.

Insider tip: A common formula for the design engineer, Manning's formula is a routine formula that we discuss often because often times flow rates are often higher in HDPE than expected because of the constant C factor in the equation. So in many cases, design engineers see higher flow rates in HDPE pipe with a smaller ID vs DIP because DIP uses a lower C factor because of tuberculation.

Values of n for Use with Manning Equation

Surface	n, typical design
PE pipe	0.009
Uncoated cast or ductile iron pipe	0.013
Corrugated steel pipe	0.024
Concrete pipe	0.013
Vitrified clay pipe	0.013
Brick and cement mortar sewers	0.015
Wood stave	0.011
Rubble masonry	0.021

Note: The n-value of 0.009 for PE pipe is for clear water applications.
An n-value of 0.010 is typically utilized for applications such as sanitary sewer, etc.

Mechanical Connections, see Joint mechanical

Medium Density Polyethylene Plastics (MDPE)

Basic: Polyethylene plastics with a standard density of 0.926M0.94 g/cm^3.

Insider tip: It is well known that the gas industry uses MDPE more than HDPE. In distribution, polyethylene is the dominant product yet the water and wastewater markets are relative newcomers to HDPE in the United States. HDPE is the dominant pipe in Europe for water and wastewater applications.

Modulus of Elasticity (E)

Basic: The modulus of elasticity is a measure of stiffness of a HDPE pipe, specifically a pipe wall.

Insider tip: It is useful in discussing how HDPE responds to external stresses. When engineers calculate the amount of hoop stress, dynamic loading or the forces of pipe bursting on a run of pipe, the modulus of elasticity of HDPE is a critical factor. ASTM D638 is a good resource.

Open Cut Excavation

Basic: Open cut is a non-trenchless method of installation in which a trench in the ground is excavated to install new pipe.

Insider tip: Open cut is a non-trenchless method of installation in which a trench in the ground is excavated to install new pipe. It is often utilized for very large diameter projects. Since HDPE can be fused aboveground, it saves excavation and reconstruction costs since workers do not need to go down into the trench to fuse the pipe together, allowing HDPE trenches to be smaller than those required by other materials. PE Pipe is a very competitive pipe product on open cut jobs because trench widths are narrower and the new 4710 resin permits thinner walls at higher pressures.

Ovality

Basic: Deviation from a circular periphery. Round is the desired state in the PE world, not oval. Once the pipe ships from the factory it tends to go out of round, particularly in the larger diameters. This is an expected occurrence and is considered a normal state for PE pipe.

Insider tip: The importance in the HDPE world relates to the deviation in the pipe diameter when it comes time to fuse pipe. The pipe must be round to fuse whether you are butt fusing or electro fusing. Thus, the fusion machines have "jaws" to hold the pipe in place and in electrofusion the operator places a clamp around the pipe. If the pipe is oval and proper procedures are not used, the pipe will not fuse properly.

PE, HDPE, POLY, Polyethylene

Basic: Abbreviation for high density polyethylene, a plastic material. Common acronyms include HDPE, PE, poly and polyethylene.

Insider tip: HDPE quickly becomes PE, but means HDPE. The present day resin is 4710 and is much more stout and high performing than 3608. PE Pipe is the future for the water and wastewater markets in the US. Consider it on your next project!

PE3408

Basic: Abbreviation for polyethylene, a plastic material. Common acronyms include HDPE, PE, poly and polyethylene.

Insider tip: HDPE with 1600 PSI and an Environmental Stress Crack Resistance equal to or greater than 600 hours or a slow crack resistance (PENT) value equal to or greater than 10 hours (in accordance with ASTM D1693 and D1473).

PE4710

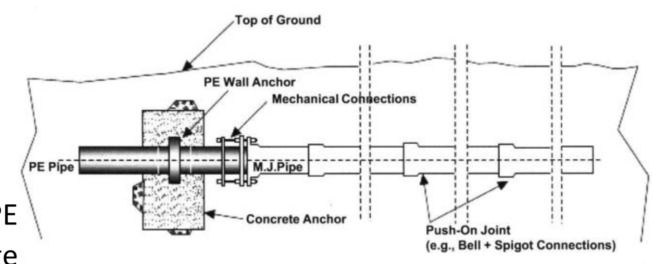
Basic: Fourth generation resin used to make HDPE pipe and fittings. Truly an amazing feat of using ethane or petroleum, this resin is far superior to previous generations.

Insider tip: The 4710 resin provides designers tremendous flexibility when design to save streetscapes, above grade development and existing utilities. The life expectancy alone is reason enough to use pipe made from this resin.

Pipe Bursting

Basic: Pipe bursting is a trenchless method of replacing buried water and sewer pipelines without the need for a traditional open cut trench. The "host pipe" is "burst" by mechanical equipment that is pulled through the host pipe from one end to the other. HDPE pipe is then pulled behind the "bursting head" replacing the host pipe.

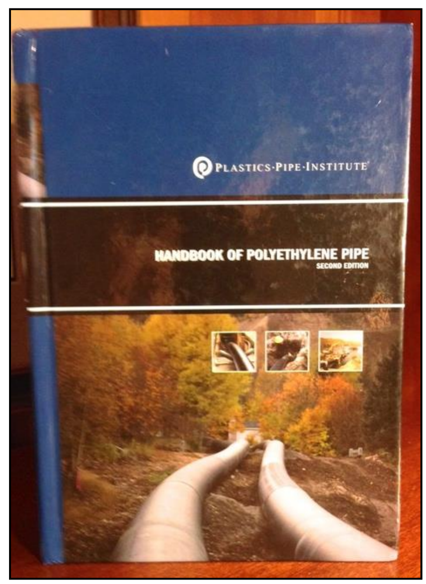
Insider tip: This trenchless rehabilitation method is really "less trench." Entry and exit pits are dug, and bursting equipment is pulled through the pipe on a cable, breaking the old pipe and pushing it into the surrounding soil with an expander while simultaneously pulling in the new length of pipe behind. Note that parallel and crossing utilities may have to be exposed to eliminate risk of damage. Static pipe bursting is powered by a hydraulic power unit and can be used for water or sewer systems. A winch and pulling cable are used to pull the pilot, bursting head, hammer and HDPE. The alternative is pneumatic pipe bursting which uses a hammer to burst the pipe.



Poisson's Effect (Ratio)

Basic: The ratio in the decrease in lateral strain to the increase in axial strain is called Poisson's ratio.

Insider tip: A primary feature that makes HDPE forgiving and flexible to ground movement and surge creates axial stress where the PE connects to the incumbent system. Consequently, it must be restrained at that point. The Poisson's effect as it is called if not properly addressed will cause pull out and line failure.



Plastic Pipe Institute, PPI

Basic: The Plastics Pipe Institute Inc. (PPI) is a technical association representing all segments of the plastics piping industry. PPI members share a common interest in broadening awareness and creating opportunities that expand market share and extend the use of plastics pipe in all its many applications.

Ref: https://plasticpipe.org/index.html

Insider tip: PPI organizes their areas of interest and advocacy into five categories: building and construction, conduit, corrugated pipe, energy piping systems and municipal and industrial. PPI continues to do a great job in developing technical data, obtaining certification for products and giving the industry the technical foundation to advance use of HDPE. PPI has now published two editions of the PE Pipe Handbook which serves as an excellent resource for the civil engineer who uses HDPE pipe, fittings and equipment. The book can be purchased for $50 at PPI's website or pdfs of each chapter are available online.

Pounds per square inch, PSI

Basic: a pressure unit used by the industry to describe the pressure capability of pipe and fitting products. It functions as the measure by how much pressure a pipe can and should withstand in use.

Insider tip: It is a given that pipe cost goes up as pressure capacity and requirements increases. In the HDPE world, the wall thickness increases as pressure class goes up. Pipe is sold by the pound, so the more resin that is used, means greater cost. Also, as pressure class goes up, wall thickness goes up, but ID goes down. Thus flow rates decrease as the ID declines. However, the C factor stays at 150 so flow rates may in fact be better than competing products. As an added tip, understanding surge is key to knowing what psi pipe to specify. Engineers are accustomed to using a higher pressure rating than working pressure because that is how incumbent pipe systems are designed. Not so with HDPE. A 100 psi HDPE pipe can handle occasional surges to 200 psi so no need to buy the 200 psi pipe. Use the 100 psi pipe and let the pipe do the work.

Pressure, Surge

Basic: Also known as water hammer, changes in the velocity of flow in an HDPE pipe system. Velocity changes can be caused by the operation of valves and pumps. Sometimes a fire event can cause surge in a pipe system.

Insider tip: Understanding how surge occurs is important, but recognizing how to design for surge in HDPE systems is critical to design success.

Pressure, Working

Basic: The maximum allowable operating pressure that a system can safely operate.

Insider tip: In the HDPE world, the working pressure refers to the typical pressure the agency sees in its system. It is helpful to know both working and surge: two psi numbers when determining which HDPE pipe pressure class (DR) to select.

Print Line

Basic: The print line appears on sticks and rolls of HDPE pipe so users can determine the specifications to which the pipe was manufactured. See ASTM F714 page 7M8, AWWA C906 page 23 and 29. specify minimum print line requirements. Most manufacturers provide information in excess of what is required.

Insider tip: Every manufacturers print line is a little different. For example, WL Plastics has series of numbers to identify their product. The print line shown below is a good example.

DIPS 12" DR17 – WL Plastics – UT – PE4710 PE445574C – PC125 – AWWA CM906 – ASTM F714 – [Shift/Line] – [MMM DDMYY] – NSFM61 – 50FT

Explanation:

Print line typically repeats at regular intervals like every 2'.

DIPS – Designated sizing system (other options IPS (iron pipe system), CTS (copper tubing sizes), ISO (metric mm sizes), DIPS (ductile iron pipe system))

12" – Nominal pipe outside diameter (note: nominal diameter may differ from actual measure diameter, ex: 12" DIPS nominal is equal to 13.20" actual measured diameter) **DR17** – Dimension Ratio (diameter/minimum wall thickness), 17 equates to 125 psig pressure class (see below)

WL Plastics – Pipe Manufacturer

UT – Location of Manufacturer

PE4710 – Pipe material designation code

PE445574C – Cell Classification per ASTM D3350 (pipe resin physical requirements)

PC125 – Pressure Class 125 psig

AWWA C906 – pipe meets American Water Works Association standard CM906

ASTM F714 – pipe meets American Society of Testing and Materials standard F714

Shift/Line – Shift that manufactured the pipe and which line it was made on (for product traceability)

MMTDDTYY – Date of manufacture

NSFT61 – pipe meets NSF M61, Product certified for use in potable water service

50FT – Pipe length designation

PSI, see Pounds per square inch

Quick Burst Test

Basic: A prescribed test conducted by pipe manufacturers to confirm the pipe they manufacturer conforms to NSF and ASTM requirements. It is a test of the internal pressure of a pipe meant to burst a pipe component in 60M70 seconds. The test is run in accordance with ASTM D1599.

Insider tip: Watch the video above and you will see a pipe burst at about 4 times its working pressure rating. This ductile failure is the proper failure mode for properly manufactured pipe and gives the viewer confidence to know that HDPE is a very strong and capable pipe system.

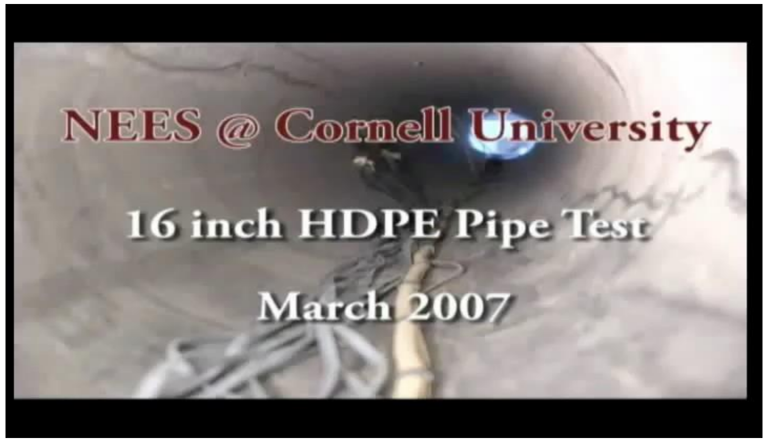
Rapid Crack Propagation (RCP)

Basic: A crack failure in a pipe typically initiated by a hard impact. RCPs are often experienced in conjunction with low temperatures and compressed gas media. RCPs run along a pipe at extremely high speeds and can be several feet in length.

Insider tip: Running cracks in HDPE occurred in extreme stress situations on occasion with previous versions of the resin. PE Engineers from Dow, Lyondell Basell and CPChem have perfected a resin that does not permit those kinds of failures to occur in the 4710 resin.

Seismically Resistant

Basic: HDPE pipe is seismically resistant as confirmed by the Water Research Foundation in their seminal report #4408 entitled Recent Earthquakes: Implications for US Water Utilities published in 2012. In other words, it will withstand earthquake activity, freeze thaw cycles, soil constriction, pressure spikes and typical ground movement that typically fractures incumbent pipe systems.



Cornell University Video simulation demonstrates how a 4' lateral shift in the soil affects a 35' long 16" diameter piece of

Insider tip: HDPE pipe is the seismically resistant pipe. It will withstand severe ground deformation without failure. That means that public agencies can specify a pipe that will withstand seismic activity and count on their pipeline infrastructure to remain intact and functioning after the seismic event.

Sliplining

Basic: A trenchless rehabilitation method for an old pipe system. Entry and exit pits are dug and a liner is pulled inside the host pipe. HDPE of a smaller diameter than the original pipe is then pulled through the liner and settled inside of the original pipe. Sliplining is an effective method if the existing system is still well intact.

Insider tip: The selection of DR is a design consideration as the host pipe provides structural integrity. There is some conversation in the industry on whether or not the annulus needs to be filled.

Specifications

Basic: Written technical descriptions in contract documents that outline the desired materials, lengths, equipment, construction methods, standards, practices and other relevant project details.

Insider tip: The Alliance will edit your specifications or provide model specifications for your use. Documents are available in editable format for easy integration.

Squeeze Off

Basic: A PE line can be squeezed off by a squeeze off tool which clamps down on the pipe to stop the flow.

Insider tip: Operator must turn the crank slowly on the manual machines and operate it slowly on the hydraulic machines in order not to damage the pipe. At release, the process must also occur slowly according to equipment manufacturer specifications.

Stress Relaxation

Basic: A decrease in stress levels over time at constant strain.

Insider tip: HDPE is a very forgiving material. That is what makes it so flexible and tolerant of ground movement. However, when mechanical connections and fittings are placed on HDPE pipe, the type of coupling, the fasteners and the method of connection all

Striping

Basic: HDPE stripe colors are coextruded into the pipe so that they cannot be removed. Stripe color is most commonly used as a pipeline identifier. For example; blue stripe is potable water, green stripe is sewer/waste water, purple is reclaimed/non-potable water, red stripe is fire water, and yellow stripe is gas.

Insider tip: The number of stripes and their location vary from manufacturer to manufacturer. Black pipe without stripes is the most commonly available pipe in the industry. A double stripe sometimes denotes DIPS pipe vs IPS.
Blue stripe – potable water
Green stripe – wastewater
Orange – conduit, cable, communication, signal, alarm
Purple stripe – reclaimed, raw water or irrigation water
Red Stripe – firewater
Yellow stripe – natural gas (all yellow HDPE pipe is also gas pipe)

Swagelining

Basic: Swagelining is a rehabilitation process that pulls thin-walled HDPE through an existing pipe with an ID than the HDPE's O.D. The HDPE forms a tight fit within the pipe, using the old pipe for support.

Insider tip: Swagelining is a trenchless method of installation of HDPE that, like sliplining, using an existing system to host the new pipe. Unlike sliplining, swagelining does not use a liner. Instead, HDPE is pulled through a die that restricts the diameter of the pipe. The HDPE is pulled through the old pipe into place and allowed to expand back out to its original diameter, forming a tight fit with the old pipe. Thin-walled HDPE is typically utilized for this, as it ensures a similar flow capacity to the old system and can use the support of the old pipe still in place.

Tensile Strength at Yield

Basic: The maximum tensile strength a pipe can withstand before yielding and elongating in a tensile test.

Insider tip: HDPE pipe can handle up to 3500 psi before yielding the pipe. This is an important number to keep in mind when designing pull in applications such as pipe bursting, or horizontal directional drilling. The yield stress is multiplied with the pipes wall area and a safety factor applied for the pull strength.

Testing

Basic: Required testing is set forth by the applicable standards. The most common for potable water applications are AWWA C906, ASTM D3035/F714, and NSF61. Required testing varies from physical strength, to chemical makeup.

Insider tip: Testing plans, or testing reports can be requested from pipe manufacturers showing what testing is performed on the pipe that is ordered.

Water Research Foundation (WRF)

Basic: WRF sponsoring cutting-edge research and promoting collaboration, the Water Research Foundation helps our subscribers with practical solutions and long-range planning to meet those challenges.

Ref: https://www.waterrf.org/

Insider tip: WRF works with a variety of professional partners to identify, prioritize, fund, manage, and communicate scientifically sound research across the globe. Since 1966, they have managed more than 1,000 high-impact research studies valued at more than $500 million. WRF is a 501(c)3 nonprofit organization that carefully invests research dollars from more than 950 subscribing organizations in the U.S. and abroad to tackle an array of issues related to water. WRF funded the study which proved the seismic resistance of HDPE pipe and cemented its position as the seismically resistant pipe in North America. See WRF report Number #4408. WRF also published a landmark report on the environmental impacts of pipe bursting with HDPE to solve the AC pipe crisis.

Working Pressure (WP)

Basic: The maximum sustained operating pressure a pipe can handle, distinct from temporary pressure changes such as pressure surges.

Insider tip: When selecting a pipe dimension ratio (DR) it is important to know what the WP is and what the maximum surge pressure is in a given system. Proper pressure class (or DR) is a function of working pressure plus maximum surge.

Sources:

PPI Handbook PPI Website
Alliance for PE Pipe Website
AWWA M55
Various ASTM standards
Engineer'sEdge.com

SECTION 02315

EXCAVATION, BACKFILL AND COMPACTION FOR UTILITIES

PART 1 GENERAL

1.01 Scope of Work

The work specified in this section consists of furnishing all materials, labor, equipment, and other services as necessary for preparing the site for work, the excavating, preparing the trench for the underground utility to be altered or installed, the backfilling and compaction. The excavation and backfill aspects of the work required for installation of underground utilities shall meet all Department of Transportation (DOT) and all local right-of-way authority requirements.

1.02 Contractor Qualifications

A. When performing trench excavation, the Contractor is to comply with the Occupational Safety and Health Administration's (OSHA) trench safety standards, 29 C.F.R., s. 1926.650, Subpart P. Submission of a bid and subsequent execution of a contract to perform the work required will serve as certification that all trench excavation will be in compliance with OSHA standards.

1.03 Referenced Standards

A. American Water Works Association (AWWA) latest edition:

1. AWWA C901 – Polyethylene Pressure Pipe and Tubing, ½ Inch Through 3 Inch for Water Service
2. AWWA C906 – Polyethylene Pressure Pipe and Fittings, 4 Inch Through 63 Inch for Water Distribution and Transmission

B. American Society for Testing and Materials (ASTM) latest edition:

1. ASTM C136 – Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates
2. ASTM D422 – Standard Test Method for Particle-Size Analysis of Soils
3. ASTM D1556 – Standard Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method
4. ASTM D2122 – Standard Method of Determining Dimensions of Thermoplastics Pipe and Fittings
5. ASTM D2167 – Standard Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method
6. ASTM D2239 – Standard Specification for Polyethylene (PE) Plastic Pipe (SIDR-PR) Based on Controlled Inside Diameter

7. ASTM D2657 – Practice for Heat-Joining of Polyolefin Pipe and Fittings
8. ASTM D2683 – Standard Specification for Socket Type Polyethylene Fittings for Outside Diameter-Controlled Polyethylene Pipe and Tubing
9. ASTM D2774 – Standard Practice for Underground Installation of Thermoplastic Pressure Piping
10. ASTM D2937 – Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method
11. ASTM D3035 – Polyethylene (PE) Plastic Pipe (DR-PE) Based on Controlled Outside Diameter
12. ASTM D3261 – Butt Heat Fusion Polyethylene (PE) Plastic Fittings for Polyethylene (PE) Plastic Pipe and Tubing
13. ASTM D3350 – Polyethylene Plastic Pipe and Fittings Material
14. ASTM D3740 – Standard Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
15. ASTM D4253 – Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table
16. ASTM D4254 – Standard Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density
17. ASTM D4318 – Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
18. ASTM D6938 – Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)
19. ASTM F412 – Standard Terminology Relating to Plastic Piping Systems
20. ASTM F714 – Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter
21. ASTM F1290 – Standard Practice for Electrofusion Joining Polyolefin Pipe and Fittings
22. ASTM F2164 – Field Leak Testing of Polyethylene (PE) Pressure Piping Systems Using Hydrostatic Pressure
23. ASTM F2620 – Standard Practice for Heat Fusion Joining of Polyethylene Pipe and Fittings
24. ASTM F2786 – Standard Practice for Field Leak Testing of Polyethylene (PE) Pressure Piping Systems Using Gaseous Testing Media Under Pressure (Pneumatic Leak Testing)
25. ASTM F3124 – Standard Practice for Data Recording the Procedure used to Produce Heat Butt Fusion Joints
26. ASTM F3190 – Standard Practice for Heat Fusion Equipment (HFE) Operator Qualifications on Polyethylene (PE) and Polyamide (PA) Pipe and Fittings

C. Occupational Safety and Health Administration's (OSHA) Trench Excavation Standard – 29 C.F.R, s.1926.650, Subpart P

D. Plastics Pipe Institute (PPI) latest edition:

1. The Plastics Pipe Institute Handbook of Polyethylene Pipe – Chapter 7 Underground Installation of PE Pipe
2. PPI – TN-36 – General Guidelines for Connecting HDPE Potable Water Pressure Pipes to DI and PVC Piping Systems
3. PPI – TN-38 – Bolt Torque for Polyethylene Flanged Joints
4. PPI – TN-44 – Long Term Resistance of AWWA C906 Polyethylene (PE) Pipe to Potable Water Disinfectants
5. PPI – TN-45 – Mechanical Couplings for Joining Polyethylene Pipe
6. PPI – TN-46 – Guidance for Field Hydrostatic Testing of High Density Polyethylene Pressure Pipelines: Owner's Considerations, Planning, Procedures, and Checklists
7. PPI – TN-49 – Recommendations for AWWA C901 Service Tubes in Potable Water Applications
8. PPI – TN-54 – General Guidelines for Squeezing Off Polyethylene Pipe in Water, Oil and Gas Applications

E. Plastics Pipe Institute Municipal Advisory Board (MAB)
1. MAB Generic Electrofusion Procedure for Field Joining of 12 Inch and Smaller Polyethylene (PE) Pipe
2. MAB Generic Electrofusion Procedure for Field Joining of 14 Inch to 30 Inch Polyethylene (PE) Pipe
3. MAB Model Specifications for PE 4710 Buried Potable Water Service, Distribution and Transmission Pipes and Fittings

1.04 Submittals

A. Submit pipe catalog information confirming that pipe, fittings, joints, and other materials conform to the requirements of the specifications.

B. Affirmation that product shipped meets or exceeds the standards set forth in this specification. This shall be in the form of a written document from the manufacturer attesting to the manufacturing process meeting the standards.

C. Submit manufacturer's recommended fusion procedures for the products.

D. Submit traffic control plan for all entrance and exit pits.

E. Provide as-built documentation. Contractor shall plot as-built conditions on the field drawings, including the location in plan and elevation of the installed pipe, at the completion of each production shift. Include on the drawings pipeline horizontal and vertical data recorded every foot along the pipeline.

F. Contractor to maintain all testing and quality control documentation and assurance procedures. Contractor to provide the following documents to the Owner:

1. Quality control test reports

2. Fusion reports for each weld as reported by the datalogger
3. Certified laboratory test data for the materials and products to be used in the work shall be submitted to the Owner for approval
4. Results of the quality control tests required during the performance of the work shall be submitted to the Owner within 48 hours of completion
5. An independent testing / inspection firm shall provide the following submittals to Owner:
    a. A statement attesting that the Contractor's work is in accordance with the requirements of the project documents
    b. Informal daily "pass" or "fail" reports
    c. Formal weekly reports including all test logs and comments to include density and moisture content test logs, indicating location of tests by coordinates and elevation
    d. Upon completion of backfill activities, all density and moisture content test logs and comments compiled and submitted
    e. Sources and test results of all borrowed materials used for backfill

PART 2 PRODUCTS

2.01 Polyethylene Pipe, Fittings and Accessories

A. Polyethylene pipe and fittings 4-30 inch diameter shall be in accordance with AWWA C906, material designation code of PE4710 and all applicable ASTM standards.

B. Polyethylene pipe ½ -3 inch diameter for main line piping shall be polyethylene pipe (not tubing) in accordance with AWWA C901, material designation code of PE4710 and all applicable ASTM standards.

C. Butt fusion fittings shall be made of HDPE material with a minimum material designation code of PE4710 and all applicable ASTM standards. Molded and fabricated fittings shall have a pressure rating equal to the pipe unless otherwise specified on the project documents. All fittings shall meet the requirements of AWWA C901, C906 and all applicable ASTM standards. Markings for molded fittings shall comply with the requirements of ASTM D3261. Fabricated fitting shall be marked in accordance with ASTM F2206. Socket fittings shall meet ASTM D2683. Fabricated fittings shall be manufactured using a McElroy DataLogger to record fusion time, pressure and temperature, and shall be marked with a unique joint identifier that corresponds to the joint report. A graphic representation of the time and pressure data for all fusion joints made producing fittings shall be maintained for a minimum of five years as part of quality control and will be available upon request of Owner.

D. Electrofusion fittings shall be made of HDPE material with a minimum material designation code of PE4710 and meet ASTM F1055. Electrofusion fittings shall have a pressure rating equal to the pipe unless otherwise specified on the project documents. All electrofusion fittings shall be suitable for use as pressure conduits and have nominal burst values of four times the working pressure rating of the fitting. Marking of electrofusion fittings shall comply with the requirements of ASTM F1055. All electrofusion fittings shall be properly stored in compliance with the manufacturer's recommendation.

E. Saddle fusion could be used to fuse branch saddles, tapping tees and other HDPE fittings onto the wall of the main pipe. Saddle fusion shall be done in accordance with ASTM F2620 or PPI TR-41 or the fitting manufacturer's recommendations. Saddle fusion joints shall be made by qualified fusion technicians. Qualification of the fusion technician shall be demonstrated by evidence of fusion training within the past two years on the equipment to be utilized on this project in accordance with ASTM F3190.

F. Socket fusion could be used to fuse branch saddles, tapping tees and other HDPE fittings onto the wall of the main pipe. Socket fusion shall be done in accordance with ASTM D2683 or the fitting manufacturer's recommendations. Socket fusion joints shall be made by qualified fusion technicians. Qualification of the fusion technician shall be demonstrated by evidence of fusion training within the past two years on the equipment to be utilized on this project in accordance with ASTM F3190. All equipment used for socket fusion should comply with ASTM F1056 and manufacturer's recommendations.

G. Flanges and Mechanical Joint Adapters (MJ) shall have a minimum material designation code of PE4710 and meet all applicable AWWA and ASTM standards. Flanged and MJ adapters can be made to ASTM D3261 or machined in compliance with ASTM F2206. Flanges and MJ adapters shall have a pressure rating equal to the pipe unless otherwise specified on the plans. Markings for molded or machined flange adapters or MJ adapters shall be per ASTM D3261. Fabricated (including machined) flange adapters shall be marked per ASTM F2206. Installation of all Flanged adapters shall follow the guidelines of the Plastics Pipe Institute TN-38.

H. Glands, bolts, and gaskets shall be manufactured in accordance with AWWA C153. Bolts and nuts shall be grade 2 or higher.

2.02 Pipeline Identification

A. All polyethylene pipe shall be marked in accordance with the standards to which it is manufactured.

B. All polyethylene pipe shall be black, and shall contain a continuous colored stripe, 2 inches wide, located at no greater than 90 degree intervals around the pipe. Stripes shall be impregnated or molded into the pipe by the manufacturer. Application of the stripes after manufacture is not acceptable. Stripe color shall be:

1. Potable Water Mains - blue stripes

2. Reclaimed Water Mains - purple stripes
3. Force Mains - brown stripes
4. Sanitary Sewer - green stripes
5. Storm Sewer - no stripes required

2.03 Soil Materials

A. Suitable on-site backfill material – suitable materials shall be defined as a mineral soil reasonably free of foreign materials (rubbish, debris, etc.), clumps, aggregate larger than three inches, rock, concrete or asphalt chunks, and other unsuitable materials, that may damage the pipe installation, prevent thorough compaction, or increase the risks of after settlement unnecessarily.

B. Imported granular material for pipe bedding and encasement – granular materials furnished for foundation, bedding, pipe encasement, or other purposes as may be specified shall consist of any natural aggregate such as sand, gravel, crushed rock, crushed stone, that shall meet the gradation requirements specified on the Standard Details or project documents. Granular material used for pipe bedding and encasement shall be comprised of virgin materials only.

C. Imported materials for backfill – when acceptable select grading material is not available within the project site, the Contractor shall furnish granular backfill material meeting DOT and all local right-of-way authority requirements. The backfill material shall be utilized for backfilling from the top of pipe encasement zone up to the subgrade (bottom of road section or bottom of topsoil) at the direction of the Owner. Granular material used for backfill of utilities pipes shall be comprised of virgin materials.

PART 3 EQUIPMENT

3.01 Data Logger

A. A data logger shall be used to record and document all butt fusion process. The data logger must be compatible and outfitted with an electronic data recording device. A digital report or printout for all fusion joints made that complies with, but is not limited to, ASTM F3124 must be delivered to the OWNER upon request and at the completion of the project. All hydraulic fusion must be recorded and able to produce a graphic representation of the time and pressure data. All manual fusion must be recorded with, but not limited to, Joint ID, Operator Name and ID, Pipe information, and Heater Plate Temperature. The recording unit shall be a DataLogger 6 as manufactured by McElroy Manufacturing, Inc, or newer model or approved equivalent.

PART 4 EXECUTION

4.01 General

A. When performing trench excavation, the Contractor is to comply with the OSHA trench safety standards, 29 C.F.R., S. 1962.620, Subpart P and all subsequent revisions or updates adopted by the Department of Labor and Employment Security. The Contractor is to ensure that trench boxes are wide enough to accommodate compaction and density testing. Submission of a bid and subsequent execution of a contract to perform the work required will serve as certification that all trench excavation will be in compliance with OSHA standards.

4.02 Excavation

A. Excavate pits to permit the placing of the full widths and lengths of trench limits as shown in project documents. Perform all excavation to foundation materials. Wherever rock bottom is secured, excavate in such manner to allow the solid rock to be exposed and prepared to support the foundation for pipe placement.

B. Excavate trenches for pipes to the elevation of the bottom of the pipe and to a width sufficient to provide adequate working room. Remove soil not meeting the classification specified as suitable backfill material to a depth of 4 inches below the bottom of the pipe elevation. Remove rock, boulders or other hard lumpy or unyielding material to a depth of 12 inches below the bottom of the pipe elevation. Remove much or other soft material to a depth necessary to establish a firm foundation. Where the soil permit, ensure that the trench sides are vertical up to at least the mid-point of the pipe.

C. For pipe lines placed above the natural ground line, place and compact the embankment, prior to excavation of the trench, to an elevation at least 2 feet above the top of the pipe and to a width equal to four pipe diameters, and then excavate the trench to the required grade.

D. For pipe trenches utilizing trench boxes, ensure that the trench box used is of sufficient width to permit thorough tamping of bedding material under and around the pipes.

E. Do not disturb the installed pipe and its embedment when moving trench boxes. Move the trench box carefully to avoid excavated wall displacement or damage. As the trench box is moved, fill any voids left by the trench box and continuously place and compact the backfill material adjacent to and all along the side of the trench box walls to fill any voids created by the trench box.

F. Use suitable excavated materials for backfilling over or around the pipe. Dispose of any unsuitable materials. Where acceptable suitable select grading material is available within the project site, the select grading materials shall be utilized for backfilling pipe trench from the top of the pipe encasement zone up to the subgrade.

4.03 Backfilling

A. Backfill and compaction should follow pipe placement and assembly as closely as possible.

B. Backfill in dry conditions whenever normal dewatering equipment and methods can accomplish the needed dewatering. A LOT is defined as one lift of backfill material placement, not to exceed 500 feet in length or a single run of pipe connecting two successive structures, whichever is less. Backfill around structures compacted separately from the pipe will be considered as separate LOTs. Backfill on each side of the pipe for the first lift will be considered a separate LOT. Backfill on opposite sides of the pipe for the remaining lifts will be considered separate LOTs, unless the same compactive effort is applied. The same compactive effort is defined as the same type of equipment (make and model) making the same number of passes on both sides of the pipe. For multiple phase backfill, a LOT shall not extend beyond the limits of the phase.

C. When placing backfill within a trench box each lift of backfill is considered a LOT. Placement of backfill within trench box limits will be considered a complete operation before trench box is moved for next backfill operation. When the trench box is moved for next backfill operation this will start new LOTs for each lift.

D. Provide normal dewatering equipment including, but not limited to, surface pumps, sump pumps, well points and header pipe and trenching/digging machinery. Provide normal dewatering methods including, but not limited to, constructing shallow surface drainage trenches/ditches, using sand blankets, perforated pipe drains, sumps and siphons.

E. Backfill to the original ground surface or subgrade surface of openings made for structures, with a sufficient allowance for settlement. The Owner may require that the material used for this backfill be obtained from a source entirely apart from the structure. Use only material accepted by the Owner.

F. Do not allow heavy construction equipment to cross over pipes until placing and compacting backfill material to the finished earthwork grade or to an elevation at least four feet above the crown of the pipe.

G. Place the material in horizontal layers not exceeding six inches compacted thickness, in depth above water level and under the haunches of the pipes.

H. The Contractor may elect to place material in thicker lifts of no more than 12 inches compacted thickness above the Soil Envelope if the Contractor can demonstrate with a successful test section that density can be achieved.

I. Where wet conditions do not permit the use of mechanical tampers, compact using hand tampers. When the backfill has reached an elevation and condition such as to make the use of the mechanical tampers practical, perform mechanical tamping in such a manner and to such extent as to transfer the compaction force into the sections previously tamped by hand.

J. For pipes greater than 15 inches in diameter, the Contractor may elect to break the backfill up into four sections: lowest zone, bedding zone, cover zone and top zone.

1. The lowest zone is backfilled for deep undercuts up to within four inches of the bottom of the pipe. Backfill areas undercut below the bedding zone of a pipe with coarse sand, or other suitable granular material. Compact the soil in the lowest zone to approximately match the density of the soil in which the trench was cut.
2. The bedding zone is usually the four inches directly under the pipe. If rock or other hard materials have been removed from the bottom of the trench, the bedding zone shall be the 12 inches of soil below the bottom of the pipe as a replaced foundation. Backfill the bedding zone with suitable Class 1, 2 or 3 materials or other approved by the Owner. If the trench was not undercut below the bottom of the pipe, loosen the soil in the bottom of the trench immediately below the middle third of the outside diameter of the pipe. If the trench was undercut, place the bedding material and leave it in a loose condition below the middle third of the outside diameter of the pipe. Place the material in lifts no greater than six inches.
3. The cover zone is backfill that is placed after the pipe is laid and extends to a height of 12 inches above the top of the pipe. Backfill the cover zone with suitable Class 1, 2 or 3 materials or other approved by the Owner. Before placing the cover zone material, lay the pipe. Place the material in six inch layers of compacted thickness, evenly deposited on both sides of the pipe, and compact with mechanical tampers suitable for this purpose. Hand tamp material below the pipe haunch that can't be reached by mechanical tampers.
4. The top zone extends from 12 inches above the top of the pipe to the final grade. Backfill the top zone with material suitable for backfill as previously mentioned in this specification. Place the material in layers that do not exceed 12 inches of compacted thickness.

4.04 Density Testing

A. Compaction of materials placed within the pipe bedding and encasement zones shall be accomplished with portable or hand equipment methods, so as to achieve thorough consolidation under and around the pipe and avoid damage to the pipe. The materials at this level shall be thoroughly compacted with a mechanical compactor to meet 95% of maximum standard proctor density.

B. Compaction of materials placed above the pipe encasement zones shall be carefully placed in relatively uniform depth layers spread over the full width and length of the trench section to provide simultaneous support on both sides of the excavation. The backfill material shall not exceed 12 inches in compacted thickness.

1. The compaction for backfill for utility pipe trench under impervious (paved) surface areas shall meet 98% of maximum standard proctor density or other requirements as determined by DOT or the right-of-way authority.
2. The compaction for backfill for utility pipe trench under pervious (non-paved) surface areas shall meet 95% of maximum standard proctor density or other requirements as determined by DOT or the local right-of-way authority.

4.05 Quality Assurance

A. Unless otherwise specified in the project documents, a qualified independent inspection and testing agency will be retained by the Owner or Contractor to perform field and laboratory testing and / or evaluations in accordance with the criteria of ASTM D3740 to very compliance of the work with the requirements of this specification.

B. The inspection / testing firm shall be responsible for quality assurance inspection and testing to ensure that the work is in accordance with the requirements of the project documents.

C. If the completed work is not in accordance with the project documents, the Contractor shall be responsible for repairing or reconstructing the deficiencies to meet the project documents at the Contractors expense.

D. Tests of gradation, plasticity, density and moisture content shall be performed for each type of fill material.

E. Unless otherwise specified in the project documents, the following in-place dry density and moisture content testing on compacted fill shall be performed using one of the following methods:

1. Sand-cone method in accordance with ASTM D1556
2. Nuclear methods in accordance with ASTM D6938
3. Rubber balloon method in accordance with ASTM D2167
4. Drive-cylinder method in accordance with ASTM D2937

F. Unless otherwise specified in the project documents, the field density testing shall be performed at the following frequencies:

1. Structural fill under roadways, railroads, pavement and parking areas – one test every 200 square feet of each lift
2. Road base and sub-base – one test every 2000 square feet of each lift
3. Backfill of trenches – one test for every 150 linear feet of each lift and one test within each segment between changes in direction

4.06 Pipe Joining

A. High density polyethylene pipe shall be heat fused and pressure tested as per manufacturer's guidelines before installation. During assembly and prior to installation, pipe must be laid out in such a way as to minimize interference to pedestrian and vehicular traffic.

B. Cuts or gouges that reduce the wall thickness by more than 10% are not acceptable and must be cut out, discarded and the pipe rejoined.

C. Each butt fusion shall be recorded and logged by a datalogger affixed to the fusion machine. Joint data shall be submitted as part of the as-built documentation.

D. Mechanical joining – Polyethylene pipe and fittings may be joined together or to other materials by means of flanged connections or mechanical couplings designed for joining polyethylene pipe or for joining polyethylene pipe to another pipe material. Mechanical couplings shall be fully pressure rated and fully thrust restrained and installed in accordance with manufacturer's recommendations.

4.07 Pressure and Leakage Testing

A. Pressure and Leakage tests

1. Conduct hydrostatic pressure testing of installed polyethylene pipe in accordance with ASTM F2164.
2. For HDPE mains, fill the main slowly ensuring fill rate does not exceed capacity of air release devices. Once air has been expelled from the system, gradually raise the pressure to 160 psi. Add makeup water as necessary to maintain this pressure as necessary for four hours. After four hour period, reduce main pressure to the 150 psi test pressure and monitor for one hour. Do not increase pressure or add make-up water during this one hour period. The test is passed and considered acceptable if the main pressure does not drop more than 5% (7.5 psi) during the one hour period.
3. If any defects or leaks are revealed, they should be corrected and the pipeline retested after a minimum 24 hour recuperation period between tests. Total testing conducted on a section of pipeline shall not exceed eight hours within a 24 hour period.

4.08 Restoration

After completion of the excavation, backfill and compaction work all work areas, staging and storage areas are to be restored to equal or better condition than pre-construction condition.

END OF SECTION

SECTION 02405

HORIZONTAL DIRECTIONAL DRILL

PART 1 GENERAL

1.01 Scope of Work

The work specified in this section consists of furnishing and installing underground utilities using the horizontal directional drilling (HDD) method of installation for pipes of various sizes, also commonly referred to as directional boring or guided horizontal boring. This work shall include all services, equipment, materials, and labor for the complete and proper installation, testing, restoration of underground utilities and environmental protection and restoration.

1.02 Contractor Qualifications

A. Contractor (or Sub-Contractor) shall provide documented evidence of successful installation of pipe through the horizontal directional drill method for work comparable in nature to the scope of work required by this project for a minimum of two years.

B. Contractor (or Sub-Contractor) to have successfully self-performed at least (5) horizontal directional drilling projects to install product pipe of a similar nominal diameter and length to the proposed project within the past two years. Owner and Engineer shall have the sole authority to determine the adequacy of the representative projects.

C. Contractor's (or Sub-Contractor's) project manager, superintendent, drill operator and guidance system operator assigned to horizontal directional drilling shall be experienced in work of this nature and shall have successfully completed projects similar in nature and shall have successfully completed similar projects using horizontal directional drilling. Contractor (or Sub-Contractor) shall submit substantiating evidence of qualifications with the bid submittal documents.

D. All drilling, drill guidance and pipe joining equipment operators shall be experienced in comparable horizontal directional drilling work, and shall have been fully trained in the use of the proposed equipment by an authorized representative of the equipment manufacturer(s) or their authorized training agents.

E. All high density polyethylene (HDPE) fusion equipment operators shall be qualified to perform pipe joining using the means, methods and equipment employed by the Contractor. Fusion equipment operators must possess and be able to provide written validation (card or certificate) of current, formal training on all fusion equipment employed on the project, including training and proper use of the data logging device on the equipment. Training received more than two years prior to operation of the fusion equipment shall not be considered current.

1.03 Referenced Standards

A. American Water Works Association (AWWA) latest edition:

1. AWWA C651 – Disinfecting Water Mains
2. AWWA C901 – Polyethylene Pressure Pipe and Tubing, ½ Inch Through 3 Inch for Water Service
3. AWWA C906 – Polyethylene Pressure Pipe and Fittings, 4 Inch Through 63 Inch for Water Distribution and Transmission

C. American Society of Civil Engineers (ASCE) – Manual of Practice 108 for Pipeline Design for Installation by Directional Drilling

B. American Society for Testing and Materials (ASTM) latest edition:

1. ASTM D638 – Tensile Method for Tensile Properties of Plastics
2. ASTM D790 – Test Materials for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
3. ASTM D2122 – Standard Method of Determining Dimensions of Thermoplastics Pipe and Fittings
4. ASTM D2239 – Standard Specification for Polyethylene (PE) Plastic Pipe (SIDR-PR) Based on Controlled Inside Diameter
5. ASTM D2657 – Practice for Heat-Joining of Polyolefin Pipe and Fittings
6. ASTM D2683 – Standard Specification for Socket Type Polyethylene Fittings for Outside Diameter-Controlled Polyethylene Pipe and Tubing
7. ASTM D2774 – Standard Practice for Underground Installation of Thermoplastic Pressure Piping
8. ASTM D2837 – Standard Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products
9. ASTM D3035 – Polyethylene (PE) Plastic Pipe (DR-PE) Based on Controlled Outside Diameter
10. ASTM D3261 – Butt Heat Fusion Polyethylene (PE) Plastic Fittings for Polyethylene (PE) Plastic Pipe and Tubing
11. ASTM D3350 – Polyethylene Plastic Pipe and Fittings Material
12. ASTM F412 – Standard Terminology Relating to Plastic Piping Systems
13. ASTM F714 – Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter
14. ASTM F905 – Standard Practice for Qualification of Polyethylene Saddle-Fused Joints
15. ASTM F1055 – Standard Specification for Electrofusion Type Polyethylene Fittings for Outside Diameter Controlled Polyethylene Pipe and Tubing

16. ASTM F1056 – Standard Specification for Socket Fusion Tools for Use in Socket Fusion Joining Polyethylene Pipe or Tubing and Fittings
17. ASTM F1290 – Standard Practice for Electrofusion Joining Polyolefin Pipe and Fittings
18. ASTM F1962-11 – Standard Guide for Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossings
19. ASTM F2164 – Field Leak Testing of Polyethylene (PE) Pressure Piping Systems Using Hydrostatic Pressure
20. ASTM F2206 – Fabricated Fittings for Butt-Fused Polyethylene Plastic Pipe
21. ASTM F2620 – Standard Practice for Heat Fusion Joining of Polyethylene Pipe and Fittings
22. ASTM F2786 – Standard Practice for Field Leak Testing of Polyethylene (PE) Pressure Piping Systems Using Gaseous Testing Media Under Pressure (Pneumatic Leak Testing)
23. ASTM F3124 – Standard Practice for Data Recording the Procedure used to Produce Heat Butt Fusion Joints
24. ASTM F3190 – Standard Practice for Heat Fusion Equipment (HFE) Operator Qualifications on Polyethylene (PE) and Polyamide (PA) Pipe and Fittings

D. North American Society for Trenchless Technology (NASTT) latest edition:

1. NASTT's Horizontal Direction Drilling (HDD) Good Practices Guidelines – 4th Edition

E. Plastics Pipe Institute (PPI) latest edition:

1. The Plastics Pipe Institute Handbook of Polyethylene Pipe – Chapter 12 Horizontal Directional Drilling
2. PPI – TN-36 – General Guidelines for Connecting HDPE Potable Water Pressure Pipes to DI and PVC Piping Systems
3. PPI – TN-38 – Bolt Torque for Polyethylene Flanged Joints
4. PPI – TN-44 – Long Term Resistance of AWWA C906 Polyethylene (PE) Pipe to Potable Water Disinfectants
5. PPI – TN-45 – Mechanical Couplings for Joining Polyethylene Pipe
6. PPI – TN-46 – Guidance for Field Hydrostatic Testing of High Density Polyethylene Pressure Pipelines: Owner's Considerations, Planning, Procedures, and Checklists
7. PPI – TN-49 – Recommendations for AWWA C901 Service Tubes in Potable Water Applications
8. PPI – TN-54 – General Guidelines for Squeezing Off Polyethylene Pipe in Water, Oil and Gas Applications
9. PPI – TR-46 – Guidelines for Use of Mini-Horizontal Directional Drilling for Placement of High Density Polyethylene Pipe

F. Plastics Pipe Institute Municipal Advisory Board (MAB)
  1. MAB Generic Electrofusion Procedure for Field Joining of 12 Inch and Smaller Polyethylene (PE) Pipe
  2. MAB Generic Electrofusion Procedure for Field Joining of 14 Inch to 30 Inch Polyethylene (PE) Pipe
  3. MAB Model Specifications for PE 4710 Buried Potable Water Service, Distribution and Transmission Pipes and Fittings

1.04 Submittals

A. Contractor shall submit personnel information detailing the names and resumes, including specific project experience, for the proposed project manager, superintendent, guidance operator and drill operator proving that the experience meets the requirements detailed in this specification.

B. Contractor shall submit personnel information, including specific project experience, for all proposed drilling, drill guidance, and pipe joining equipment operators, including evidence of training in the use of the proposed equipment by an authorized representative of the equipment manufacturer or their qualified agent.

C. Provide technical data for the equipment to be used on the project, including make, model and technical specifications for each of the following:

  1. Horizontal directional drill rig
  2. Drilling system components
  3. Downhole drilling assembly and reaming equipment
  4. Downhole pressure sub
  5. Guidance and control system
  6. Pulling head
  7. Swivels
  8. Rollers
  9. Solids separation and drill fluid recirculation systems
  10. Pipe fusion equipment
  11. Pipe fusion data logger
  12. Pipe handling equipment
  13. Pigs and pigging equipment
  14. Calibration certification for the pilot bore guidance and control system
  15. Calibration certification for the heat fusion datalogger

D. Submit pipe catalog information confirming that pipe, fittings, joints, and other materials conform to the requirements of the specifications.

E. Submit pipe manufacturer's most current calculations regarding tensile load limitations for trenchless installations.

F. Provide information showing staging and pipe fusion areas, site access during work activities, pipe storage and handling and procedure for pipe joining.

G. Submit a proposed bore path layout in both plan and profile. The proposed bore path shall conform to the drilling equipment and pipe material constraints.

H. Provide a work plan detailing the procedure and schedule to be used to execute the project. Horizontal directional drilling shall not commence until the contractor has received written approval of all work plan submittals. The Contractor shall provide complete descriptions of proposed plans, procedures and personnel, as well as supporting calculations for the following:

1. Drilling operations, addressing procedures for pilot hole drilling and reaming, tracking and controlling the drilling head locations and the preparation of as-built documentation
2. Drilling fluid management
3. Spoils handling and disposal
4. Pipe pullback and pullback monitoring.
5. Prevention of inadvertent fluid losses and spills, including contingencies for rapid containment and cleanup, including procedures for monitoring and controlling drilling fluid flows and pressures, equipment, resources and procedures for identifying, containing and cleaning up fluid losses and spills
6. Quality control and testing procedures
7. Safety plan

I. Provide a supplemental work plan in advance of performing the horizontal directional drill work. Horizontal directional drilling shall not commence until the contractor has received written approval of all supplemental work plan submittals. The work plan shall specifically address the following potential problems:

1. Obstructions along bore path during reaming or pull back
2. Drill pipe or product pipe cannot be advanced
3. Deviations from design line and grade exceed allowable tolerances
4. Drill pipe or product pipe broken off in borehole
5. Collapse of product pipe or excessive deformation
6. Damage to existing utilities
7. Excessive subsidence or heave

J. Design Requirements

1. Horizontal alignment shall be as shown on the project documents. The maximum depth shall be determined based on a minimum clearance from existing or proposed utilities to be crossed or the minimum clearances shown on the Drawings, whichever is greater. Bending radius shall not be less than the manufacturer's recommended minimum bending radius of the pipe. Compound curvatures may be used, but shall not exceed the

maximum deflections as set forth by the manufacturer or AWWA standards, whichever is more strict.

2. In accordance with ASTM F1962-11, Bore Entry (Pipe exit) angle shall be between 8 and 20 degrees and Bore Exit (Pipe Entry) angle shall be relatively shallow, preferably less than 10 degrees. Any deviation from these angles should be submitted to the Owner for approval.

K. Provide detailed design calculations in accordance with ASTM F1962. The calculations shall support the Contractor's specific proposed means, methods and products. The Contractor's final design calculations shall be prepared and sealed by a Licensed Professional Engineer registered in the State as to which the Project is located. Horizontal directional drilling shall not commence until the contractor has received written approval of all design calculation submittals. Design calculations shall demonstrate that the proposed pipe, equipment and means and methods comply with the requirements of this specification and have been designed based on the design borepath, installation means and methods, for anticipated installation and handling, hydrostatic, earth and live loads, installation temperature and site conditions. Contactor shall provide the following calculations:

1. Maximum allowable pipe loading limits
2. Design radius of the proposed bore path, including minimum radii for all curves
3. Pullback load calculation based on proposed drill path plan and profile including pipe stress calculations
4. Confirmation that the design parameters do not result in installation stress that exceeds allowable pipe stresses
5. Bouyancy effect calculations (if applicable)
6. Effects of ballasting plan on pipe pullback forces (if applicable)
7. Hydrofracture analysis

L. Contractor shall provide a plan to locate and protect all adjacent utilities and infrastructure.

M. Submit traffic control plan for all entrance and exit pits.

N. Submit bore logs that clearly indicate the pipe diameter, location (by station), and depth below grade of the installed pipeline, recorded every 10 feet maximum along the pipeline. Submit within 7 days of the completion of each bore.

O. Provide as-built documentation. Contractor shall plot as-built conditions on the field drawings, including the location in plan and elevation of the drill string, reaming head, and installed pipe, at the completion of each production shift. Include on the drawings pipeline horizontal and vertical data recorded every 10 feet along the pipeline or once per joint of drill pipe.

P. Contractor to maintain all testing and quality control documentation and assurance procedures. Contractor to provide the following documents to the Owner:

1. Quality control test reports
2. Fusion reports for each weld as reported by the datalogger

1.05 Utility Locating

A. The Contractor shall be responsible for following the procedures in this specification to identify, locate and verify the presence of existing utilities along the route of the proposed pipeline or work areas.

B. Utility locating will be performed in three parts: identification, designating and verification.

1. Utility Identification – Identify the presence of underground utilities through Florida One Call service and visual observation of surface markers or other indicators such as manholes, valve boxes, fire hydrants, etc.
2. Utility Designation – Marking the location of underground utilities with paint or flags based on utility owner information or third party locating equipment.
3. Utility Verification – Verification of Utility Identification and Designation by excavation or other methods to determine the horizontal and vertical location of the underground utility. This also provides the size and material of the underground utility. Approved methods to accomplish this task include vaccum excavation, potholing, and test holes with traditional equipment (backhoes, etc.)

C. The Contractor shall record the location (horizontal and vertical) of all known utilities, as defined within this specification, on the project documents. At a minimum, utilities shall be located by station and offset from the project baseline or with state plan coordinates. Vertical location can be based on depth from existing grade or elevation using the project vertical datum.

D. The project documents showing all known existing utilities shall be submitted to the Owner's Representative for review and to document, prior to construction, the known utilities within the project limits. The Owner's Representative will have a five (5) working day period to review and approve or comment on the utility locations.

E. The approved project documents showing the existing utilities shall be the basis for changes to the contract as addressed within these specifications.

F. Utilities located and documented as described above then subsequently damaged by the Contractor under this contract will have no basis for claims against the Owner for costs associated with repairs, delays, etc.

G. Damage to existing underground utilities that were not identified by the procedures noted above will be the utility owner's responsibility to repair or replace.

PART 2 PRODUCTS

2.01 Polyethylene Pipe, Fittings and Accessories

A. Polyethylene pipe and fittings 4-30 inch diameter shall be in accordance with AWWA C906, material designation code of PE4710 and all applicable ASTM standards.

B. Polyethylene pipe ½ -3 inch diameter for main line piping shall be polyethylene pipe (not tubing) in accordance with AWWA C901, material designation code of PE4710 and all applicable ASTM standards.

C. Butt fusion fittings shall be made of HDPE material with a minimum material designation code of PE4710 and all applicable ASTM standards. Molded and fabricated fittings shall have a pressure rating equal to the pipe unless otherwise specified on the project documents. All fittings shall meet the requirements of AWWA C901, C906 and all applicable ASTM standards. Markings for molded fittings shall comply with the requirements of ASTM D3261. Fabricated fitting shall be marked in accordance with ASTM F2206. Socket fittings shall meet ASTM D2683. Fabricated fittings shall be manufactured using a McElroy DataLogger to record fusion time, pressure and temperature, and shall be marked with a unique joint identifier that corresponds to the joint report. A graphic representation of the time and pressure data for all fusion joints made producing fittings shall be maintained for a minimum of five years as part of quality control and will be available upon request of owner.

D. Electrofusion fittings shall be made of HDPE material with a minimum material designation code of PE4710 and meet ASTM F1055. Electrofusion fittings shall have a pressure rating equal to the pipe unless otherwise specified on the project documents. All electrofusion fittings shall be suitable for use as pressure conduits and have nominal burst values of four times the working pressure rating of the fitting. Marking of electrofusion fittings shall comply with the requirements of ASTM F1055. All electrofusion fittings shall be properly stored in compliance with the manufacturers recommendation.

E. Saddle fusion could be used to fuse branch saddles, tapping tees and other HDPE fittings onto the wall of the main pipe. Saddle fusion shall be done in accordance with ASTM F2620 or PPI TR-41 or the fitting manufacturer's recommendations. Saddle fusion joints shall be made by qualified fusion technicians. Qualification of the fusion technician shall be demonstrated by evidence of fusion training within the past two years on the equipment to be utilized on this project in accordance with ASTM F3190.

F. Socket fusion could be used to fuse branch saddles, tapping tees and other HDPE fittings onto the wall of the main pipe. Socket fusion shall be done in accordance with ASTM D2683 or the fitting manufacturer's recommendations. Socket fusion joints shall be made by qualified fusion technicians. Qualification of the fusion technician shall be demonstrated by evidence of fusion training within the past two years on the equipment to be utilized on this project in accordance with ASTM F3190. All equipment used for socket fusion should comply with ASTM F1056 and manufacturer's recommendations.

G. Flanges and Mechanical Joint Adapters (MJ) shall have a minimum material designation code of PE4710 and meet all applicable AWWA and ASTM standards. Flanged and MJ adapters can be made to ASTM D3261 or machined in compliance with ASTM F2206. Flanges and MJ adapters shall have a pressure rating equal to the pipe unless otherwise specified on the project documents. Markings for molded or machined flange adapters or MJ adapters shall be per ASTM D3261. Fabricated (including machined) flange adapters shall be marked per ASTM F2206. Installation of all Flanged adapters shall follow the guidelines of the Plastics Pipe Institute TN-38.

H. Glands, bolts, and gaskets shall be manufactured in accordance with AWWA C153. Bolts and nuts shall be grade 2 or higher.

2.02 Pipeline Identification

A. All polyethylene pipe shall be marked in accordance with the standards to which it is manufactured.

B. All polyethylene pipe shall be black, and shall contain a continuous colored stripe, 2 inches wide, located at no greater than 90 degree intervals around the pipe. Stripes shall be impregnated or molded into the pipe by the manufacturer. Application of the stripes after manufacture is not acceptable. Stripe color shall be:

1. Potable Water Mains - blue stripes
2. Reclaimed Water Mains - purple stripes
3. Force Mains - brown stripes
4. Sanitary Sewer - green stripes
5. Storm Sewer - no stripes required

2.03 Tracer Wire

A. Installation of Tracer Wire. The Contractor shall be required to install tracer wire during the horizontal directional drilling operations including along all pits for connections. The tracer wire shall be installed simultaneously with the PE piping system. Tracer wire shall be properly spliced at each end connection and each service connection. Care should be taken to adequately wrap and protect wire at all splice locations. No bare tracer wire shall be accepted. Provide Magnesium alloy anode for cathodic protection that conforms to the requirements of ASTM B843. Install tracer wire per local and manufacturer's requirements. A minimum of three separate tracer wires shall be installed with the Directional Bore. Contractor shall be required to provide as many wires as necessary to maintain continuity throughout the length of the directional bore. Failure of continuous continuity in the locating wire shall result in abandonment and reinstallation of the directional drill, at the discretion of the Owner.

1. Tracer wire shall be three (3) 3/16-inch, 7 x 7 (or stronger) Stranded Copper Clad Steel Extreme Strength with 4,700 lb. break load, or braided stainless steel (A304 or A316), with minimum 50 mil HDPE insulation thickness.

2.04 Drilling Fluids

A. All drilling fluids should be a bentonite slurry mixture with any applicable amendments as determined by the drill operators.

2.05 Delivery, Storage and Handling of Materials

A. Contractor is required to inspect materials delivered to the site for damage. All materials found during inspection or during the progress of work to have cracks, flaws, or other defects shall be rejected and removed from the job site without delay.

B. Contractor is responsible for obtaining, transporting and sorting any fluids, including water, to the work site.

C. Contractor is responsible for disposal of fluids on the project site. The disposal of fluids shall be done in compliance with all permits and applicable federal, state or local environmental regulations. The bentonite drilling slurry may be recycled for reuse in the hole opening operation, or shall be hauled by the Contractor to an approved location or landfill for proper disposal. Contractor shall thoroughly clean the project area or any fluid residue upon completion of installation and replace any and all plants and sod damaged, discolored or stained by drilling fluids.

PART 3 EQUIPMENT

3.01 General

A. The directional drilling equipment shall consist of a directional drilling rig of sufficient capacity to perform the bore and pullback the pipe, a drilling fluid mixing, delivery and recovery system of sufficient capacity to successfully complete the drill, a drilling fluid recycling system to remove solids from the drilling fluid so that the fluid can be re-used, a guidance system to accurately guide boring operations, a vacuum truck of sufficient capacity to handle the drilling fluid volume and trained and competent personnel to operate the system. All equipment shall be in good, safe operating condition with sufficient supplies, materials and spare parts on hand to maintain the system in good working order for the duration of the project.

3.02 Drilling System

A. Drilling Rig – the directional drilling machine shall consist of a power system to rotate, push and pull hollow drill pipe into the ground at a variable angle while delivering a pressurized fluid mixture to a guidable drill (bore) head. The power system shall be self contained with sufficient pressure and volume to power drilling operations. Hydraulic system shall be free of leaks. Rig shall have a system to monitor and record maximum pull-back pressure during pull-back operations. The rig shall be grounded during drilling and pull-back operations. There shall be a system to detect electrical current from the drilling string and an audible alarm which automatically sounds when an electrical current is detected.

B. Drill Head – the drill head shall be steerable by changing its rotation and shall provide the necessary cutting surfaces and drilling fluid jets.

3.03 Guidance System

The guidance system used shall provide real time electronic data to the inspector on request. All daily data and project data shall be displayed on the As-built documentation. The guidance system shall be capable of tracking a depth of 40 feet or 20 feet below design bore path, whichever is greater, and in any soil condition, including hard rock. It shall enable the driller to guide the drill head by providing immediate information on the tool face, azimuth (horizontal direction,) and inclination (vertical direction.) The guidance system shall be accurate to +/- 2% of the vertical depth of the borehole at sensing position at depths up to one hundred feet and accurate within 2 feet horizontally.

The Guidance System shall be of a proven type and shall be operated by personnel trained and experienced with this system. The equipment operator shall be aware of any magnetic anomalies on the surface of the drill path and shall consider such influences in the operation of the guidance system if using a magnetic system.

A. Bore Tracking and Monitoring – at all times during the pilot bore, the Contractor shall provide and maintain a bore tracking system that is capable of accurately locating the position of the drill head in the x, y, and z axes. The Contractor shall record these data at least once per drill pipe length or every twenty-five (25) feet, whichever is more frequent.

B. Downhole and Surface Grid Tracking System – the Contractor shall monitor and record x, y, and z coordinates relative to an established surface survey bench mark.

The data shall be continuously monitored and recorded at least once per drill pipe length or at twenty-five (25) feet, whichever is more frequent.

C. Deviations between the recorded and design bore path shall be calculated and reported on the daily log. If the deviations exceed the allowable tolerances from the design path, such occurrences shall be reported to the Owner. The Contractor shall undertake all necessary measures to correct deviations and return to design line and grade.

D. Drilling Fluid Pressures and Flow Rates – Drilling fluid pressures and flow rates shall be continuously monitored and recorded by the Contractor. The pressures shall be monitored at the pump. These measurements shall be made during pilot bore drilling, reaming and pullback operations.

3.04 Drilling Fluid (Mud) System

A. Mixing System – a self contained, closed, drilling fluid mixing system shall be of sufficient size to mix and deliver drilling fluid. Mixing system shall continually agitate the drilling fluid during operations.

B. Drilling Fluids – drilling fluid shall be composed of clean water, appropriate additives and clay. Water for mixing the drilling fluid shall be potable water, procured by the Contractor. The water and additives shall be mixed thoroughly and be absent of any clumps or clods. Vary the fluid viscosity to best fit the soil conditions encountered. Do not use any other chemicals or polymer surfactants in the drilling fluid without written consent from the Engineer. Certify to the Engineer in writing that any chemicals to be added are environmentally safe and not harmful or corrosive to the facility.

C. Delivery System – the delivery system shall have filters in-line to prevent solids from being pumped into the drill pipe. Connections between the pump and drill pipe shall be relatively leak-free. Used drilling fluid and drilling fluid spilled during drilling operations shall be contained and conveyed to the drilling fluid recycling system. A berm, minimum of 12” high, shall be maintained around drill rigs, drilling fluid mixing system, entry and exit pits and drilling fluid cycling systems to prevent spills into the surrounding environment. Pumps and or vacuum truck(s) of sufficient size shall be in place to convey excess drilling fluid from containment areas to storage and recycling facilities.

D. Drilling Fluid Viscosity – in the event that inadvertent returns or returns loss of drilling fluid occurs during pilot hole drilling operations, the Contractor shall cease drilling, wait at least 30 minutes, inject a quantity of drilling fluid with an appropriate viscosity and then wait another 30 minutes. If mud fracture or returns loss continues, the Contractor shall cease operations and notify the Owner.

E. Drilling Fluid Recycling System – the drilling fluid recycling system shall separate sand, dirt and other solids from the drilling fluid to render the drilling fluid re-usable. Spoils are separated from the drilling fluid will be stockpiled for later use or disposed.

F. Control of Drilling Fluids – the Contractor shall follow all requirements of the proposed work plan and supplemental work plan as submitted and approved and shall control operations pressures, drilling mud weights, drilling speeds and any other operational factors to avoid hydrofracture fluid losses to formations, and control drilling fluid spillage. This includes any spillages or returns at entry and exit pit locations or at any intermediate point. All inadvertent returns or spills shall be promptly contained and cleaned up. The Contractor shall maintain on-site mobile spoil removal equipment during all drilling, pre-reaming and pullback operations and shall be capable of quickly removing spoils. The Contractor shall immediately notify the Owner of any inadvertent returns or spills and immediately contain and clean up the return or spill.

3.05 Other Equipment

A. Pipe Rollers – pipe rollers, if used, shall be of sufficient size to fully support the weight of the pipe while being hydro-tested and during pull back operations. Sufficient number of rollers shall be used to prevent excess sagging of pipe.

3.06 Data Logger

A. A data logger shall be used to record and document all butt fusion process. The data logger must be compatible and outfitted with an electronic data recording device. A digital report or printout for all fusion joints made that complies with, but is not limited to, ASTM F3124 must be delivered to the OWNER upon request and at the completion of the project. All hydraulic fusion must be recorded and able to produce a graphic representation of the time and pressure data. All manual fusion must be recorded with, but not limited to, Joint ID, Operator Name and ID, Pipe information, and Heater Plate Temperature. The recording unit shall be a DataLogger 6 as manufactured by McElroy Manufacturing, Inc, or newer model or approved equivalent.

PART 4 EXECUTION

4.01 General

A. Locate positions of entry and exit pits, establish elevation and horizontal datum for bore head control, and lay out pipe assembly area. Lay out and assemble pipe in a manner that does not obstruct adjacent roads, and commercial or residential activities adjacent to construction areas.

B. Proposed deviations from the bore path due to underground obstructions shall be approved by the Engineer prior to construction.

C. Horizontal and vertical tolerance of the installed bore path from approved bore path shall be within ± 6 inches in the vertical plane and within ± 2 feet in the horizontal plane.

D. The maximum allowable pull load determined during the design calculations for the installed Polyethylene pipe system should not be exceeded. If the maximum observed pull load exceeds the maximum allowable pull load, the Owner may request the drill be re-installed with new Polyethylene pipe at the Contractor's expense.

E. Final acceptance including final payment of directional bored pipelines will not be made until directional bore logs have been submitted and the information on the bore logs documents the depth of the installed pipeline is in accordance with these specifications.

4.02 Directional Drilling

A. The installation of pipeline by directional drilling shall be within the limits indicated on the drawings, unless otherwise approved by the Owner or Engineer.

B. Install erosion control measures and dewater as required.

C. Steering of the bore must be performed with a method approved by the boring equipment manufacturer. Such methods include walkover, wire line, wire line with surface grid and other accepted methods. Use a locating and tracking system capable of ensuring that the proposed installation is installed as intended. The locating and tracking system must provide information on:

1. Clock and pitch information
2. Depth
3. Transmitter temperature
4. Battery status
5. Position (x,y)
6. Azimuth, where direct overhead readings (walkover) are not possible (i.e. subaqueous or limited access transportation facility)

D. Ensure proper calibration of all equipment before commencing drilling operation. Take and record alignment readings or plot points such that elevations on top of and offset dimensions from the center of the product to a permanent fixed feature are provided. Such permanent fixed feature must have prior approval of the Owner or Engineer. Provide elevations and dimensions at all bore alignment corrections (vertical and horizontal) with a minimum distance between points of 20 feet. Provide a sufficient number of elevations and offset distances to accurately plot the vertical and horizontal alignment of the installed product. A minimum of three elevation and plot points are required.

E. The depth of the directional drilling shall be the minimum necessary to prevent surface heave, unless the drawings require the installation to be at deeper depths. Any proposed changes to the depth of the directional bore from what is shown on the drawings must be approved by the Engineer in writing, prior to commencement of drilling. Where utilities cross under department of transportation (DOT) roads, the depth of cover shall comply with any applicable DOT permits.

F. Borings shall be conducted using a mechanical boring head, assisted by and cooled by drilling fluid of low pressure and volume. Material Safety Data Sheets must be provided and approved by the Engineer for all drilling slurry compounds.

G. Back reaming shall be conducted to enlarge and prepare the bore hole for pipe installation. Minimize potential damage from soil displacement or settlement by limiting the ratio of the bore hole to the product size. The size of the back reamer bit or pilot bit, if no back reaming is required, shall be limited relative to the product diameter.

H. Ensure adequate removal of soil cuttings and stability of the bore hole by monitoring the drilling fluids such as the pumping rate, pressures, viscosity and density during the pilot bore, back reaming and pipe installation. Obtain the Engineer's approval of the location and all conditions necessary to construct relief holes to relieve excess pressure and ensure the proper disposition of drilling fluids is maintained.

I. Minimize heaving during pull back. The pull back rate used shall maximize the removal of soil cuttings without building excess down hole pressure. Contain excess drilling fluids at entry and exit points until they are recycled or removed from the site or vacuumed during drilling operations. Entry and exit pits are to be of sufficient size to contain the expected return of drilling fluids and soil cuttings.

J. Ensure that all drilling fluids are disposed of or recycled in a manner acceptable to the appropriate local, state, or federal regulatory agencies. If in the drilling process it becomes evident that the soil is contaminated, contact the Engineer immediately. Do not continue drilling without the Engineer's approval.

K. Install the carrier in the bore hole within the same day that the pre-bore is completed to ensure stability.

4.03 Pipe Joining

A. High density polyethylene pipe shall be heat fused and pressure tested as per manufacturer's guidelines before installation in the bore hole. During assembly and prior to pullback, pipe must be laid out in such a way as to minimize interference to pedestrian and vehicular traffic.

B. Cuts or gouges that reduce the wall thickness by more than 10% are not acceptable and must be cut out, discarded and the pipe rejoined.

C. Each butt fusion shall be recorded and logged by a datalogger affixed to the fusion machine. Joint data shall be submitted as part of the As-built documentation.

D. Mechanical joining – Polyethylene pipe and fittings may be joined together or to other materials by means of flanged connections or mechanical couplings designed for joining polyethylene pipe or for joining polyethylene pipe to another pipe material. Mechanical couplings shall be fully pressure rated and fully thrust restrained and installed in accordance with manufacturer's recommendations.

E. Install required locator wire along polyethylene pipe prior to pulling through bore hole as per these specifications.

F. After pulling pipe, clean exposed ends for installation of fittings, test locator wire for continuity.

4.04 Boring Failure

A. If an obstruction is encountered during boring which prevents completion of the installation in accordance with the drawings and specifications, either remove the pipe or abandon the pipe in place at the discretion of the Engineer.

B. If the pipe cannot be withdrawn and Engineer approves abandoning the pipe in place, cut pipe off at least 3 feet below ground surface, fill annular space and pipe with excavatable flowable fill and cap ends of pipe with blind flange.

C. In the event of failure to install pipe, retain possession of pipe and remove it from the site.

D. Upon approval of the Engineer, fill the abandoned bore hole with excavatable flowable fill.

E. Submit a new installation procedure and revised plans to the Engineer for approval before resuming work at another location.

F. If, during construction, damage is observed to the facility, cease all work until resolution to minimize further damage and a plan of action for restoration is obtained and approved by the Engineer.

G. If the submitted boring logs indicate the installed alignment does not meet vertical or horizontal alignment requirements, the boring is considered a failure, and the directional bored pipeline shall be either re-bored or otherwise remedied at the discretion of the Owner.

4.05 Swabbing

A. The purpose of swabbing a new pipeline is to conserve water while thoroughly cleaning the pipeline of all foreign material, sand, gravel, construction debris and other items not found in a properly cleaned system. Prior to pressure testing of a new pipeline swabbing shall be utilized as specified on the project documents for each project.

B. New water, sewer force and reclaimed mains greater than 12” ID (unless determined otherwise by the Owner) shall be hydraulically cleaned with a polypropylene swabbing device to remove dirt, sand and debris from main.

C. If swabbing access and egress points are not provided in the design drawings, it will be the responsibility of the Contractor to provide temporary access and egress points for the cleaning, as required.

D. Cleaning of the system shall be done in conjunction with, and prior to, the initial filling of the system for its hydrostatic test.

E. The line to be cleaned shall only be connected to the existing distribution system at a single connection point.

F. At the receiver or exit point for the poly swab, the Contractor is responsible for creating a safe environment for collection of debris, water and the swab. Considerations shall be made for protecting surrounding personnel and property and safe retrieval of the swab.

4.06 Testing

A. Disinfection tests

1. All water pipe and fittings shall be thoroughly disinfected prior to being placed in service. Disinfection shall follow the applicable provisions of the procedure established for the disinfection of water mains as set forth in AWWA C651. Bacteriological testing on the water main shall be scheduled, completed and sent for water analysis (lab testing.) The results of the lab testing shall be sent to the Owner. No pipeline shall be placed into service until it is properly disinfected and water analysis proves it is disinfected.

2. Temporary blow-offs shall be installed for the purpose of cleaning the water main. Temporary blow-offs shall be removed and plugged after the main is cleared. The main shall be flushed prior to disinfection.

3. The new water main shall be connected to the existing water main at one point only for flushing purposes. The new main MUST have a blow off on the end as required. After the new main is thoroughly flushed, the open end shall be sealed and restrained and the main shall be thoroughly disinfected.

B. Pressure and Leakage tests

1. Conduct hydrostatic pressure testing of installed polyethylene pipe in accordance with ASTM F2164.

2. For HDPE mains, fill the main slowly ensuring fill rate does not exceed capacity of air release devices. Once air has been expelled from the system, gradually raise the pressure to 160 psi. Add makeup water as necessary to maintain this pressure as necessary for 4 hours. After the 4 hour period, reduce main pressure to the 150 psi test pressure and monitor for 1 hour. Do not increase pressure or add makeup water during this one hour period. The test is passed and considered acceptable if the main pressure does not drop more than 5% (7.5 psi) during the one hour period.

3. If any defects or leaks are revealed, they should be corrected and the pipeline retested after a minimum 24 hour recuperation period between tests. Total testing conducted on a section of pipeline shall not exceed 8 hours within a 24 hour period.

4.07 Disposal of Surplus Fluids

A. All drill fluid excess shall be contained in entry and/or exit pits and pumped as needed into additional on-site storage tanks, tanker trucks, vacuum trucks, etc. Dispose of excess drill fluid offsite as allowed by local rules and regulations.

B. Dispose of all material not needed or not suitable for backfilling over or around the entry and receiving pits. The disposal shall be subject to local codes and regulations.

4.08 Restoration

After extraction, drill fluids, pits, work areas, staging and storage areas are to be restored to equal or better condition than pre-construction condition.

END OF SECTION

SECTION 02410

POTABLE WATER PIPE BURSTING

PART 1 GENERAL

1.01 Scope of Work

The work specified in this section consists of furnishing and installing underground water mains using the pipe bursting method of installation for pipes of various sizes. This work shall include all services, equipment, materials, and labor for the complete and proper installation, testing, and restoration of underground water mains and environmental protection and restoration.

The pipe bursting method will repeat the method, outlined below for each section of pipe being replaced. These processes may be performed in series or in parallel with other sections of pipe within the job; however each section will require these steps. The outline below of the process does not dictate the means and methods of the Contractor but provides an overview of the pipe bursting process.

1. Deliver notice of service outage to each affected property Owner in advance of work
2. Chlorinate a length of product pipe that yields passing bacteriological test results for potable water per American Water Works Association (AWWA) and any applicable regulatory authority
3. Perform hydrostatic test of the product pipe section
4. Excavate a machine pit at one end of the section down to pipe grade for placement of the pipe bursting equipment
5. Excavate an insertion pit at the opposite end of the section down to pipe grade for entry of the product pipe
6. Excavate service connection pits
7. Isolate the section to be rehabilitated from the rest of the system to maintain pressure integrity of the system as well as preventing any backflow of chlorinated solution or non-potable water into the system
8. Excavate and remove hydrant tees and valve tees from the host pipe
9. Assemble the rod string as it is thrust through the host pipe from machine pit to insertion pit
10. Burst tooling and product pipe attached to rod end at insertion pit
11. Pull back and disassemble rod string simultaneously while tooling and product pipe travels from insertion pit to machine pit
12. Install service connections to the newly installed mains
13. Super-chlorinate main for 15 minutes to 300 ppm, de-chlorinate the residual chlorine when flushing and flush the newly installed main with potable water
14. Inspect for leaks at new connections
15. Perform final connection of the replaced section of pipe to the system

It should be noted that items “4” through “15” can be accomplished within a single ten hour day if the need for temporary services is to be eliminated. The length of pipe to be burst per run should be chosen to conform to this time frame. Items “4” though “6” (excavation items) may be performed in advance of the bursting operations to expedite the process.

1.02 Contractor Qualifications

A. Contractor (or Sub-Contractor) shall provide documented evidence of successful installation of pipe through the pipe bursting method for work comparable in nature to the scope of work required by this project for a minimum of two years.

B. Contractor (or Sub-Contractor) to have successfully self-performed at least (5) pipe bursting projects to install product pipe of a similar nominal diameter and length to the proposed project within the past two years. Owner and Engineer shall have the sole authority to determine the adequacy of the representative projects.

C. Contractor’s (or Sub-Contractor’s) project manager, superintendent, and pipe bursting machine operator assigned to pipe bursting shall be experienced in work of this nature shall have successfully completed projects similar in nature and shall have successfully completed similar projects using pipe bursting. Contractor (or Sub-Contractor) shall submit substantiating evidence of qualifications with the bid submittal documents.

D. All pipe bursting equipment operators shall be experienced in comparable pipe bursting work, and shall have been fully trained in the use of the proposed equipment by an authorized representative of the equipment manufacturer(s) or their authorized training agents.

E. All high density polyethylene (HDPE) fusion equipment operators shall be qualified to perform pipe joining using the means, methods and equipment employed by the Contractor. Fusion equipment operators must possess and be able to provide written validation (card or certificate) of current, formal training on all fusion equipment employed on the project, including training and proper use of the data logging device on the equipment. Training received more than two years prior to operation of the fusion equipment shall not be considered current.

1.03 Referenced Standards

A. American Water Works Association (AWWA) latest edition:

1. AWWA C622 – Pipe Bursting of Potable Water Mains 4 In. (100 mm) to 36 In. (900 mm)
2. AWWA C651 – Disinfecting Water Mains
3. AWWA C901 – Polyethylene Pressure Pipe and Tubing, ½ Inch Through 3 Inch for Water Service

4. AWWA C906 – Polyethylene Pressure Pipe and Fittings, 4 Inch Through 63 Inch for Water Distribution and Transmission

B. American Society of Civil Engineers (ASCE) – Manual of Practice 112 – Pipe Bursting Projects

C. American Society for Testing and Materials (ASTM) latest edition:

1. ASTM D638 – Tensile Method for Tensile Properties of Plastics
2. ASTM D790 – Test Materials for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
3. ASTM D2122 – Standard Method of Determining Dimensions of Thermoplastics Pipe and Fittings
4. ASTM D2239 – Standard Specification for Polyethylene (PE) Plastic Pipe (SIDR-PR) Based on Controlled Inside Diameter
5. ASTM D2657 – Practice for Heat-Joining of Polyolefin Pipe and Fittings
6. ASTM D2683 – Standard Specification for Socket Type Polyethylene Fittings for Outside Diameter-Controlled Polyethylene Pipe and Tubing
7. ASTM D2774 – Standard Practice for Underground Installation of Thermoplastic Pressure Piping
8. ASTM D2837 – Standard Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products
9. ASTM D3035 – Polyethylene (PE) Plastic Pipe (DR-PE) Based on Controlled Outside Diameter
10. ASTM D3261 – Butt Heat Fusion Polyethylene (PE) Plastic Fittings for Polyethylene (PE) Plastic Pipe and Tubing
11. ASTM D3350 – Polyethylene Plastic Pipe and Fittings Material
12. ASTM F412 – Standard Terminology Relating to Plastic Piping Systems
13. ASTM F714 – Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter
14. ASTM F905 – Standard Practice for Qualification of Polyethylene Saddle-Fused Joints
15. ASTM F1055 – Standard Specification for Electrofusion Type Polyethylene Fittings for Outside Diameter Controlled Polyethylene Pipe and Tubing
16. ASTM F1056 – Standard Specification for Socket Fusion Tools for Use in Socket Fusion Joining Polyethylene Pipe or Tubing and Fittings
17. ASTM F1290 – Standard Practice for Electrofusion Joining Polyolefin Pipe and Fittings
18. ASTM F2164 – Field Leak Testing of Polyethylene (PE) Pressure Piping Systems Using Hydrostatic Pressure
19. ASTM F2206 – Fabricated Fittings for Butt-Fused Polyethylene Plastic Pipe
20. ASTM F2620 – Standard Practice for Heat Fusion Joining of Polyethylene Pipe and Fittings

21. ASTM F2786 – Standard Practice for Field Leak Testing of Polyethylene (PE) Pressure Piping Systems Using Gaseous Testing Media Under Pressure (Pneumatic Leak Testing)
22. ASTM F3124 – Standard Practice for Data Recording the Procedure used to Produce Heat Butt Fusion Joints
23. ASTM F3190 – Standard Practice for Heat Fusion Equipment (HFE) Operator Qualifications on Polyethylene (PE) and Polyamide (PA) Pipe and Fittings

C. North American Society for Trenchless Technology (NASTT) latest edition:
1. NASTT's Pipe Bursting Good Practices Guidelines – 3rd Edition

D. Plastics Pipe Institute (PPI) latest edition:
1. The Plastics Pipe Institute Handbook of Polyethylene Pipe – Chapter 16 Pipe Bursting
2. PPI – TN-36 – General Guidelines for Connecting HDPE Potable Water Pressure Pipes to DI and PVC Piping Systems
3. PPI – TN-38 – Bolt Torque for Polyethylene Flanged Joints
4. PPI – TN-44 – Long Term Resistance of AWWA C906 Polyethylene (PE) Pipe to Potable Water Disinfectants
5. PPI – TN-45 – Mechanical Couplings for Joining Polyethylene Pipe
6. PPI – TN-46 – Guidance for Field Hydrostatic Testing of High Density Polyethylene Pressure Pipelines: Owner's Considerations, Planning, Procedures, and Checklists
7. PPI – TN-49 – Recommendations for AWWA C901 Service Tubes in Potable Water Applications
8. PPI – TN-54 – General Guidelines for Squeezing Off Polyethylene Pipe in Water, Oil and Gas Applications

E. Plastics Pipe Institute (PPI) Municipal Advisory Board (MAB)
1. MAB Generic Electrofusion Procedure for Field Joining of 12 Inch and Smaller Polyethylene (PE) Pipe
2. MAB Generic Electrofusion Procedure for Field Joining of 14 Inch to 30 Inch Polyethylene (PE) Pipe
3. MAB Model Specifications for PE 4710 Buried Potable Water Service, Distribution and Transmission Pipes and Fittings
4. MAB Guidelines for PE 4710 Pipe Bursting of Potable Water Mains

1.04 Submittals

A. Contractor shall submit personnel information detailing the names and resumes, including specific project experience, for the proposed project manager, superintendent, and pipe bursting equipment operator proving that the experience meets the requirements detailed in this specification.

B. Contractor shall submit personnel information, including specific project experience, for all proposed pipe bursting equipment operators, including evidence of training in the use of the proposed equipment by an authorized representative of the equipment manufacturer or their qualified agent.

C. Contractor to submit a plan to the Owner on a marked-up copy of the project documents showing the Contractor's construction phasing and plans. Plan details shall include the following:

1. Pit locations for machine pit and insertion pit
2. Pit locations for service connection pits
3. Burst schedule detailing which locations are to be replaced
4. Lengths of each section to be burst
5. Isolation points to be used to seal the system during pipe bursting
6. Location of temporary services or pre-chlorination guidelines
7. Staging area to be used for fusion and material storage
8. Pipe bursting equipment information to be used on the project such as tonnage and tooling
9. Shoring system to be used with the bursting equipment
10. Risk management plan
11. Tracer wire to be used

D. Submit pipe catalog information confirming that pipe, fittings, joints, and other materials conform to the requirements of the specifications.

E. Submit pipe manufacturer's most current calculations regarding tensile load limitations for trenchless installations.

F. Provide information showing staging and pipe fusion areas, site access during work activities, pipe storage and handling and procedure for pipe joining.

G. Contractor shall provide a plan to locate and protect all adjacent utilities and infrastructure.

H. Submit traffic control plan for all entrance and exit pits.

I. Provide as-built documentation. Contractor shall plot as-built conditions on the field drawings, including the location of pits and service connections at the completion of each production shift.

J. Contractor to maintain all testing and quality control documentation and assurance procedures. Contractor to provide the following documents to the Owner:

1. Quality control test reports
2. Fusion reports for each weld as reported by the datalogger

1.05 Utility Locating

A. The Contractor shall be responsible for following the procedures in this specification to identify, locate and verify the presence of existing utilities along the route of the proposed pipeline or work areas.

B. Utility locating will be performed in three parts: identification, designating and verification.

1. Utility Identification – Identify the presence of underground utilities through Florida One Call service and visual observation of surface markers or other indicators such as manholes, valve boxes, fire hydrants, etc.
2. Utility Designation – Marking the location of underground utilities with paint or flags based on utility owner information or third party locating equipment.
3. Utility Verification – Verification of Utility Identification and Designation by excavation or other methods to determine the horizontal and vertical location of the underground utility. This also provides the size and material of the underground utility. Approved methods to accomplish this task include vacuum excavation, potholing, and test holes with traditional equipment (backhoes, etc.)

C. The Contractor shall record the location (horizontal and vertical) of all known utilities, as defined within this specification, on the project documents. At a minimum, utilities shall be located by station and offset from the project baseline or with state plan coordinates. Vertical location can be based on depth from existing grade or elevation using the project vertical datum.

D. The project documents showing all known existing utilities shall be submitted to the Owner's Representative for review and to document, prior to construction, the known utilities within the project limits. The Owner's Representative will have a five (5) working day period to review and approve or comment on the utility locations.

E. The approved project documents showing the existing utilities shall be the basis for changes to the contract as addressed within these specifications.

F. Utilities located and documented as described above then subsequently damaged by the Contractor under this contract will have no basis for claims against the Owner for costs associated with repairs, delays, etc.

G. Damage to existing underground utilities that were not identified by the procedures noted above will be the utility owner's responsibility to repair or replace.

PART 2 PRODUCTS

2.01 Polyethylene Pipe, Fittings and Accessories

A. Polyethylene pipe and fittings 4-30 inch diameter shall be in accordance with AWWA C906, material designation code of PE4710 and all applicable ASTM standards.

B. Polyethylene pipe ½ -3 inch diameter for main line piping shall be polyethylene pipe (not tubing) in accordance with AWWA C901, material designation code of PE4710 and all applicable ASTM standards.

C. Butt fusion fittings shall be made of HDPE material with a minimum material designation code of PE4710 and all applicable ASTM standards. Molded and fabricated fittings shall have a pressure rating equal to the pipe unless otherwise specified on the project documents. All fittings shall meet the requirements of AWWA C901, C906 and all applicable ASTM standards. Markings for molded fittings shall comply with the requirements of ASTM D3261. Fabricated fitting shall be marked in accordance with ASTM F2206. Socket fittings shall meet ASTM D2683. Fabricated fittings shall be manufactured using a McElroy DataLogger to record fusion time, pressure and temperature, and shall be marked with a unique joint identifier that corresponds to the joint report. A graphic representation of the time and pressure data for all fusion joints made producing fittings shall be maintained for a minimum of five years as part of quality control and shall be available upon request of owner.

D. Electrofusion fittings shall be made of HDPE material with a minimum material designation code of PE4710 and meet ASTM F1055. Electrofusion fittings shall have a pressure rating equal to the pipe unless otherwise specified on the project documents. All electrofusion fittings shall be suitable for use as pressure conduits and have nominal burst values of four times the working pressure rating of the fitting. Marking of electrofusion fittings shall comply with the requirements of ASTM F1055. All electrofusion fittings shall be properly stored in compliance with the manufacturers recommendation.

E. Saddle fusion could be used to fuse branch saddles, tapping tees and other HDPE fittings onto the wall of the main pipe. Saddle fusion shall be done in accordance with ASTM F2620 or PPI TR-41 or the fitting manufacturer's recommendations. Saddle fusion joints shall be made by qualified fusion technicians. Qualification of the fusion technician shall be demonstrated by evidence of fusion training within the past two years on the equipment to be utilized on this project in accordance with ASTM F3190.

F. Socket fusion could be used to fuse branch saddles, tapping tees and other HDPE fittings onto the wall of the main pipe. Socket fusion shall be done in accordance with ASTM D2683 or the fitting manufacturer's recommendations. Socket fusion joints shall be made by qualified fusion technicians. Qualification of the fusion technician shall be demonstrated by evidence of fusion training within the past two years on the equipment to be utilized on this project in accordance with ASTM F3190. All equipment used for socket fusion should comply with ASTM F1056 and manufacturer's recommendations.

G. Flanges and Mechanical Joint Adapters (MJ) shall have a minimum material designation code of PE4710 and meet all applicable AWWA and ASTM standards. Flanged and MJ adapters can be made to ASTM D3261 or machined in compliance with ASTM F2206. Flanges and MJ adapters shall have a pressure rating equal to the pipe unless otherwise specified on the project documents. Markings for molded or machined flange adapters or MJ adapters shall be per ASTM D3261. Fabricated (including machined) flange adapters shall be marked per ASTM F2206. Installation of all Flanged adapters shall follow the guidelines of the Plastics Pipe Institute TN-38.

H. Glands, bolts, and gaskets shall be manufactured in accordance with AWWA C153. Bolts and nuts shall be grade 2 or higher.

2.02 Pipeline Identification

A. All polyethylene pipe shall be marked in accordance with the standards to which it is manufactured.

B. All polyethylene pipe shall be black, and shall contain a continuous colored stripe, 2 inches wide, located at no greater than 90 degree intervals around the pipe. Stripes shall be impregnated or molded into the pipe by the manufacturer. Application of the stripes after manufacture is not acceptable. Stripe color shall be:

1. Potable Water Mains - blue stripes

2.03 Tracer Wire

A. Installation of Tracer Wire. The Contractor shall be required to install tracer wire during the pipe bursting operations including along all pits for connections. The tracer wire shall be installed simultaneously with the PE piping system. Tracer wire shall be properly spliced at each end connection and each service connection. Care should be taken to adequately wrap and protect wire at all splice locations. No bare tracer wire shall be accepted. Provide Magnesium alloy anode for cathodic protection that conforms to the requirements of ASTM B843. Install tracer wire per local and manufacturer's requirements. A minimum of three separate tracer wires shall be installed with the pipe bursting activities. Contractor shall be required to provide as many wires as necessary to maintain continuity throughout the length of the pipe bursting activity. Failure of continuous continuity in the locating wire shall result in abandonment and reinstallation of the pipe bursting activity, at the discretion of the Owner.

1. Tracer wire shall be three (3) 3/16-inch, 7 x 7 (or stronger) Stranded Copper

Clad Steel Extreme Strength with 4,700 lb. break load, or braided stainless steel (A304 or A316), with minimum 50 mil HDPE insulation thickness.

PART 3 EQUIPMENT

3.01 General

A. The pipe bursting equipment shall consist of a pipe bursting unit that is capable of generating sufficient force to burst and compact the existing pipe fragments into the surrounding soil while pulling in the replacement pipe and trained and competent personnel to operate the system. All equipment shall be in good, safe operating condition with sufficient materials and spare parts on hand to maintain the system in good working order for the duration of the project.

3.02 Other Equipment

A. Pipe Rollers – pipe rollers, if used, shall be of sufficient size to fully support the weight of the pipe while being hydro-tested and during pull back operations. Sufficient number of rollers shall be used to prevent excess sagging of pipe.

3.03 Data Logger

A. A data logger shall be used to record and document all butt fusion process. The data logger must be compatible and outfitted with an electronic data recording device. A digital report or printout for all fusion joints made that complies with, but is not limited to, ASTM F3124 must be delivered to the OWNER upon request and at the completion of the project. All hydraulic fusion must be recorded and able to produce a graphic representation of the time and pressure data. All manual fusion must be recorded with, but not limited to, Joint ID, Operator Name and ID, Pipe information, and Heater Plate Temperature. The recording unit shall be a DataLogger 6 as manufactured by McElroy Manufacturing, Inc, or newer model or approved equivalent.

PART 4 EXECUTION

4.01 General

A. Locate positions of machine and insertion pits and lay out pipe assembly area. Lay out and assemble pipe in a manner that does not obstruct adjacent roads, and commercial or residential activities adjacent to construction areas.

B. Temporary water service connections shall be provided, if the pre-chlorination process is not used with an acceptable pre-determined outage period. The Contractor is to use a temporary bypass line comprised of large enough diameter polyethylene pipe above ground to provide service to existing connections. The above ground polyethylene pipe is to be protected by Contractor at all times.

4.02 Pipe Joining

A. High density polyethylene pipe shall be heat fused and pressure tested as per manufacturer's guidelines before installation in the bore hole. During assembly and prior to pullback, pipe must be laid out in such a way as to minimize interference to pedestrian and vehicular traffic.

B. Cuts or gouges that reduce the wall thickness by more than 10% are not acceptable and must be cut out, discarded and the pipe rejoined.

C. Each butt fusion shall be recorded and logged by a datalogger affixed to the fusion machine. Joint data shall be submitted as part of the As-built documentation.

D. Mechanical joining – Polyethylene pipe and fittings may be joined together or to other materials by means of flanged connections or mechanical couplings designed for joining polyethylene pipe or for joining polyethylene pipe to another pipe material. Mechanical couplings shall be fully pressure rated and fully thrust restrained and installed in accordance with manufacturer's recommendations.

E. Install required locator wire along polyethylene pipe prior to pulling through bore hole as per these specifications.

F. After pulling pipe, clean exposed ends for installation of fittings, test locator wire for continuity.

4.03 Swabbing (if Pre-chlorination is approved, see Section 4.05)

A. The purpose of swabbing a new pipeline is to conserve water while thoroughly cleaning the pipeline of all foreign material, sand, gravel, construction debris and other items not found in a properly cleaned system. Prior to pressure testing of a new pipeline swabbing shall be utilized as specified on the project documents for each project.

B. New water mains greater than 12" ID (unless determined otherwise by the Owner) shall be hydraulically cleaned with a polypropylene swabbing device to remove dirt, sand and debris from main.

C. If swabbing access and egress points are not provided in the design drawings, it will be the responsibility of the Contractor to provide temporary access and egress points for the cleaning, as required.

D. Cleaning of the system shall be done in conjunction with, and prior to, the initial filling of the system for its hydrostatic test.

E. The line to be cleaned shall only be connected to the existing distribution system at a single connection point.

F. At the receiver or exit point for the poly swab, the Contractor is responsible for creating a safe environment for collection of debris, water and the swab. Considerations shall be made for protecting surrounding personnel and property and safe retrieval of the swab.

4.04 Testing (if Pre-chlorination is approved, see Section 4.05)

A. Disinfection tests

1. all water pipe and fittings shall be thoroughly disinfected prior to being placed in service. Disinfection shall follow the applicable provisions of the procedure established for the disinfection of water mains as set forth in AWWA C651. Bacteriological testing on the water main shall be scheduled, completed and sent for water analysis (lab testing.) The results of the lab testing shall be sent to the Owner. No pipeline shall be placed into service until it is properly disinfected and water analysis proves it is disinfected.
2. Temporary blow-offs shall be installed for the purpose of cleaning the water main. Temporary blow-offs shall be removed and plugged after the main is cleared. The main shall be flushed prior to disinfection.
3. The new water main shall be connected to the existing water main at one point only for flushing purposes. The new main MUST have a blow off on the end as required. After the new main is thoroughly flushed, the open end shall be sealed and restrained and the main shall be thoroughly disinfected.

B. Pressure and Leakage tests

1. Conduct hydrostatic pressure testing of installed polyethylene pipe in accordance with ASTM F2164.
2. For HDPE mains, fill the main slowly ensuring fill rate does not exceed capacity of air release devices. Once air has been expelled from the system, gradually raise the pressure to 160 psi. Add makeup water as necessary to maintain this pressure as necessary for 4 hours. After the 4 hour period, reduce main pressure to the 150 psi test pressure and monitor for 1 hour. Do not increase pressure or add makeup water during this one hour period. The test is passed and considered acceptable if the main pressure does not drop more than 5% (7.5 psi) during the one hour period.
3. If any defects or leaks are revealed, they should be corrected and the pipeline retested after a minimum 24 hour recuperation period between tests. Total testing conducted on a section of pipeline shall not exceed 8 hours within a 24 hour period.

4.05 Pre-chlorination of Product Pipe (replaces Swabbing and Testing sections above)

Chlorination of pipes prior to bursting shall be carried out per ANSI/AWWA C651-99 Standard for Disinfecting Water Mains and in cooperation with the Owner. Any information here shall facilitate that method when performed on pipes not yet placed on grade. In general, the method includes the following:

A. Disinfect all equipment, tools, end caps, pipe fittings or product that may contact pipe.

B. Disinfection shall be carried out by immersing or rinsing items in a hypochlorus solution containing 1 to 5 percent chlorine measured by weight.

C. Product pipe shall be fused into a string of sufficient length to complete the designated section or be coiled in a manner suitable for delivery on a pipe reel. Maximum allowable length is 800 feet.

D. The surface upon which the product pipe rests during chlorination shall be relatively impervious and free from visible contamination. Coiled pipe must be laid horizontally to allow all air to be expelled.

E. Swabbing, chlorination and testing of the inside diameter of the pipe shall be accomplished by the following:

1. Swab being inserted at the lowest end of the pipe.
2. Calcium Hypochlorite tablets or granules as described in Section 02510 shall be placed behind the swab
3. Pressure tight end cap shall be mounted to the low end of the pipe either by fusing or mechanically assembled to the pipe.
4. Potable water shall be introduced through this end cap at a controlled rate such that the swab is propelled at a velocity less than or equal to one foot per second. All air is to be dispelled from the pipe.
5. Upon discharge of the swab from the elevated end of the pipe, the elevated end shall be capped with a pressure tight seal. This seal having a tapped access hole of size at least 1.25" NPT or incorporating the ability to leak (purge) air or water at will by adjustment of clamping bolts. Additional potable water should be added after capping to ensure that no air remains between the caps.
6. Pressure testing of the pipe section should be performed per this specification.
7. Chlorinated solution should be maintained in the pipe for a minimum of 24 hours prior to flushing when water temperature is above 41 ºF (5ºC), 48 hours when water temperature is 41ºF (5ºC) or less. Time for retention of the chlorinated solution shall not be significantly over designated holding time so as to prevent damage to the pipe or end caps.
8. After designated holding time, the pipe shall be drained, flushed and filled with potable water so as to expel the highly chlorinated solution. The spent chlorinated solution shall not be allowed to enter any water shed, a sanitary sewer or any other area where environmental damage may occur without neutralizing it in an industry acceptable manner. Flushing water shall be from a source known to be of drinking water standard.

9. Test samples shall be taken from each end of the pipe on consecutive days, 24 hours apart. Samples shall be tested by a state certified lab within 30 hours of being taken.
10. Failure of any sample to pass a bacteriological test should result in the related section of pipe being re-flushed and retested. Should any sample again fail, the section must be chlorinated before retest.
11. Time before re-connection of a passing pipe section shall be limited to 14 days from the last sampling. After this time the pipe must be retested to be acceptable for use.
12. Drain the section of pipe prior to pipe bursting. The pipe shall be drained on the day of the pipe bursting, and sealed after draining and for the pipe bursting process.
13. Swabs should be designated by the manufacturer as suitable for potable water system use. Swabs are to be manufactured by Knapp Industries or be of equivalent design.

4.06 Pipe Bursting

A. The pipe bursting operation described within provides guidance on the basic process. It is to be understood that the need to make exceptions or additions to this process are common. These changes are made to accommodate nonstandard conditions. The contractor experience requirements make it reasonable to put the responsibility of devising these exceptions upon the Contractor.

B. Pit Location and Excavation

1. Machine pit and insertion pit locations shall be placed such that excavations are minimized. This may be accomplished by placing either or both of these pits at the point of service connection, valve or hydrant location.
2. Initial burst lengths shall be 400 feet (+/-) 50 feet in length for first two bursts to determine soil pipe friction and specific site conditions that may impact bursting lengths. After site specific factors are evaluated, longer burst runs may be performed.
3. All pits shall be shored to ensure worker safety per OSHA or other local regulations.
4. All pits shall be roped off and or covered when not active per OSHA or local regulations to ensure public safety.
5. Traffic control shall be accommodated for by Contractor as per the Contract specifications. Safe traffic passage around pit excavations that are located in or adjacent to streets or highways shall meet Right-of-way Department requirements. Parking of related employee vehicles, trucks and auxiliary and equipment shall be such that congestion and traffic delays are minimized.
6. Utilities intersecting the existing pipe shall be exposed using an excavation technique appropriate for the utility. As a general rule, both horizontal and vertical distance between the pipe to be burst and the existing adjacent pipe

should be at least two diameters of the replacement pipe. If adjacent utilities are within this area, or the adjacent utility location is unknown, the excavation (Utility Crossing Pit) shall be excavated prior to commencement of bursting. Worker entry shoring is not required, except as determined by OSHA, however appropriate safety precautions should be made.

C. Pipe Bursting Machine Location and Shoring: Bursting machines of the static pull style require preparation and planning for the machine pit that they are to operate from.

1. Forward face of the machine pit or the surface that the machine bears against while pulling back, shall be shored in a safe manner. This shoring shall maintain perpendicular burst machine alignment to the pipe during pullback. Any loss of perpendicular alignment during pull shall result in stopping of the bursting process and improvement of the forward face shoring.
2. Rearward shoring shall be provided to react rod thrust forces during payout. While these forces are substantially lower than pullback forces, shoring must be used to stabilize the bursting machine so as to maintain perpendicular alignment of the machine during payout. The weight of the machine cannot be depended on to react thrust forces. Existing pipe at rear face of pit may only be utilized for rearward shoring if scheduled for replacement.
3. Pipe face for Cast Iron, Ductile Iron or PVC shall be cut off using a saw or similar device to produce a square face for the bursting machine forward face to bear against. Final separation of cast iron pipe with a wedge may provide a clean face. Existing pipe shall be removed in sufficient length to accommodate pipe burst machine.
4. Pipe burst machine must be positioned so as to have rod centerline at approximate centerline of existing pipe.
5. Rod box delivery and removal between temporary rod storage location and burst pit must be accommodated for with appropriate lifting equipment and techniques. Additionally, movement and or placement of lifting machine must be included in traffic control plans.

D. Rod Payout Operation

1. Rod payout is the process of assembling a string of rods and pushing them in a step wise manner from machine pit, through the interior of the existing pipe to insertion pit.
2. Lifting of rod boxes into or out of the machine pit shall be performed per OSHA or other applicable requirements with respect to equipment and method.
3. Threads shall be cleaned of foreign matter before assembly.

4. Counting of rods during payout, or quantity of rods per box shall be monitored such that the equipment operator is aware of the distance between the burst machine and the lead end of the rod string.
5. Thrust force should be monitored by the operator. Should an unexpected sudden and significant increase in thrust force be experienced, the process shall be halted. The operator or Contractor shall review the results with the Owner to remedy in an attempt to determine if offsets, valves or other features or obstruction exist that may cause the rod string to leave the pipe.
    a. Front end of the rod string should be located by distance from the machine pit. Location should be painted and compared to as built documents.
    b. Appropriate action should be taken to remedy the cause. This action may include an additional pit at the obstruction to determine the cause, and remove or accommodate for the obstruction. The Contractor shall follow the process provided in the approved Risk Management Plan.
6. Existing pipe in the insertion pit shall be cut or broken prior to arrival of the rod string. Sufficient length shall be removed so as to allow the burst tooling to enter the existing pipe and bend the product within the allowable radius specified by the pipe manufacturer. The second end of the existing pipe in the insertion pit shall be positioned or worked so as not to damage the product pipe as it travels through the insertion pit.
7. Workmen shall not enter the insertion pit when the rod string is nearing the pit. A workman shall be in visual or radio contact with the burst machine operator so as to have the payout halted in a position that allows attachment of the burst tooling. Burst tooling style shall be chosen based on anticipated properties of existing pipe and existing pipe repairs.
    a. Cast iron or asbestos cement existing pipe anticipated to be free of either ductile repair sections or dressor style couplings may use a simple conical burst head with a single or double longitudinal blade.
    b. Ductile iron, PVC or existing pipe with ductile iron repair sections or dressor style couplings require use of a rolling blade cutter (slitter) ahead of the conical expander.

E. Tooling and Attachment

1. The new polyethylene pipe shall be moved into position for attachment to the rod string. Appropriate traffic or pedestrian control will be exercised along the path of the polyethylene pipe.
2. The lead and second rod shall be painted orange or yellow so as to give notice to the burst machine operator position of the burst tooling.
3. Attachment of the burst tooling to the rod shall be through the use of removable pin joint allowing the tooling to pivot to the rod axis.
4. Burst head diameter will be on average 15% over size to the outside diameter of the new polyethylene pipe. Actual size is left to the discretion

of the Contractor. A greater outside diameter allows for reduced pipe friction but increases bursting forces with increased soil displacement.

5. Attachment of the polyethylene pipe to the burst tooling shall be with a swivel that permits rotation to relieve torsional (twist) stress on the polyethylene pipe.
6. Burst head shall slide on the rod string such that the rear of the burst head overlaps the forward end of the polyethylene pipe to eliminate the chance of damage to the polyethylene pipe.

F. Pullback Operation

1. The burst machine operator will begin the pullback with the approval of the insertion pit observer. Progress will be made at a slow rate until the observer sees the burst tooling has completely entered the existing pipe.
2. As the burst tooling nears any utility crossing pit, an observer in radio or visual contact with the burst machine operator will monitor and control movement of the burst tooling past the utility.
3. Should the forward shoring upon which the bursting machine bears yield sufficiently to bring the bursting machine out of square to the existing pipe, the shoring will be reworked.

G. Tooling Removal

1. Burst machine operator shall note rod count and anticipate entry of painted rods into the burst pit. As the pin joint connection nears the burst machine forward face, the burst is to be halted. Load on the forward face is relieved by reversing the rod direction slightly.
2. The burst machine shore plate is to be removed, allowing the tooling to enter a cage or the hull of the burst machine. The tooling string will be disassembled and removed, in sections if necessary until the product pipe face has been pulled beyond the face of the machine pit. The distance past the face of the machine pit shall be at the discretion of the Contractor anticipating the length required for connection/fusing.

4.07 Reinstating Service Connections

Upon completion of the pipe bursting, certain tasks must be followed through in order to complete the overall process.

A. Maintaining sanitary conditions within the product pipe after pipe bursting must take high priority. Should any foreign matter, including ground water be allowed to enter the pipe interior, the condition of the pipe is no longer suitable for connection to the system. For this reason connections may not be made in standing water. Such water must be pumped or bailed prior to making the connection or unsealing the pipe. Areas under connections should be excavated below the pipe invert.

B. Before joining a surface and before any special surface preparation to accommodate that joining, external surfaces should be clean and dry. Dust may be removed by wiping with clean, lint free cloth. Heavier deposits must be washed from the surface with soap and water and dried with a clean, lint free cloth.

C. Incidental exposure of the interior of the pipe to any foreign matter shall require that one of the two following remedies be carried out:

1. Complete chlorination per AWWA specifications for buried pipe and specifications.
2. Localized contamination at the end of the pipe may be removed and the contaminated interior surface of the pipe wiped with a solution of 1 to 5% hypochlorite disinfecting solution.

D. Service taps shall be of a type approved by the Engineer and must meet AWWA C906. Construction of taps shall be per the manufacturer's recommendation and section T2.06.

E. Replacement or rehabilitation of service lines, if required, shall be according to contract.

F. Post-chlorination: The section of main will be super-chlorinated to 300 ppm by inserting a swab at one end. The swab shall travel the entire length of the pipe section.

G. Service Reinstatement: Prior to connection of the newly installed pipe, the section of pipe shall be fully flushed with the use of a de-chlorination unit and ascorbic acid to neutralize the residual chlorine. Following flushing, the newly installed section may be connected to the main at both ends and service reinstated.

4.08 Restoration

After completion of the pipe bursting operation work areas, staging and storage areas are to be restored to equal or better condition than pre-construction condition.

END OF SECTION

SECTION 02515

HIGH DENSITY POLYETHYLENE PIPE AND FITTINGS

PART 1 GENERAL

1.01 Scope of Work

The Contractor shall provide solid wall high density polyethylene pipe (HDPE) and fittings which conform to AWWA, ASTM and other referenced documents listed in this specification with flanged and thermal butt fusion joints complete in place.

1.02 Manufacturer Qualifications

A. Manufacturer shall have a minimum of 5 years recent experience producing HDPE pressure pipe and fittings for at least the specified sizes and lengths, and shall be able to submit documentation of at least 5 installations in satisfactory operation for at least 5 years.

B. HDPE pipe and fittings manufacturers and distributors shall be listed as current members of the Alliance for PE Pipe.

C. Contractor shall have a minimum of 5 years recent experience installing HDPE pressure pipe and fittings for at least the specified pipe and fittings sizes and lengths and shall be able to submit documentation of at least 5 installations in satisfactory operation for at least 5 years.

D. All pipe and fittings of each material type shall be furnished by the same manufacturer.

E. The HDPE utility pipe and fittings manufacturer shall review and approve or prepare all Shop Drawings and other submittals for all components furnished under this Section.

F. Pipe and fittings, including linings and coatings, that will convey potable water or water that will be treated to become potable, shall be certified by an accredited organization in accordance with NSF 61 as being suitable for contact with potable water, and shall comply with requirements of authorities having jurisdiction at Site.

1.03 Referenced Standards

A. American Water Works Association (AWWA) latest edition:

1. AWWA C901 - Polyethylene Pressure Pipe and Tubing, ½ Inch Through 3 Inch for Water Service

2. AWWA C906 - Polyethylene Pressure Pipe and Fittings, 4 Inch Through 65 Inch for Water Distribution and Transmission

B. American Society for Testing and Materials (ASTM) latest edition:

1. ASTM D638 – Tensile Method for Tensile Properties of Plastics
2. ASTM D790 – Test Materials for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
3. ASTM D2122 – Standard Method of Determining Dimensions of Thermoplastics Pipe and Fittings
4. ASTM D2239 – Standard Specification for Polyethylene (PE) Plastic Pipe (SIDR-PR) Based on Controlled Inside Diameter
5. ASTM D2657 – Practice for Heat-Joining of Polyolefin Pipe and Fittings
6. ASTM D2683 – Standard Specification for Socket Type Polyethylene Fittings for Outside Diameter-Controlled Polyethylene Pipe and Tubing
7. ASTM D2774 – Standard Practice for Underground Installation of Thermoplastic Pressure Piping
8. ASTM D2837 – Standard Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products
9. ASTM D3035 – Polyethylene (PE) Plastic Pipe (DR-PE) Based on Controlled Outside Diameter
10. ASTM D3261 – Butt Heat Fusion Polyethylene (PE) Plastic Fittings for Polyethylene (PE) Plastic Pipe and Tubing
11. ASTM D3350 – Polyethylene Plastic Pipe and Fittings Material
12. ASTM F412 – Standard Terminology Relating to Plastic Piping Systems
13. ASTM F714 – Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter
14. ASTM F905 – Standard Practice for Qualification of Polyethylene Saddle-Fused Joints
15. ASTM F1055 – Standard Specification for Electrofusion Type Polyethylene Fittings for Outside Diameter Controlled Polyethylene Pipe and Tubing
16. ASTM F1056 – Standard Specification for Socket Fusion Tools for Use in Socket Fusion Joining Polyethylene Pipe or Tubing and Fittings
17. ASTM F1290 – Standard Practice for Electrofusion Joining Polyolefin Pipe and Fittings
18. ASTM F2164 – Field Leak Testing of Polyethylene (PE) Pressure Piping Systems Using Hydrostatic Pressure
19. ASTM F2206 – Fabricated Fittings for Butt-Fused Polyethylene Plastic Pipe
20. ASTM F2620 – Standard Practice for Heat Fusion Joining of Polyethylene Pipe and Fittings
21. ASTM F2786 – Standard Practice for Field Leak Testing of Polyethylene (PE) Pressure Piping Systems Using Gaseous Testing Media Under Pressure (Pneumatic Leak Testing)
22. ASTM F3124 – Standard Practice for Data Recording the Procedure used to Produce Heat Butt Fusion Joints

23. ASTM F3190 – Standard Practice for Heat Fusion Equipment (HFE) Operator Qualifications on Polyethylene (PE) and Polyamide (PA) Pipe and Fittings

C. Plastics Pipe Institute (PPI) latest edition:
1. The Plastics Pipe Institute Handbook of Polyethylene Pipe
2. PPI – TN-36 – General Guidelines for Connecting HDPE Potable Water Pressure Pipes to DI and PVC Piping Systems
3. PPI – TN-38 – Bolt Torque for Polyethylene Flanged Joints
4. PPI – TN-44 – Long Term Resistance of AWWA C906 Polyethylene (PE) Pipe to Potable Water Disinfectants
5. PPI – TN-45 – Mechanical Couplings for Joining Polyethylene Pipe
6. PPI – TN-46 – Guidance for Field Hydrostatic Testing of High Density Polyethylene Pressure Pipelines: Owner's Considerations, Planning, Procedures, and Checklists
7. PPI – TN-49 – Recommendations for AWWA C901 Service Tubes in Potable Water Applications
8. PPI – TN-54 – General Guidelines for Squeezing Off Polyethylene Pipe in Water, Oil and Gas Applications

D. Plastics Pipe Institute Municipal Advisory Board (MAB)
1. MAB Generic Electrofusion Procedure for Field Joining of 12 Inch and Smaller Polyethylene Pipe
2. MAB Generic Electrofusion Procedure for Field Joining of 14 Inch to 30 Inch Polyethylene Pipe
3. MAB Model Specifications for PE 4710 Buried Potable Water Service, Distribution and Transmission Pipes and Fittings

1.04 SYSTEM DESIGN PARAMETERS

A. The HDPE system working pressure rating accommodates the normal operating pressure and the repetitive surges. The pressure rating applies at 80° F or less. Piping installed that may experience operating temperatures up to 95° F shall be de-rated in accordance with manufacturer's recommendation.

B. Per AWWA 901 and C906, the repetitive surge pressure allowance is one half the pressure class of the pipe, and the occasional surge over pressure allowance is equal to the pressure class of the pipe. Allowable Total Pressure during Recurring Surge conditions equals 1.5 times the pipe's pressure class. Allowable Total Pressure during Occasional Surge conditions equals 2.0 times the pipe's pressure class.

Table 1 gives the Pressure Class per AWWA C906, Pressure Rating and Allowable Total Pressure during Recurring and Occasional Surge for PE4710 pipe at 80°F or less.

Table 1				
Pressure Class per AWWA C906 for PE 4710 at 80° F or Less				
Pipe Dimension Ratio (DR)	**Pressure Class (psi)**	**Pressure Rating (psi)**	**Allowable Total Pressure During Recurring Surge (psi)**	**Allowable Total Pressure During Occasional Surge (psi)**
DR 9	250	250	375	500
DR 11	200	200	300	400
DR 13.5	160	160	240	320
DR 17	125	125	187.5	250
DR 21	100	100	150	200
DR 26	80	80	120	160

1.05 Submittals

A. Contractor shall submit information detailing the manufacturer's experience requirements to satisfy the requirements of this specification.

B. Submit pipe catalog information confirming that pipe, fittings, joints, and other materials conform to the requirements of the specifications.

C. Affirmation that product shipped meets or exceeds the standards set forth in this specification. This shall be in the form of a written document from the manufacturer attesting to the manufacturing process meeting the standards.

D. Submit manufacturers recommended fusion procedures for the products.

PART 2 PRODUCTS

2.01 Polyethylene Pipe, Fittings and Accessories

A. Polyethylene pipe and fittings 4 - 30 inch diameter shall be in accordance with AWWA C906, material designation code of PE4710 and all applicable ASTM standards.

B. Polyethylene pipe ½ - 3 inch diameter for main line piping shall be polyethylene pipe (not tubing) in accordance with AWWA C901, material designation code of PE4710 and all applicable ASTM standards.

C. Butt fusion fittings shall be made of HDPE material with a minimum material designation code of PE4710 and all applicable ASTM standards. Molded and fabricated fittings shall have a pressure rating equal to the pipe unless otherwise specified on the project documents. All fittings shall meet the requirements of AWWA C901, C906 and all applicable ASTM standards. Markings for molded fittings shall comply with the requirements of ASTM D3261. Fabricated fittings shall be marked in accordance with ASTM F2206. Socket fittings shall meet ASTM D2683. Fabricated fittings shall be manufactured using a McElroy DataLogger to record fusion time, pressure and temperature, and shall be marked with a unique joint identifier that corresponds to the joint report. A graphic representation of the time and pressure data for all fusion joints made producing fittings shall be maintained for a minimum of five years as part of quality control and will be available upon request of owner.

D. Electrofusion fittings shall be made of HDPE material with a minimum material designation code of PE4710 and meet ASTM F1055. Electrofusion fittings shall have a pressure rating equal to the pipe unless otherwise specified on the project documents. All electrofusion fittings shall be suitable for use as pressure conduits and have nominal burst values of four times the working pressure rating of the fitting. Marking of electrofusion fittings shall comply with the requirements of ASTM F1055. All electrofusion fittings shall be properly stored in compliance with the manufacturer's recommendation.

E. If saddle fusion is used to fuse branch saddles, tapping tees and other HDPE fittings onto the wall of the main pipe, it shall be done in accordance with ASTM F2620 or PPI TR-41 or the fitting manufacturer's recommendations. Saddle fusion joints shall be made by qualified fusion technicians. Qualification of the fusion technician shall be demonstrated by evidence of fusion training within the past two years on the equipment to be utilized on this project in accordance with ASTM F3190.

F. If socket fusion is used to fuse branch saddles, tapping tees and other HDPE fittings onto the wall of the main pipe, it shall be done in accordance with ASTM D2683 or the fitting manufacturer's recommendations. Socket fusion joints shall be made by qualified fusion technicians. Qualification of the fusion technician shall be demonstrated by evidence of fusion training within the past two years on the equipment to be utilized on this project in accordance with ASTM F3190. All equipment used for socket fusion should comply with ASTM F1056 and manufacturer's recommendations.

G. Flanges and Mechanical Joint Adapters (MJ) shall have a minimum material designation code of PE4710 and meet all applicable AWWA and ASTM standards. Flanged and MJ adapters can be made to ASTM D3261 or machined in compliance with ASTM F2206. Flanges and MJ adapters shall have a pressure rating equal to the pipe unless otherwise specified on the plans. Markings for molded or machined flange adapters or MJ adapters shall be per ASTM D3261. Fabricated (including machined) flange adapters shall be marked per ASTM F2206. Installation of all Flanged adapters shall follow the guidelines of the Plastics Pipe Institute TN-38.

H. Glands, bolts, and gaskets shall be manufactured in accordance with AWWA C153. Bolts and nuts shall be grade 2 or higher.

2.02 Pipeline Identification

A. All polyethylene pipe shall be marked in accordance with the standards to which it is manufactured.

B. All polyethylene pipe shall be black, and shall contain a continuous colored stripe, 2 inches wide, located at no greater than 90 degree intervals around the pipe. Stripes shall be impregnated or molded into the pipe by the manufacturer. Application of the stripes after manufacture is not acceptable. Stripe color shall be:

1. Potable Water Mains - blue stripes
2. Reclaimed Water Mains - purple stripes
3. Force Mains - brown stripes
4. Sanitary Sewer - green stripes
5. Storm Sewer - no stripes required

PART 3 EQUIPMENT

3.01 Data Logger

A. A data logger shall be used to record and document all butt fusion process. The data logger must be compatible and outfitted with an electronic data recording device. A digital report or printout for all fusion joints made that complies with, but is not limited to, ASTM F3124 must be delivered to the Owner upon request and at the completion of the project. All hydraulic fusion must be recorded and able to produce a graphic representation of the time and pressure data. All manual fusion must be recorded with, but not limited to, Joint ID, Operator Name and ID, Pipe information, and Heater Plate Temperature. The recording unit shall be a DataLogger 6 as manufactured by McElroy Manufacturing, Inc, or newer model or approved equivalent.

PART 4 EXECUTION

4.01 Pipe Joining

A. High density polyethylene pipe shall be heat fused and pressure tested as per manufacturer's guidelines before installation. During assembly and prior to installation, pipe must be laid out in such a way as to minimize interference to pedestrian and vehicular traffic.

B. Cuts or gouges that reduce the wall thickness by more than 10% are not acceptable and must be cut out, discarded and the pipe rejoined.

C. Each butt fusion shall be recorded and logged by a datalogger affixed to the fusion machine. Joint data shall be submitted as part of the as-built documentation.

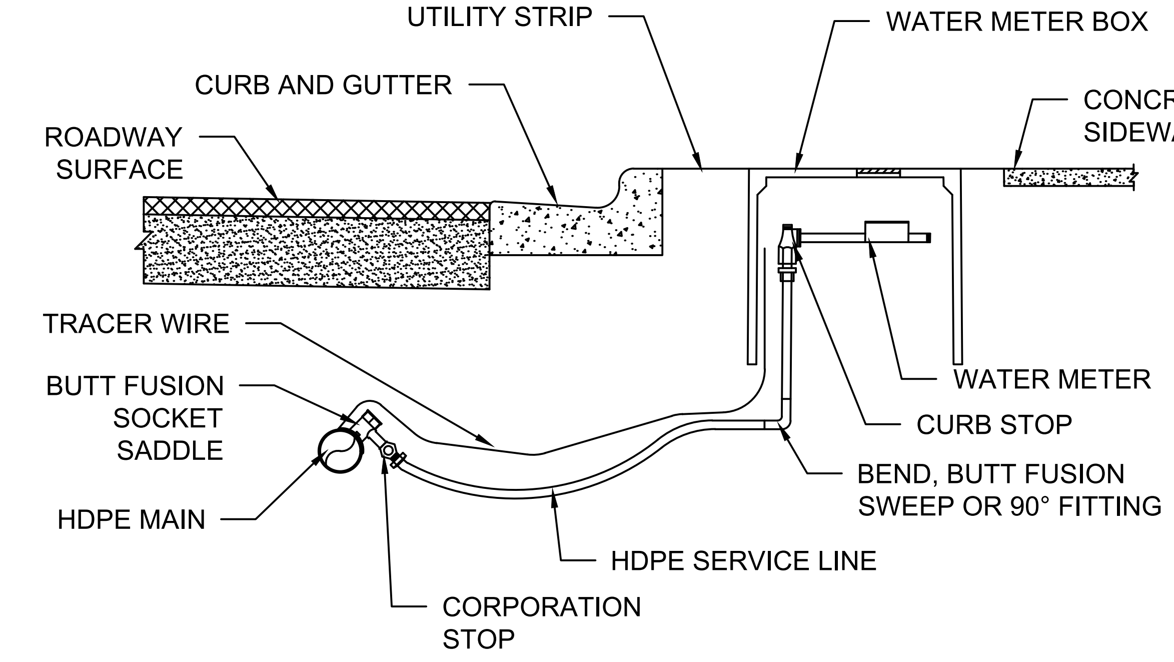
D. Mechanical joining – Polyethylene pipe and fittings may be joined together or to other materials by means of flanged connections or mechanical couplings designed for joining polyethylene pipe or for joining polyethylene pipe to another pipe material. Mechanical couplings shall be fully pressure rated and fully thrust restrained and installed in accordance with manufacturer's recommendations.

4.02 Testing

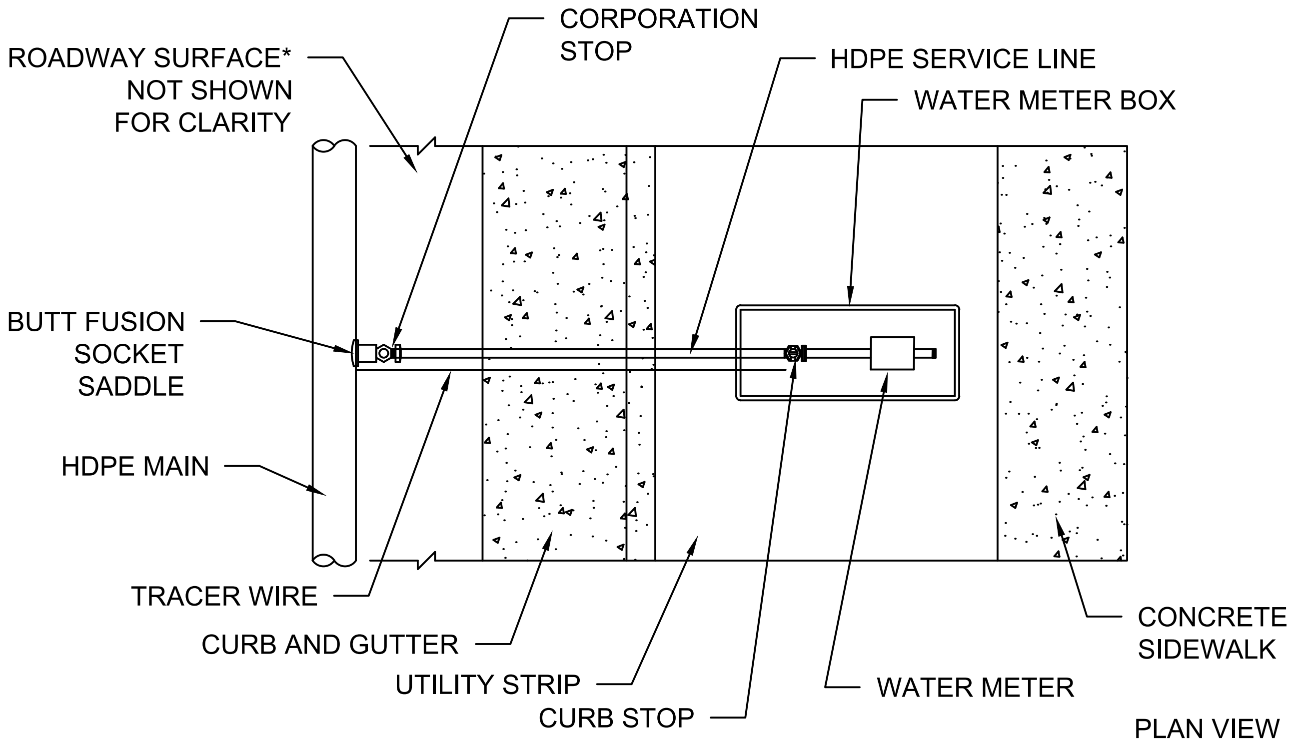
A. Pressure and Leakage tests

1. Conduct hydrostatic pressure testing of installed polyethylene pipe in accordance with ASTM F2164.
2. For HDPE mains, fill the main slowly ensuring fill rate does not exceed capacity of air release devices. Once air has been expelled from the system, gradually raise the pressure to 160 psi. Add makeup water as necessary to maintain this pressure as necessary for four hours. After the four hour period, reduce main pressure to the 150 psi test pressure and monitor for one hour. Do not increase pressure or add makeup water during this one hour period. The test is passed and considered acceptable if the main pressure does not drop more than 5% (7.5 psi) during the one hour period.
3. If any defects or leaks are revealed, they should be corrected and the pipeline retested after a minimum 24 hour recuperation period between tests. Total testing conducted on a section of pipeline shall not exceed eight hours within a 24 hour period.

END OF SECTION

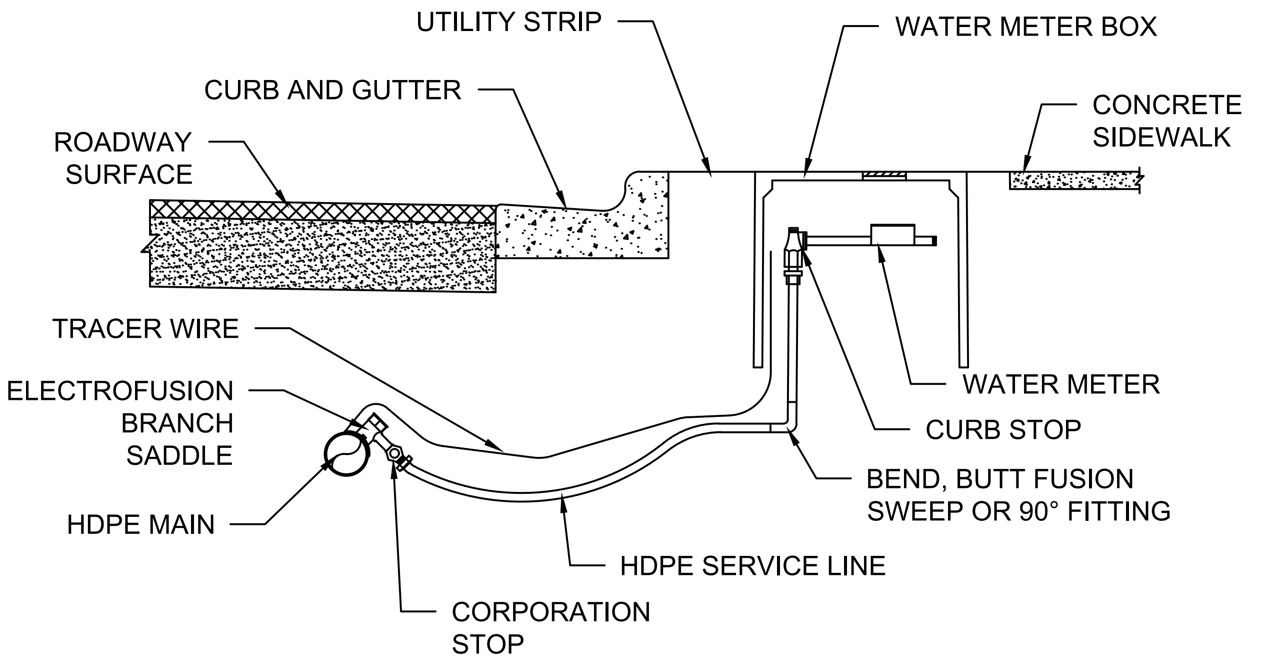


SECTION VIEW



PLAN VIEW

WATER SERVICE WITH BUTT FUSION SOCKET SADDLE	ALLIANCE FOR pe pipe
ALLIANCE FOR PE PIPE	Standard Detail CO-1A Scale: NTS REV 5/2020



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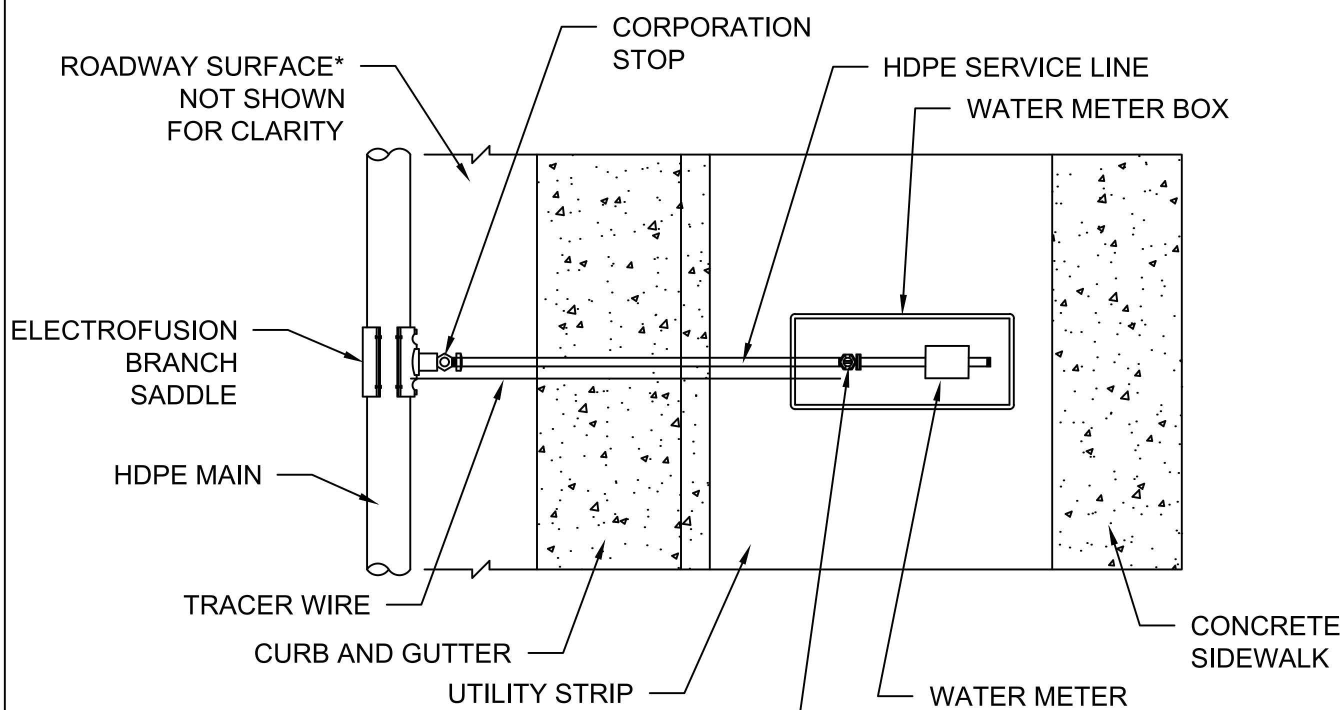
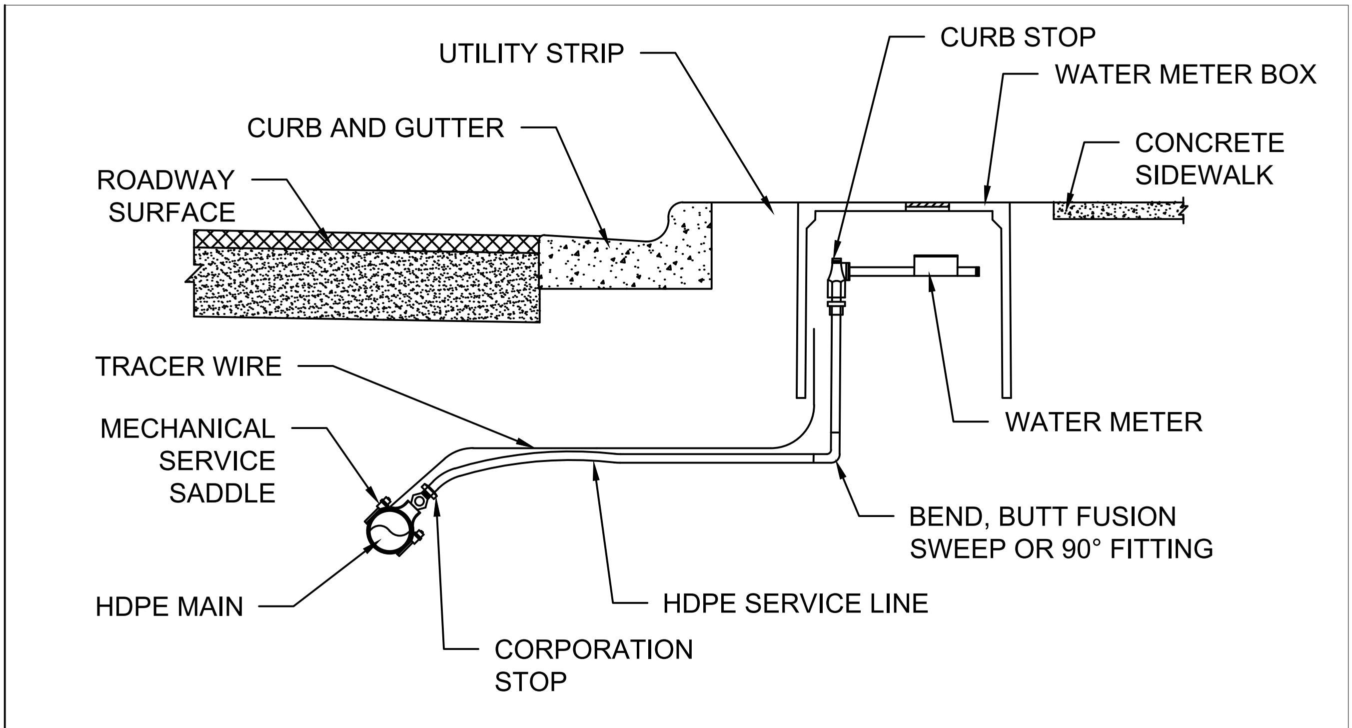


PLAN VIEW

WATER SERVICE WITH ELECTROFUSION SADDLE	ALLIANCE FOR pepipe
ALLIANCE FOR PE PIPE	Standard Detail CO-1B Scale: NTS REV 5/2020



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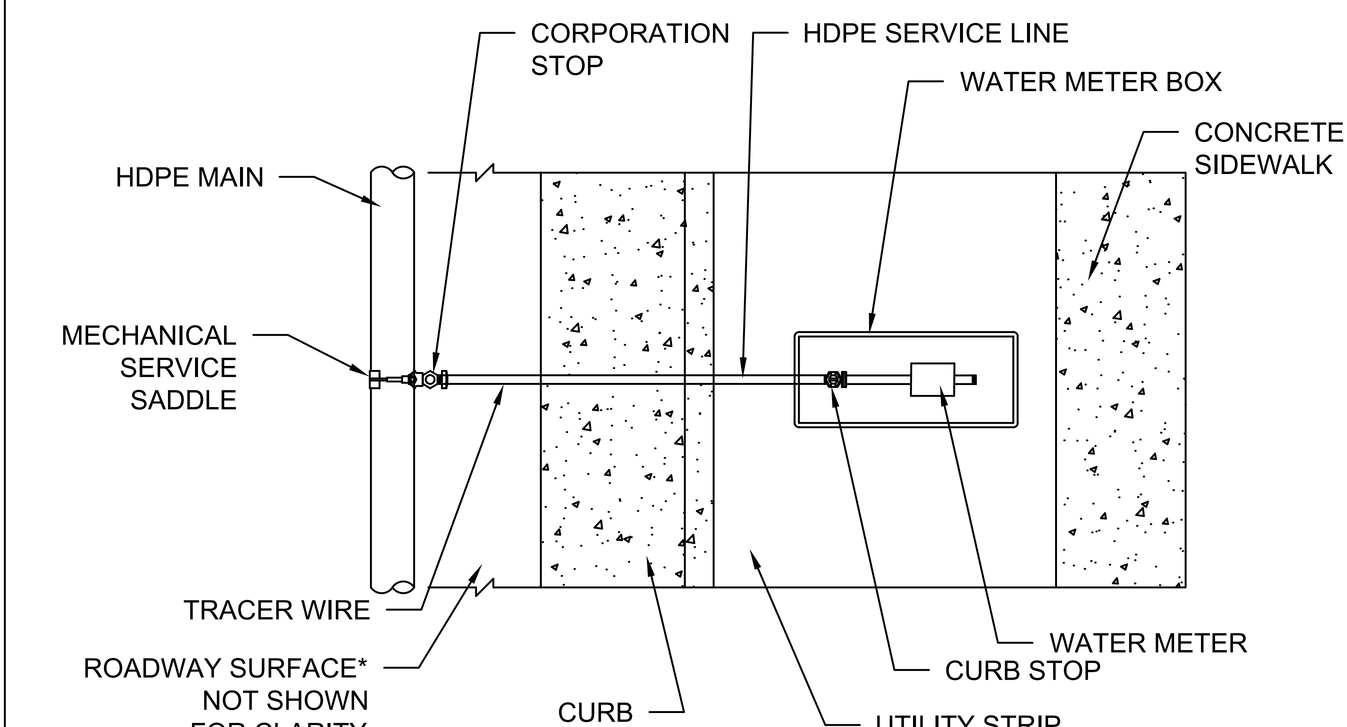
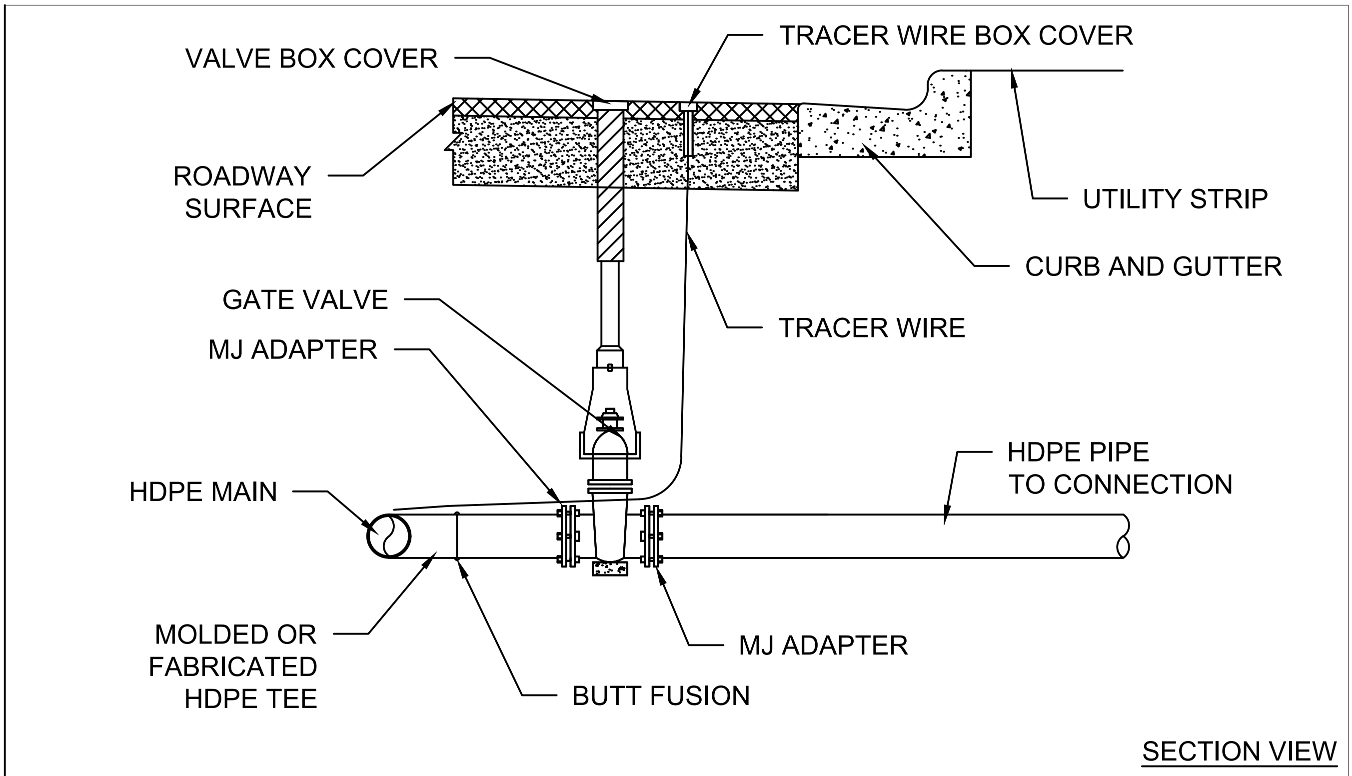
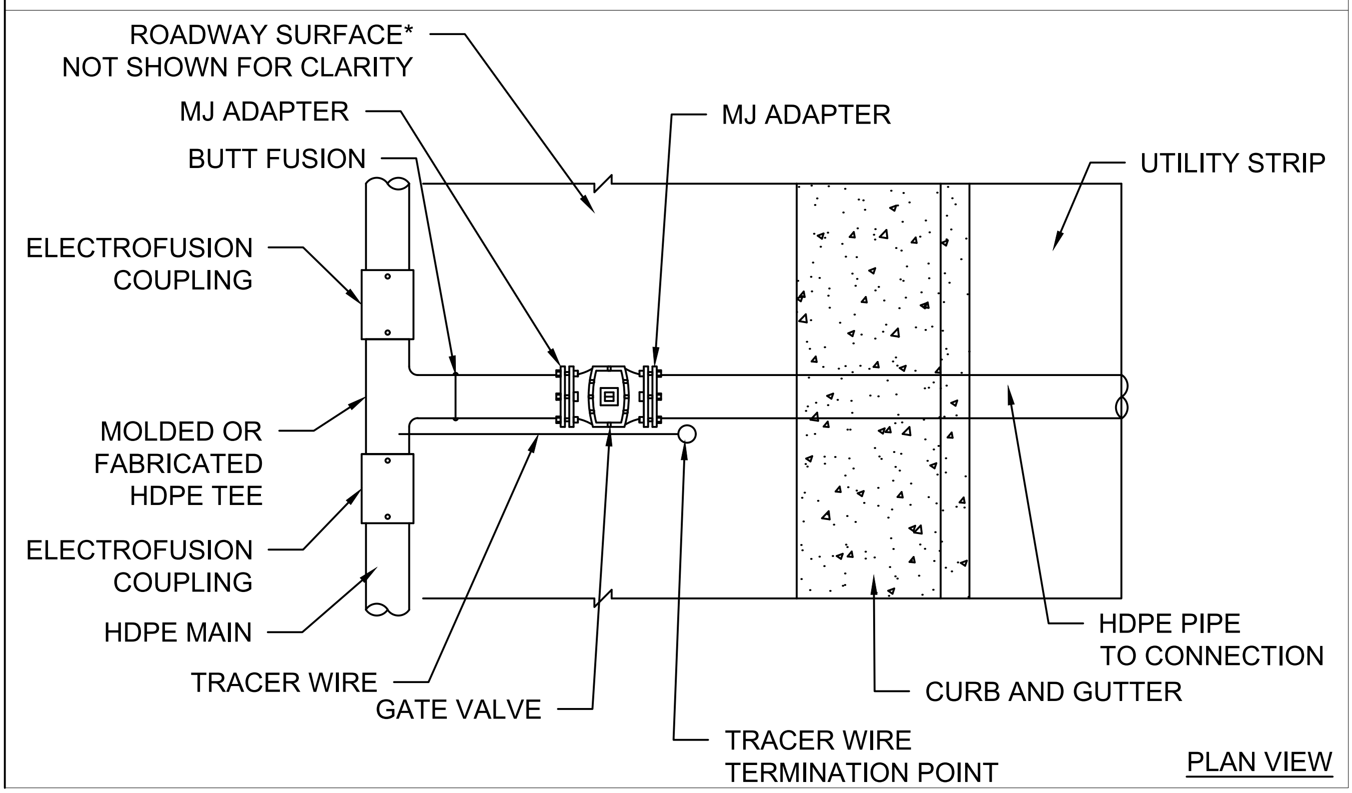


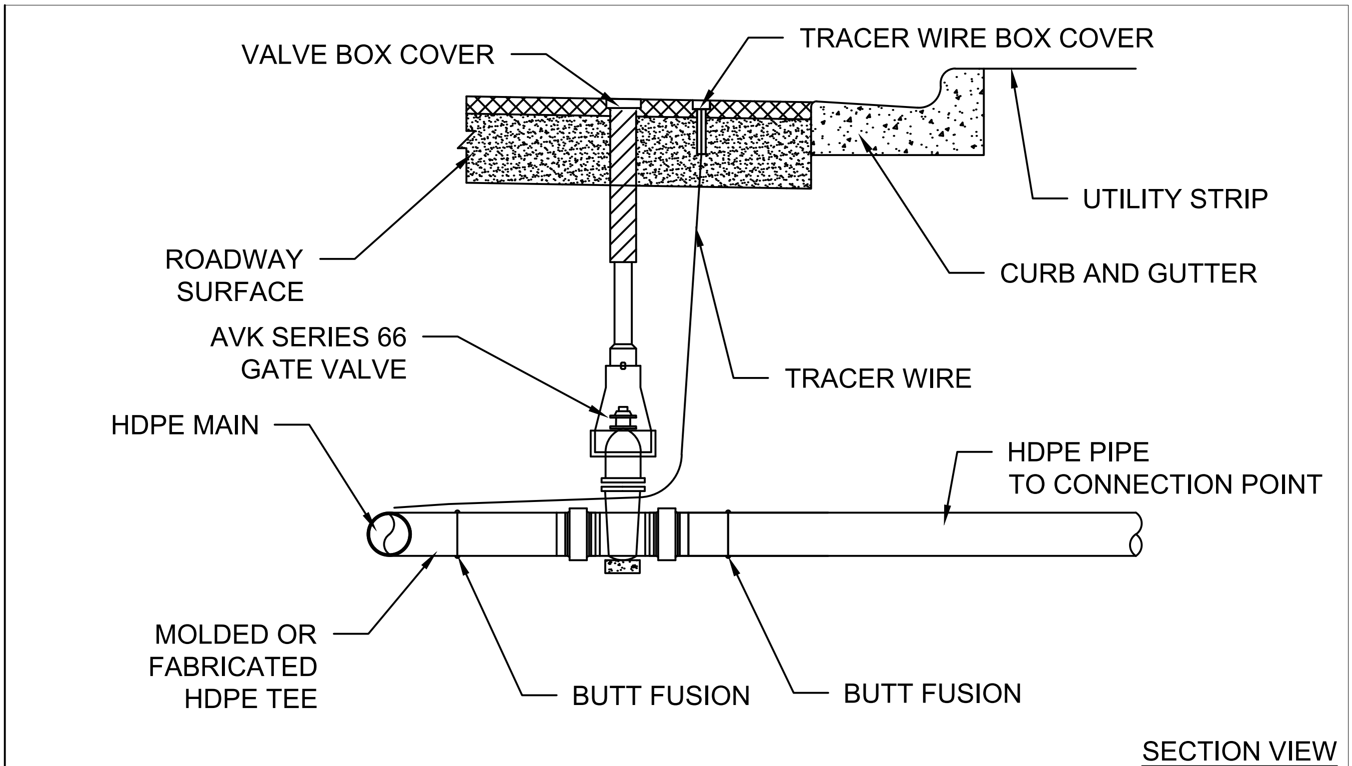
PLAN VIEW

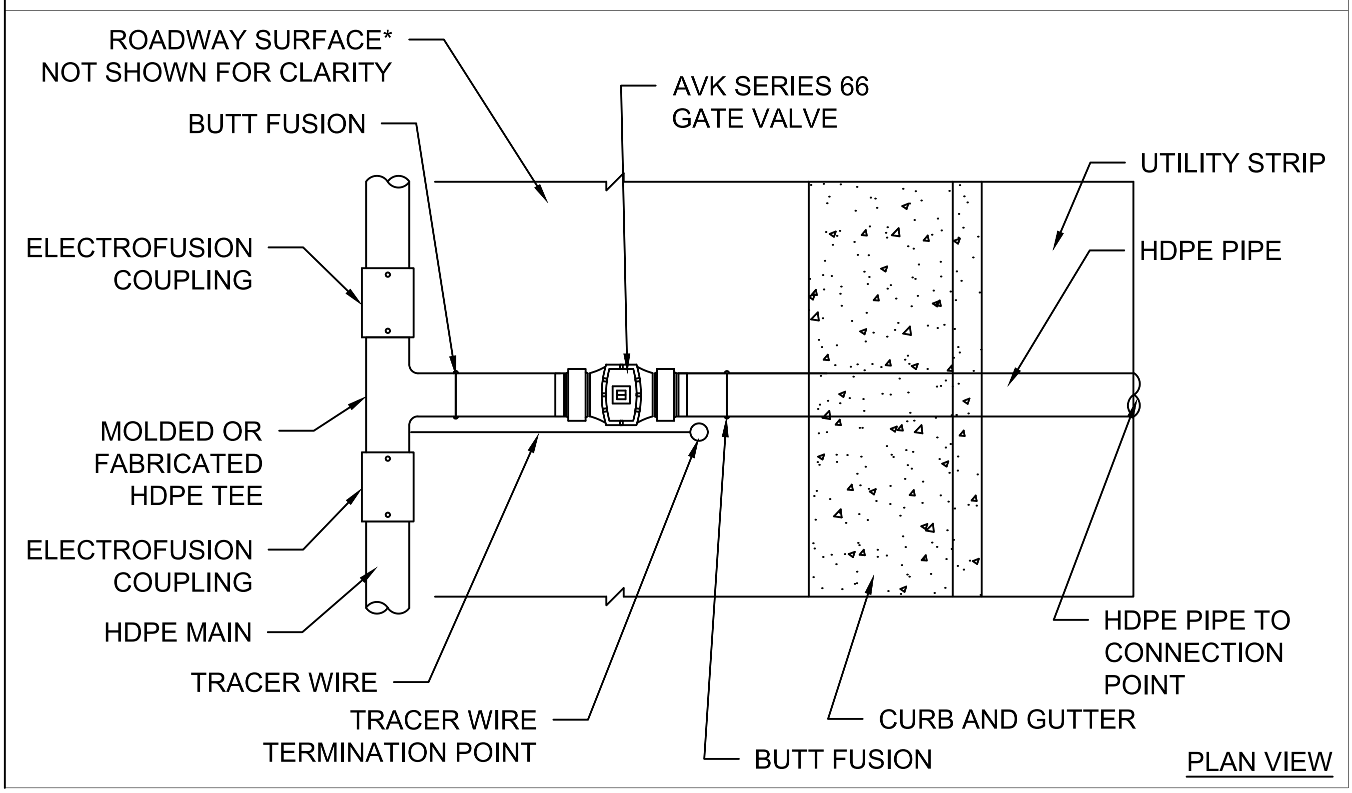
WATER SERVICE WITH MECHANICAL SADDLE	ALLIANCE FOR pe pipe
ALLIANCE FOR PE PIPE	Standard Detail CO-2 Scale: NTS REV 5/2020



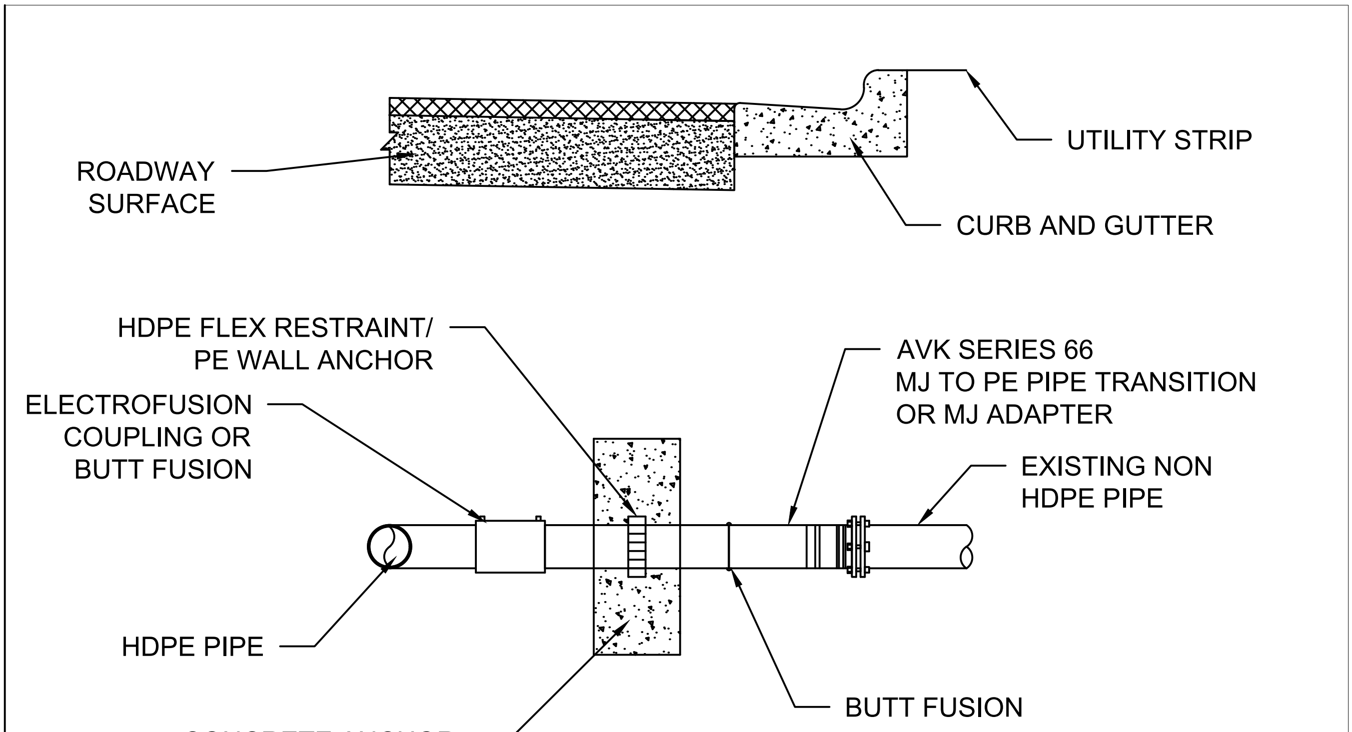


MECHANICAL CONNECTION TO GATE VALVE	ALLIANCE FOR pe pipe
ALLIANCE FOR PE PIPE	Standard Detail CO-3 Scale: NTS REV 5/2020





AVK SERIES 66 GATE VALVE	ALLIANCE FOR pe pipe
ALLIANCE FOR PE PIPE	Standard Detail CO-4 Scale: NTS REV 5/2020



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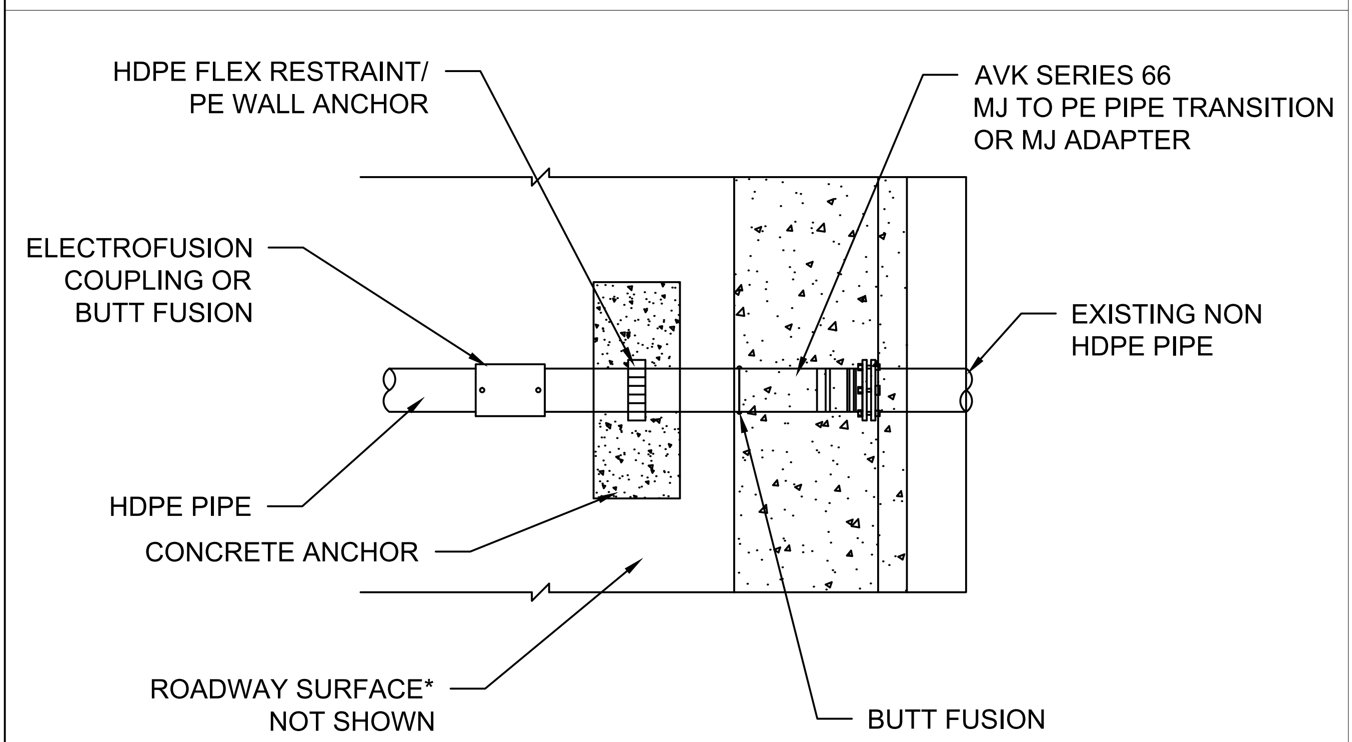
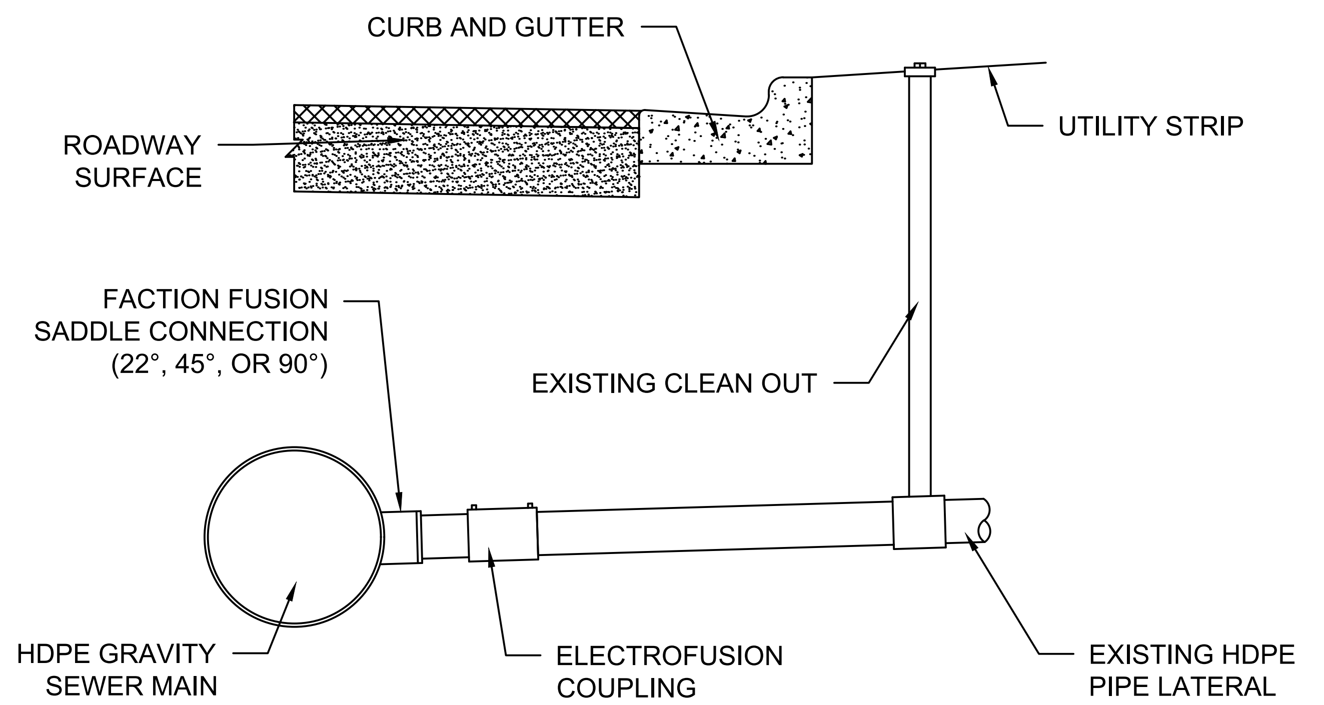
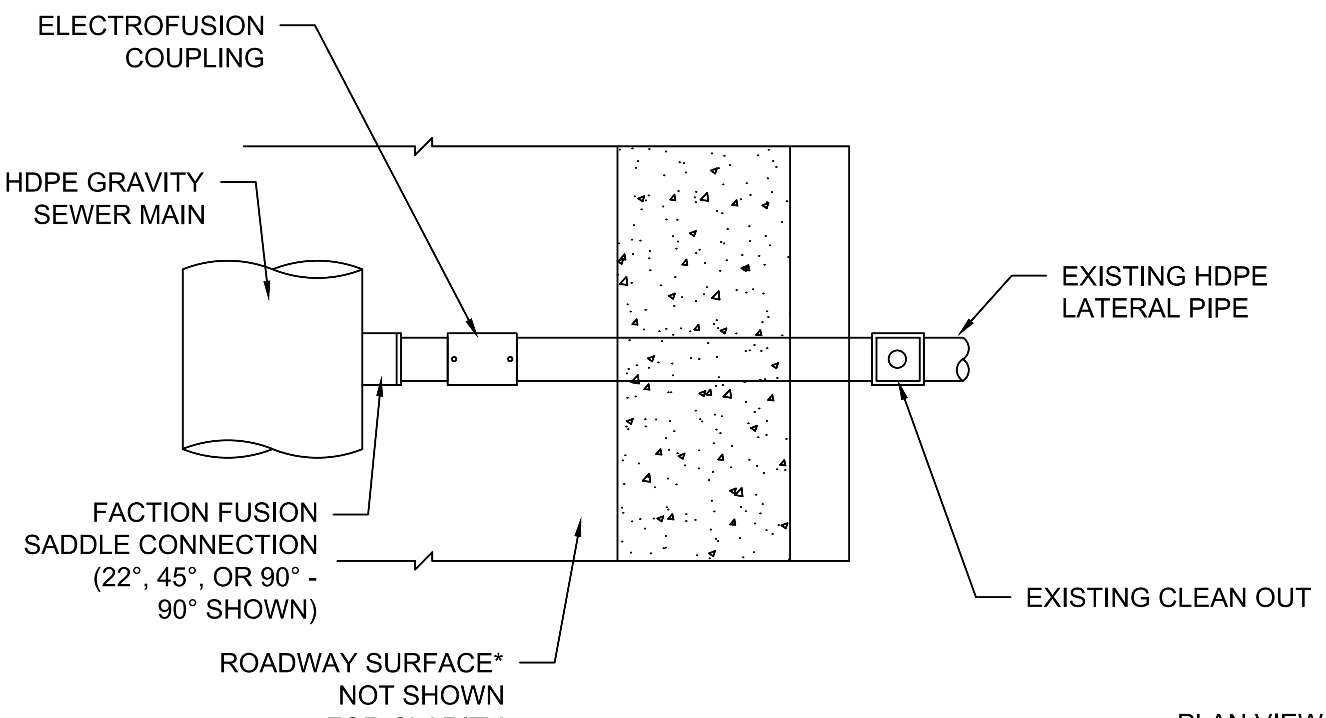


PLAN VIEW

HDPE CONNECTION TO ALTERNATE PIPE MATERIAL	ALLIANCE FOR pepipe
ALLIANCE FOR PE PIPE	Standard Detail CO-5 Scale: NTS REV 5/2020

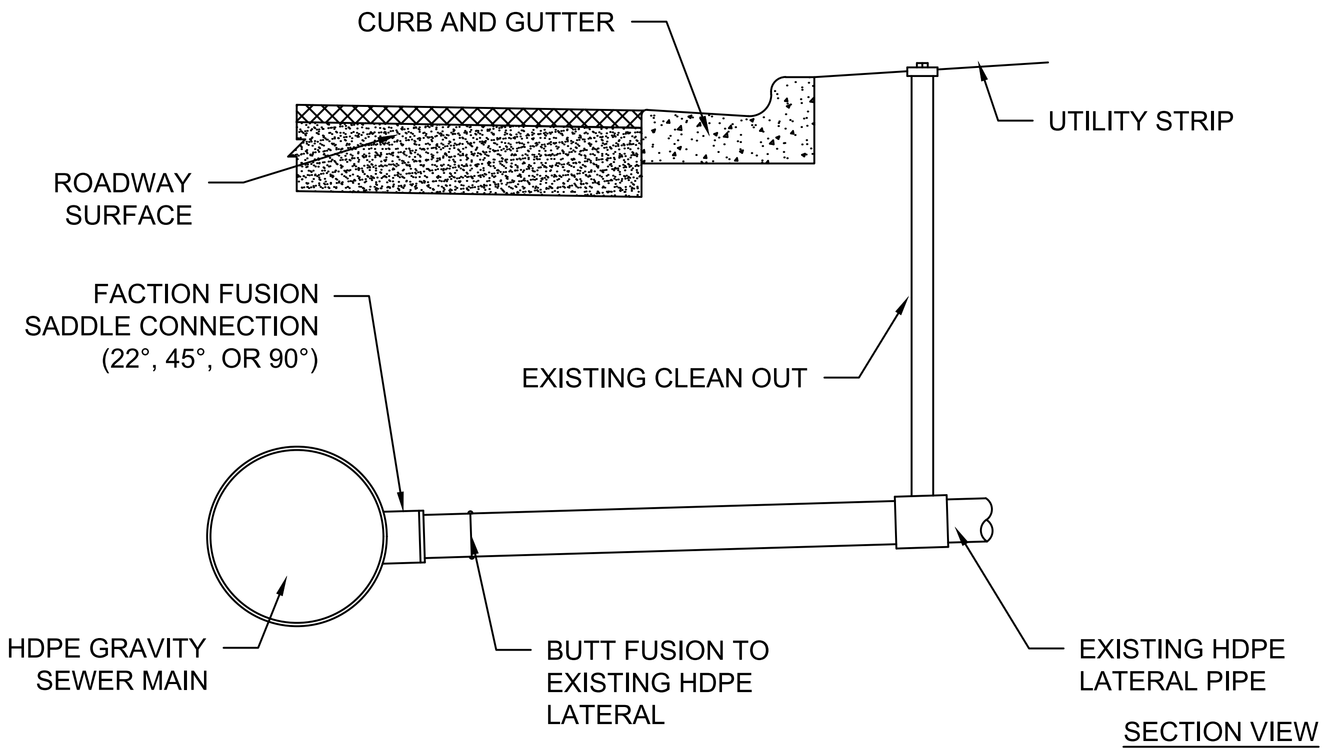


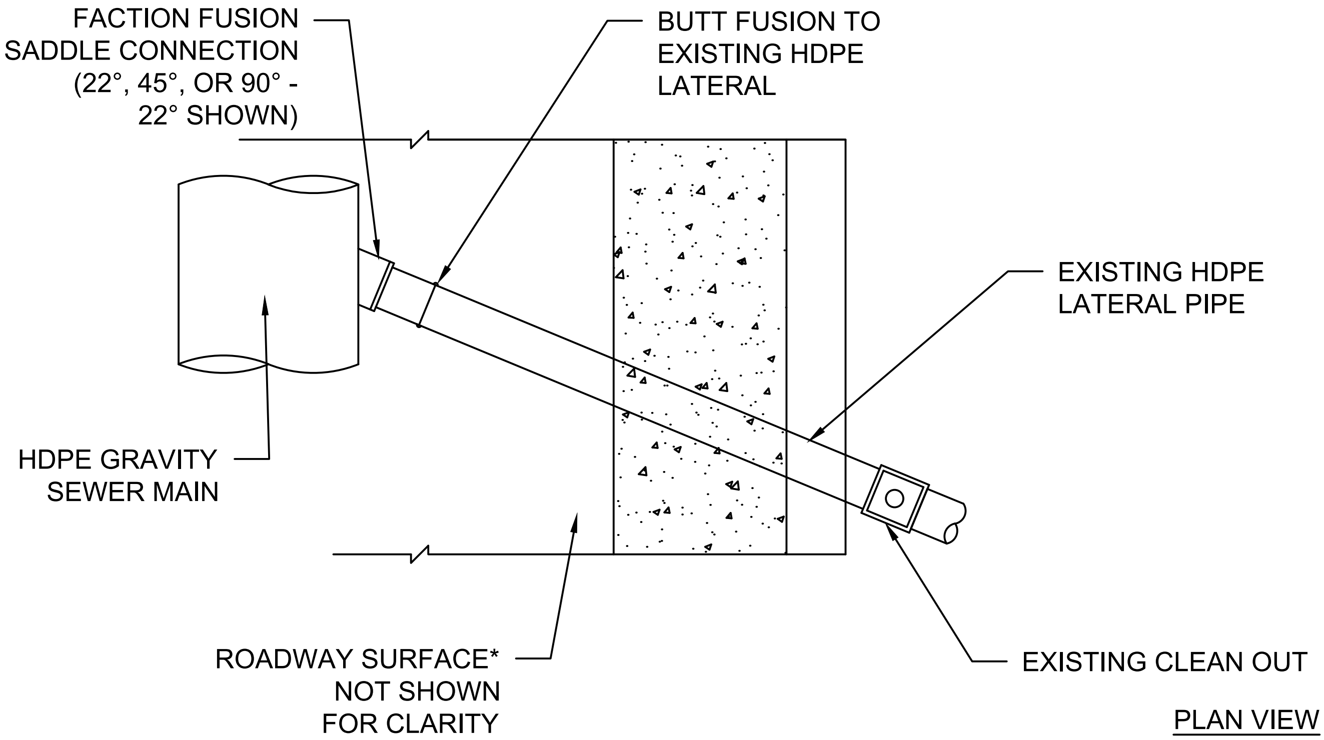
SECTION VIEW



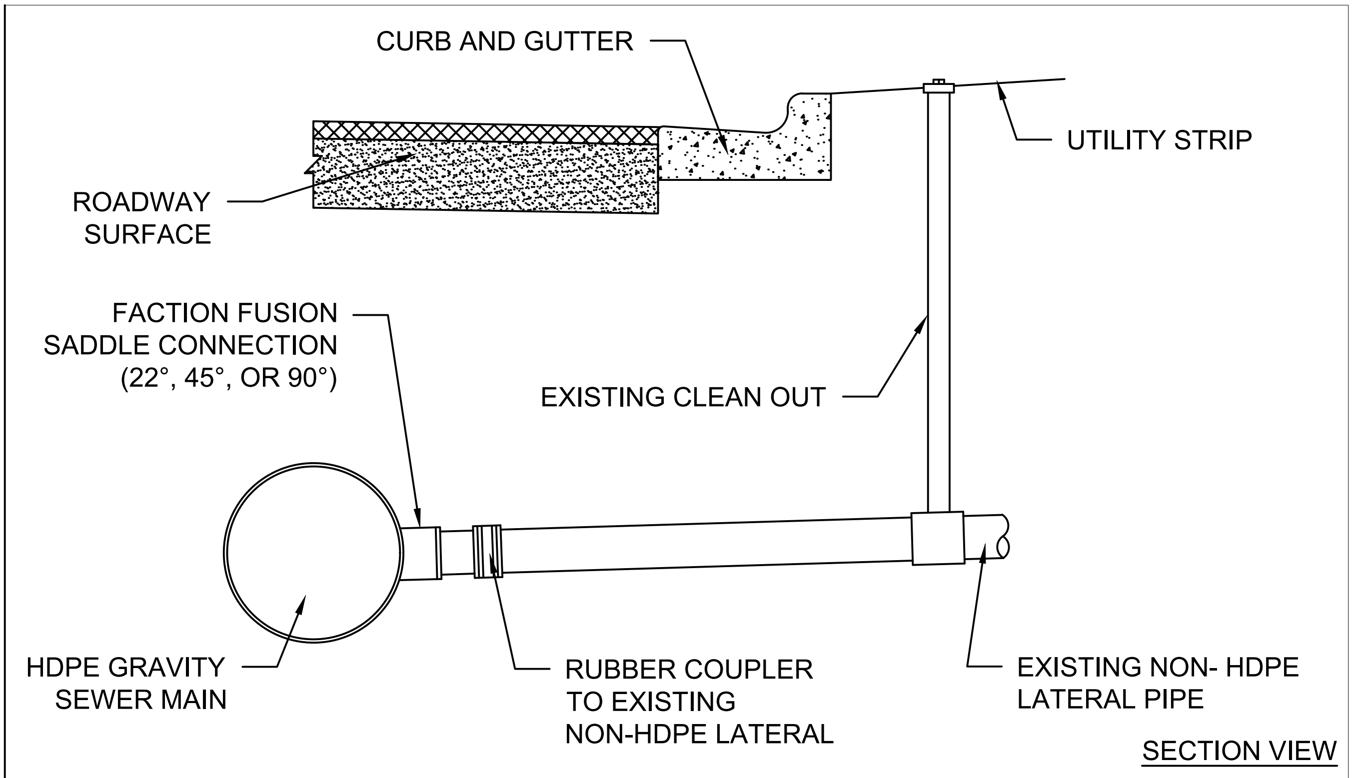
PLAN VIEW

FACTION FUSION SADDLE CONNECTION AND ELECTROFUSION TO LATERAL	ALLIANCE FOR pe pipe
ALLIANCE FOR PE PIPE	Standard Detail CO-6 Scale: NTS REV 5/2020

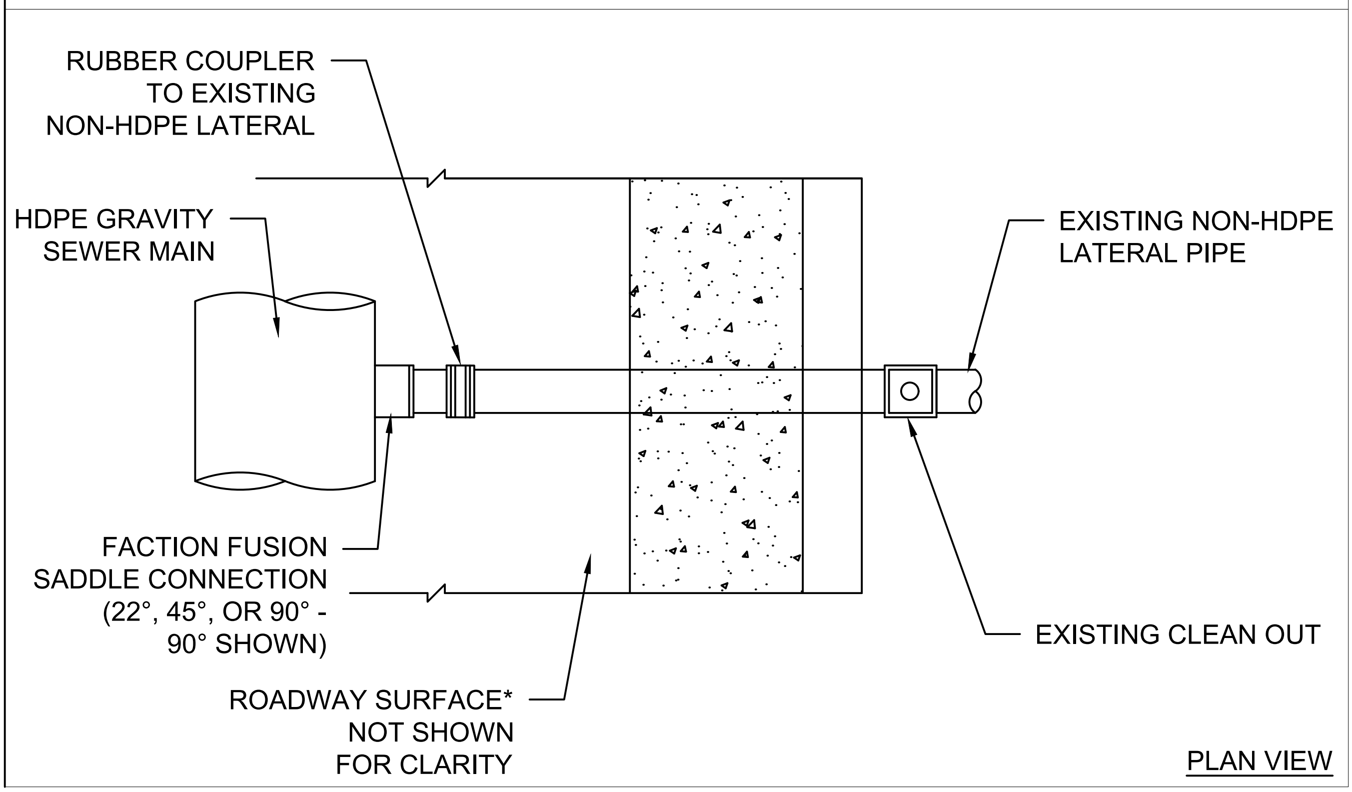




FACTION FUSION SADDLE CONNECTION AND BUTT FUSION TO LATERAL	ALLIANCE FOR pe pipe
ALLIANCE FOR PE PIPE	Standard Detail CO-7 Scale: NTS REV 5/2020

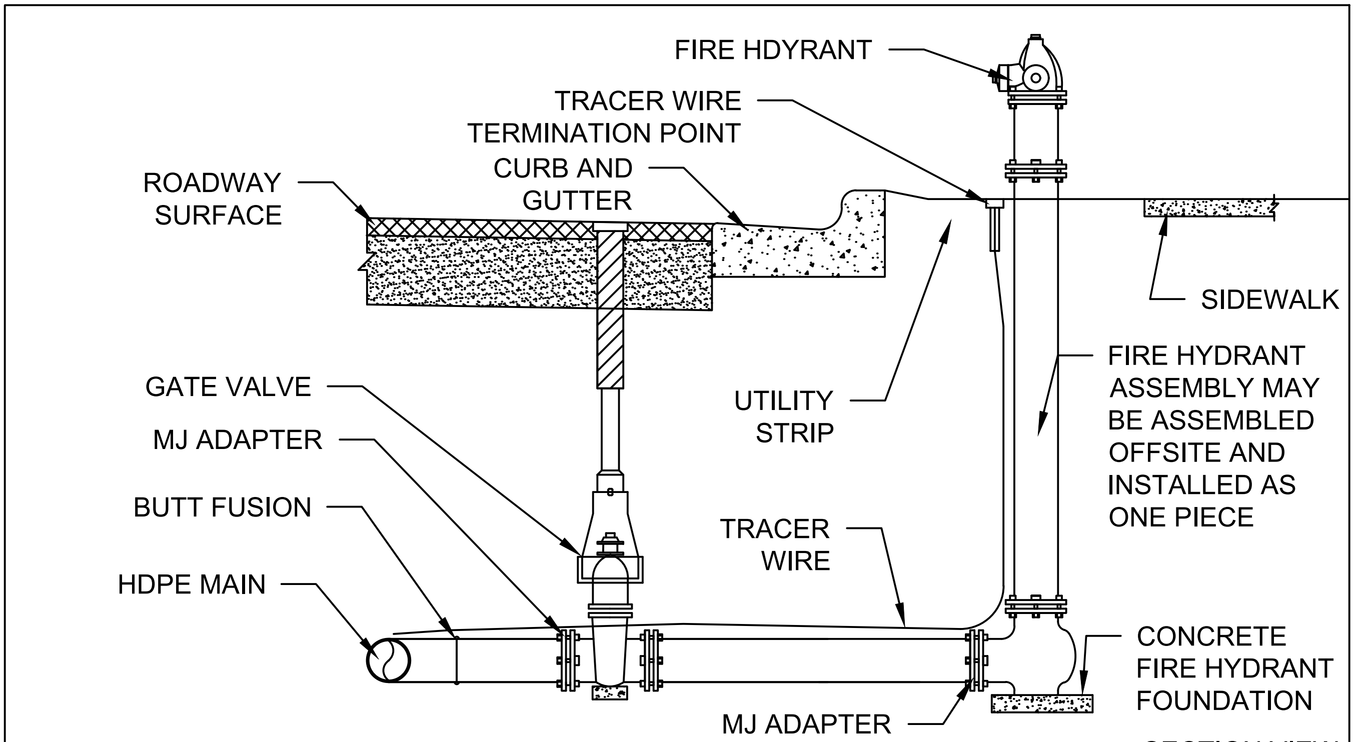


SECTION VIEW

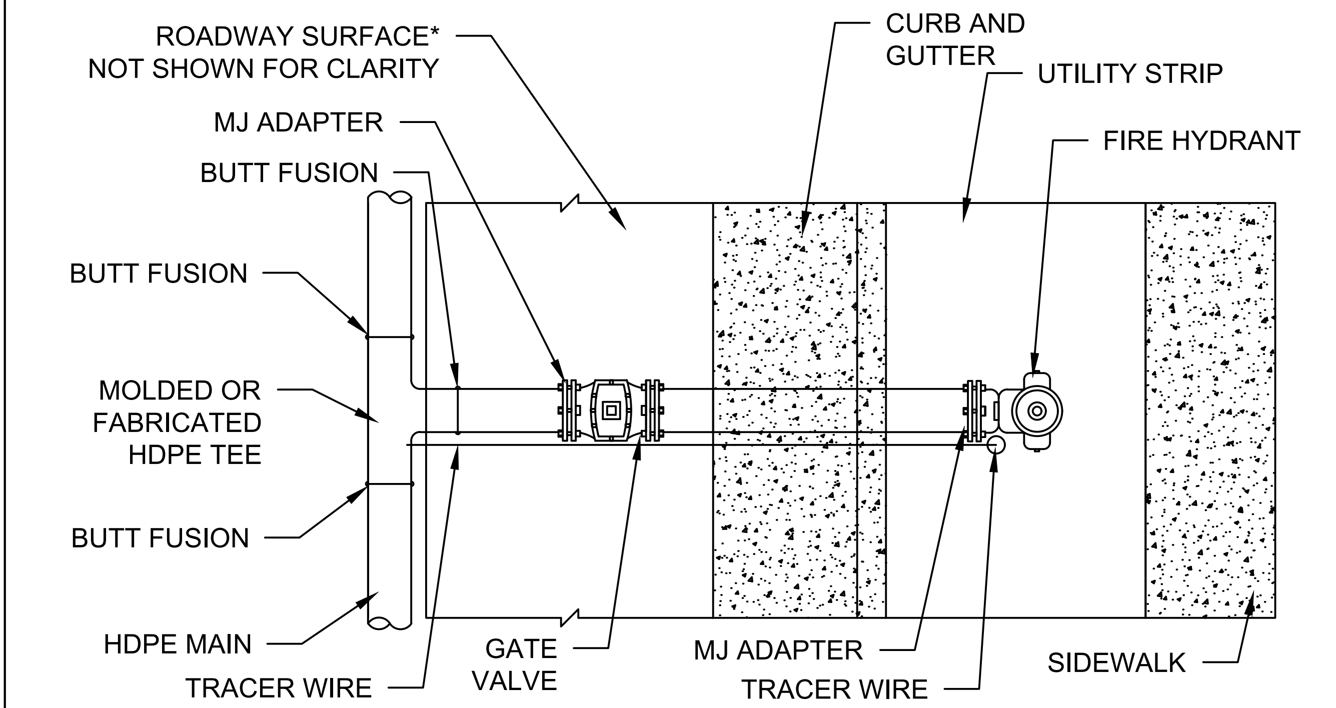


PLAN VIEW

FACTION FUSION SADDLE CONNECTION AND RUBBER COUPLER TO LATERAL	ALLIANCE FOR pe pipe
ALLIANCE FOR PE PIPE	Standard Detail CO-8 Scale: NTS REV 5/2020

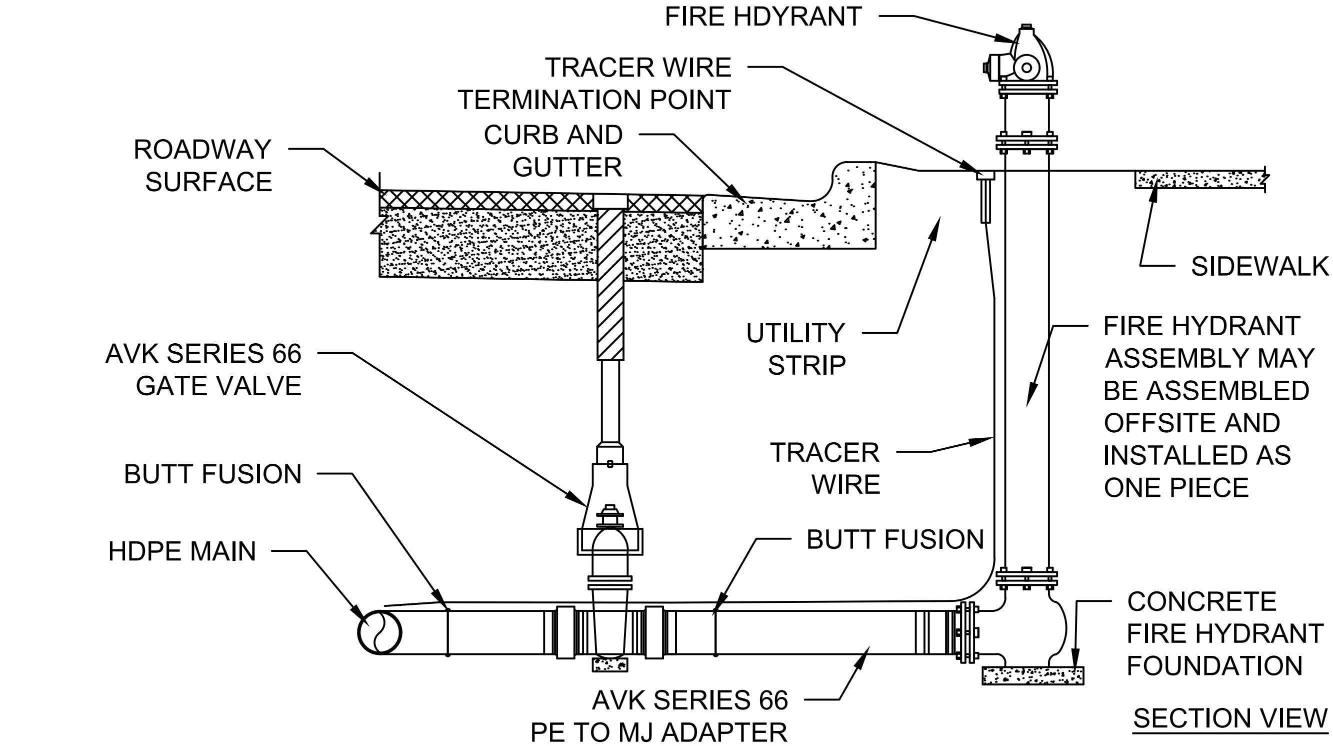


SECTION VIEW

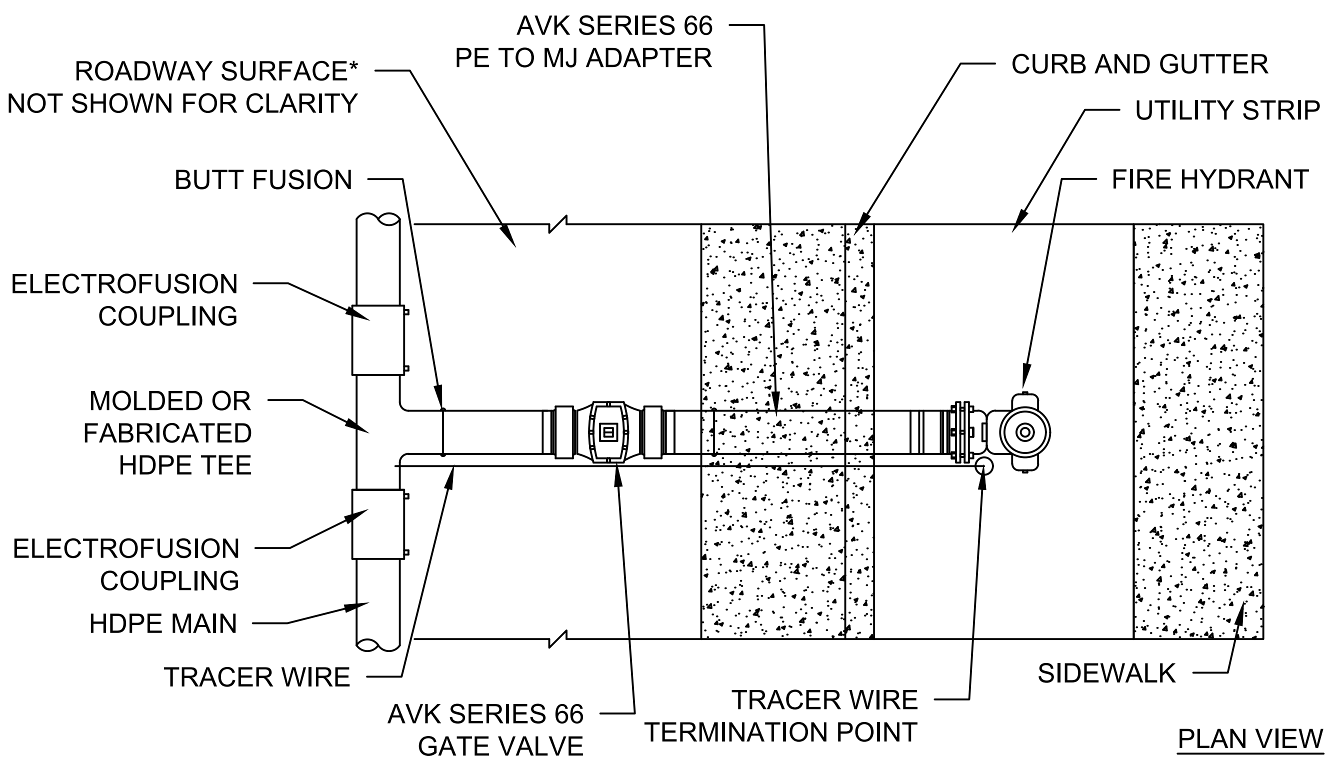


PLAN VIEW

FIRE HYDRANT ASSEMBLY MECHANICAL CONNECTION	ALLIANCE FOR pe pipe
ALLIANCE FOR PE PIPE	Standard Detail FH-1 Scale: NTS REV 5/2020

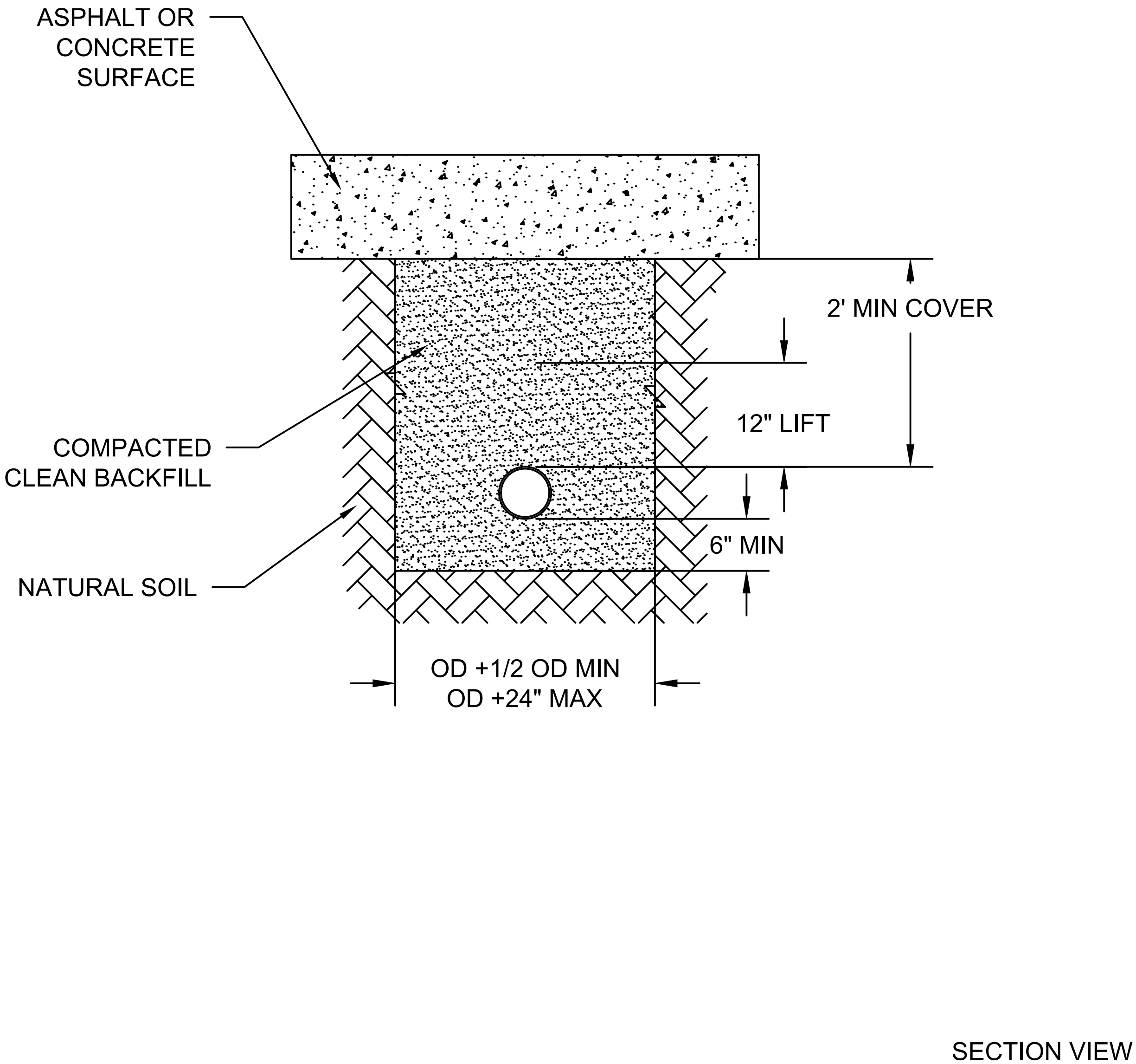


SECTION VIEW

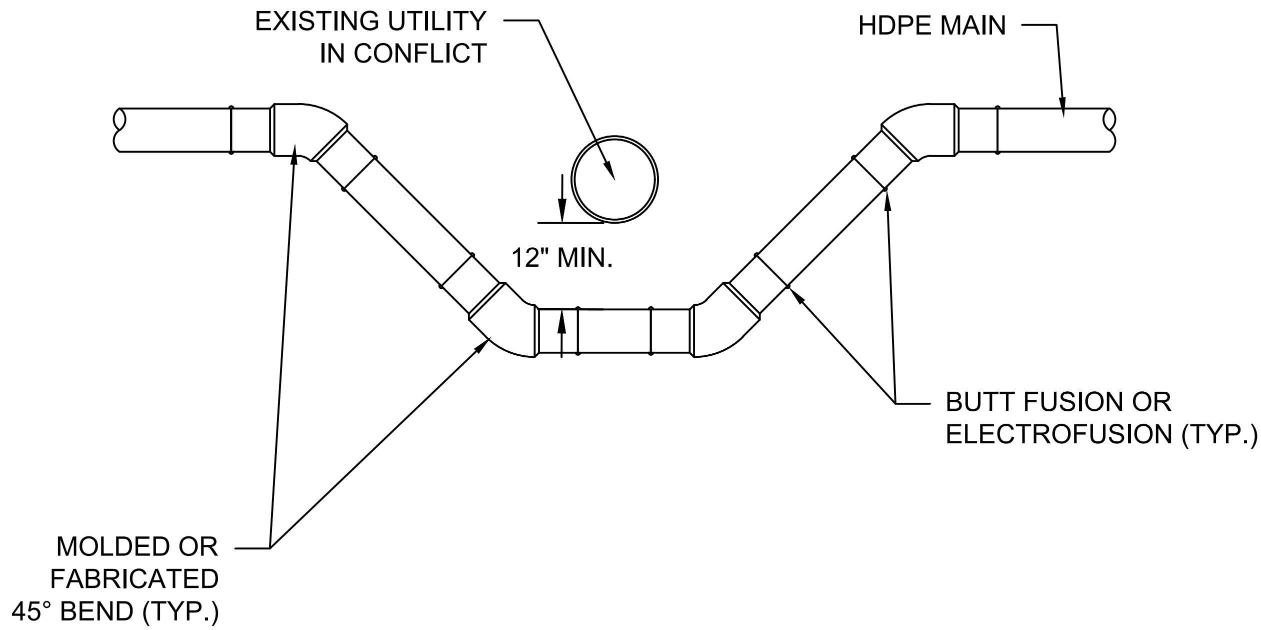


PLAN VIEW

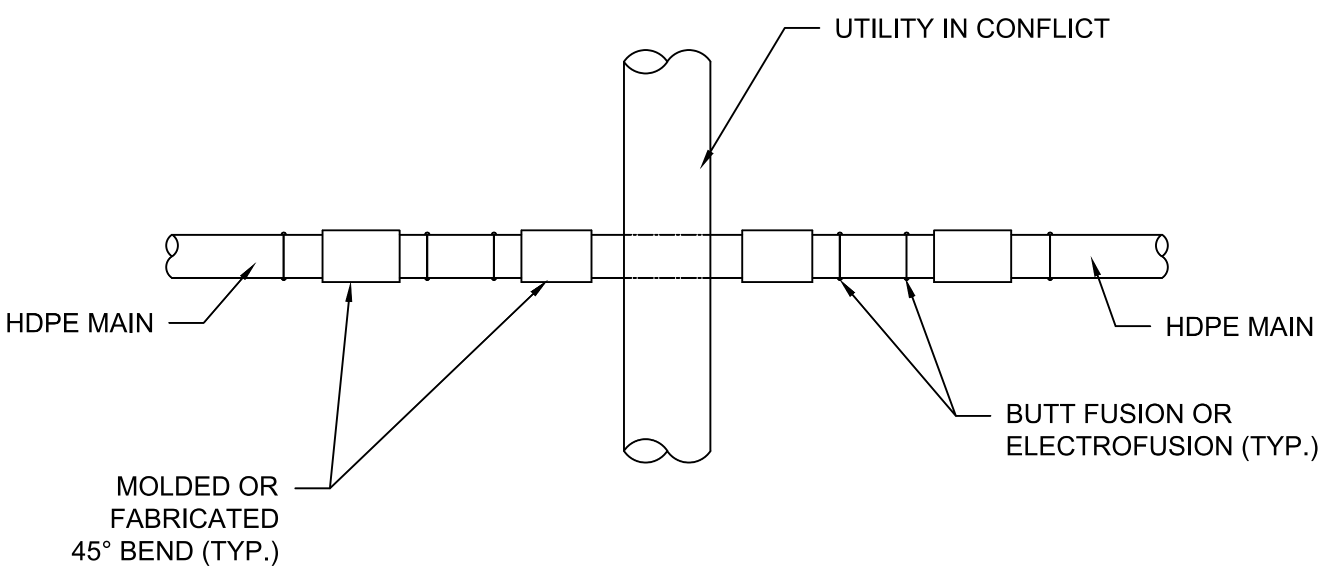
FIRE HYDRANT ASSEMBLY AVK SERIES 66	ALLIANCE FOR pepipe
ALLIANCE FOR PE PIPE	Standard Detail FH-2 Scale: NTS REV 5/2020



PIPE BEDDING DETAIL	ALLIANCE FOR pe pipe
ALLIANCE FOR PE PIPE	Standard Detail INST-1A Scale: NTS REV 5/2020

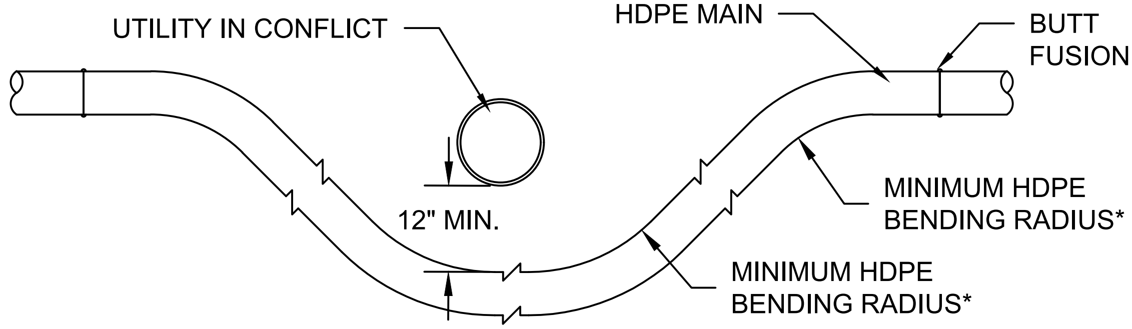


SECTION VIEW



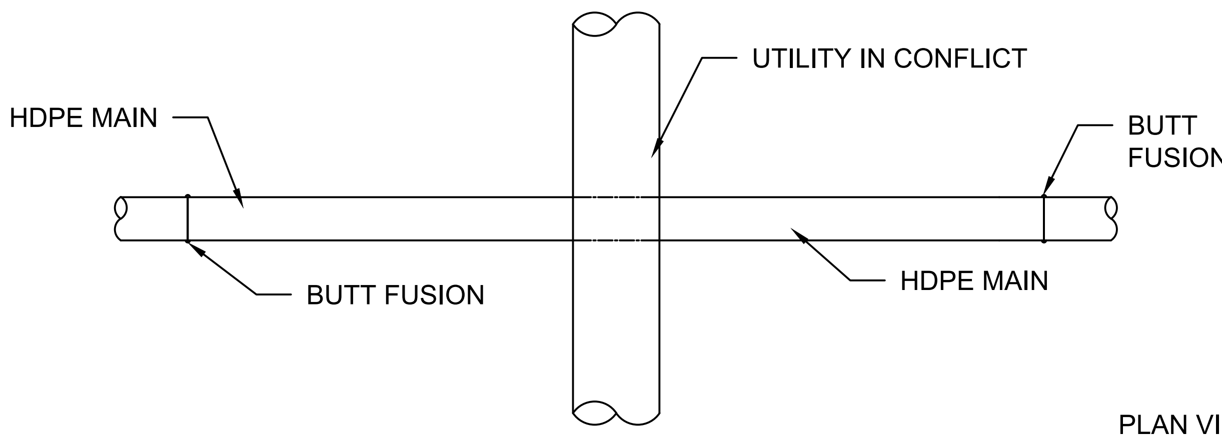
PLAN VIEW

UTILITY CONFLICT FUSION TO HDPE FITTINGS	ALLIANCE FOR pe pipe
ALLIANCE FOR PE PIPE	Standard Detail INST-2A Scale: NTS REV 5/2020



NOTE:
IF NOT ENOUGH CLEARANCE LENGTH IS AVAILABLE TO AVOID EXISTING UTILITY, USE DETAIL INST-2A WITH FITTINGS.

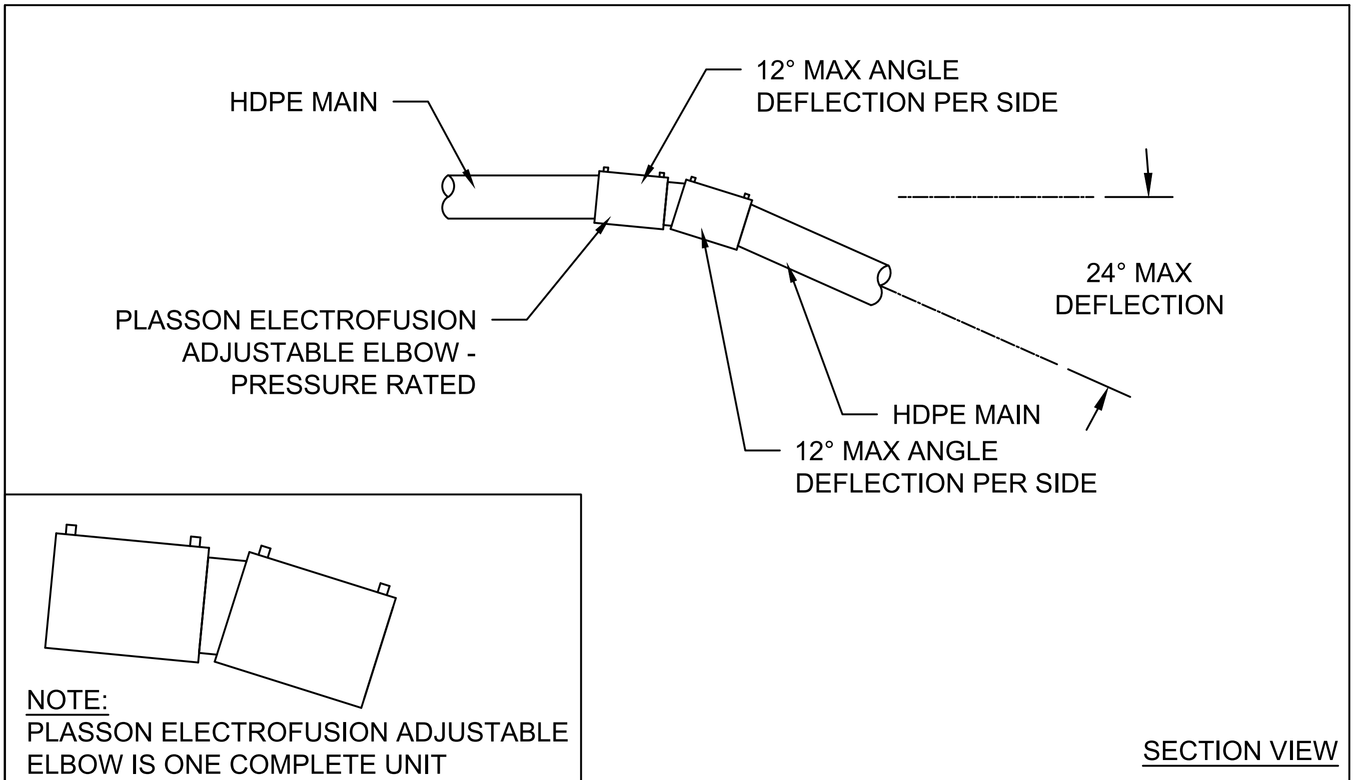
SECTION VIEW

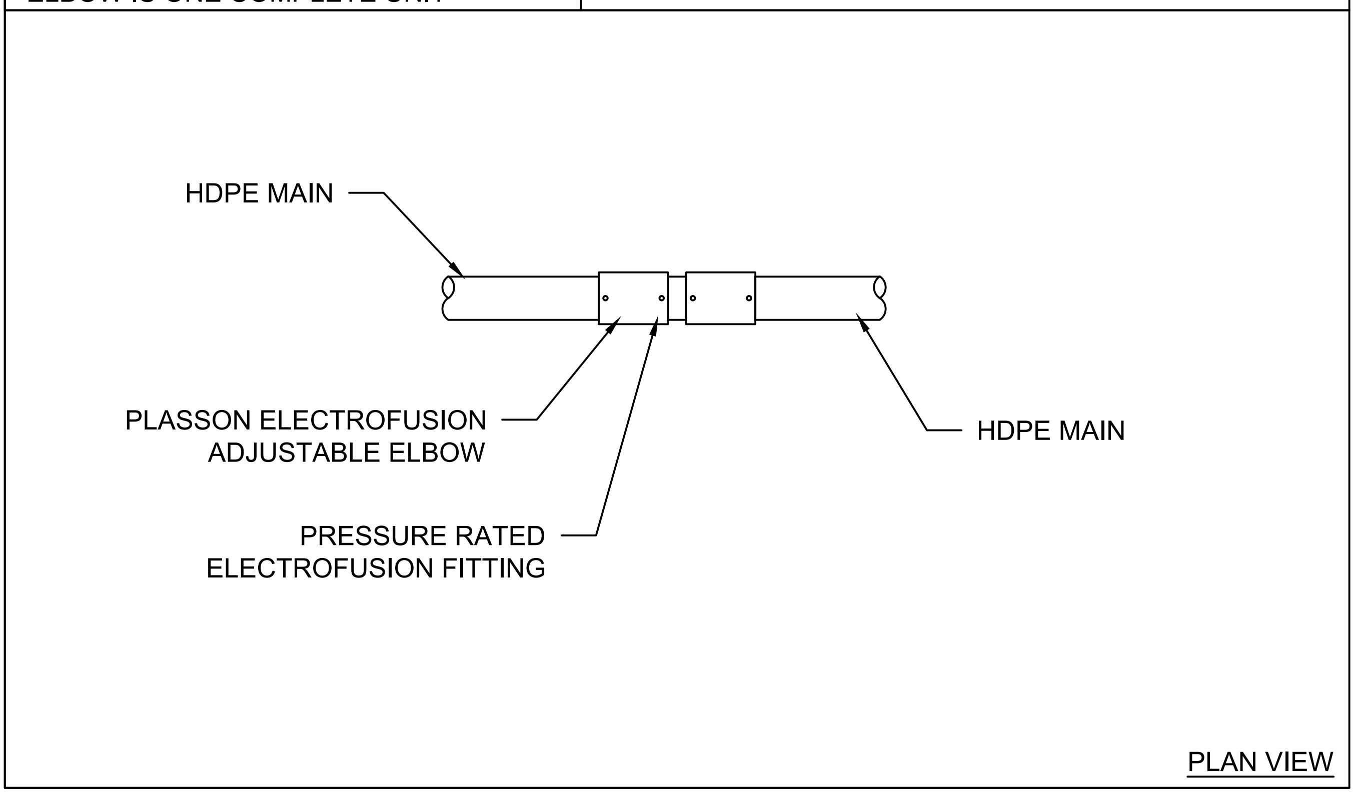


PLAN VIEW

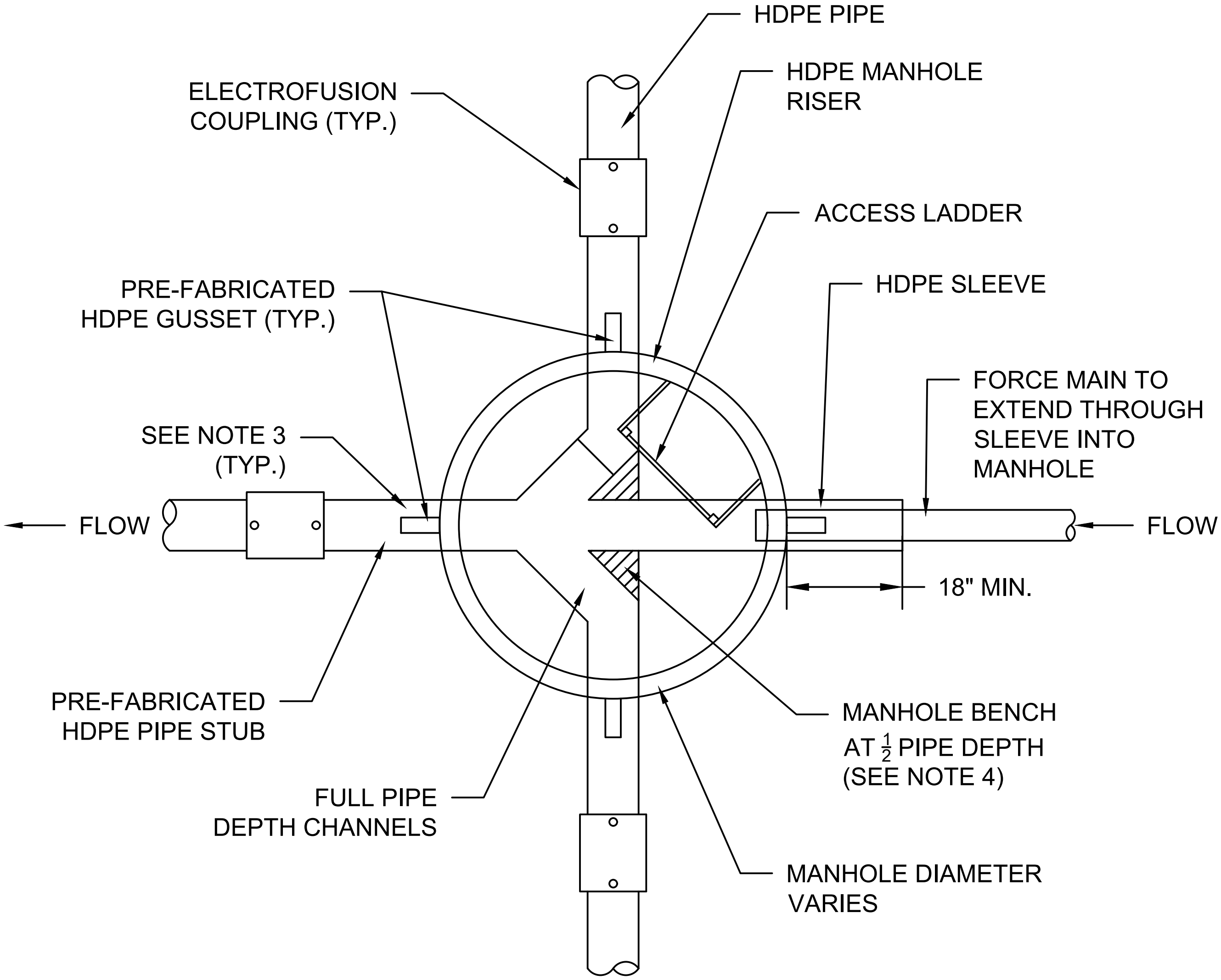
OD - DIPS (INCHES)	OD - NOMINAL (INCHES)	* MINIMUM BENDING RADIUS PER SDR (FEET)							
		7	9	11	13.5	17	21	26	32.5
		20* R	20 * R	25 * R	25 * R	27 * R	27 * R	34 * R	42 * R
4	4.8	8.0	8.0	10.0	10.0	10.8	10.8	13.6	16.8
6	6.9	11.5	11.5	14.4	14.4	15.5	15.5	19.6	24.2
8	9.1	15.1	15.1	18.9	18.9	20.4	20.4	25.6	31.7
10	11.1	18.5	18.5	23.1	23.1	25.0	25.0	31.5	38.9
12	13.2	22.0	22.0	27.5	27.5	29.7	29.7	37.4	46.2
14	15.3	25.5	25.5	31.9	31.9	34.4	34.4	43.4	53.6
16	17.4	29.0	29.0	36.3	36.3	39.2	39.2	49.3	60.9
18	19.5	32.5	32.5	40.6	40.6	43.9	43.9	55.3	68.3
20	21.6	36.0	36.0	45.0	45.0	48.6	48.6	61.2	75.6
24	25.8	43.0	43.0	53.8	53.8	58.1	58.1	73.1	90.3
30	32.0	53.3	53.3	66.7	66.7	72.0	72.0	90.7	112.0
36	38.3	63.8	63.8	79.8	79.8	86.2	86.2	108.5	134.1

UTILITY CONFLICT AND HDPE BEND RADIUS	ALLIANCE FOR pe pipe
ALLIANCE FOR PE PIPE	Standard Detail INST-2B Scale: NTS REV 5/2020





PLASSON ELECTROFUSION ADJUSTABLE ELBOW	ALLIANCE FOR pepipe
ALLIANCE FOR PE PIPE	Standard Detail INST-2C Scale: NTS REV 5/2020

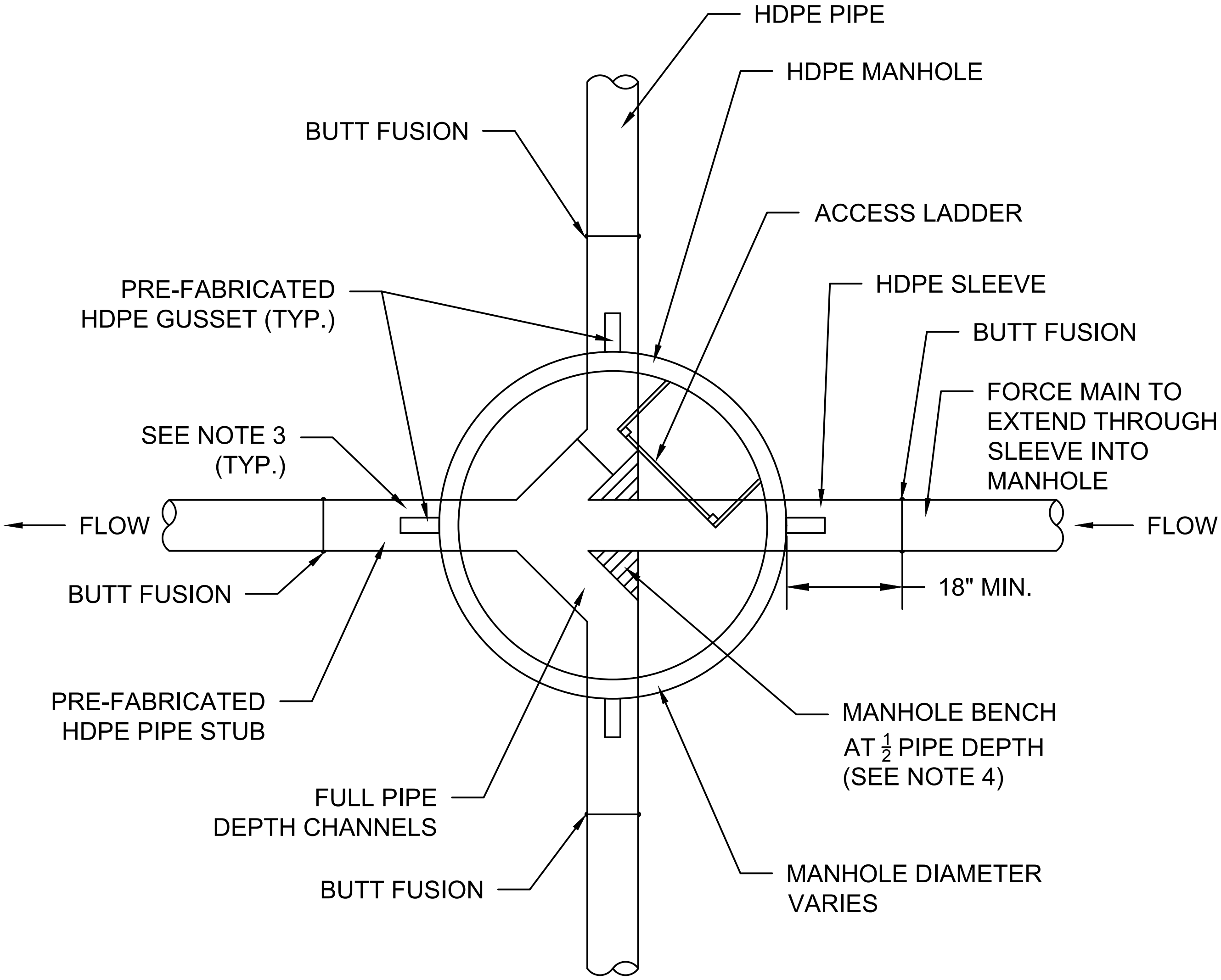


PLAN VIEW
FOR SECTION VIEW SEE STANDARD DETAIL MH-2A

NOTES:

1. BACKFILL SHALL BE PLACED AROUND THE MANHOLE RISER FOR THE FULL HEIGHT OF THE MANHOLE.
2. BACKFILL SHALL EXTEND A MINIMUM OF 3.5' FROM THE RISER OR TO THE TRENCH WALL (NOT SHOWN), WHICHEVER IS GREATER.
3. PIPE STUB WALL THICKNESS SHALL BE EQUAL TO OR GREATER THAN THE HDPE MAINLINE PIPE SDR.
4. BENCH AND PIPE TO BE AT FULL PIPE DEPTH IN NON-HATCHED AREAS, HATCH LOCATIONS TO BE HALF PIPE DEPTH.

HDPE MANHOLE WITH ELECTROFUSION CONNECTIONS	ALLIANCE FOR pe pipe
ALLIANCE FOR PE PIPE	Standard Detail MH-1A Scale: NTS REV 05/2020

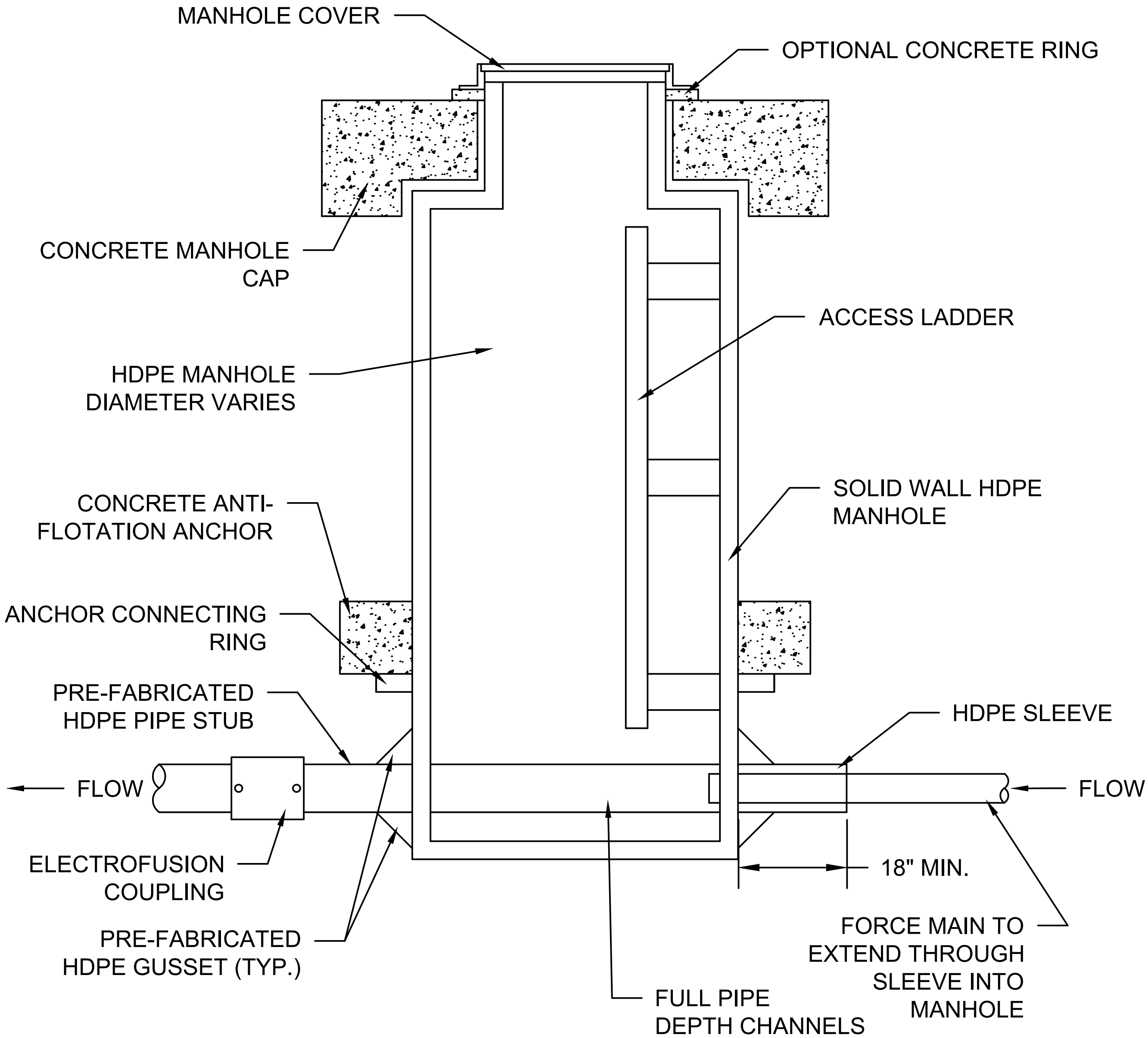


PLAN VIEW
FOR SECTION VIEW SEE STANDARD DETAIL MH-2A

NOTES:

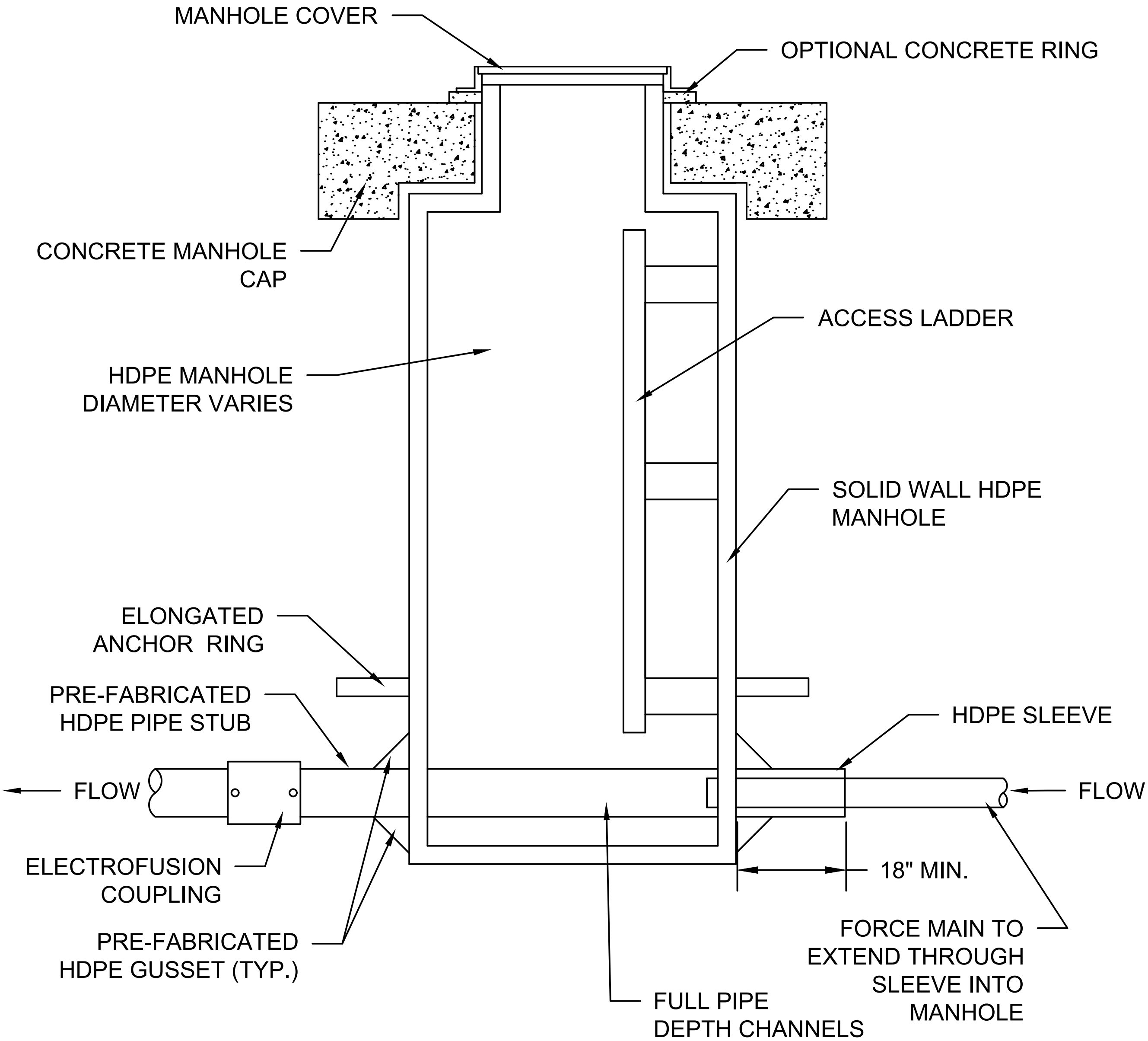
1. BACKFILL SHALL BE PLACED AROUND THE MANHOLE RISER FOR THE FULL HEIGHT OF THE MANHOLE.
2. BACKFILL SHALL EXTEND A MINIMUM OF 3.5' FROM THE RISER OR TO THE TRENCH WALL (NOT SHOWN), WHICHEVER IS GREATER.
3. PIPE STUB WALL THICKNESS SHALL BE EQUAL TO OR GREATER THAN THE HDPE MAINLINE PIPE SDR.
4. BENCH AND PIPE TO BE AT FULL PIPE DEPTH IN NON-HATCHED AREAS, HATCH LOCATIONS TO BE HALF PIPE DEPTH.

HDPE MANHOLE WITH BUTT FUSION CONNECTIONS	ALLIANCE FOR pe pipe
ALLIANCE FOR PE PIPE	Standard Detail MH-1B Scale: NTS REV 05/2020



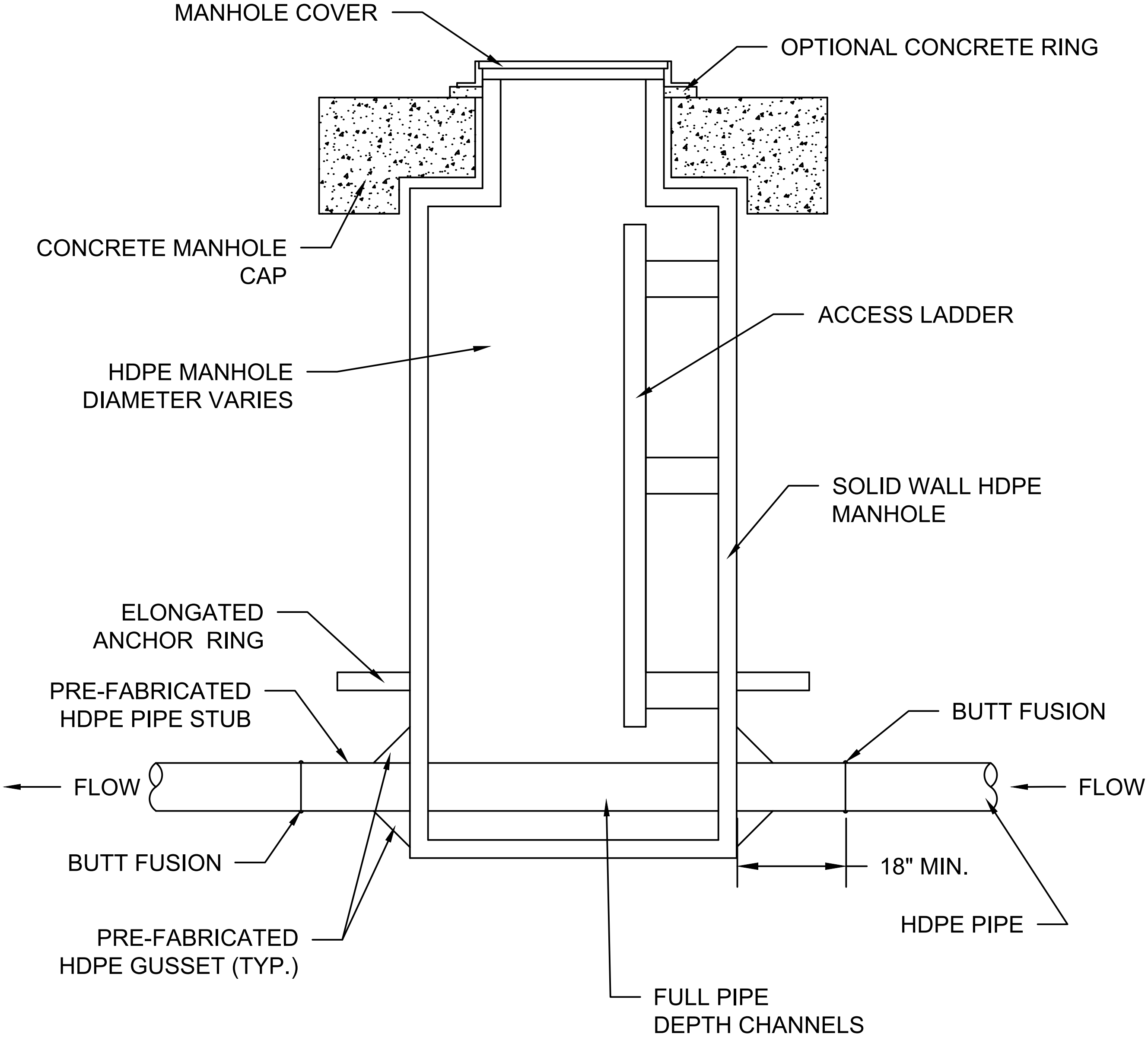
SECTION VIEW
FOR PLAN VIEW SEE
STANDARD DETAIL MH-1A

HDPE MANHOLE WITH ELECTROFUSION CONNECTIONS	ALLIANCE FOR pe pipe
ALLIANCE FOR PE PIPE	Standard Detail MH-2A Scale: NTS REV 05/2020



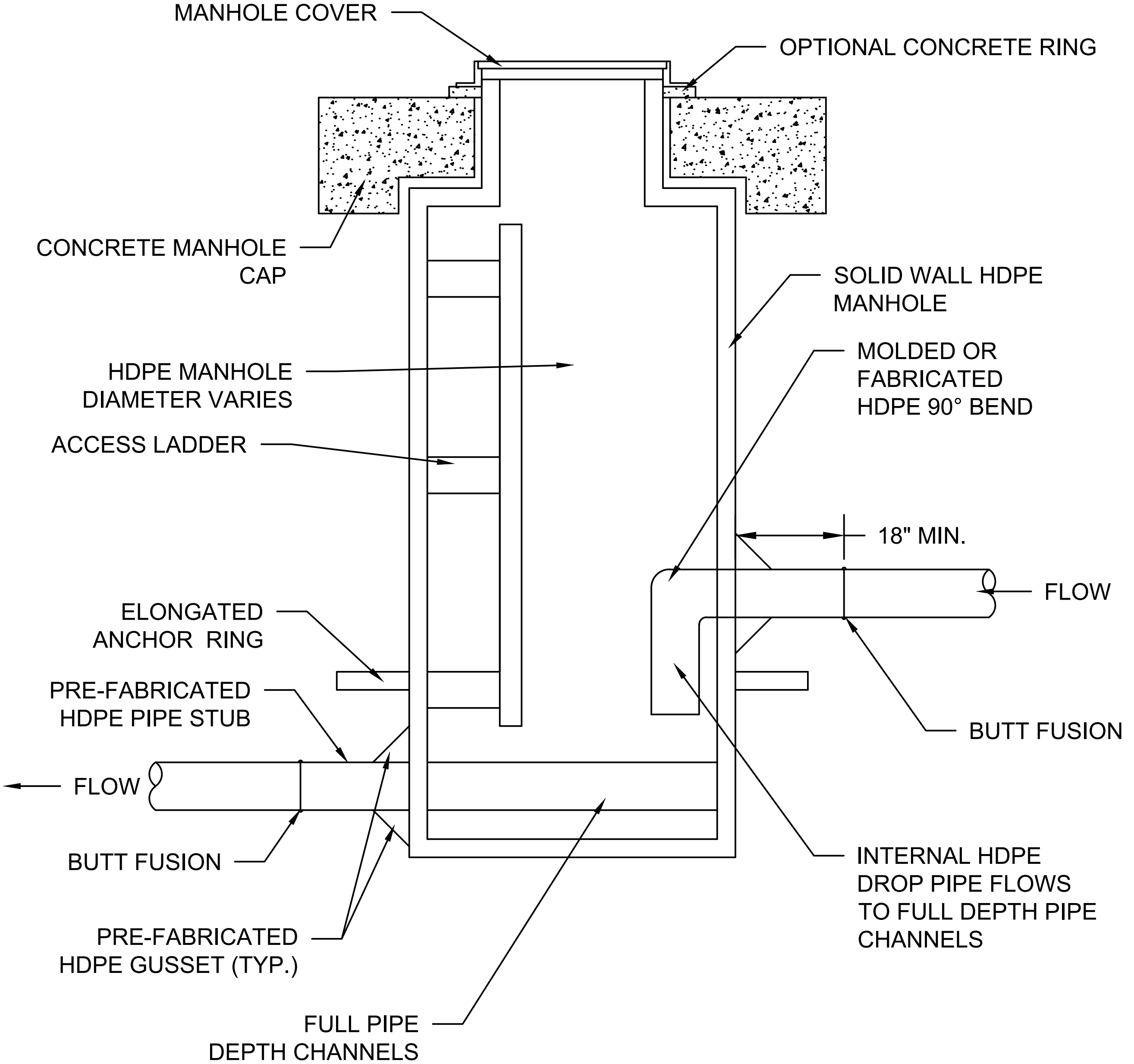
SECTION VIEW
FOR PLAN VIEW SEE STANDARD DETAIL MH-1A

HDPE MANHOLE WITH ELECTROFUSION CONNECTIONS AND ELONGATED ANCHOR RING	ALLIANCE FOR pe pipe
ALLIANCE FOR PE PIPE	Standard Detail MH-2B Scale: NTS REV 05/2020



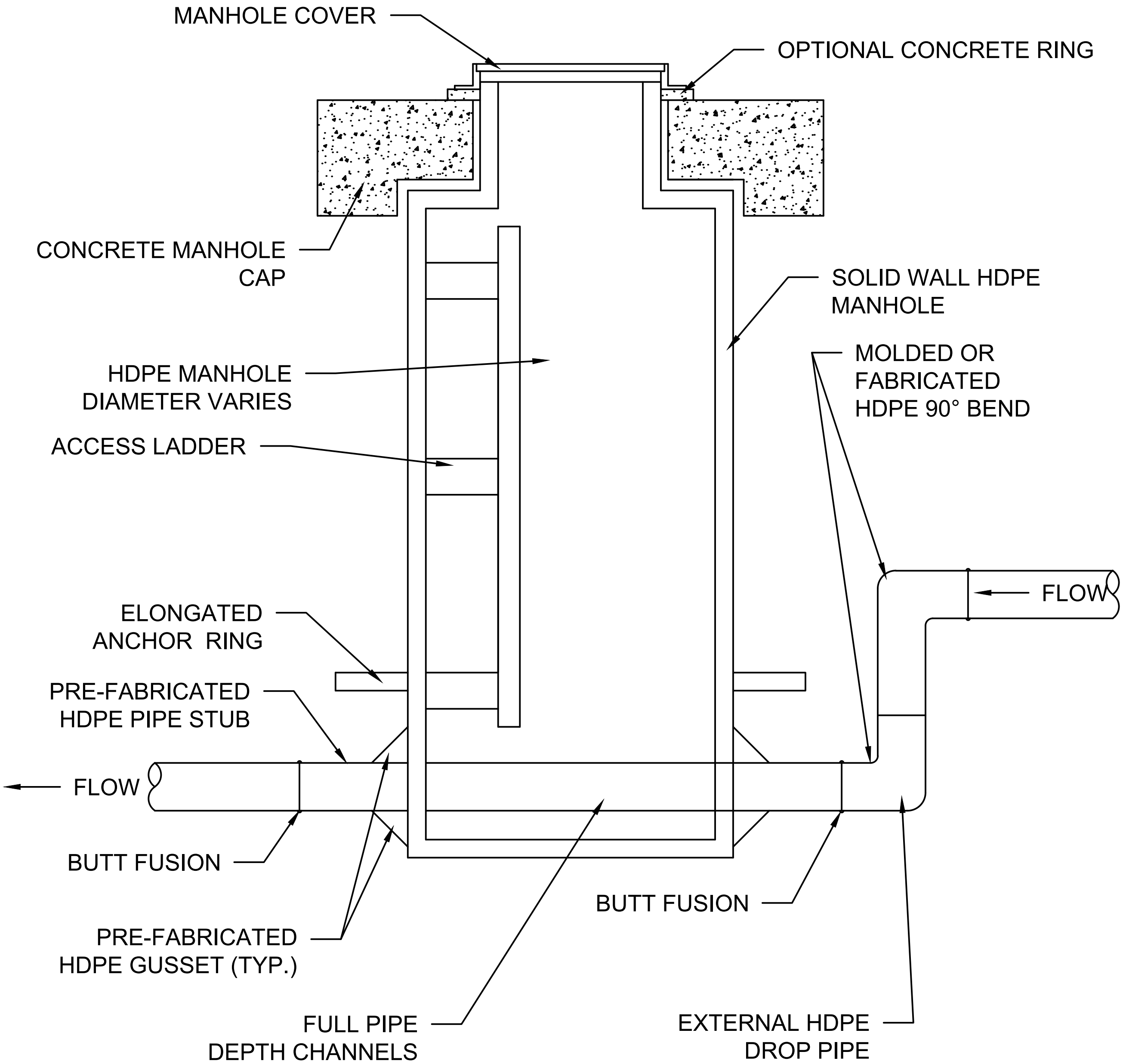
SECTION VIEW
FOR PLAN VIEW SEE
STANDARD DETAIL MH-1A

HDPE MANHOLE WITH BUTT FUSION CONNECTIONS AND ELONGATED ANCHOR RING	ALLIANCE FOR pepipe
ALLIANCE FOR PE PIPE	Standard Detail MH-2C Scale: NTS REV 05/2020



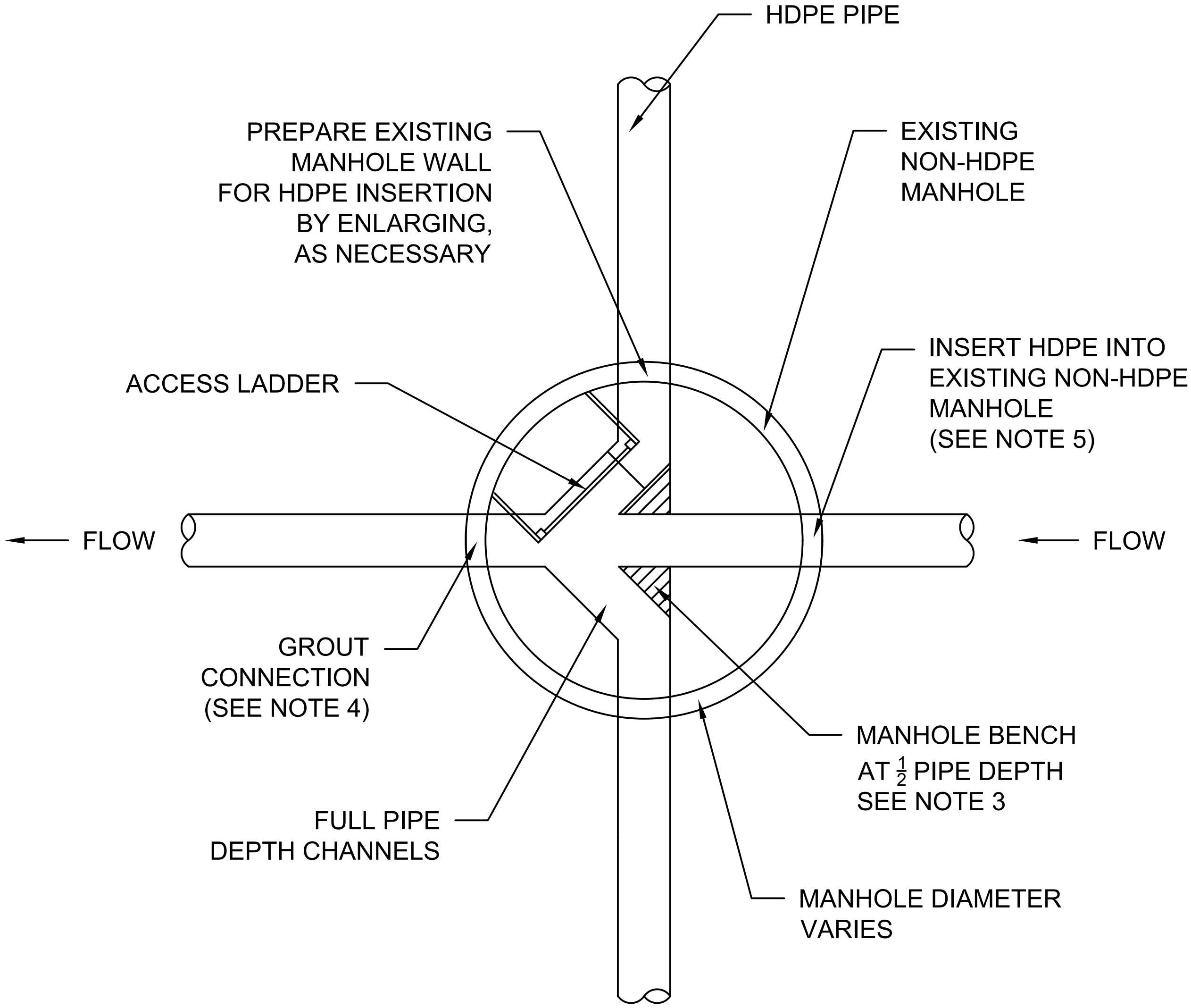
SECTION VIEW
FOR PLAN VIEW SEE
STANDARD DETAIL MH-1A

HDPE MANHOLE WITH BUTT FUSION CONNECTIONS AND INTERNAL HDPE DROP PIPE	ALLIANCE FOR pe pipe
ALLIANCE FOR PE PIPE	Standard Detail MH-2D Scale: NTS REV 05/2020



SECTION VIEW
FOR PLAN VIEW SEE STANDARD DETAIL MH-1A

HDPE MANHOLE WITH BUTT FUSION CONNECTIONS AND EXTERNAL HDPE DROP PIPE	ALLIANCE FOR pe pipe
ALLIANCE FOR PE PIPE	Standard Detail MH-2E Scale: NTS REV 05/2020

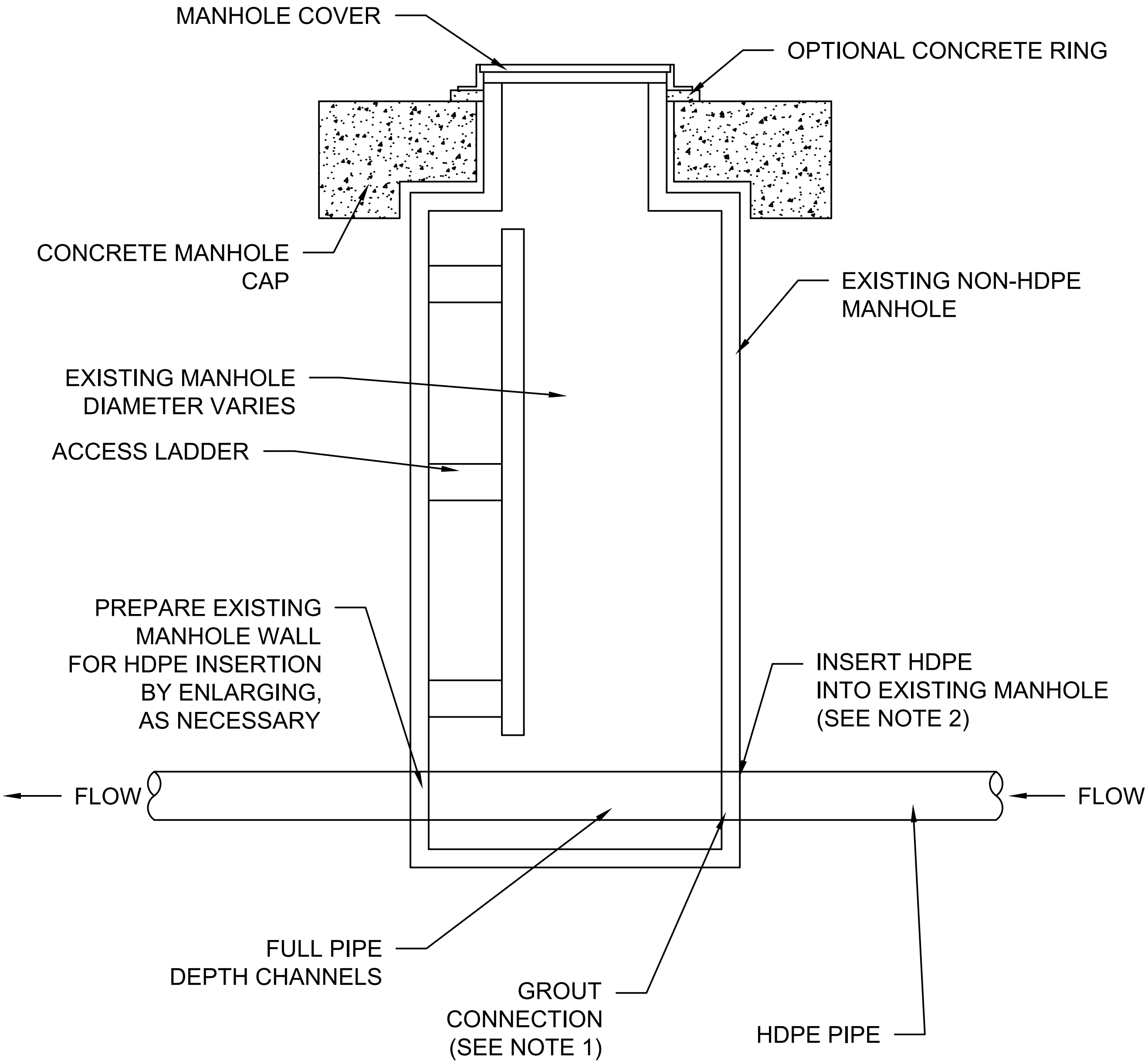


PLAN VIEW
FOR PLAN VIEW SEE
STANDARD DETAIL MH-3C

NOTES:

1. BACKFILL SHALL BE PLACED AROUND THE MANHOLE RISER FOR THE FULL HEIGHT OF THE MANHOLE.
2. BACKFILL SHALL EXTEND A MINIMUM OF 3.5' FROM THE RISER OR TO THE TRENCH WALL, WHICHEVER IS GREATER.
3. BENCH AND PIPE TO BE AT FULL PIPE DEPTH IN NON-HATCHED AREAS, HATCH LOCATIONS TO BE HALF PIPE DEPTH.
4. ALLOW HDPE TO RELAX PRIOR TO INSTALLING GROUT
5. INSERT LONGER LENGTH OF HDPE PIPE INTO MANHOLE AND ALLOW TO RELAX PRIOR TO INSTALLING GROUT

CONNECTING HDPE TO NON-HDPE MANHOLE	ALLIANCE FOR pepipe
ALLIANCE FOR PE PIPE	Standard Detail MH-3A Scale: NTS REV 05/2020

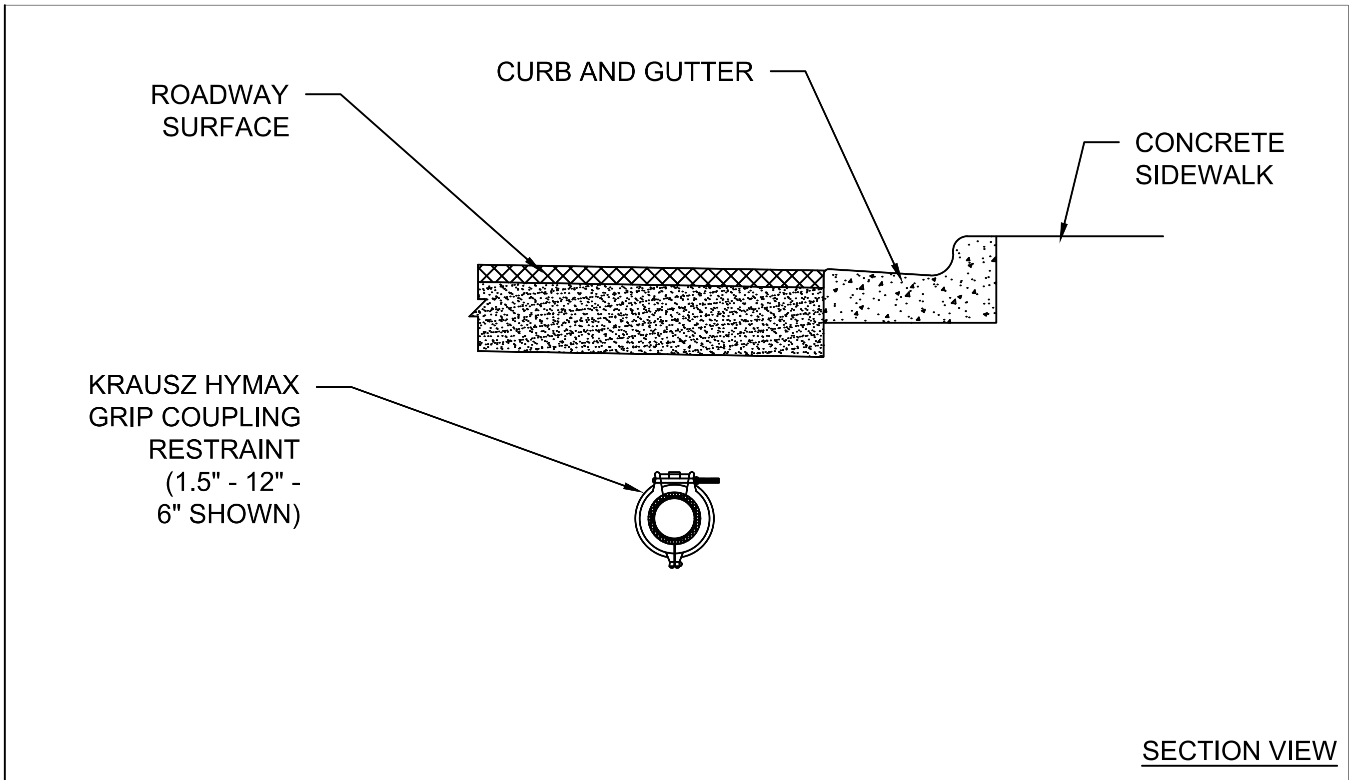


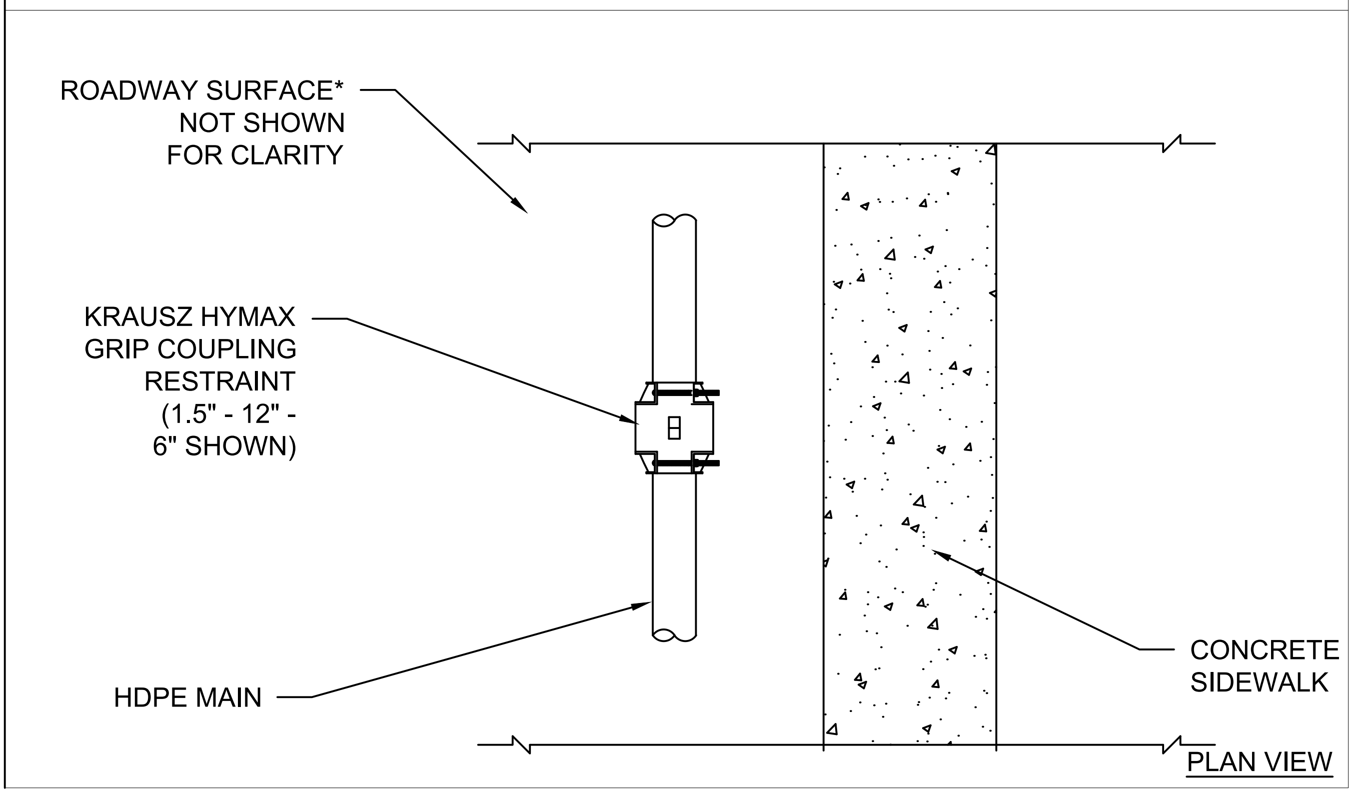
SECTION VIEW
FOR PLAN VIEW SEE STANDARD DETAIL MH-3A

NOTES:

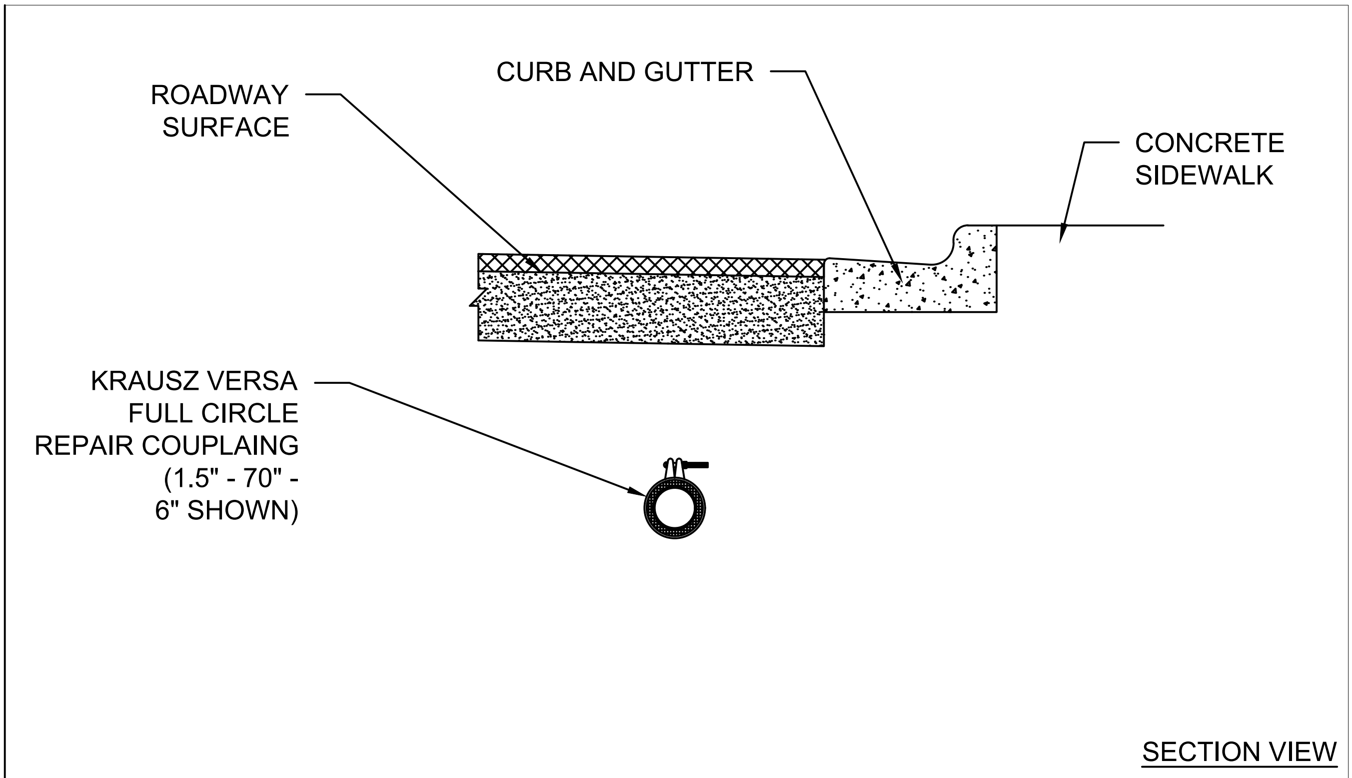
1. ALLOW HDPE TO RELAX PRIOR TO INSTALLING GROUT
2. INSERT LONGER LENGTH OF HDPE PIPE INTO MANHOLE AND ALLOW TO RELAX PRIOR TO INSTALLING GROUT

CONNECTING HDPE TO NON-HDPE MANHOLE	ALLIANCE FOR pe pipe
ALLIANCE FOR PE PIPE	Standard Detail MH-3B Scale: NTS REV 05/2020

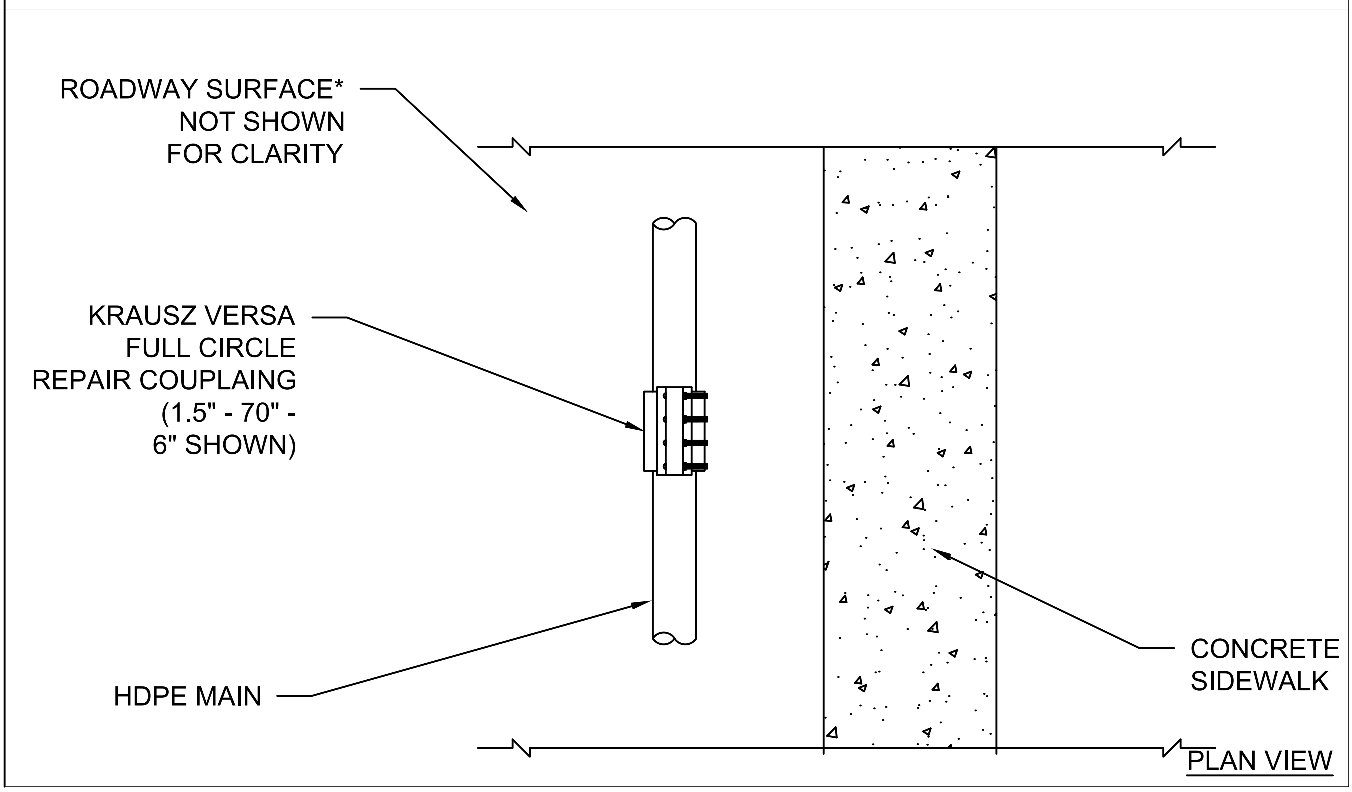




KRAUSZ HYMAX GRIP COUPLING - REPAIR OR RESTRAINED CONNECTION	ALLIANCE FOR pe pipe
ALLIANCE FOR PE PIPE	Standard Detail REP-1 Scale: NTS REV 05/2020



SECTION VIEW



PLAN VIEW

KRAUSZ VERSA FULL CIRCLE REPAIR COUPLING - NON-RESTRAINED (1.5" - 70-")	ALLIANCE FOR pe pipe
ALLIANCE FOR PE PIPE	Standard Detail REP-2 Scale: NTS REV 05/2020

Contractor and Fusion Operator Qualification Specification

In order to ensure a smooth and successful HDPE piping project, it is of paramount importance to select an experienced HDPE contractor whose operators and technicians are properly trained in HDPE pipe fusion procedures, using industry-approved standard protocols, fittings, and equipment. The specification as set forth in this document is useful for municipalities and consulting engineers when creating a contractor pool or selecting a contractor for the installation of high-density polyethylene (HDPE) pipe. The following information provides guidance for all aspects of HDPE contractor selection.

This specification covers:

- Background
- Definitions and Acronyms
- Qualified Fusion Contractor
- Qualified Fusion Operator
- Fusion Records
- Data Logging – Butt fusion and Electrofusion
- References

Background

In order to create a leak free, monolithic, HDPE piping system for your potable and wastewater applications, you and your contractor should understand and follow proper fusion and related procedures. When we discuss fusion of HDPE pipe, all approved methods of fusion are included. Such methods include:

- Butt Fusion
- Saddle Fusion
- Socket Fusion
- Electrofusion

In order for a contractor's technician to perform any of the aforementioned types of fusions, personnel require formal training specific to the size and dimension ratio (DR) of the piping system. Although each of the various fusion procedures and methodologies is similar to the others, the key difference between them is in operating a specific type or size of fusion equipment and understanding the methodologies for handling the pipe or fitting itself.

Approved fusion procedures are well-documented in the Plastics Pipe Institute's (PPI) technical reports, notes, and its *Handbook of Polyethylene Pipe* (PPI, 2008, 2012, 2013). Other sources for fusion procedures include documentation from the American Society for Testing and Materials (ASTM) (ASTM, 2013) and from manufacturers' literature. Working with fusion technicians that understand HDPE and the importance of adherence to such procedures will help ensure a leak-free and monolithic system that will provide long service life to the water or wastewater piping system.

Definitions and Acronyms

Butt Fusion - A method of joining HDPE pipe where two pipe ends are heated and rapidly brought together under pressure to form a homogeneous bond. It is estimated that at least 90% of the fusions in the HDPE pipe industry are butt fusion welds.

Ductile Iron Pipe Sizing (DIPS) – DIPS is used for HDPE pipe when HDPE pipe is OD controlled. DIPS pipe OD is larger than IPS pipe OD by almost half an inch.

Dimension Ratio (DR) - The ratio of pipe diameter to wall thickness, where DR= outer diameter divided by the minimum wall thickness.

$$DR = \frac{OD}{t_{MIN}}$$

Electrofusion (EF) – A heat fusion joining process where the heat source is an integral part of the fitting.

High Density Polyethylene (HDPE) or Polyethylene (PE) – HDPE pipe or fitting.

Iron Pipe Sizing Convention (IPS) – IPS is used for HDPE pipe when HDPE pipe is OD controlled. IPS pipe OD is always smaller than DIPS pipe OD.

Example - An 8" DR11 IPS pipe features an 8.6" average OD and a .78" minimum wall with a 7.0" average ID; an 8" DR11 DIPS pipe features a 9.1" average OD and minimum wall of .82" with an average ID of 7.3"

Pressure Rating - Estimated maximum internal pressure allowed with a high certainty that failure of the pipe will not occur. HDPE can handle as a part of its design occasional surges to 2 times its pressure rating and 1.5 times for recurring surges.

Standard Dimension Ratio (SDR) - A specific ratio of the average specified outside diameter to the minimum specified wall thickness for outside diameter-controlled plastic pipe. Common reference is DR. DR and SDR are the same and used interchangeably.

Thermoplastic - A plastic, such as PE, that can be repeatedly softened by heating and hardened by cooling through a temperature range characteristic of the plastic and that in the softened state can be shaped by molding or extrusion.

Qualified HDPE Fusion Contractor

Contractors and their personnel conducting and performing HDPE pipe fusions in the field must be formally trained and have experience related to the pipe size and equipment required for the job. The contractor must have experience with the type of fusion being conducted and knowledge of best handling practices in the field to reduce potential damage or future problems related to the installation.

Appropriate record keeping and documentation is also highly recommended to track technician experience and abilities and to provide traceable evidence to ensure proper procedures and methodologies were followed. Electronic data collection, such as data logging and written logs, serve the dual purposes of procedure verification as well as documentation of contractor history and experience.

Documentation should be provided showing current and up-to-date qualification (i.e. a qualification card not older than 24 months) of training obtained to fuse HDPE pipe in the appropriate sizes and equipment types for the job. This type of training is readily available from the fusion equipment manufacturer and distribution companies that sell polyethylene products. Accountability for the entirety of the fusion and proper installation of a polyethylene piping system lies with the installer.

A **Qualified Fusion Contractor** (QFC) is a contracting company that has managed, either as the prime contractor or the fusion subcontractor, two or more HDPE fusion projects similar to the project being considered by the owner within the last 36 months. Contractors who are qualified may also have served as a subcontractor handling the slip-lining, pipe bursting, or horizontal directional drilling elements of an HDPE project.

Because many jobs find HDPE as a part of a larger pipeline job, instances may also occur where a contractor is handling both HDPE and another material. These projects should also assist in qualifying a contractor.

The owner should understand that a QFC may be qualified to operate fusion equipment, but may not have experience in the installation method necessary to use the HDPE. Thus, the qualified contractor must not only demonstrate qualification in fusion, but s/he should also demonstrate experience in the construction method required to fulfill the project requirements.

The QFC's project history that meets the 36-month criteria must be of similar type. For example, if the owner is proposing a 24" open cut HDPE job, the QFC's experience must be open cut and must have included work with equipment capable of the same size range.

If the project is a slip-lining job, the QFC must have HDPE slip-lining experience using pipes of a similar diameter. If the project is a pipe-bursting job, a QFC must have experience with pipes bursting at any diameter. In those cases where a contractor has limited experience with pipe bursting or drilling operations but proposes the use of technicians with training from the manufacturers of equipment used in such operations, a contractor shall be considered as a qualified.

Qualified HDPE Fusion Operator (QFO)

Using approved manufacturers of HDPE pipe and associated equipment, the QFC, as described above, shall ensure that personnel performing heat fusion and related operations are qualified to perform such procedures. To ensure that all practices of pipe handling and fusing meet or exceed manufacturers' specifications and recommendations, only qualified technicians shall be permitted to fuse and install HDPE pipe. A QFO is an individual who:

(i) is competent and knowledgeable in heat fusion procedures;

(ii) is qualified and has proof of qualification within the last 24 months via a manufacturers recognized training facility and/or program;

(iii) has received training in heat fusion procedures according to ASTM F2620 for Butt Fusion and ASTM F1055 for Electro Fusion;

(iv) has received training in the equipment being used to perform fusion procedures;

(v) has received training in accordance for the size of installation (e.g., small diameter (1/2" CTS to 6" DPS (16 mm to 180 mm)); medium diameter (2" IPS to 20" OD (63 mm to 500 mm)); or large diameter (20" IPS to 74" OD (225 mm to 1600 mm));

(vi) has received training in handling and testing methods;

(vii) understands the effects of changing conditions in the surrounding environments and adjusts or checks fusion parameters to avoid negative impacts on the fusions (e.g., weather changes – cold or wet, wind and dust, bend radius, etc.)

(viii) has documented prior experience (logs) in performing HDPE pipe installations, heat fusion procedures, and testing methods.

The required training and experience described above shall also be consistent with published guidance (current PPI literature, ASTM, American Water Works Association (AWWA), CSA, etc). The QFC is required to maintain records of personnel training and experience and said records shall be made available for inspection.

Fusion Records and Marking

Central to competency as a QFC in the HDPE world is record keeping. Paper or electronic records of appropriate joint fusion procedure details shall be kept for all HDPE pipes fusions. Data logger information and drawings showing locations shall be submitted for review and recordation purposes before final approval of the contract. Electrofusion records should be printed or downloaded and saved to maintain a record log of EF. Note that fusion locations and fusion placement could be two separate locations. Using Global Positioning System (GPS) coordinates can help pinpoint the location of a specific fusion. All fusions regardless of where they are actually fused should be marked on the pipe for reference to when they are located in or above ground.

Data loggers and EF machines do NOT capture certain aspects of fusion. Such aspects should be recognized and verified by the QFO to ensure proper protocols and procedures were followed and include the following:

(i) *Pipe preparation* – ensure the pipe ends are free of contaminants that could negatively affect fusion. The only cleaner recommended is 95% or greater purity isopropyl alcohol using lint free, white, non-synthetic paper towels or cloths.

   a. Dirt, mud or dust, water or moisture, chainsaw oils and grease or any oils, facing shavings or facing tags, lint from non-lint free clothes, etc.

(ii) *Pipe alignments* – confirm the pipes are properly aligned prior to heating and fusion steps. If adjustments to the machine are made, the pipes should be refaced and checked again.

(iii) *Machine and heater operation checks* – ensure a clean and balanced heating surface. Ensure heater surface temperatures are within the specified range, and heater faces are clear of contaminates and build up.

(iv) *Visual inspections* - study pipe prior to and after unloading (gouging, scratching, notching, etc.) inside and outside surfaces. Inspect the OD of pipe after it has been handled or moved in the field to insure that scratches of no greater than 10% of the wall thickness have occurred.

The permanent type markers, such as the, "Sharpie," (e.g. Sharpie brand, permanent, silver metallic) and "Magic Marker" by Avery are adequate for marking light colored pipe. Fast drying paint pens, such as those manufactured by PENTEL and Faber Castell, also work well and are available in colors that will show well on black pipe; it is sometimes necessary to allow for drying when using paint type pens. A wax based "China Marker," although not permanent, works well for marking black pipe. We have found no advantage of one type of marker, permanent or paint, over the other.

Such labels are still considered temporary markings because they will wear off over time unless they are not protected or covered. These marking should include as a minimum:

(i) Date/time;
(ii) Operator Name or Company;
(iii) Fusion identification (ID) number assigned (link to data logger); and
(iv) Project number.

An example of the minimum typical information to be given is shown in Figure 1. Follow all guidelines and recommendations provided by data logger manufacturers to ensure that quality is maintained.

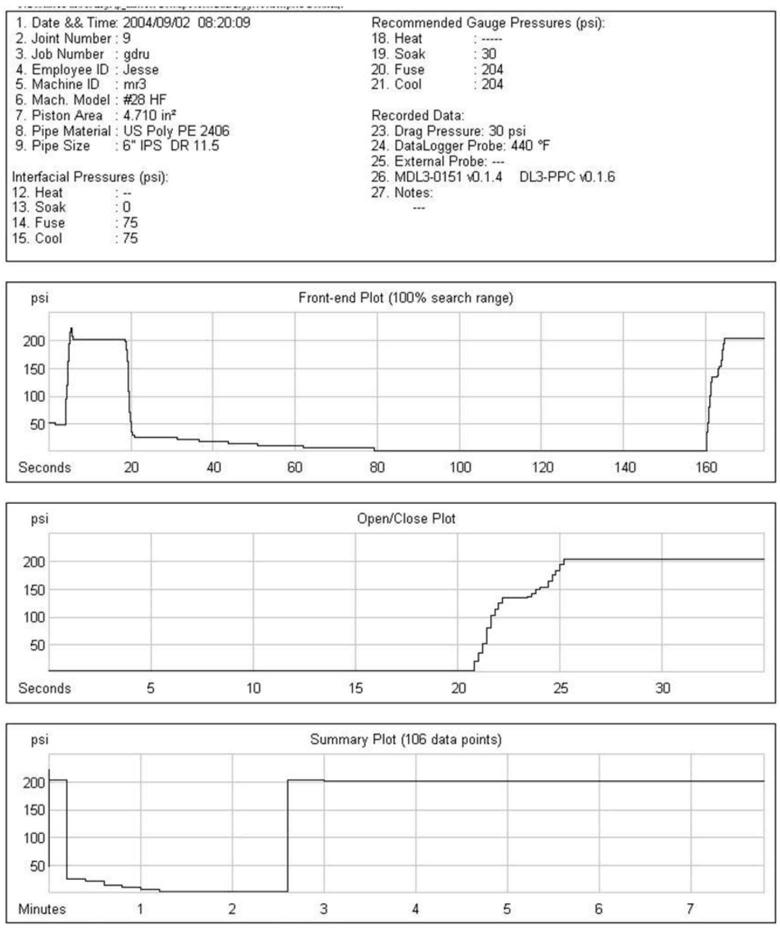


Figure 1. Example of a heat fusion joint record output for a McElroy Data Logger

(Colorado Springs Utilities, 2014)

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Handbook of Polyethylene (PE) Pipe

Foreword

PE piping, has been successfully utilized for a variety of piping applications for over 50 years. Despite this relatively short history, the engineering community has embraced the overall toughness and durability of PE pipe and the latitude afforded by the variety of installation methods that can be employed using PE pipe to expand its use at a quickening rate.

Today, we see PE piping systems operating in a broad array of installations; from pressure-rated potable water and natural gas lines to gravity sewers, from industrial and chemical handling to telecommunications and electrical ducting; from oil and gas production to marine installations and directional drilling.

This text has been developed to assist designers, installers and owners in the design, rehabilitation and installation of solid wall PE pipe. Applications using profile wall PE pipe are addressed briefly; applications using PEX pipe (for plumbing, heating, ...) and applications using corrugated PE pipe (for drainage, ...) are covered in multiple and separate PPI publications.

This Handbook discusses material properties, design, installation and applications of solid wall PE pipe and to a lesser extent, profile wall PE pipe. Corrugated PE pipe for drainage applications is covered in a separate handbook.

This Handbook discusses material properties, design, installation and applications of solid wall PE pipe and to a lesser extent, profile wall PE pipe. Corrugated PE pipe for drainage applications is covered in a separate handbook.

The material presented in this text has been written in a manner that is easily understood, with an emphasis on organization to provide the reader with ease of reference. It is only because of our efforts to be as comprehensive as possible with respect to the subject matter that have resulted in such an extensive publication.

The overall work consists of essentially three fairly discreet sections, each consisting of several chapters. The chapters in the first section cover introductory type information including the origins and growth of the PE pipe industry in North America, the unique features of PE pipe material, its manufacture, handling, storage, field inspection and testing, and safety considerations. This section also includes a chapter dealing with the subject of the product specifications and codes that apply to PE pipe. Completing this section is a comprehensive chapter covering the engineering and physical properties of the PE pipe materials and of the finished pipe product itself.

The second section, or design section, consists primarily of design considerations and includes chapters on pipe design, joining procedures, and basic information on buried and above-ground installations.

The final section of this text is comprised of a set of chapters that provide the reader with detailed information regarding design considerations, installation techniques, repairs and operation of PE pipe in a variety of specific applications, such as directional drilling, pipe bursting, marine, conduit, HVAC.

The overall work concludes with an extensive glossary and, of course, an index to provide ease of reference for specific topics of interest. The organization of the subject matter should allow the reader to quickly reference a specific area of interest or, moreover, for the college educator to utilize specific sections of the handbook within the context of a college curriculum.

This handbook has been developed by the PPI as a service to the industry. The information in this handbook is offered in good faith and believed to be accurate at the time of its preparation, but is offered without any warranty, expressed or implied, including warranties of merchantability and fitness for a particular purpose. Additional information may be needed in some areas, especially with regard to unusual or special applications. In these situations, the reader is advised to consult the manufacturer or material supplier for more detailed information. A list of member companies is available on the PPI website. Also, the reader has to refer to the website to download a copy of the Errata Sheet.

PPI intends to revise this handbook from time to time, in response to comments and suggestions from member companies and from users of the handbook. To that end, please send suggestions for improvements to PPI. Information on other publications can be obtained by visiting the website.

The Plastics Pipe Institute

This handbook has been developed as a result of a task group initiative within the Plastics Pipe Institute (PPI). Founded in 1950, the PPI is the major trade association representing all segments of the plastics piping industry. PPI is dedicated to the advancement of PE pipe systems by:

- Contributing to the development of research, standards and design guides
- Educating designers, installers, users and government officials
- Collecting and publishing industry statistics
- Maintaining liaisons with industry, educational and government groups
- Providing a technical focus for the plastics piping industry
- Communicating up-to-date information through our website www.plasticpipe.org

The Plastics Pipe Institute, Inc.

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Contents

CHAPTER 1

Introduction

Since its discovery in 1933, PE has grown to become one of the world's most widely used and recognized thermoplastic materials.(1) The versatility of this unique plastic material is demonstrated by the diversity of its use and applications. The original application for PE was as a substitute for rubber in electrical insulation during World War II. PE has since become one of the world's most widely utilized thermoplastics. Today's modern PE resins are highly engineered for much more rigorous applications such as pressure-rated gas and water pipe, landfill membranes, automotive fuel tanks and other demanding applications.

Figure I Joining Large Diameter PE Pipe with Butt Fusion

PE's use as a piping material first occurred in the mid 1950's. In North America, its original use was in industrial applications, followed by rural water and then oil field production where a flexible, tough and lightweight piping product was needed to fulfill the needs of a rapidly developing oil and gas production industry. The success of PE's pipe in these installations quickly led to its use in natural gas distribution where a coilable, corrosion-free piping material could be fused in the field to assure a "leak-free" method of transporting natural gas to homes and businesses. PE's success in this critical application has not gone without notice and today it is the material of choice for the natural gas distribution industry. Sources now estimate that nearly 95% of all new gas distribution pipe installations in North America that are 12" in diameter or smaller are PE piping.[2]

The performance benefits of polyethylene pipe in these original oil and gas related applications have led to its use in equally demanding piping installations such as potable water distribution, industrial and mining pipe, force mains and other critical applications where a tough, ductile material is needed to assure long-term performance. It is these applications, representative of the expanding use of polyethylene pipe that are the principle subject of this handbook. In the chapters that follow, we shall examine all aspects of design and use of polyethylene pipe in a broad array of applications. From engineering properties and material science to fluid flow and burial design; from material handling and safety considerations to modern installation practices such as horizontal directional drilling and/or pipe bursting; from potable water lines to industrial slurries we will examine those qualities, properties and design considerations which have led to the growing use of polyethylene pipe in North America.

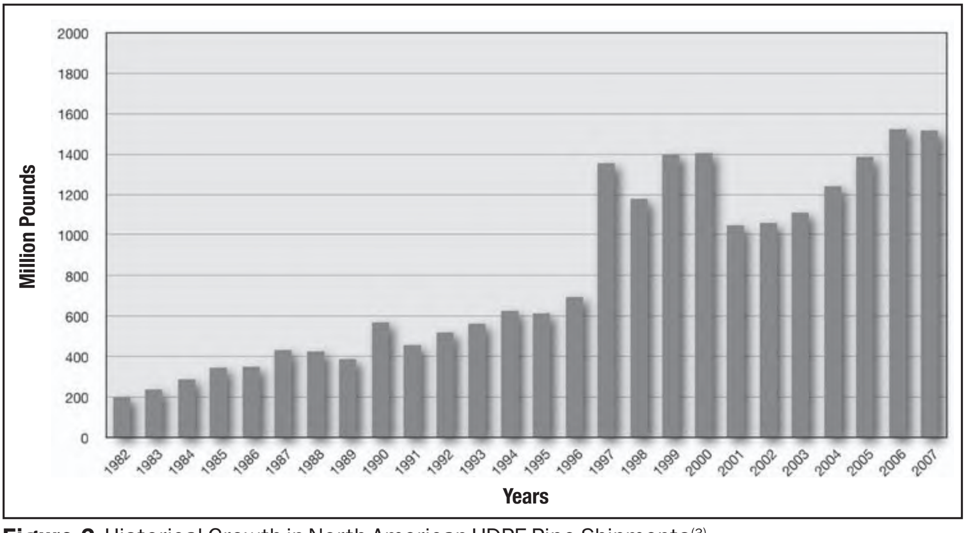

Figure 2 Historical Growth in North American HDPE Pipe Shipments(3)

Features and Benefits of PE Pipe

When selecting pipe materials, designers, owners and contractors specify materials that provide reliable, long-term service durability, and cost-effectiveness.

Solid wall PE pipes provide a cost-effective solution for a wide range of piping applications including natural gas distribution, municipal water and sewer, industrial, marine, mining, landfill, and electrical and communications duct applications. PE pipe is also effective for above ground, buried, trenchless, floating and marine installations. According to David A. Willoughby, P.O.E., "… one major reason for the growth in the use of the plastic pipe is the cost savings in installation, labor and equipment as compared to traditional piping materials. Add to this the potential for lower maintenance costs and increased service life and plastic pipe is a very competitive product."[4]

Natural gas distribution was among the first applications for medium-density PE (MDPE) pipe. In fact, many of the systems currently in use have been in continuous service since 1960 with great success. Today, PE pipe represents over 95% of the pipe installed for natural gas distribution in diameters up to 12" in the U.S. and Canada. PE is the material of choice not only in North America, but also worldwide. PE pipe has been used in potable water applications for almost 50 years, and has been continuously gaining approval and growth in municipalities. PE pipe is specified and/or approved in accordance with AWWA, NSF, and ASTM standards.

Some of the specific benefits of PE pipe are discussed in the parargraphs which follow.

- **Life Cycle Cost Savings** – For municipal applications, the life cycle cost of PE pipe can be significantly less than other pipe materials. The extremely smooth inside surface of PE pipe maintains its exceptional flow characteristics, and heat fusion joining eliminates leakage. This has proven to be a successful combination for reducing total system operating costs.
- **Leak Free, Fully Restrained Joints** – PE heat fusion joining forms leak-free joints that are as strong as, or stronger than, the pipe itself. For municipal applications, fused joints eliminate the potential leak points that exist every 10 to 20 feet when using the bell and spigot type joints associated with other piping products such as PVC or ductile iron. All these bell and spigot type joints employ elastomeric gasket materials that age over time and thus have the potential for leaks. As a result of this, the "allowable water leakage" for PE pipe is zero as compared to the water leakage rates of 10% or greater typically associated with these other piping products. PE pipe's fused joints are also self-restraining, eliminating the need for costly thrust restraints or thrust blocks while still insuring the integrity of the joint. Notwithstanding the advantages of the butt fusion method of joining, the engineer also has other available means for joining PE pipe and fittings such as electrofusion and mechanical fittings. Electrofusion fittings join the pipe and/or fittings together using embedded electric heating elements. In some situations, mechanical fittings may be required to facilitate joining to other piping products, valves or other system appurtenances. Specialized fittings for these purposes have been developed and are readily available to meet the needs of most demanding applications.
- **Corrosion & Chemical Resistance** – PE pipe will not rust, rot, pit, corrode, tuberculate or support biological growth. It has superb chemical resistance and is the material of choice for many harsh chemical environments. Although unaffected

by chemically aggressive native soil, installation of PE pipe (as with any piping material) through areas where soils are contaminated with organic solvents (oil, gasoline) may require installation methods that protect the PE pipe against contact with organic solvents. It should be recognized that even in the case of metallic and other pipe materials, which are joined by means of gaskets, protection against permeation is also required. Protective installation measures that assure the quality of the fluid being transported are typically required for all piping systems that are installed in contaminated soils.

- **Fatigue Resistance and Flexibility** – PE pipe can be field bent to a radius of about 30 times the nominal pipe diameter or less depending on wall thickness (12" PE pipe, for example, can be cold formed in the field to a 32-foot radius). This eliminates many of the fittings otherwise required for directional changes in piping systems and it also facilitates installation. The long-term durability of PE pipe has been extremely well researched. PE has exceptional fatigue resistance and when, operating at maximum operating pressure, it can withstand multiple surge pressure events up to 100% above its maximum operating pressure without any negative effect to its long-term performance capability.
- **Seismic Resistance** – The toughness, ductility and flexibility of PE pipe combined with its other special properties, such as its leak-free fully restrained heat fused joints, make it well suited for installation in dynamic soil environments and in areas prone to earthquakes.

Figure 3 Butt Fused PE Pipe "Arched" for Insertion into Directional Drilling Installation

- **Construction Advantages** – PE pipe's combination of light weight, flexibility and leak-free, fully restrained joints permits unique and cost-effective installation methods that are not practical with alternate materials. Installation methods such as horizontal directional drilling, pipe bursting, sliplining, plow and plant, and submerged or floating pipe, can greatly simplify construction and save considerable time and money on many installations. At approximately one-eighth the weight of comparable sized steel pipe, and with integral and dependable leakfree joining methods, installation is simpler, and it does not need heavy lifting equipment. PE pipe is produced in standard straight lengths to 50 feet or longer and coiled in diameters up through 6". Coiled lengths over 1000 feet are available in certain diameters. PE pipe can withstand impact much better than PVC pipe, especially in cold weather installations where other pipes are more prone to cracks and breaks. Because heat fused PE joints are as strong as the pipe itself, it can be joined into long runs conveniently above ground and later, installed directly into a trench or pulled in via directional drilling or using the re-liner process. Of course, the conditions at the construction site have a big impact on the preferred method of installation.
- **Durability** – PE pipe installations are cost-effective and have long-term cost advantages due to the pipe's physical properties, leak-free joints and reduced maintenance costs. The PE pipe industry estimates a service life for PE pipe to be, conservatively, 50-100 years provided that the system has been properly designed, installed and operated in accordance with industry established practice and the manufacturer's recommendations. This longevity confers savings in replacement costs for generations to come. Properly designed and installed PE piping systems require little on-going maintenance. PE pipe is resistant to most ordinary chemicals and is not susceptible to galvanic corrosion or electrolysis.

Figure 4 PE Pipe Weighted and Floated for Marine Installation

- **Hydraulically Efficient** – The internal surface of PE pipe is devoid of any roughness which places it in the "smooth pipe" category, a category that results in the lowest resistance to fluid flow. For water applications, PE pipe's Hazen Williams C factor is 150 and does not change over time. The C factor for other typical pipe materials declines dramatically over time due to corrosion and tuberculation or biological build-up. Without corrosion, tuberculation, or biological growth PE pipe maintains its smooth interior wall and its flow capabilities indefinitely to insure hydraulic efficiency over the intended design life.
- **Temperature Resistance** – PE pipe's typical operating temperature range is from 0°F to 140°F for pressure service. However, for non-pressure and special applications the material can easily handle much lower temperatures (e.g., to – 40°F and lower) and there are specially formulated materials that can service somewhat higher temperatures. Extensive testing and very many applications at very low ambient temperatures indicates that these conditions do not have an adverse effect on pipe strength or performance characteristics. Many of the PE resins used in PE pipe are stress rated not only at the standard temperature, 73° F, but also at an elevated temperature, such as 140°F. Typically, PE materials retain greater strength at elevated temperatures compared to other thermoplastic materials such as PVC. At 140° F, PE materials retain about 50% of their 73°F strength, compared to PVC which loses nearly 80% of its 73° F strength when placed in service at 140°F.(5) As a result, PE pipe materials can be used for a variety of piping applications across a very broad temperature range.

The features and benefits of PE are quite extensive, and some of the more notable qualities have been delineated in the preceding paragraphs. The remaining chapters of this Handbook provide more specific information regarding these qualities and the research on which these performance attributes are based.

Many of the performance properties of PE piping are the direct result of two important physical properties associated with PE pressure rated piping products. These are ductility and visco-elasticity. The reader is encouraged to keep these two properties in mind when reviewing the subsequent chapters of this handbook.

- **Ductility**

  Ductility is the ability of a material to deform in response to stress without fracture or, ultimately, failure. It is also sometimes referred to as increased strain capacity and it is an important performance feature of PE piping, both for above and below ground service. For example, in response to earth loading, the vertical diameter of buried PE pipe is slightly reduced. This reduction causes a slight increase in horizontal diameter, which activates lateral soil forces that tend to stabilize the pipe against further deformation. This yields a process that produces a soil-pipe Introduction 11 structure that is capable of safely supporting vertical earth and other loads that can fracture pipes of greater strength but lower strain capacity.

  Ductile materials, including PE, used for water, natural gas and industrial pipe applications have the capacity to safely handle localized stress intensifications that are caused by poor quality installation where rocks, boulders or tree stumps may be in position to impinge on the outside surface of the pipe. There are many other construction conditions that may cause similar effects, e.g. bending the pipe beyond a safe strain limit, inadequate support for the pipe, misalignment in connections to rigid structures and so on. Non- ductile piping materials do not perform as well when it comes to handling these types of localized high stress conditions.

Materials with low ductility or strain capacity respond differently. Strain sensitive materials are designed on the basis of a complex analysis of stresses and the potential for stress intensification in certain regions within the material. When any of these stresses exceed the design limit of the material, crack development occurs which can lead to ultimate failure of the part or product. However, with materials like PE pipe that operate in the ductile state, a larger localized deformation can take place without causing irreversible material damage such as the development of small cracks. Instead, the resultant localized deformation results in redistribution and a significant lessening of localized stresses, with no adverse effect on the piping material. As a result, the structural design with materials that perform in the ductile state can generally be based on average stresses, a fact that greatly simplifies design protocol.

To ensure the availability of sufficient ductility (strain capacity) special requirements are developed and included into specifications for structural materials intended to operate in the ductile state; for example, the requirements that have been established for "ductile iron" and mild steel pipes. On the other hand, ductility has always been a featured and inherent property of PE pipe materials. And it is one of the primary reasons why this product has been, by far, the predominant material of choice for natural gas distribution in North America over the past 30 plus years. The new or modern generation of PE pipe materials, also known as high performance materials, have significantly improved ductility performance compared to the traditional versions which have themselves, performed so successfully, not only in gas but also in a variety of other applications including, water, sewer, industrial, marine and mining since they were first introduced about 50 years ago.

For a more detailed discussion of this unique property of PE material, especially the modern high performance versions of the material, and the unique design benefits it brings to piping applications, the reader is referred to Chapter 3, Material Properties.

Visco-Elasticity

PE pipe is a visco-elastic construction material.(6) Due to its molecular nature, PE is a complex combination of elastic-like and fluid-like elements. As a result, this material displays properties that are intermediate to crystalline metals and very high viscosity fluids. This concept is discussed in more detail in the chapter on Engineering Properties within this handbook.

The visco-elastic nature of PE results in two unique engineering characteristics that are employed in the design of PE water piping systems, creep and stress relaxation.

- **Creep** is the time dependent viscous flow component of deformation. It refers to the response of PE, over time, to a constant static load. When PE is subjected to a constant static load, it deforms immediately to a strain predicted by the stressstrain modulus determined from the tensile stress-strain curve. At high loads, the material continues to deform at an ever decreasing rate, and if the load is high enough, the material may finally yield or rupture. PE piping materials are designed in accordance with rigid industry standards to assure that, when used in accordance with industry recommended practice, the resultant deformation due to sustained loading, or creep, is too small to be of engineering concern.
- **Stress relaxation** is another unique property arising from the visco-elastic nature of PE. When subjected to a constant strain (deformation of a specific degree) that is maintained over time, the load or stress generated by the deformation slowly decreases over time, but it never relaxes completely. This stress relaxation response to loading is of considerable importance to the design of PE piping systems. It is a response that decreases the stress in pipe sections which are subject to constant strain.

  As a visco-elastic material, the response of PE piping systems to loading is time-dependent. The apparent modulus of elasticity is significantly reduced by the duration of the loading because of the creep and stress relaxation characteristics of PE. An instantaneous modulus for sudden events such as water hammer is around 150,000 psi at 73°F. For slightly longer duration, but short-term events such as soil settlement and live loadings, the short-term modulus for PE is roughly 110,000 to 130,000 psi at 73° F, and as a long-term property, the apparent modulus is reduced to something on the order of 20,000-30,000 psi. As will be seen in the chapters that follow, this modulus is a key criterion for the long-term design of PE piping systems.

This same time-dependent response to loading also gives PE its unique resiliency and resistance to sudden, comparatively short-term loading phenomena. Such is the case with PE's resistance to water hammer phenomenon which will be discussed in more detail in subsequent sections of this handbook.

Summary

As can been seen from our brief discussions here, PE piping is a tough, durable piping material with unique performance properties that allow for its use in a broad range of applications utilizing a variety of different construction techniques based upon project needs. The chapters that follow offer detailed information regarding the engineering properties of PE, guidance on design of PE piping systems, installation techniques as well as background information on how PE pipe and fittings are produced, and appropriate material handling guidelines. Information such as this is intended to provide the basis for sound design and the successful installation and operation of PE piping systems. It is to this end, that members of the Plastics Pipe Institute have prepared the information in this handbook.

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CHAPTER 2

Inspections, Tests and Safety Considerations

Scope

Once a PE piping system has been selected and designed for an application, the design is implemented by procuring the pipe, fittings and other necessary appurtenances, installing the system, and placing it in service. Piping installation involves people and machines in motion to move, assemble, install, inspect and test the piping system. Whenever moving machinery, piping parts, and personnel are engaged in piping system construction, safety must be a primary consideration. This chapter presents some of the inspections, tests and safety considerations related to installing PE piping, placing an installed system in service, and operating a PE piping system.

Cautionary statements are provided in this chapter, but this chapter does not purport to address all of the product applications, inspections, tests, or construction practices that could be used, nor all of the safety practices necessary to protect persons and property. It is the responsibility of the users of this chapter, installers, inspectors and operators of piping systems to establish appropriate safety and health practices, and to determine the applicability of regulatory limitations before any use, installation, inspection, test or operation.

Introduction

Generally, piping system installation begins with the arrival and temporary storage of pipe, fittings, and other goods required for the system. Assembly and installation follow, then system testing and finally, release for operation. Throughout the installation process, various inspections and tests are performed to ensure that the installation is in accordance with specification requirements and that the system when completed is capable of functioning according to its design specifications. In the selection, design, and installation of PE piping systems, professional engineering services, and qualified installers should be used.

PE piping products are integrated pipe and fitting systems for a broad range of commercial, municipal, utility and industrial applications. They may be buried, laid on the surface, supported above grade, installed underwater, or floated on the surface of lakes or rivers.

PE piping products are manufactured from 1/4" (6 mm) diameter through 120" (3050 mm) diameter under applicable industry standards (ASTM, AWWA, etc.) for pressure and non-pressure applications. As well, PE fittings, custom fabrications, special structures and appurtenances are available for full pressure rated, reduced pressure rated, or non-pressure rated applications.

Conventionally extruded PE pipes have homogeneous walls and smooth interior and exterior surfaces. Profile pipes are manufactured by extruding a profile over a mandrel. These pipes have smooth interiors, and may have a smooth or a profiled exterior.

Fittings, fabricated structures, tanks, and manholes are constructed for pressure, low pressure and non-pressure applications. Smaller size fittings are usually injection molded. Larger fittings, fabricated structures, tanks, and manholes are fabricated in manufacturer's facilities. Thermal joining techniques used for fabrication usually limit the design pressure capacity of the structure. Complex structures are generally not suitable for field fabrication.

PE Piping in the Field

After the piping system has been designed and specified, the piping system components must be procured. Typically, project management and purchasing personnel work closely together so that the necessary components are available when they are needed for the upcoming construction work.

Packaging for Commercial Transport

PE fittings, fabrications and pipe are shipped by commercial carriers who are responsible for the products from the time they leave the manufacturing plant until they are accepted by the receiver. Molded fittings and small fabrications and components are usually packaged in cartons. Large orders may be palletized. Large fabrications may require custom packaging. Commercial transport may be by parcel service or commercial carrier in enclosed vans or on flatbed trailers depending on packaging.

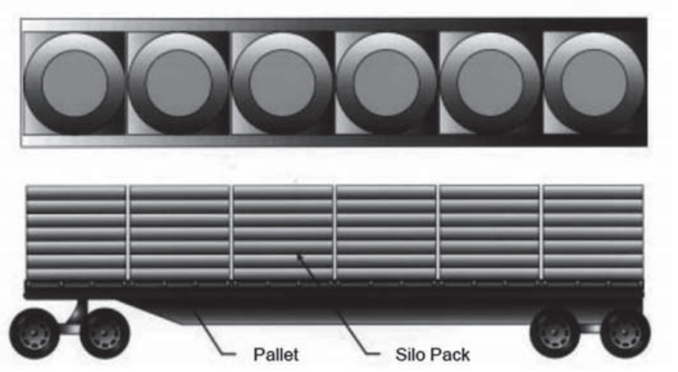

Figure 1 Typical Truckload of Coiled, Silo-Pack Pipe (40' Trailer)

PE pipe is produced in coils or in straight lengths and shipped on flatbed trailers. Coils are typically limited to 6-inch and smaller sizes. Coils may be laid flat and stacked together into silo packs, or may be individual large vertical coils, or may be reels of coiled pipe. Straight lengths are bundled together in bulk packs or loaded on the trailer in strip loads. Standard straight lengths for extruded pipe are 40 feet long; however, shorter lengths or lengths 60 feet long or longer depending on transportation restrictions may be produced. State transportation restrictions on length, height and width usually govern allowable load configurations. Higher freight costs may apply to loads that exceed length, height, or width restrictions. Although PE pipe is lightweight, weight limitations may restrict load size for very heavy wall or longer length pipe. Profile wall extruded pipes 96-inch ID (2438 mm ID) and 120-inch ID (3048 mm ID) will exceed 8 feet overall permissible width, and are subject to wide load restrictions.

Figures 1 through 3 are general illustrations of truckload and packaging configurations for conventionally extruded PE pipes. Actual truckloads and packaging may vary from the illustrations. "Nesting", or sliding a smaller pipe length inside a larger pipe, is generally not practiced for commercial flatbed loads because it is difficult to remove the inner pipe when the load is delivered at the jobsite, because nesting can result in an overweight load, and because most commercial flatbed trailers do not have structural bulkheads at both ends to prevent nested pipes from sliding out during acceleration or braking. Fully enclosed containers for overseas delivery can occasionally be nested. Occasionally, silos of small tubing sizes may be "nested" in silos of larger coiled pipe. Nested silos must have special packaging to lift the tubing silo out of the pipe silo. De-nesting should only be performed after the nested silos have been unloaded from the truck and placed on the ground.

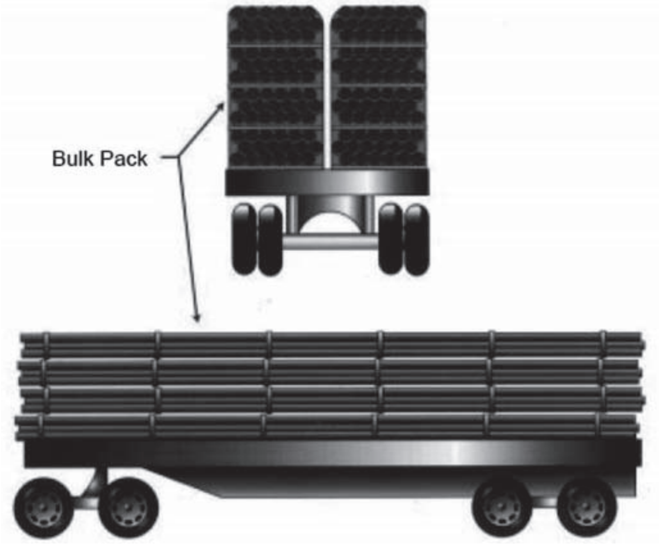

Figure 2 Typical Straight Length Bulk Pack Truckload

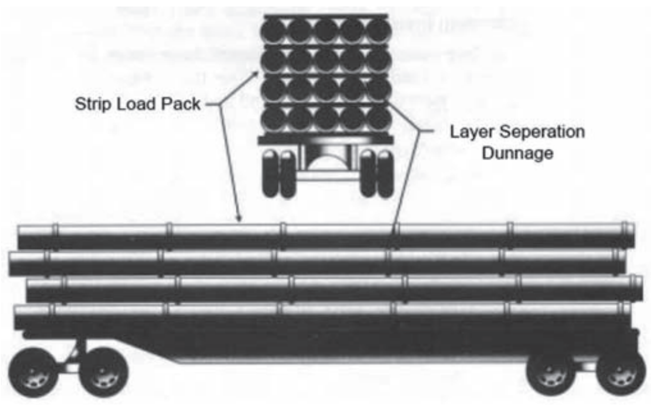

Figure 3 Typical Straight Length Strip Load Truckload

Occasionally, when coiled pipe silo packs and boxed fittings are shipped together, fitting cartons are placed in the center of the silo packs. Tanks, manholes, and large fittings and custom fabrications are usually loaded directly onto flatbed trailers.

Receiving Inspection

Few things are more frustrating and time consuming than not having what you need, when you need it. Before piping system installation begins, an important initial step is a receiving inspection of incoming products. Construction costs can be minimized, and schedules maintained by checking incoming goods to be sure the parts received are the parts that were ordered, and that they arrived in good condition and ready for installation.

Checking and Inspecting the Order

When a shipment is received, it should be checked to see that the correct products and quantities have been delivered in a condition that is suitable for installation. Several documents are used here. The Purchase Order or the Order Acknowledgment lists each item by its description, and the required quantity. The incoming load will be described in a Packing List which is attached to the load. The descriptions and quantities on the Packing List should match those on the Purchase Order or the Order Acknowledgment.

The carrier will present a Bill of Lading that generally describes the load as the number of packages the carrier received from the manufacturing plant. The Order Acknowledgment, Packing List, and Bill of Lading should all be in agreement. Any discrepancies must be reconciled among the shipper, the carrier, and the receiver. The receiver should have a procedure for reconciling any such discrepancies.

There is no substitute for visually inspecting an incoming shipment to verify that the paperwork accurately describes the load. Products are usually identified by markings on each individual product. These markings should be checked against the Order Acknowledgment and the Packing List. The number of packages and their descriptions should be checked against the Bill of Lading.

Before and during unloading, the load should be inspected for damage that may occur anytime products are handled. Obvious damage such as cuts, abrasions, scrapes, gouges, tears, and punctures should be carefully inspected. Manufacturers should be consulted for damage assessment guidelines. Product with damage that could compromise product performance should be segregated and a resolution discussed with the manufacturer.

When pipe installation involves saddle fusion joining, diesel smoke on the pipe outside surface may be a concern because it may reduce the quality of saddle fusion joints. Smoke damage is effectively prevented by covering at least the first third of the load with tarpaulins or by using truck tractors with low exhaust. If smoke tarps are required, they should be in place covering the load when it arrives.

Receiving Report & Reporting Damage

The delivering truck driver will ask the person receiving the shipment to sign the Bill of Lading, and acknowledge that the load was received in good condition. Any damage, missing packages, etc., should be noted on the bill of lading at that time.

Shipping problems such as damage, missing packages, document discrepancies, incorrect product, etc., should be reported to the product supplier immediately. Shipping claims must be filed within 7 days.

Field Handling

PE piping product transportation and handling is generally subject to governmental safety regulations such as OSHA in the United States or CCOSH in Canada. Persons transporting and handling PE piping products should be familiar with applicable governmental safety regulations. Additional PE pipe handling and transportation information is available in the PPI Material Handling Guide[1], and in handling and unloading recommendations from product manufacturers. The responsibility for safe transport and handling; however, rests primarily with persons that actually perform transport and handling activities.

Manufacturer handling and unloading recommendations are typically given to the truck driver when the load leaves the manufacturing plant with instructions for the truck driver to give the manufacturer's handling and unloading recommendations to jobsite personnel upon delivery.

Always observe applicable governmental safety regulations and manufacturer's handling and unloading recommendations when transporting or handling PE piping products in the field. Unsafe handling can result in damage to property or equipment, and be hazardous to persons in the area. Keep unnecessary persons away from the area during unloading and while handling pipe and piping components. See and be seen at all times. All persons involved in unloading and handling PE pipe and piping components should be sure that they can see all other persons and be seen by all other persons engaged in unloading and handling.

PE pipe is tough, lightweight, and flexible. Installation does not usually require high capacity lifting equipment. Pipe up to about 8" (219 mm) diameter and weighing roughly 6 lbs per foot (9 kg per m) or less can frequently be handled manually. Heavier, larger diameter pipe will require appropriate handling equipment to lift, move and lower the pipe. Pipe must not be dumped, dropped, pushed, or rolled into a trench.

Lengths of heat fused PE pipe may be cold bent in the field. The PE pipe manufacturer should be consulted for field bending radius recommendations. Field bending usually involves sweeping or pulling the pipe string into the desired bend radius, then installing permanent restraint such as embedment around a buried pipe, to maintain the bend. If used, temporary blocking should be removed before backfilling to avoid point loads against the pipe.

Considerable force may be required to field bend larger pipe, and the pipe may spring back forcibly if holding devices slip or are inadvertently released while bending. Observe appropriate safety precautions during field bending.

Handling Equipment

Unloading and handling equipment must be appropriate for the type of packaging, must be in safe operating condition, and must have sufficient capacity (load rating) to safely lift and move the product as packaged. Equipment operators should be trained and preferably, certified to operate the equipment. Safe handling and operating procedures must be observed.

Although PE piping components are lightweight compared to similar components made of metal, concrete, clay, or other materials, larger components can be heavy. Lifting and handling equipment must have adequate rated capacity to safely lift and move components. Equipment that lifts from the bottom of the load such as a forklift, or from above the load such as a crane, a side boom tractor, or an extension boom crane is used for unloading. Above the load lifting equipment may employ slings or slings and spreader bars to lift the load.

When using a forklift, or forklift attachments on equipment such as articulated loaders or bucket loaders, lifting capacity must be adequate at the load center on the forks. Forklift equipment is rated for a maximum lifting capacity at a distance from the back of the forks. If the weight-center of the load is farther out on the forks, lifting capacity is reduced.

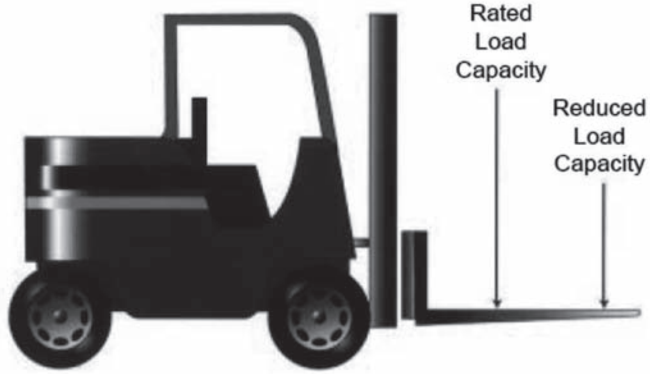

Figure 4 Forklift Load Capacity

Before lifting or transporting the load, forks should be spread as wide apart as practical, forks should extend completely under the load using fork extensions if necessary, and the load should be as far back on the forks as possible. During transport, a load on forks that are too short or too close together, or a load too far out on the forks, may become unstable and pitch forward or to the side, and result in damage to the load or property, or hazards to persons.

Above the load lifting equipment such as cranes, extension boom cranes, and side boom tractors, should be hooked to wide fabric choker slings that are secured around the load or to lifting lugs on the component. Wire rope slings and chains can damage components, can slip, and should not be used. Spreader bars should be used when lifting pipe or components longer than 20'. *Before use, inspect slings and lifting equipment. Equipment with wear or damage that impairs function or load capacity should not be used.*

Unloading Site

A suitable unloading site will be generally level and large enough for the carrier's truck, handling equipment and its movement, and for temporary load storage.

Unloading Bulk Packaged Pipe, Fittings and Fabrications

Silo packs and other palletized packages should be unloaded from the side or end with a forklift. Non-palletized pipe, fittings, fabrications, manholes, tanks, or other components should be unloaded from above with suitable lifting equipment and wide fabric slings, or from the side with a forklift.

Pipe, fittings, fabrications, tanks, manholes, and other components must not be pushed or rolled or dumped off the truck, or dropped.

Unloading Large Fabrications, Manholes and Tanks

Large fabrications, manholes and tanks should be unloaded using a wide web choker sling and lifting equipment such as an extension boom crane, crane, or lifting boom. The choker sling is fitted around the manhole riser or near the top of the tank. Do not use stub outs, outlets, or fittings as lifting points, and avoid placing slings where they will bear against outlets or fittings. Larger diameter manholes and tanks are typically fitted with lifting lugs. All lifting lugs must be used. *The weight of the manhole or tank is properly supported only when all lugs are used for lifting. Do not lift tanks or manholes containing liquids.*

Pre-Installation Storage

The size and complexity of the project and the components, will determine pre-installation storage requirements. For some projects, several storage or staging sites along the right-of-way may be appropriate, while a single storage location may be suitable for another job.

The site and its layout should provide protection against physical damage to components. General requirements are for the area to be of sufficient size to accommodate piping components, to allow room for handling equipment to get around them and to have a relatively smooth, level surface free of stones, debris, or other material that could damage pipe or components, or interfere with handling. Pipe may be placed on 4-inch wide wooden dunnage, evenly spaced at intervals of 4 feet or less.

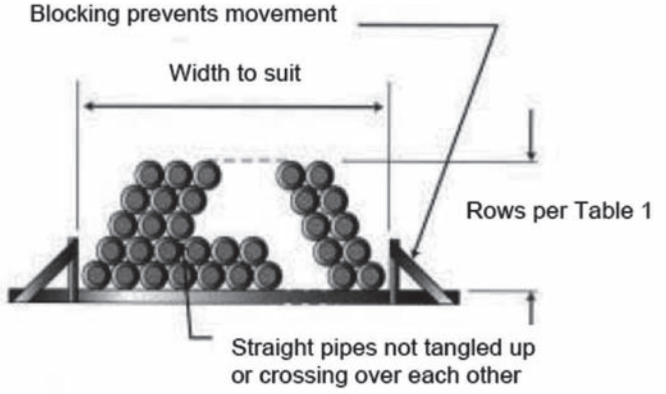

Figure 5 Loose Pipe Storage

Pipe Stacking Heights

Coiled pipe is best stored as-received in silo packs. Individual coils may be removed from the top of the silo pack without disturbing the stability of the remaining coils in the silo package.

Pipe received in bulk packs or strip load packs should be stored in the same package. If the storage site is flat and level, bulk packs or strip load packs may be stacked evenly upon each other to an overall height of about 6′. For less flat or less level terrain, limit stacking height to about 4′.

Before removing individual pipe lengths from bulk packs or strip load packs, the pack must be removed from the storage stack, and placed on the ground.

TABLE 1
Suggested Jobsite Loose Storage Stacking Height Limits for PE Pipe

Conventionally Extruded Solid Wall Pipe OD Size	Suggested Stacking Height Limits, Rows		Profile Wall Pipe ID Size (ASTM F 894[2])	Suggested Stacking Height, Rows
	DR Above 17	DR 17 & Below		
4	15	12	18	4
5	12	10	21	3
6	10	8	24	3
8	8	6	27	2
10	6	5	30	2
12	5	4	33	2
14	5	4	36	2
16	4	3	42	1
18	4	3	48	1
20	3	3	54	1
22	3	2	60	1
24	3	2	66	1
26	3	2	72	1
28	2	2	84	1
30	2	2	96	1
32	2	2	120	1
36	2	1		
42	1	1		
48	1	1		
54	1	1		
63	1	1		

Individual pipes may be stacked in rows. Pipes should be laid straight, not crossing over or entangled with each other. The base row must be blocked to prevent sideways movement or shifting. The interior of stored pipe should be kept free of debris and other foreign matter.

Exposure to UV and Weather

PE pipe products are protected against deterioration from exposure to ultraviolet light and weathering effects with antioxidants, and thermal and UV stabilizers. UV stabilization formulations for color products and for black products are different.

Color products use sacrificial UV stabilizers that are depleted by the UV energy absorbed. For this reason, unprotected outdoor storage for color products is generally about 2 years or less; however, some manufacturers may use UV stabilization formulations that allow longer unprotected outside storage. Where extended storage is anticipated, color products should be covered or measures should be taken to protect color product from direct UV exposure. Consult color product manufacturers for unprotected outdoor storage recommendations.

Black products contain at least 2% carbon black to shield the material against UV deterioration(3). Black products with and without stripes are generally suitable for outdoor storage without covering or protection against UV exposure. Products that are stored for many years may be affected by other environmental conditions or obsolescence due to improvements in materials or processes.

Cold Weather Handling

Temperatures near or below freezing will affect PE pipe by increasing stiffness and reducing resistance to impact damage. PE remains ductile at temperatures below -40ºF (-40ºC). In colder conditions, allow more time to conduct handling and installation procedures that bend and flex the pipe. Extra care should be taken not to drop pipe or fabricated structures, and to keep handling equipment and other things from forcefully impacting the pipe.

Ice, snow, and rain are not harmful to the material, but unsure footing and traction require greater care and caution to prevent damage or injury. Inclement weather can make pipe surfaces especially slippery. Do not walk on pipe.

General Considerations Before and During Installation

Pre-Construction

Inspections and tests begin before construction. Jobsite conditions dictate how piping may be installed and what equipment is appropriate for construction. Soil test borings and test excavations may be useful to determine soil bearing strength and whether or not native soils are suitable as backfill materials in accordance with project specifications.

In slipline or pipe bursting rehabilitation applications, the deteriorated pipeline should be inspected by remote TV camera to locate structurally deteriorated areas, obstructions, offset and separated joints, undocumented bends, and service connections.

The installer should carefully review contract specifications and plans. Different piping materials require different construction practices and procedures. These differences should be accurately reflected in the contract documents. Good plans and specifications help protect all parties from unnecessary claims and liabilities. Good documents also set minimum installation quality requirements, and the testing and inspection requirements that apply during the job.

Joining and Connections

For satisfactory material and product performance, system designs and installation methods rely on appropriate, properly made connections. An inadequate or improperly made field joint may cause installation delays, may disable or impair system operations, or may create hazardous conditions. Joining and connection methods will vary depending upon requirements for internal or external pressure, leak tightness, restraint against longitudinal movement (thrust load capacity), application and operation conditions, construction and installation requirements, and the products being joined.

PE pressure piping products are connected to themselves and to piping products from other materials using methods that seal and restrain against longitudinal thrust loads. These methods include butt, socket and saddle fusion, electrofusion couplings and saddles, and mechanical methods such as MJ Adapters, flanges, and restrained mechanical couplings.

In some circumstances, external restraint may be necessary for connections between PE and non-PE piping, such as for connections between butt-fused PE pressure pipe and bell and spigot joined PVC or ductile iron pipe. Longitudinal thrust forces that may develop in PE pressure pipe may be sufficient to disjoin unrestrained PVC or ductile iron joints that seal but do not restrain. To restrain longitudinal thrust forces, PE pressure pipe may be fitted with a wall anchor or electrofusion restraints to anchor against movement from longitudinal thrust forces.

PE non-pressure piping may require less or no restraint and may be connected using gasketed bell and spigot joints, extrusion welding, compression couplings, and various types of elastomeric seals. Sealed, unrestrained joints that may be suitable for non-pressure service are not suitable for PE pressure service.

Before using a joining or connection method, the limitations of the joining or connection method must be taken into account. Where a joining or connection method is suitable, the manufacturer's joining procedures, tools and components required to construct and install joints in accordance with manufacturer's recommendations should always be used.

Field connections are controlled by and are the responsibility of the field installer. Some joining procedures such as heat fusion, electrofusion and thermal welding require trained and qualified personnel. Some joining equipment such as larger butt fusion machines, saddle fusion and electrofusion equipment require persons that are properly trained in equipment operation. For regulated pipelines, the authority having jurisdiction may require certification of joining proficiency. Before heat fusion or electrofusion joining is performed at the jobsite, the contractor should obtain joining procedures and inspection criteria from the PE product manufacturer, and should obtain documentation of joining proficiency and qualification for persons making heat fusion or electrofusion joints. A discussion of joining and connecting PE piping products is presented in the Polyethylene Joining Procedures chapter in this handbook and in PPI TN-36[4].

Cleaning Before Joining

All field connection methods and procedures require component ends to be clean, dry, and free of detrimental surface defects before the connection is made. Contamination and unsuitable surface conditions usually produce an unsatisfactory connection. Gasketed joints may require appropriate lubrication.

Cleaning component ends before joining may require removing surface deposits to planning (facing), abrading or scraping the pipe surface. Surface dust and light soil may be removed by wiping the surfaces with clean, dry, lint free cloths. Heavier soil may be washed or scrubbed off with soap and water solutions, followed by thorough rinsing with clear water, and drying with dry, clean, lint-free cloths.

Before using chemical cleaning solvents, the user should know the potential risks and hazards and appropriate safety precautions should be taken. Hazard information is available from chemical manufacturer's instructions and the MSDS for the chemical. Some solvents may leave a residue on the pipe, or may be incompatible or deleterious when used with PE, for example, solvents that contain hydrocarbon liquids such as WD-40 or kerosene will contaminate the pipe and prevent heat fusion bonding. General information on PE compatibility with various chemicals is available in PPI Technical Report TR-19[5].

Surface damage that could detrimentally affect sealing or pipe performance generally requires removing the damaged section. See "Damage Inspections" below.

Field Fusion Joining

Heat fusion joining may be performed in any season and in hot or cold conditions. During inclement weather, a temporary shelter should be set-up around the joining operation to shield heat fusion operations from rain, frozen precipitation, and high wind conditions. Wind chill can reduce heating plate temperature or chill melted component ends before joining. If fusion joining operations cannot be protected against dust contamination during severe windblown dust conditions, joining may need to be temporarily suspended until conditions improve.

Most heat fusion equipment is electrically powered, but is not explosion proof. The fusion equipment manufacturer's instructions should be observed at all times and especially when heat fusion is to be performed in an atmosphere that may be volatile, such as coal or grain dust or in areas where gas or gas fumes may be present.

When installing large diameter PE pipe in a butt fusion machine, do not bend the pipe against an open fusion machine collet or clamp. The pipe may suddenly slip out of the open clamp, and cause injury or damage.

During Construction and Installation

Tests and inspections performed during construction may include damage inspections, butt fusion joint quality tests, soil tests, pipe deflection tests for ID controlled products such as extruded profile wall pipe, or pressure leak tests.

Damage Inspections

Damage such as cuts, scrapes, gouges, tears, cracks, punctures, and the like may occur during handling and installation. Damage may affect joint integrity or sealing, or may compromise pipeline performance. The following guidelines may be used to assess surface damage significance.

For PE pipelines, damage should not exceed about 10% of the minimum wall thickness required for the pipeline's operating pressure or the minimum wall thickness required to meet structural design requirements. Excessive damage generally requires removing the damaged section or reinforcement with a full encirclement repair clamp. Excessively deep cuts, abrasions or grooves cannot be repaired by using hot gas or extrusion welding to fill the damaged area with PE material because these methods do not provide sufficient bond strength for pressure service or to restore structural strength.

If damage is not excessive, the shape of the damage may be a consideration. Sharp notches and cuts may be dressed smooth so the notch is blunted. Blunt scrapes or gouges should not require attention. Minor surface abrasion from sliding on the ground or insertion into a casing should not be of concern.

Damage such as punctures and tears will generally require cutting the pipe to remove the damaged section and replacement with undamaged pipe. Small punctures may occasionally be repaired with patching saddles that are saddle fused or electrofused over the puncture.

Butt Fusion Joint Quality

Visual inspection is the most common butt fusion joint evaluation method for all sizes of conventionally extruded PE pipe. Visual inspection criteria for butt fusion joints should be obtained from the pipe manufacturer. Hydraulic butt fusion equipment is typically fitted for connection to data logging devices that can record equipment temperature, time and pressure conditions during joining. The record may be used to document equipment conditions when making field fusions, and to supplement field joining quality assurance using visual inspection and procedural oversight. Data logger records may be used to compare equipment operation during field fusion joining to data logger equipment operation records of properly made fusions (Butt fusion joining procedures are addressed in Chapter 9) where joint integrity has been verified.

To confirm joint integrity, operator procedure, and fusion machine set-up, fusion joints may be destructively tested. Destructive laboratory tests of tensile specimens prepared from butt fusion joined pipes may be performed per ASTM D 638[6] (standard tensile) or ASTM F 2634[7] (tensile impact). Tensile tests are usually compared to specimens without joints prepared from the parent pipe. Bent strap tests are usually limited to smaller pipe sizes. Bent strap test specimens from pipe with heavier walls require considerable bending force and attention to safety. Specially designed hydraulic press equipment may be used in the shop to conduct bend tests of heavy wall products. Bent strap tests in the shop or in the field require safety measures against inadvertent release, joint failure or springback during bending.

The bent strap test specimen is prepared by making a trial butt fusion and allowing it to cool to ambient temperature. A test strap that is at least 6" or 15 pipe wall thicknesses long on each side of the fusion, and about 1" or 1-1/2 wall thicknesses wide is cut out of the trial fusion pipe as illustrated in Figure 6. The strap is then bent so that the ends of the strap touch. Any disbondment at the fusion is unacceptable and indicates poor fusion quality. If failure occurs, fusion procedures and/or machine set-up should be changed, and a new trial fusion and bent strap test specimen should be prepared and tested. Field fusion should not proceed until a test joint has passed the bent strap test.

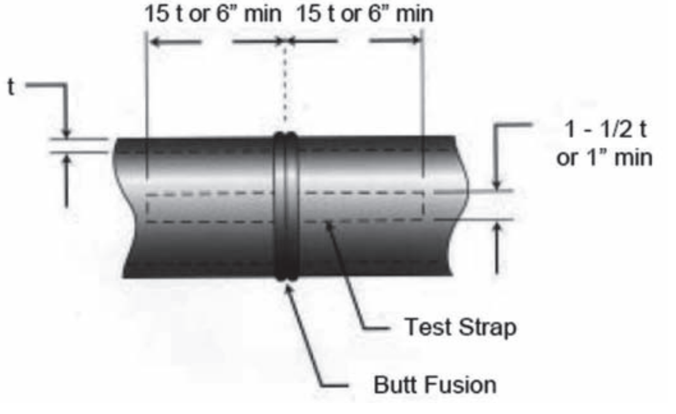

Figure 6 Bent Strap Test Specimen

Soil Tests

During buried pipe installation, work should be checked throughout the construction period by an inspector who is thoroughly familiar with the jobsite, contract specifications, materials, and installation procedures. Inspections should reasonably ensure that significant factors such as trench depth, grade, pipe foundation (if required), quality and compaction of embedment backfill, and safety are in compliance with contract specifications and other requirements. To evaluate soil stability, density and compaction, appropriate ASTM tests may be required in the contract specifications.

Deflection Tests for ID controlled Pipes

Deflection tests are typically based on an allowable percent vertical deflection of the pipe inside diameter. Deflection tests are generally limited to ID controlled PE piping such as extruded profile wall pipe. Conventionally extruded solid wall pipe is OD controlled so it is difficult if not impossible to determine a base ID for vertical deflection tests. Solid wall pipe extrusion also produces in a slight toe-in at the pipe ends. While internal fusion beads have negligible effects on fluid flows, the ID at butt fusions is reduced at butt fusions. For these reasons deflection testing is limited to ID controlled pipes and is not recommended for OD controlled conventionally extruded solid wall PE piping.

For ID controlled extruded profile pipes, pipe deflection may be used to monitor the installation quality. Improperly embedded pipe can develop significant deflection in a short time, thus alerting the installer and the inspector to investigate the problem. Inspection should be performed as the job progresses, so errors in the installation procedure can be identified and corrected.

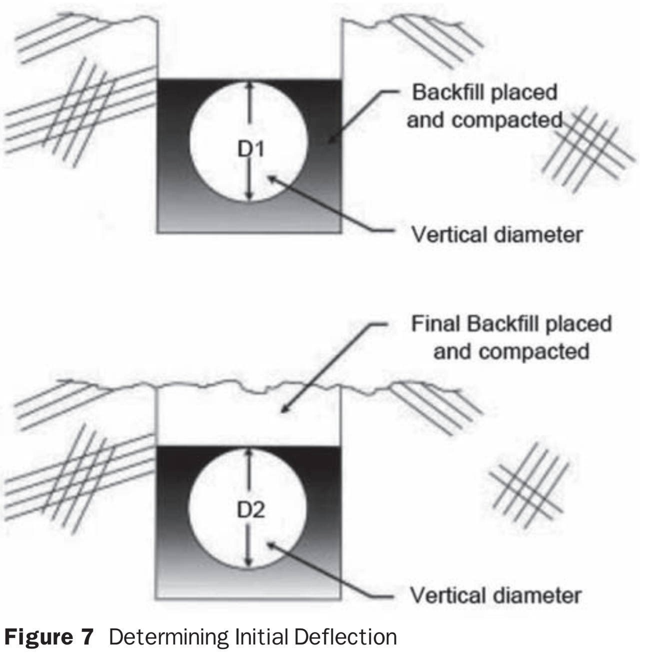

Figure 7 Determining Initial Deflection

Initial deflection checks of ID controlled extruded profile pipe may be performed after embedment materials have been placed and compacted. The inside diameter of the pipe is measured after backfill materials have been placed to the pipe crown, and compacted. This is D1. Then final backfill materials are placed and compacted, and the pipe inside diameter is measured again at the exact location where the prior measurement was taken. This is D2.

Percent initial deflection is calculated using the following:

(1)
$$\%\ Deflection = \left(\frac{D1\ -\ D2}{D1}\right)100$$

Where *D*1 and *D*2 are as defined above and depicted in Figure 7.

Another method to measure deflection is to pull a pre-sized mandrel (sewer ball) through the pipe. The mandrel should be sized so that if the pipe exceeds allowable deflection, the mandrel is blocked.

To properly size the mandrel, the allowable vertical diameter of the pipe must be established. It is necessary to account for pipe ID manufacturing tolerances and any ovality that may occur during shipping. Pipe base ID dimensions and tolerances should be obtained from the manufacturer. The maximum mandrel diameter is calculated as follows:

(2)
$$D_M = D - \left(\frac{Dy}{100}\right)$$

WHERE
D_M = maximum mandrel diameter, in
D = base pipe ID, in
y = allowable deflection, percent

(3)
$$D = D_i - \sqrt{A^2 + B^2}$$

D_i = nominal pipe ID, in
A = ID manufacturing tolerance, in

(4)
$$B = 0.03\,D_i$$

B = shipping ovality, in

For buried large diameter PE pipe that has been poorly backfilled, excessive deflection may be correctable using point excavation to remove backfill, then reinstalling embedment materials in accordance with recommended procedures.

Post Installation

Leak Testing – Considerations for All Procedures

The intent of leak testing is to find unacceptable joint leakage in pressure or non-pressure piping systems. If leaks exist, they may manifest themselves by leakage or rupture. Leak tests of pressure systems generally involve filling the system or a section of the system with a liquid or gaseous fluid and applying internal pressure to determine resistance to leakage. Leak tests of non-pressure systems typically involve testing sections of the system or individual joints using end plugs or bulkheads to determine resistance to leakage.

Safety is of paramount importance when conducting pressurized internal fluid leak tests. Although routinely performed, leak tests may be the very first time a newly installed system or repair will be subjected to stress.

- *Even at relatively low internal pressures, leak testing with a pressurized internal fluid can generate very high forces that can be dangerous or even fatal if suddenly released by the failure of a joint or a system component or a testing component.*
- *Always take safety precautions when conducting pressurized fluid leak tests.*
- *Restrain pipe, components and test equipment against movement in the event of failure. Joints may be exposed for leakage inspection provided that restraint is maintained.*
- *Keep persons not involved in testing a safe distance away while testing is being conducted.*

Liquids such as water are preferred as test fluids because less energy is released if something in the test section fails catastrophically. During a pressure leak test, energy (internal pressure) is applied to stress the test section. If the test fluid is an incompressible liquid such as water, the energy applied to pressurize the liquid transfers primarily to the pipe and components in the test section. However, if the test fluid is a compressible gas, energy is applied to compress the gas as well as to stress the piping section. If a catastrophic failure occurs during a pressurized liquid leak test, the overall applied energy is much lower, and energy dissipation is rapid. However, if catastrophic failure occurs during a pressurized gas test, energy release is many times greater, much more forceful and longer duration.

- Where hydrostatic testing is specified, never substitute compressed gas (pneumatic) for liquid (hydrostatic) testing.
- *Test pressure is temperature dependent.* If possible, test fluid and test section temperatures should be less than 80ºF (27ºC). At temperatures above 80ºF (27ºC), reduced test pressure is required. Contact the pipe manufacturer for technical assistance with elevated temperature pressure reduction. Sunlight heating of exposed PE pipe especially black PE pipe can result in high pipe temperature. Before applying test pressure, allow time for the test fluid and the test section to

temperature equalize. Hydrostatic leak tests typically use cooler liquids so the liquid filled test section will tend to equalize to a lower temperature near test liquid temperature. Compressed gases used in pneumatic leak tests do not have similar temperature lowering effects, so it is more likely that test pressures will have to be reduced due elevated temperature effects when conducting pneumatic leak tests. Bursting can result if test pressure is not reduced for elevated test section temperature.

- *Leak Test Pressure and Duration* – The maximum allowable leak test pressure and leak test time including initial expansion, and time at leak test pressure should be in accordance with equation (5) and Tables 1 and 2.

(5)
$$P_{(T)} = \frac{2 \times HDS \times F_t \times H_T}{(DR - 1)}$$

WHERE

$P_{(T)}$ = Leak Test Pressure, psi (MPa), for Leak Test Time, T
T = Leak Test Time, hours
HDS = PE material hydrostatic design stress for water at 73ºF (23ºC), psi (MPa)
F_t = PE material temperature reduction factor
H_T = Leak test duration factor for leak test time, T
DR = Pipe dimension ratio

TABLE 2
Leak Test Duration Factor, “H_T”

Leak Test Pressure, $P_{(T)}$, psi (MPa)	Leak Test Time, T, hours	Leak Test Duration Factor, H_T
$P_{(8)}$	≤ 8	1.50
$P_{(48)}$	≤ 48	1.25
$P_{(120)}$	≤ 120	1.00

TABLE 3
PE Material Hydrostatic Design Stress

PE Material Designation	HDS for Water at 73ºF (23ºC), psi (MPa)
PE2606 (PE2406)	630 (4.3)
PE2708	800 (5.5)
PE3608 (PE3408)	800 (5.5)
PE3710 & PE4710	1000 (6.9)

Various PE materials can have different elevated temperature performance. Consult the PE pipe manufacturer for the applicable temperature reduction factor, “Ft”.

Examples:

1. What is the maximum leak test pressure for a DR 11 PE4710 pipe for a 24 hour leak test where the pipe temperature is 125°F (52°C)?

   Answer: From Table 1, "H_T" = 1.25, and from Table 2, HDS = 1000 psi. The PE pipe manufacturer provided a temperature reduction factor, "F_t", of 0.70.

$$P_{(24)} = \frac{2 \times 1000 \times 0.70 \times 1.25}{(11-1)} = 175\, psi$$

2. What is the maximum leak test pressure for a DR 13.5 PE2606 pipe for a 6 hour leak test where the pipe temperature is 68°F (20°C)? For a 96 hour leak test?

   Answer: From Table 1, "H_T" = 1.50 for a 6 hour leak test, and "H_T" = 1.00 for a 96 hour leak test; from Table 2, HDS = 630 psi. The PE pipe manufacturer provided a temperature reduction factor, "F_t", of 1.00.

$$P_{(6)} = \frac{2 \times 630 \times 1.00 \times 1.50}{(13.5-1)} = 151.2\, psi$$

$$P_{(96)} = \frac{2 \times 630 \times 1.00 \times 1.00}{(13.5-1)} = 100.8\, psi$$

The piping manufacturer should be consulted before using pressure testing procedures other than those presented here. Other pressure testing procedures may or may not be applicable depending upon piping products and/or piping applications.

Pressure System Leak Testing – Hydrostatic

Hydrostatic pressure leak tests of PE pressure piping systems should be conducted in accordance with ASTM F 2164[8]. The preferred hydrostatic testing liquid is clean water. Other non-hazardous liquids may be acceptable.

- *Restraint* –The pipeline test section must be restrained against movement in the event of catastrophic failure. Joints may be exposed for leakage examination provided that restraint is maintained.
- The testing equipment capacity and the pipeline test section should be such that the test section can be pressurized and examined for leaks within test duration time limits. Lower capacity testing and pressurizing equipment may require a shorter test section.

- Test equipment and the pipeline test section should be examined before pressure is applied to ensure that connections are tight, necessary restraints are in place and secure, and components that should be isolated or disconnected are isolated or disconnected. All low pressure filling lines and other items not subject to the test pressure should be disconnected or isolated.

For pressure piping systems where test pressure limiting components or devices have been isolated, or removed, or are not present in the test section, the maximum allowable test pressure for a leak test duration of 8 hours or less is 1.5 times the system design pressure at the lowest elevation in the section under test. If lower pressure rated components cannot be removed or isolated from the test section, the maximum test pressure is the pressure rating of the lowest pressure rated component that cannot be isolated from the test section. Test pressure is temperature dependent and must be reduced at elevated temperatures.

- The test section should be completely filled with the test liquid, taking care to bleed off any trapped air. Venting at high points may be required to purge air pockets while the test section is filling. Venting may be provided by bleed valves or equipment vents.
- The test procedure consists of initial expansion, and test phases. For the initial expansion phase, the test section is pressurized to test pressure and make-up test liquid is added as required to maintain maximum test pressure for four (4) hours. For the test phase, the test pressure is reduced by 10 psi. This is the target test pressure. If the pressure remains steady (within 5% of the target test pressure) for an hour, leakage is not indicated.
- If leaks are discovered, depressurize the test section before repairing leaks. Correctly made fusion joints do not leak. *Leakage at a butt fusion joint may indicate imminent catastrophic rupture. Depressurize the test section immediately if butt fusion leakage is discovered.* Leaks at fusion joints require the fusion joint to be cut out and redone.
- If the pressure leak test is not completed due to leakage, equipment failure, etc., the test section should be de-pressurized and repairs made. Allow the test section to remain depressurized for at least eight (8) hours before retesting.

Pressure System Leak Testing – Pneumatic

The Owner and the responsible Project Engineer should approve compressed gas (pneumatic) leak testing before use. Pneumatic testing should not be considered unless one of the following conditions exists:

- The piping system is so designed that it cannot be filled with a liquid;

  or

- The piping system service cannot tolerate traces of liquid testing medium.

The pressurizing gas should be non-flammable and non-toxic.

- *Restraint* – The pipeline test section must be restrained against movement in the event of catastrophic failure. Joints may be exposed for leakage examination provided that restraint is maintained.
- Leak test equipment and the pipeline test section should be examined before pressure is applied to ensure that connections are tight, necessary restraints are in place and secure, and components that should be isolated or disconnected are isolated or disconnected. All low pressure filling lines and other items not subject to the leak test pressure should be disconnected or isolated.
- *Leak Test Pressure* – For pressure piping systems where test pressure limiting components or devices have been isolated, removed, or are not present in the test section, the maximum allowable test pressure is 1.5 times the system design pressure for a leak test duration of 8 hours or less. If lower pressure rated components cannot be removed or isolated, the maximum test pressure is the pressure rating of the lowest pressure rated component that cannot be isolated from the test section. Leak test pressure is temperature dependent and must be reduced at elevated temperatures.
- The pressure in the test section should be gradually increased to not more than one-half of the test pressure; then increased in small increments until the required leak test pressure is reached. Leak test pressure should be maintained for ten (10) to sixty (60) minutes; then reduced to the design pressure rating (compensating for temperature if required), and maintained for such time as required to examine the system for leaks.
- Leaks may be detected using mild soap solutions (strong detergent solutions should be avoided), or other non-deleterious leak detecting fluids applied to the joint. Bubbles indicate leakage. After leak testing, all soap solutions or leak detecting fluids should be rinsed off the system with clean water.
- If leaks are discovered, depressurize the test section before repairing leaks. Correctly made fusion joints do not leak. *Leakage at a butt fusion joint may indicate imminent catastrophic rupture. Depressurize the test section immediately if butt fusion leakage is discovered.* Leaks at fusion joints require the fusion to be cut out and redone.
- If the pressure leak test is not completed due to leakage, equipment failure, etc., the test section should be de-pressurized and repairs made. Allow the test section to remain depressurized for at least eight (8) hours before retesting.

Pressure System Leak Testing – Initial Service

An initial service leak test may be acceptable when other types of tests are not practical, or where leak tightness can be demonstrated by normal service, or when initial service tests of other equipment are performed. An initial service test may apply to systems where isolation or temporary closures are impractical, or where checking out pumps and other equipment affords the opportunity to examine the system for leakage prior to full scale operations.

- *Restraint* – The pipeline section to be tested must be restrained against movement in the event of catastrophic failure. Joints may be exposed for leakage examination provided that restraint is maintained.

Test equipment and the pipeline should be examined before pressure is applied to ensure that connections are tight, necessary restraints are in place and secure, and components that should be isolated or disconnected are isolated or disconnected. All low pressure filling lines and other items not subject to the test pressure should be disconnected or isolated.

- *Leak test fluid* – The initial service leak test fluid will usually be the liquid or gas being transported in the pipeline. The leak test fluid may or may not need to be purged or flushed from the system.
- *Leak Test Pressure* – The piping system should be gradually brought up to normal operating pressure, and held at operating pressure for at least ten (10) minutes. During this time, joints and connections should be examined for leakage.
- If leaks are discovered, depressurize the test section before repairing leaks. Correctly made fusion joints do not leak. Leaks at fusion joints require the fusion to be cut out and redone. *Leakage at a butt fusion joint may indicate imminent catastrophic rupture. Depressurize the test section immediately if butt fusion leakage is discovered*.

Non-Pressure System Leak Testing

Pressure testing of non-pressure systems such as sewer lines should be conducted in accordance with ASTM F 1417[9].

Non-Testable Systems

Some systems may not be suitable for pressure leak testing. These systems may contain non-isolatable components, or temporary closures may not be practical. Such systems should be carefully inspected during and after installation. Inspections such as visual examination of joint appearance, mechanical checks of bolt or joint tightness, and other relevant examinations should be performed.

Considerations for Post Start-Up and Operation

Disinfecting Water Mains

Applicable procedures for disinfecting new and repaired potable water mains are presented in standards such as ANSI/AWWA C651[10] that uses liquid chlorine, sodium hypochlorite, or calcium hypochlorite to chemically disinfect the main. Disinfecting solutions containing chlorine should not exceed 12% active chlorine, because greater concentration can chemically attack and degrade PE.

Cleaning

Pipelines operating at low flow rates (around 2 ft/sec or less) may allow solids to settle in the pipe invert. PE has a smooth, non-wetting surface that resists the adherence of sedimentation deposits. If the pipeline is occasionally subject to higher flow rates, much of the sedimentation will be flushed from the system during these peak flows. If cleaning is required, sedimentation deposits can usually be flushed from the system with high pressure water.

Water-jet cleaning is available from commercial services. It usually employs high pressure water sprays from a nozzle that is drawn through the pipe system with a cable.

Pressure piping systems may be cleaned with the water-jet process, or may be pigged. Pigging involves forcing a resilient plastic plug (soft pig) through the pipeline. Soft pigs must be used with PE pipe. Scraping finger type or bucket type pigs may severely damage a PE pipe and must not be used. Usually, hydrostatic or pneumatic pressure is applied behind the pig to move it down the pipeline. Pigging should employ a pig launcher and a pig catcher.

A pig launcher is typically a tee assembly or a removable spool. In the tee assembly, the main flow is into the tee branch and out through a run outlet. The opposite tee run outlet is used to launch the pig. The pig is fitted into the opposite tee run; then the run behind the pig is pressurized to move the pig into the pipeline and downstream. In the removable pipe spool, the pig is loaded into the spool, the spool is installed into the pipeline, and then the pig is forced downstream. (Note – Fully pressure rated wyes suitable for pig launching are generally not available.)

A pig may discharge from the pipeline with considerable velocity and force. The pig catcher is a basket or other device at the end of the line to safely receive or catch the pig when it discharges from the pipeline.

Squeeze-Off

Squeeze-off (or pinch-off) is a means of controlling flow in smaller diameter PE pipe and tubing by flattening the pipe between parallel bars. Flow control does not imply complete flow stoppage in all cases. For larger pipes, particularly at higher pressures, some seepage is likely. If the situation will not allow seepage, then it may be necessary to vent the pipe between two squeeze-offs.

PE gas pipe manufactured to ASTM D 2513[11] is suitable for squeeze-off; however, squeeze-off practices are not limited to gas applications. Squeeze-off is applicable to PE pressure pipe up to 16" IPS, and up to 100 psi internal pressure, and conveying various gases or liquids. Larger sizes and higher pressures may be possible if suitable commercial equipment is available. Manufacturers of squeeze-off equipment should be consulted for equipment applicability, availability and capabilities.

Squeeze-off is applicable ONLY to PE pipe and tubing. The pipe or tubing manufacturer should be consulted to determine if squeeze-off is applicable to his product, and for specific squeeze-off procedures.

Squeeze-off tools should comply with ASTM F 1563[12]. Typical squeeze-off tools use a manual mechanical screw or hydraulic cylinders, incorporate gap stops to prevent over-squeeze, and a mechanism to prevent accidental bar separation.

Closing and opening rate are key elements to squeezing-off without damaging the pipe. It is necessary to close slowly and release slowly, with slow release being more important. Squeeze-off procedures should be in accordance with ASTM F 1041[13] and should be qualified in accordance with ASTM F 1734[14].

Lower temperatures will reduce material flexibility and ductility, so in colder weather, closure and opening time must be slowed further.

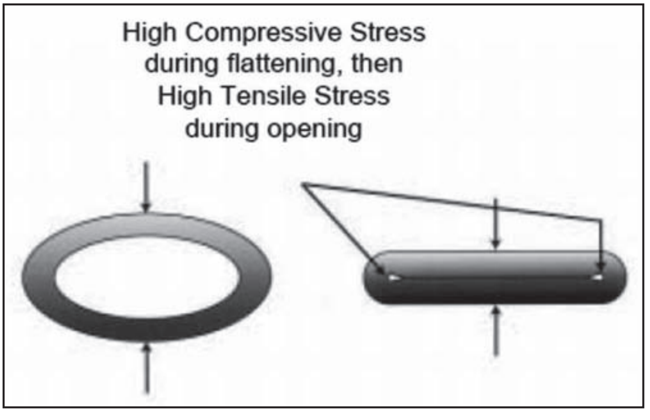

Figure 8 Squeeze-Off Stress

Testing of PE piping has shown that squeeze-off can be performed without compromising the expected service life of the system, or pipe can be damaged during squeeze-off. Damage occurs:

- If the manufacturer's recommended procedures are not followed, or
- If the squeeze is held closed too long, or

- From static electric discharge, or
- When closure stops are altered or circumvented, or
- By squeezing-off more than once in the same location.

Pipe known or suspected to have been damaged during squeeze-off should be removed from the system, or should be reinforced at the squeeze-off point using a full encirclement clamp and replacement repair scheduled.

Static Electricity Control – When pipe conveying a compressed gas is being flattened, the gas flow velocity through the flattened area increases. High velocity, dry gas, especially with particles present in the flow, can generate a static electric charge on pipe surfaces that can discharge to ground. *Before flattening the pipe, the tool should be grounded and procedures to control static charge build-up on pipe surfaces such as wetting surfaces with conductive fluids and applying conductive films or fabrics to ground should be employed.* Grounding and static control procedures should remain in place for the entire squeeze-off procedure.

Identify the squeezed-off area by wrapping tape around the pipe, or installing a full encirclement clamp over the area.

Squeeze-off procedures may be used for routine, scheduled changes to piping systems, or as an emergency procedure to control gasses or liquids escaping from a damaged pipe. For scheduled piping changes, ASTM F 1041 procedures that are qualified per ASTM F 1734 should be observed so that the pipe's service life is not compromised.

However, an emergency situation may require quickly flattening the pipe and controlling flow because the escaping fluid may be an immediate hazard of greater concern than damaging the pipe. *If an emergency situation requires rapid flattening, the pipe or tubing may be damaged.* When the emergency situation is resolved, a full encirclement clamp should be installed over the squeezed off area, and repair to replace the damaged pipe should be scheduled.

Conclusion

A successful piping system installation is dependent on a number of factors. Obviously, a sound design and the specification and selection of the appropriate quality materials are paramount to the long term performance of any engineered installation. The handling, inspection, testing, and safety considerations that surround the placement and use of these engineered products is of equal importance.

In this chapter, we have attempted to provide fundamental guidelines regarding the receipt, inspection, handling, storage, testing, and repair of PE piping products.

While this chapter cannot address all of the product applications, test and inspection procedures, or construction practices, it does point out the need to exercise responsible care in planning out these aspects of any job site. It is the responsibility of the contractor, installer, site engineer, or other users of these materials to establish appropriate safety and health practices specific to the job site and in accordance with the local prevailing codes that will result in a safe and effective installation.

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9. ASTM F 1417 Standard Test Method for Installation Acceptance of Plastic Gravity Sewer Lines Using Low Pressure Air, ASTM, West Conshohocken, PA.
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14. ASTM F 1734 Standard Practice for Qualification of a Combination of Squeeze Tool, Pipe, and Squeeze-Off Procedures to Avoid Long-Term Damage in Polyethylene (PE) Gas Pipe, ASTM, West Conshohocken, PA.

Chapter 3

Material Properties

Scope

A principal objective of the following brief review of the nature of polyethylene (PE) piping materials, of their physical and chemical properties, and of their mechanical and engineering behavior, is to impart a basic understanding of the factors that lie behind the discussions and recommendations contained in this Handbook for the proper storage, handling, installation, design and operation of PE piping systems.

Also included in this Chapter is an Appendix that lists values for the more common engineering design properties of PE piping materials.

Introduction

A number of important performance advantages accounts for the widespread adoption of PE piping for so many pressure and non-pressure applications. A major one is PE's virtual freedom from attack by soils, and by ambient water and moisture. PE, being a non-conductor of electricity, is immune to the electrochemical based corrosion process that is induced by electrolytes such as salts, acids and bases. In addition, PE piping is not vulnerable to biological attack, and its smooth, non-stick inner surface results in low friction factors and exceptional resistance to fouling.

Another unique performance advantage is the flexibility of PE pipe. It allows for changes in direction with minimal use of fittings, facilitates installation, and makes it possible for piping up to about 6-inches in diameter to be offered in coils of longer lengths. A further one is strainability, a term denoting a capacity for high deformation without fracture. In response to earth loading a buried PE pipe can safely deflect and thereby gain additional and substantial support from the surrounding soil. So much so, that a properly installed PE pipe is capable of supporting earth fills and surface live loads that would fracture pipes that, although much stronger, can crack and fail at low strains. And, as proven by actual experience, PE pipe's high strainabilty makes it very resistive to seismic effects.

PE pipe and PE fittings can be joined to each other by thermal fusion processes which result in leak-proof bottle-tight joints that are as strong and as tough as the pipe itself. These advantages combine to make PE a preferred pipe for special applications, such as for horizontal directional drilling, for the renewal of old pipes by insertion, and for marine outfalls. For the first two named applications the butt-fusion process – which avoids the use of larger diameter couplings – enables installation to be conducted by pipe pulling and it permits the use of a larger diameter pipe.

Another recognized advantage of PE piping is its toughness. PE pipes, as well as the heat fusion joints in PE piping, greatly resist the propagation of an initial small failure into a large crack – a major reason for the overwhelming preference for PE piping for gas distribution applications. And, PE piping retains its toughness even at lower temperatures. In addition, PE piping exhibits very high fatigue resistance. Potential damage by repetitive variations in operating pressure (surges) is highly resisted.

Notwithstanding the above and various other advantages of PE piping, its successful design and application requires adequate recognition of its more complex stress/strain and stress/fracture behavior. PE piping does not exhibit the simple proportionality between stress and strain that is characteristic of metal pipes. And, its capacity to resist fracture is reduced as duration of loading is increased. In addition, these and its other mechanical properties exhibit a greater sensitivity to temperature and certain environments. Furthermore, the specific mechanical responses by a PE pipe can vary somewhat depending on the PE material from which it is made – mostly, depending on the nature of the PE polymer (e.g., its molecular weight, molecular weight distribution, degree of branching (density) but, also somewhat on the type and quantity of additives that are included in the piping composition. The particular behavior of the PE pipe that is selected for an application must be given adequate recognition for achieving an effective design and optimum quality of service. A brief explanation of the engineering behavior of PE and the listing of its more important properties is a major objective of this Chapter.

An additional objective of this Chapter is the presentation of values for the major properties that are used for material classification and piping design, and a brief description of the methods based on which these properties are determined.

PE Plastics

Plastics are solid materials that contain one or more polymeric substances which can be shaped by flow. Polymers, the basic ingredient of plastics, compose a broad class of materials that include natural and synthetic polymers. Nearly all plastics are made from the latter. In commercial practice, polymers are frequently designated as resins. For example, a PE pipe compound consists of PE resin combined with colorants, stabilizers, anti-oxidants or other ingredients required to protect and enhance properties during fabrication and service.

Plastics are divided into two basic groups, thermoplastics and thermosets, both of which are used to produce plastic pipe.

Thermoplastics include compositions of PE, polypropylene, and polyvinyl chloride (PVC). These can be re-melted upon the application of heat. The solid state of thermoplastics is the result of physical forces that immobilize polymer chains and prevent them from slipping past each other. When heat is applied, these forces weaken and allow the material to soften or melt. Upon cooling, the molecular chains stop slipping and are held firmly against each other in the solid state. Thermoplastics can be shaped during the molten phase of the resin and therefore can be extruded or molded into a variety of shapes, such as pipe, pipe fittings, flanges or valves.

Thermoset plastics are similar to thermoplastics prior to “curing,” a chemical reaction by which polymer chains are chemically bonded to each other by new cross-links. The curing is usually done during or right after the shaping of the final product. Cross-linking is the random bonding of molecules to each other to form a giant three-dimensional network. Thermoset resins form a permanent insoluble and infusible shape after the application of heat or a curing agent. They cannot be re-melted after they have been shaped and cured. This is the main difference between thermosets and thermoplastics. As heat is applied to a thermoset part, degradation occurs at a temperature lower than the melting point. The properties of thermosetting resins make it possible to combine these materials with reinforcements to form strong composites. Fiberglass is the most popular reinforcement, and fiberglass-reinforced pipe (FRP) is the most common form of thermoset-type pipe.

History of PE

The Imperial Chemical Company (ICI) in England first invented PE in 1933. The early polymerization processes used high-pressure (14,000 to 44,000 psi) autoclave reactors and temperatures of 200° to 600° F (93° to 316° C). The PE that came from these reactors was called "high pressure PE." It was produced in a free radical chain reaction by combining ethylene gas under high pressure with peroxide or a trace amount of oxygen.

The original process was dangerous and expensive, so other safer and less expensive processes were developed. PE produced at low pressure was introduced in the 1950's. These methods also afforded greater versatility in tailoring molecular structures through variations in catalysts, temperatures, and pressures.

Manufacture of PE

Polymers are large molecules formed by the polymerization (i.e. the chemical linking) of repeating small molecular units. To produce PE, the starting unit is ethylene, a colorless gas composed of two double-bonded carbon atoms and four hydrogen atoms (see Figure 1).

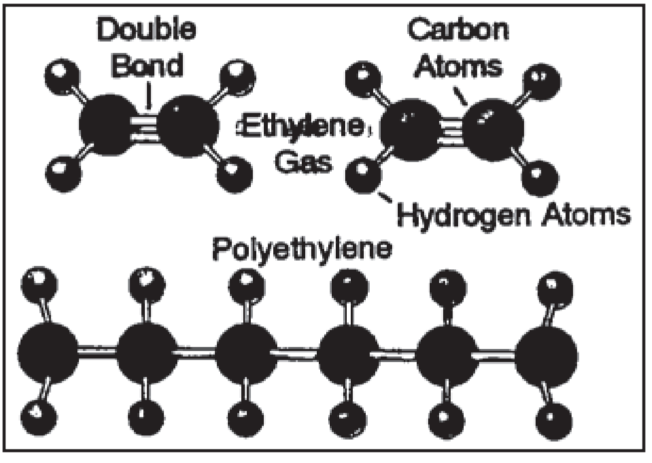

Figure 1 Manufacture of PE

There are currently three primary low-pressure methods for producing PE: gas-phase, solution and slurry (liquid phase). The polymerization of ethylene may take place with various types of catalysts, under varying conditions of pressure and temperature and in reactor systems of radically different design. Ethylene can also be copolymerized with small amounts of other monomers such as butene, propylene, hexene, and octene. This type of copolymerization results in small modifications in chemical structure, which are reflected in certain differences in properties, such as density, ductility, hardness, etc. Resins that are produced without comonomer are called homopolymers.

Regardless of process type, the chemical process is the same. Under reaction conditions, the double bond between the carbon atoms is broken, allowing a bond to form with another carbon atom as shown in Figure 1. Thus, a single chain of PE is formed. This process is repeated until the reaction is terminated and the chain length is fixed. PE is made by the linking of thousands of monomeric units of ethylene.

Polymer Characteristics

PE resins can be described by three basic characteristics that greatly influence the processing and end-use properties: density, molecular weight and molecular weight distribution. The physical properties and processing characteristics of any PE resin require an understanding of the roles played by these three major parameters.

Density

The earliest production of PE was done using the high-pressure process which resulted in a product that contained considerable "side branching." Side branching is the random bonding of short polymer chains to the main polymer chain. Since branched chains are unable to pack together very tightly, the resulting material had a relatively low density, which led to it being named low-density PE (LDPE).

As time passed and PEs of different degrees of branching were produced, there was a need for an industry standard that would classify the resin according to density. The American Society for Testing of Materials (ASTM) originally established the following classification system. It is a part of ASTM D1248, Standard Specification for Polyethylene Plastics Molding and Extrusion Materials[2,5]. This standard has since been replaced by ASTM D 3350; ASTM D 1248 is no longer applicable to PE piping materials.

Type	Density
I	0.910 - 0.925 (low)
II	0.926 - 0.940 (medium)
III	0.941 - 0.959 (high)
IV	0.960 and above (high, homopolymer)

Type I is a low-density resin produced mainly in high-pressure processes. Also contained within this range are the linear-low-density polyethylenes (LLDPE), which represent a recent development in the PE area using low-pressure processes.

Type II is a medium density resin produced either by low- or high-pressure processes.

Types III and IV are high-density polyethylenes. Type III materials are usually produced with a small amount of a comonomer (typically butene or hexene) that is used to control chain branching. Controlled branching results in improved performance in applications where certain types of stresses are involved. Type IV resins are referred to as homopolymers since only ethylene is used in the polymerization process, which results in least-branched and highest-possible-density material. Figure 2 depicts the various molecular structures associated with each type of PE.

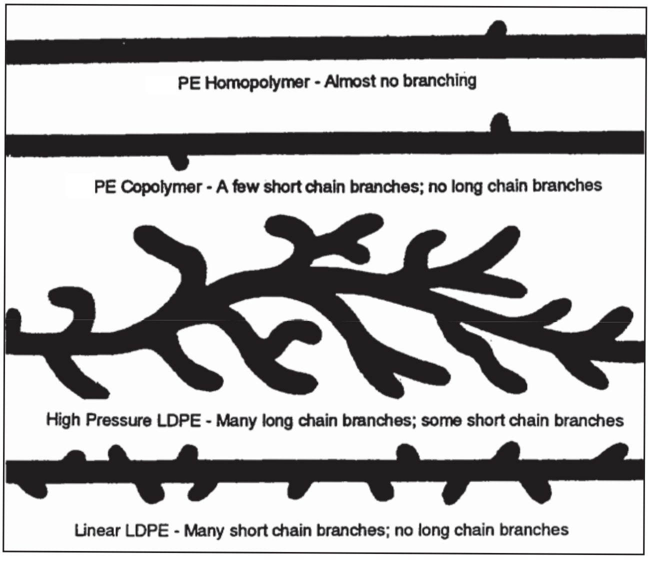

Figure 2 Chain Structure of PE

Crystallinity

The amount of side branching determines the density of the PE molecule. The more side branches, the lower the density. The packing phenomenon that occurs in PE can also be explained in terms of crystalline versus non-crystalline or amorphous regions as illustrated in Figure 3. When molecules pack together in tight formation, the intermolecular spacing is reduced.

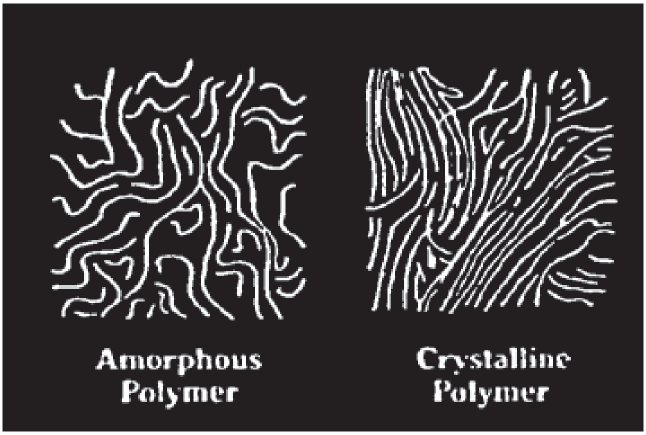

Figure 3 Crystallinity in PE

PE is one of a number of polymers in which portions of the polymer chain in certain regions align themselves in closely packed and very well ordered arrangements of polyhedral-shaped, microscopic crystals called spherulites. Other portions of the polymer chain lie in amorphous regions having no definite molecular arrangement. Since polyethylene contains both crystalline and amorphous regions, it is called a semicrystalline material. Certain grades of high density PE can consist of up to 90% crystalline regions compared to 40% for low density PE. Because of their closer packing, crystalline regions are denser than amorphous regions. Polymer density, therefore, reflects the degree of crystallinity.

As chain branches are added to a PE backbone through co-polymerization, the site and frequency of chain branches affect other aspects of the crystalline/amorphous network. This includes the site and distribution of spherulites, as well as the nature of the intermediate network of molecules that are between spherulites. For example, using butene as co-monomer results in the following "ethyl" side chain structure[8]:

$$(\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-})n$$
$$|$$
$$CH_2$$
$$|$$
$$CH_3$$

or using hexene results in this "butyl" side chain:

$$(\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-})n$$
$$|$$
$$CH_2$$
$$|$$
$$CH_2$$
$$|$$
$$CH_2$$
$$|$$
$$CH_3$$

If two polymers were produced, one using butyl and the other hexene monomer, the polymer that contained the resultant butyl branches would have a lower density. Longer side branching reduces crystallinity and therefore lowers density. For high-density PE, the number of short chain branches is on the order of 3 to 4 side chains per 1,000 carbon atoms. It only takes a small amount of branching to affect the density.

Resin density influences a number of physical properties. Characteristics such as tensile yield strength and stiffness (flexural or tensile modulus) are increased as density is increased.

Molecular Weight

The size of a polymer molecule is represented by its molecular weight, which is the total of the atomic weights of all the atoms that make up the molecule. Molecular weight exerts a great influence on the processability and the final physical and mechanical properties of the polymer.

Molecular weight is controlled during the manufacturing process. The amount of length variation is usually determined by catalyst, conditions of polymerization, and type of process used. During the production of polyethylene, not all molecules grow to the same length. Since the polymer contains molecules of different lengths, the molecular weight is usually expressed as an average value.

There are various ways to express average molecular weight, but the most common is the number average (Mn) and weight average (Mw). The definitions of these terms are as follows:

Mn = Total weight of all molecules ÷ Total number of molecules

Mw = (Total weight of each size) (respective weights) ÷
Total weight of all molecules

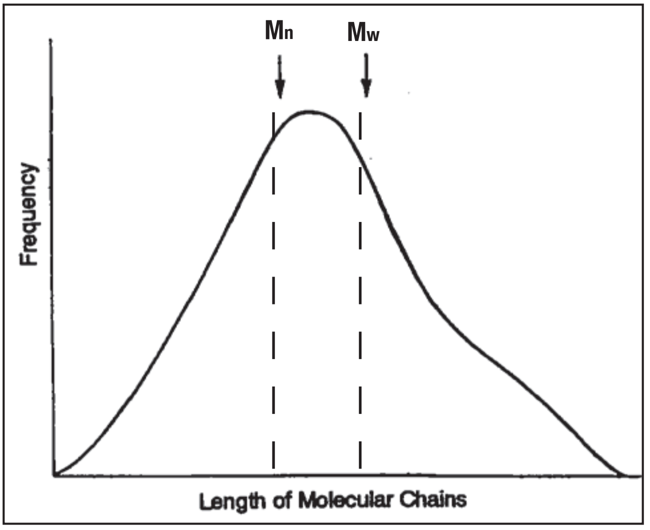

Figure 4 Typical Molecular Weight Distribution

Figure 4 illustrates the significance of these terms and includes other less frequently used terms for describing molecular weight.

Molecular weight is the main factor that determines the durability-related properties of a polymer. Long-term strength, toughness, ductility, and fatigue-endurance improve as the molecular weight increases. The current grades of highly durable materials result from the high molecular weight of the polymer.

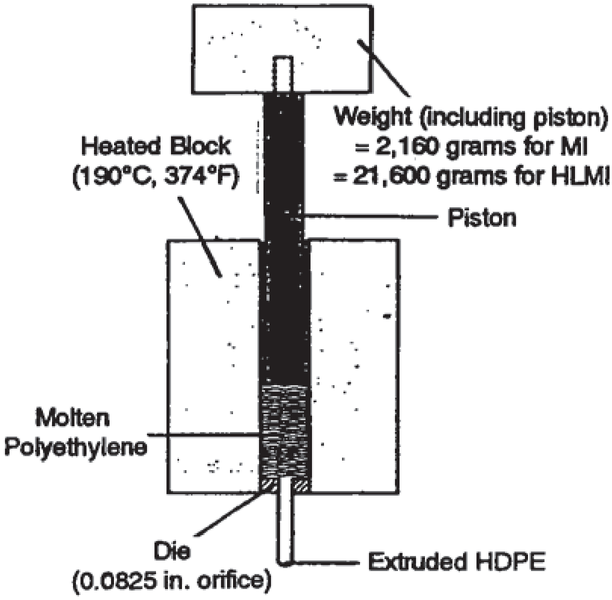

Figure 5 The Melt Flow Test (per ASTM D1238)

Molecular weight affects a polymer's melt viscosity or its ability to flow in the molten state. The standard method used to determine this "flowability" is the melt flow rate apparatus, which is shown in Figure 5. ASTM D1238, *Standard Test Method for Flow Rates of Thermoplastics by Extrusion Plastometer*[2], is the industry standard for measuring the melt flow rate. The test apparatus measures the amount of material that passes through a certain size orifice in a given period of time when extruded at a predetermined temperature and under a specified weight. The melt flow rate is the measured weight of material that passes through the orifice in ten minutes.
The standard nomenclature for melt flow rate, as described in ASTM D1238, lists the test temperature and weight used. A typical designation is condition 190/2.16 that indicates the test was conducted at a temperature of 190°C while using a 2.16-kg weight on top of the piston. Other common weights include: 5 kg, 10 kg, 15 kg and 21.6 kg.

The term "melt index"(MI) is the melt flow rate when measured under a particular set of standard conditions – 190°C/2.16 kg. This term is commonly used throughout the polyethylene industry.

Melt flow rate is a rough guide to the molecular weight and processability of the polymer. This number is inversely related to molecular weight. Resins that have a low molecular weight flow through the orifice easily and are said to have a high melt flow rate. Longer chain length resins resist flow and have a low melt flow rate. The melt flow rates of these very viscous (stiff) resins are very difficult to measure under the common conditions specified by this test. Therefore, another procedure is used where the weight is increased to 21.6 kg from the 2.16 kg weight used in the normal test procedure. This measurement is commonly referred to as the High Load Melt Index (HLMI) or 10X scale. There are other melt flow rate scales that use 5 kg, 10 kg or 15 kg weights.

There are various elaborate analytical techniques for determining molecular weight of a polymer. The melt flow rate gives a very quick, simple indication of the molecular weight. The more sophisticated methods include Gel Permeation Chromatography (GPC). The essence of GPC is to dissolve the polymer in a solvent and then inject the solution into a column (tubing). The column contains a porous packing material that retards the movements of the various polymer chains as they flow through the column under pressure. The time for the polymer to pass through the column depends upon the length of the particular polymer chain. Shorter chains take the longest time due to a greater number of possible pathways. Longer chain molecules will pass more quickly since they are retained in fewer pores. This method measures the distribution of the lengths of polymer chains along with the average molecular weight.

Effect of Molecular Weight Distribution on Properties

The distribution of different sized molecules in a polyethylene polymer typically follows the bell shaped normal distribution curve described by Gaussian probability theory. As with other populations, the bell shaped curve can reflect distributions ranging from narrow to broad. A polymer with a narrow molecular weight distribution (MWD) contains molecules that are nearly the same in molecular weight. It will crystallize at a faster, more uniform rate. This results in a part that will have less warpage.

A polymer that contains a broader range of chain lengths, from *short* to *long* is said to have a broad MWD. Resins with this type of distribution have good slow crack growth (SCG) resistance, good impact resistance and good processability.

Polymers can also have a bimodal shaped distribution curve which, as the name suggests, seem to depict a blend of two different polymer populations, each with its particular average and distribution. Resins having a bimodal MWD contain both very short and very long polyethylene molecules, giving the resin excellent physical properties while maintaining good processability. Figure 6 shows the difference in these various distributions.

The latest generation of high density PE pipe materials, known as high performance materials (e.g. PE 4710), are, for the most part, produced from bimodal resins. Pipe made from these materials are characterized by truly exceptional and unique resistance to slow crack growth (SCG), significantly improved long term performance, higher pressure ratings or increased flow capacity, and improved chemical resistance, all of which are achieved without compromising any of the other traditional benefits that are associated with the use of PE pipe.

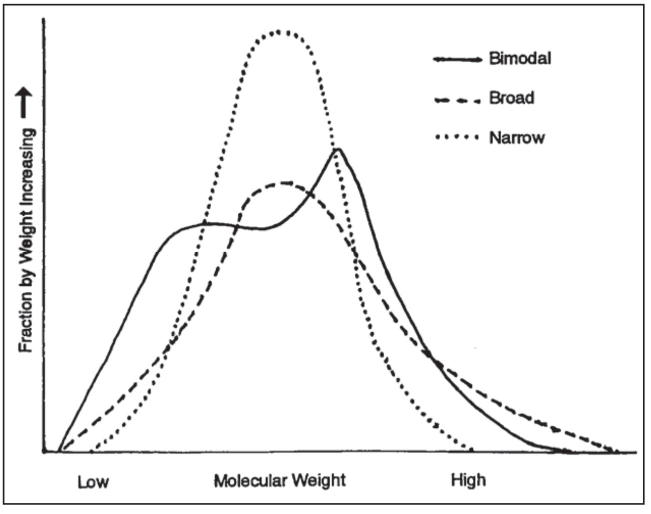

Figure 6 Molecular Weight Distribution

MWD is very dependent upon the type of process used to manufacture the particular polyethylene resin. For polymers of the same density and average molecular weight, their melt flow rates are relatively independent of MWD. Therefore, resins that have the same density and MI can have very different molecular weight distributions. The effects of density, molecular weight, and molecular weight distribution on physical properties are summarized in Table 1.

TABLE 1
Effects of Changes in Density, Melt Index, and Molecular Weight Distribution

Property	As Density Increases, Property	As Melt Index Increases, Property	As Molecular Wt. Distribution Broadens, Property
Tensile Strength (@ Yield)	Increases	Decreases	—
Stiffness	Increases	Decreases Slightly	Decreases Slightly
Impact Strength	Decreases	Decreases	Decreases
Low Temperature Brittleness	Increases	Increases	Decreases
Abrasion Resistance	Increases	Decreases	—
Hardness	Increases	Decreases Slightly	—
Softening Point	Increases	—	Increases
Stress Crack Resistance	Decreases	Decreases	Increases
Permeability	Decreases	Increases Slightly	—
Chemical Resistance	Increases	Decreases	—
Melt Strength	—	Decreases	Increases
Gloss	Increases	Increases	Decreases
Haze	Decreases	Decreases	—
Shrinkage	Increases	Decreases	Increases

PE Piping Materials

The Nature of PE Piping Materials

A PE piping material consists of a polyethylene polymer (commonly designated as the resin) to which has been added small quantities of colorants, stabilizers, anti-oxidants and other ingredients that enhance the properties of the material and that protect it during the manufacturing process, storage and service. PE piping materials are classified as thermoplastics because they soften and melt when sufficiently heated and harden when cooled, a process that is totally reversible and may be repeated. In contrast, thermosetting plastics become permanently hard when heat is applied.

Because PE is a thermoplastic, PE pipe and fittings can be fabricated by the simultaneous application of heat and pressure. And, in the field PE piping can be joined by means of thermal fusion processes by which matching surfaces are permanently fused when they are brought together at a temperature above their melting point.

PE is also classified as a semi-crystalline polymer. Such polymers (e.g., nylon, polypropylene, polytetrafluoroethylene), in contrast to those that are essentially amorphous (e.g., polystyrene, polyvinylchloride), have a sufficiently ordered structure so that substantial portions of their molecular chains are able to align closely to portions of adjoining molecular chains. In these regions of close molecular alignment crystallites are formed which are held together by secondary bonds. Outside these regions, the molecular alignment is much more random resulting in a less orderly state, labeled as amorphous. In essence, semi-crystalline polymers are a blend of a two phases, crystalline and amorphous, in which the crystalline phase is substantial in population.

A beneficial consequence of PE's semi-crystalline nature is a very low glass transition temperature (Tg), the temperature below which a polymer behaves somewhat like a rigid glass and above which it behaves more like a rubbery solid. A significantly lower Tg endows a polymer with a greater capacity for toughness as exhibited by performance properties such as: a capacity to undergo larger deformations before experiencing irreversible structural damage; a large capacity for safely absorbing impact forces; and a high resistance to failure by shattering or rapid crack propagation. These performance aspects are discussed elsewhere in this Chapter. The Tg for PE piping materials is approximately -130°F (-90°C) compared to approximately 221°F (105°C) for polyvinyl chloride and 212°F (100°C) for polystyrene, both of which are examples of amorphous polymers that include little or no crystalline content.

In the case of amorphous polymers, their melting temperature, the temperature at which a transition occurs between the rubbery solid and the liquid states, is not much higher than their Tg. Also for amorphous polymers, the transition between a rubbery solid and a viscous liquid is not very emphatic. This contrasts with semi-crystalline polymers, for which this transition corresponds with the melting of all crystallites, and above which a highly viscous liquid state is reached. This more emphatic transition in PE between the semi-crystalline solid and highly viscous liquid states facilitates manufacture, fabrication and field joining because it allows for more efficient 'welding' to be conducted – when in a liquid state the polymer molecules are able to more effectively diffuse into each other and thereby, form a monolithic structure. In contrast, the melting point of amorphous polymers is less defined and, across this melting point there is not as definite a transition between a rubbery, or plastic state, and a liquid viscous state.

Structural Properties

PE Pipe Material Designation Code Identifies the Standard Classification of Essential Properties

Standards for PE piping define acceptable materials in accordance with a standard designation code. This code, which is explained in greater detail in Chapter 5, has been designed for the quick identification of the pipe material's principal structural and design properties. As this section deals with this subject, it is appropriate to first describe the link between the code designations and these principal properties. For this purpose, and as an example, the significance of one designation, PE4710, is next explained.

- The letters PE designate that it is a polyethylene piping material.
- The first digit, in this example the number 4, identifies the PE resin's density classification in accordance with ASTM D3350, Standard Specification for Polyethylene Plastic Pipe and Fittings Materials [4].

  Certain properties, including stress/strain response, are dependent on a PE's crystalline content. An increase in this phase is reflected by an increase in density. An increase in density affects certain properties, for example an increase in tensile strength and stiffness. Also, a higher density results in changes to other properties. For this reason, the Table for Apparent Modulus that is included in the Appendix of this chapter lists values in accordance with the material's standard density classification. This ASTM standard classification can range from 2, the lowest value, to 4 the highest value.
- The second digit, in this example the number 7, identifies the material's standard classification for slow crack growth resistance – also, in accordance with ASTM D3350 – relating its capacity for resisting the initiation and propagation of slowly growing cracks when subjected to a sustained localized stress intensification.

  The standard classification for current commercial grades is either 6 or 7. The 6 denotes very high resistance and the 7 even higher. The test method for determining quality of resistance to SCG is described later in this chapter.
- The third and fourth digits combined, the number 10 in this example, denote the material's recommended hydrostatic design stress (HDS) for water at 73°F (23°C), in units of 100psi. In this example the number 10 designates the HDS is 1,000psi.

  There are two basic performance criteria based on which a recommended HDS is determined. The first is the material's long term hydrostatic strength (LTHS), a value that is required to comply with certain additional validation or substantiation requirements that are discussed later in this Chapter. The second is the material's quality of resistance to the initiation and growth of slowly growing cracks. An explanation of both of these criteria is included in this section. And, the standard method by which an LTHS is reduced into an HDS is explained in Chapter 5, "Standard Specifications, Test Methods and Codes for PE Piping Systems".

Stress/Strain Response and its Representation by Means of an Apparent Modulus

The potential range of the stress/strain response of a material is bounded by two extremes. At one extreme the response can be perfectly elastic; that is, in conformity to Hook's law whereby the magnitude of strain is always proportional to the magnitude of the applied stress. The resultant proportionality between stress and strain is labeled the modulus of elasticity. Elastic deformation is instantaneous, which means that total deformation (or strain) occurs at the instant the stress is applied. Upon the release of the external stress the deformation is instantaneously and totally recovered. This behavior is represented in Figure 7b as strain versus time for the instantaneous load-time curve depicted in Figure 7a. Under the modulus of elasticity concept, the stress/strain relationship is independent of duration of load application.

At the other extreme, under what is referred to as viscous behavior, deformation caused by the application of a stress is neither instantaneous nor proportional to the stress. Deformation is delayed and the rate and the final extent of deformation are dependent on the magnitude and the duration of the applied stress. Also, the deformation that occurs is not reversible after the stress is released. This response is depicted by Figure 7c.

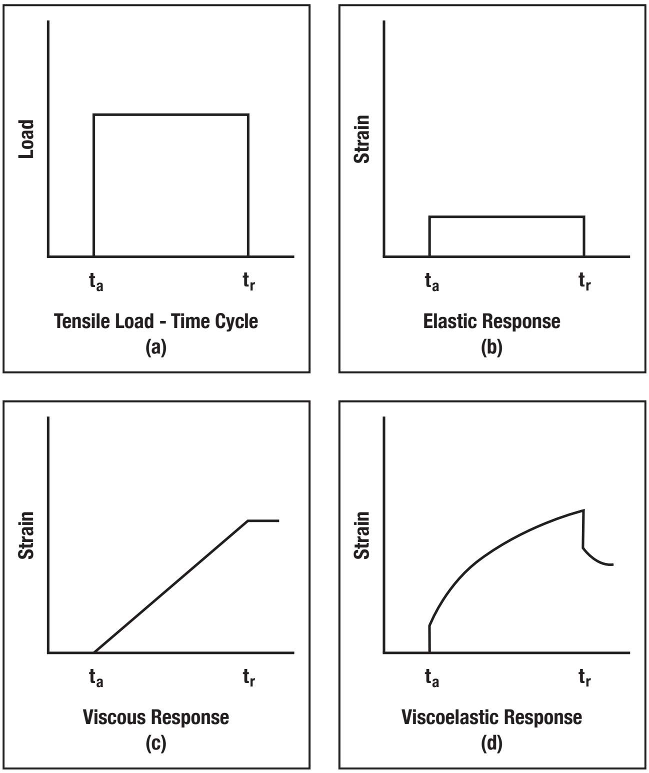

Figure 7 Strain Response (b-d) to a Load (a)

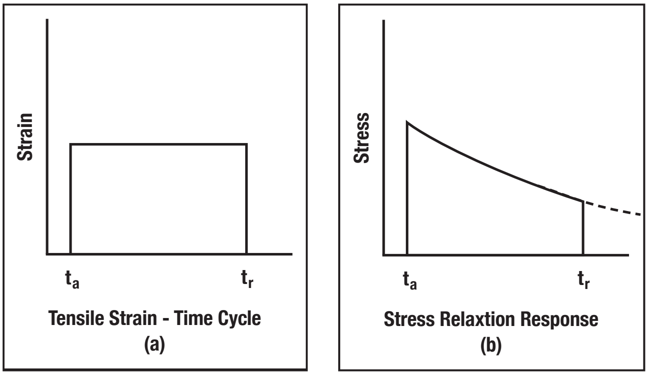

Figure 8 Stress Relaxation Response by a Viscoelastic Material

Viscoelastic behavior, which is depicted by Figure 7d, covers the intermediate region between these extremes. The imposition of a stress in the manner of Figure 7a results in a small instantaneous elastic strain that is then followed by a time-dependent strain. Upon removal of the stress there is a small elastic recovery of strain that is then followed by a time-dependent recovery. This time dependent recovery occurs more quickly for lower values of initial strain and more slowly for an initially larger strain. While the strain recovery may eventually be nearly total, there is almost always some remaining permanent deformation, which, again, is larger for an initially larger deformation.

Figure 7d illustrates viscoelastic response under the condition of constant tensile stress. However, if a strain is imposed and then kept constant, the initially required stress gradually decreases in the course of time. This reaction, which is illustrated by Figure 8, is called stress-relaxation. Stress relaxation is a beneficial response in situations where further deformation is either restrained or counteracted.

Models based on springs – which represent elastic response – and on dashpots –representing viscous response – have been developed to illustrate and to simulate the viscoelastic behavior of PE piping materials.[11 12] A simple one, known as the Maxwell model[29], is shown on the right side of Figure 9. In this model the lone spring represent the elastic reaction, the parallel arrangement of spring and dashpot represents the viscoelastic reaction and, the dashpot represents the viscous reaction.

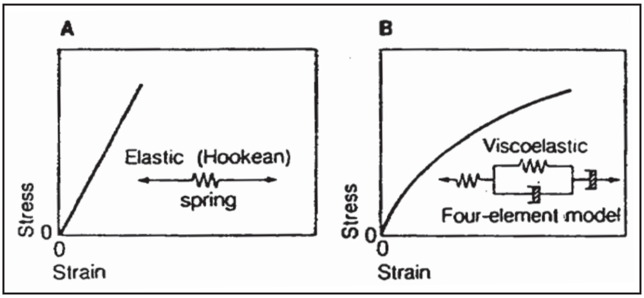

Figure 9 The Maxwell Model

A resultant stress/strain relationship for a viscoelastic/thermoplastic material is determined by a number of variables, principally the following:

1. The magnitude of the initial stress or strain (a larger stress or strain results in a larger viscous response)
2. The multi-axiality of the resultant stress (when a material is simultaneously pulled in more than one direction this inhibits its freedom to deform)
3. The duration of the sustained stress or of the sustained strain (increased duration results in a larger total response)
4. The temperature (it mostly affects the rate of the viscous response)
5. The environment (if an organic substance is adsorbed to some extent by PE, this may result in a plasticizing effect that mostly accelerates the viscous response – air and water are inert in this respect and they produce equivalent results)
6. Possible external restraints on the freedom to deform (e.g., the embedment around a buried pipe restricts free-creeping)

A frequently used method for evaluating the stress/strain response of PE piping materials is by means of tensile/creep tests that are conducted on test bars. In these tests, the specimens are subjected to a uni-axial stress and they are allowed to free-creep, meaning that their deformation is unrestrained. This combination of test parameters yields the maximum possible deformation under a certain sustained stress. When the logarithm of the strain (deformation) resulting from such tests is plotted against the logarithm of duration of loading it yields an essentially straight line for each level of sustained test stress. This behavior is illustrated by Figure 10. This essentially straight line behavior facilitates extrapolation of experimental results to longer durations of loading than covered by the data (the extrapolation is denoted by the dotted lines in Figure 10).

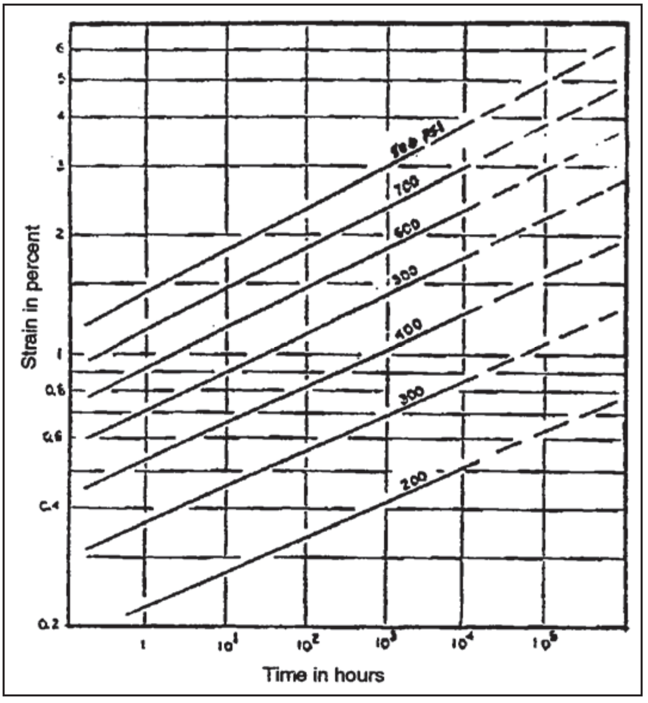

Figure 10 Typical Tensile Stress/Creep Response for a PE3XXX Piping Material When Subjected to a Sustained Uni-axial Tensile Stress, in Air at 73°F

Any point on a tensile/creep diagram, such as in Figure 10 gives a stress/strain ratio. To differentiate this ratio from the modulus of elasticity, which only applies to elastic behaving materials, it is designated as the apparent modulus under tension. For correct engineering use, a value of apparent modulus must identify the conditions under which that value has been established: the kind of stress (uni-axial versus bi- or multi-axial); the magnitude of the principal stress; the duration of stress application; the temperature; and, the test environment. Figure 11 illustrates the manner by which the apparent modulus of a PE3XXX material varies, at 73°F and in air, after different durations of sustained loading and in response to uni-axial stresses of different intensities.

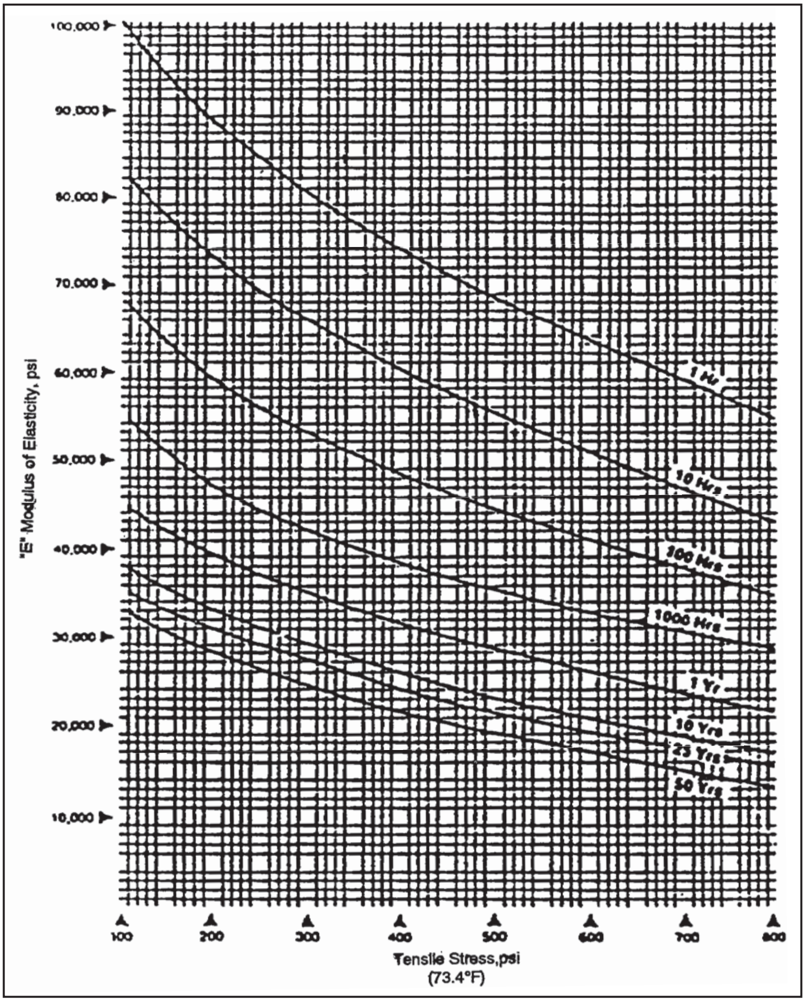

Figure 11 Apparent Modulus Versus Stress-Intensity for PE3XXX* Material when Evaluated Under Uni-Axial Stressing, In Air and at 73°F

* The PE3XXX designation covers all pipe materials that are made using a PE resin that meets the requirements for the Class 3 density classification, in accordance with ASTM D3350.

Apparent moduli have also been evaluated on pressurized pipe specimens by measuring the increase in pipe diameter as a function of pressure (stress) and time under pressure. In these tests the pipe specimen is subjected to bi-axial stressing – a circumferential stress and an axial stress that is about one-half of the magnitude of the circumferential stress. This combination of stresses works to restrain deformation. The result is an apparent modulus that is about 25% larger than that determined under uni-axial tension.

Analogous apparent moduli can also be derived from stress-relaxation data. However, the numerical difference between an apparent modulus derived from tensile creep data and one derived from stress relaxation data is generally small for typical working stresses and when the times under a continuous load, or strain, are matched. Accordingly, the two can be used interchangeably for common engineering design.

Apparent Modulus Under Compressive Stress

Apparent moduli can also be derived for the condition of compressive stress. Such a value tends to be somewhat larger because the resultant deformation causes a slight increase in the area that resists the applied stress. However, the resultant increase is generally small, allowing the tensile stress value to adequately and conservatively represent the compression state.

In summary

The apparent modulus concept has proven to be very useful and effective. Even though PE piping materials exhibit viscoelastic behavior, this concept allows for piping design to be conducted by means of the same equations that have been developed based on the assumption of elastic behavior. However, it is important to recognize that a value of an apparent modulus that is used for a design must adequately reflect the viscoelastic response that is expected to occur under the anticipated service conditions. In this regard it should be noted, as illustrated by Figure 11, that a value of apparent modulus is dependent not only on duration of loading but also, on stress intensity. However, in nearly all PE pipe applications the maximum stresses that are generated by reactions other than that which is caused by internal pressure – a reaction that, as shown by the section that follows, is treated as a separate design issue – are of a magnitude that seldom exceeds the range of about 300 to 400psi. Accordingly, the apparent modulus values within this stress range may be accepted as an appropriate and conservative value for general design purposes. This is the major consideration behind the design values that are presented in Table B.1.1 in the Appendix to this Chapter. It should also be recognized that the values in this table apply to the condition of uni-axial stressing. Thus, these values tend to be conservative because in most applications there exists some multi-axiality of stressing, a condition that leads to a somewhat larger apparent modulus.

There is one kind of operation that results in a temporary tensile stress that is significantly beyond the maximum range of 300-400psi for which Table B.1.1 applies. This is an installation by pipe pulling, a procedure that is the subject of Chapter 12. At the significantly greater uni-axial stresses that result under this installation procedure, the resultant apparent modulus is about 2/3rds of the values that are listed in Table B.1.1.

An aspect of Table B.1.1 worth noting is that it presents values in accordance with the standard density classification of the PE resin (the first numeral after the PE designation), in accordance with ASTM D3350 (Refer to Chapter 5 for a detailed explanation of the D3350 classification system). As discussed earlier in this Chapter, a higher resin density reflects a higher crystalline content. And, the higher the content, the greater a material's apparent modulus.

As mentioned earlier, the apparent modulus varies with temperature. Table B.1.2 in the Appendix to this Chapter lists multipliers for the converting of the apparent modulus for the base temperature of 73°F to another temperature of design interest.

Stress/Fracture Behavior and the Determination of Working Strength

Introduction

Successful design requires that the working strength of a material be defined in relation to the various conditions under which it is intended to be used and in recognition of its structural behavior. The working tensile strength of PE is affected by essentially the same variables that affect its stress/strain relationship, principally magnitude of load, duration of loading, temperature and environment. However, there is one important difference. Whereas strain response is in reaction to the nominal value (the so called bulk or, average value) of applied stress, fracture can result from either the effect of a nominal stress, or from that of a local intensified stress. Under an excessively large nominal stress PE continues to slowly deform until a sufficiently large deformation is reached at which the material begins to yield. Yielding is then quickly followed by structural failure. This failure mechanism, because it is preceded by yielding or plastic deformation, occurs in what is referred to as the ductile state.

In contrast, a locally intensified stress can sometimes lead to the initiation and subsequent propagation of a localized and very slowly growing crack. When the crack grows to a size that spans from the inside to the outside wall of a pressure pipe a leak is the end result. Even though a failure in PE pipe which results from slow crack growth (SCG) is greatly resistant of its propagation into a larger crack – a very beneficial feature of PE pipe – it is identified as brittle-like because it occurs absent of any localized yielding or plastic deformation. Such absence is symptomatic of the fracture process that occurs in what is known as the brittle state. The working strength of each commercial grade of PE pipe material is determined in consideration of both of these possible failure mechanisms.

In a pressure pipe application the major nominal stress is that which is induced by internal hydrostatic pressure. Accordingly, standards for pressure rated PE pipe require that each material from which a PE pipe is made have an experimentally established long-term hydrostatic strength (LTHS). The pressure rating of a PE pipe is based on this hydrostatic strength after it has been reduced to a hydrostatic design stress (HDS) by means of a design factor (DF) that gives adequate consideration to the additional nominal and localized stresses that can be generated by other conditions, as well as to the various other factors that can affect reliability and durability under actual service conditions. A discussion of these factors is included in Chapter 5 under the subtopic "Determining a PE's Appropriate Hydrostatic Design Stress (HDS) Category".

The methodology for establishing an HDS for PE pipe presumes that at the assigned value of HDS, and also under proper installation, the pipe shall operate in the ductile state. In other words, when it operates at its sustained pressure rating it also has sufficient reserve strength for safely absorbing anticipated add-on stresses, particularly localized stress intensifications. Normal stress increasing situations can result from scratches, gouges, changes in geometry (like those at fittings), rock impingements, etc.

The possible adverse effect by localized stress intensifications on the working strength of engineering materials is well recognized and is addressed by means of these two general strategies:

1. By recognizing a material's sensitivity to the effect of stress intensifications through

a) the application of a larger 'safety factor' when establishing a safe design stress; and, or,

b) by conducting pipe design not based on the average value of a major stress, but doing so in consideration of the maximum localized stress that may be generated, wherever it is expected to occur – for example, by the application of a special stress concentration factor. (31, 32)

2. By ensuring that the pipe material has the capacity to operate in the ductile state under the anticipated installation and service conditions. In this case pipe design can proceed on the basis of the nominal (average) value of a major stress.

The latter is the strategy that is employed for qualifying PE materials for piping applications. Because a design that is based on nominal stress presumes a capability for performing in the ductile state, PE piping standards require that the pipe material must not only have an established long-term hydrostatic strength (LTHS), but that it also has to exhibit a very high resistance to the development and growth of slowly growing cracks (SCG), the failure mechanism that may be initiated and then propagated by a localized stress intensification. These are two of three major considerations in the determination of the recommended hydrostatic design stress (HDS) of a PE piping material.

The determination of an HDS needs to also consider the potential effect on working strength by the add-on stresses of very temporary duration – those that result from pressure surges. This leads to a third consideration: The potential adverse effect on working strength by pressure surges.

The methods by which each of these three considerations – long term hydrostatic strength, resistance to slow crack growth and resistance to pressure surges – is evaluated, and the manner in how the results are considered for the establishment of an HDS, is briefly described in the sections that follow.

Establishing a PE's Long-Term Hydrostatic Strength (LTHS) and its Derivative, The Hydrostatic Design Basis (HDB)

It is well recognized that the working strength of materials that exhibit viscoelastic behavior – which includes not just thermoplastics but also other materials such as metals and ceramics at high temperatures – decreases with increased duration of loading [8, 13]. For such materials their long-term working strength for a temperature and other condition of interest is determined based on the result of a sustained-stress versus time-to-rupture (i.e., a stress-rupture) evaluation. The working strength of PE materials is similarly evaluated and a standard protocol has been established for doing so.

The standard basis for determining an LTHS value for PE piping materials is from results of pressure testing in water, or air, for the base temperature of 73°F (23°C). However, many commercial grades of PE materials also have an LTHS that has been determined at an elevated temperature, generally 140°F (60°C). The determination of an LTHS involves three steps, as follows:

1. Circumferential (hoop) stress versus time-to -rupture data are obtained by means of longer-term sustained hydrostatic pressure tests that are conducted on pipe specimens made from the material under evaluation. This testing is performed in accordance with ASTM D1598, Time to Failure of Plastic Pipe Under Constant Internal Pressure[5]. Sufficient stress-rupture data points are obtained for the adequate defining of the material's stress-rupture behavior from about 10hrs to not less than 10,000hrs.

2. The obtained data are then analyzed in accordance with ASTM D2837, Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials,[5] to determine if it constitutes an acceptable basis for forecasting a PE's LTHS. To be acceptable, the data must satisfy the following two requirements:

   a. A statistical analysis of the stress-rupture data must confirm that a plot of the logarithm of circumferential (hoop) stress versus the logarithm of time-to-fail yields a straight line.

b. An analysis of separately obtained elevated temperature stress-rupture data that are obtained on the same population of pipe specimens must validate the expectation that the above experimentally established straight line behavior shall continue significantly past the experimental period, through at least 100,000hrs (11.4 years). For the case of materials that are labeled high performance, it must be demonstrated that this straight line behavior shall continue through at least the 50-year intercept. This latter demonstration is labeled substantiation. A description of the validation and substantiation methods appears later in this discussion.

3. When both of the above (2a and 2b) requirements are satisfied this qualifies the mathematical representation of the stress-rupture behavior that is indicated by the experimental data. This mathematical model is then used for forecasting the average stress at which failure will occur at the 100,000hr intercept. The resultant value is labeled the long-term hydrostatic strength (LTHS) of the material under evaluation.

For purposes of simplifying standards that cover pressure rated pipes, an LTHS that is established by the above procedure is next reduced to one of a limited number of standard long-term hydrostatic strength categories, each of which is designated as a Hydrostatic Design Basis (HDB). The hydrostatic design stress (HDS) is then determined by applying an appropriate strength reduction factor – what is termed as the design factor (DF) – to the resultant HDB. The standard convention is to also express the DF in terms of a preferred number. The reduction of an HDB that is stated in terms of a preferred number by means of a DF that is also stated in terms of a preferred number results in an HDS that is always expressed in terms of a preferred number. The interested reader is referred to Chapter 5 for further information on the use of preferred numbers. A detailed description of the standard procedure for the reducing of an LTHS to an HDB, and the subsequent determination of an HDS, is included in Chapter 5, "Standard Specifications, Test Methods and Codes for PE Piping Systems".

It is important to recognize that because the LTHS is determined at the 100,000hr intercept this does not mean that the intended design life is only for that time period, essentially only about 11 years. This time intercept only represents the standard accepted basis for defining the PE material's LTHS. The design of a service life for a much longer period is one of the important functions of the DF, based on which an HDB (a categorized LTHS) is reduced to an HDS.

Once the HDS is determined for a particular material the standard pressure rating (PR), or pressure class (PC), for a pipe made from that material may be computed. The Appendix to this Chapter presents the equations that are used for this purpose as well as a table of the resultant PR's and PC's of pipes that are made to various dimension ratios (DR's).

The results of a stress-rupture evaluation of a PE pipe that has been produced from a high density material are presented in Figure 12. In this evaluation water was present inside and outside the pipe and the testing was conducted at a temperature of 20°C (68°F), and also at two elevated temperatures: 60 and 80°C (140 and 176°F). In this case all of the resultant data have been analyzed by means of a standard mathematical program[14] that also forecasts the long term strength of the PE material at each of these test temperatures. Two forecasts are shown: The higher line is a forecast of the mean value of strength; and, the lower line is a forecast of the lower predictive limit, the LPL. It can be observed that the 80°C data show that a "down-turn" occurs after about 2500hrs. At the lower test temperature of 60°C the downturn occurs about a log decade later. By taking into account the effect of temperature on this shift in strength, the mathematical program projects that for the tested material the straight line behavior at 20°C (68°F) shall continue beyond the 50 year intercept, considerably past the minimum 100,000 hours that is imposed by the validation requirement of ASTM D2837.

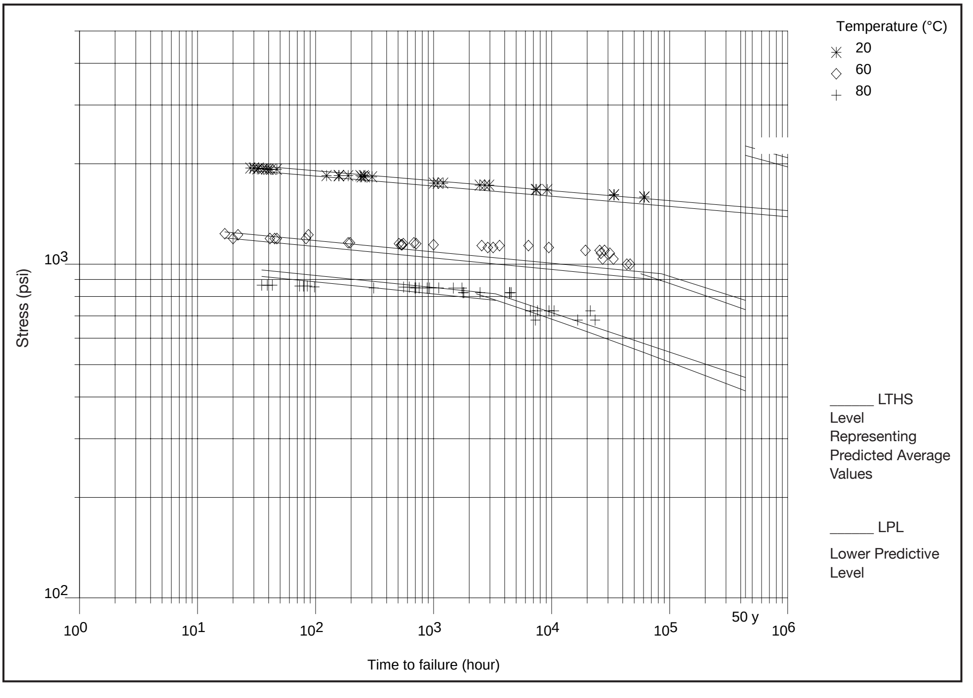

Figure 12 Stress-Rupture Characteristics of an HDPE Pipe Material Similar or Equivalent to PE 4710 (this is not a creep-rupture diagram and the 'higher performance' designation refers to the fact that there is no downturn even after 50 years.)

As already stated, a principal objective of the validation requirement is to confirm compliance to the expectation that the straight-line behavior that is exhibited by the experimental data shall continue through at least 100,000hrs. Should this expectation not be realized, then the LTHS as projected by the straight line assumption will be overstated. But, there is another important objective of the validation requirement. It has been determined that the shift to a down turn in the stress-rupture behavior of PE piping materials is the result of a shift in failure mechanism; from ductile to brittle-like. Studies show that brittle-like failures are the end result of a slow crack growth (SCG) mechanism that is initiated by localized stress intensifications that are generated at natural and normal flaws in the pipe material. In the case of PE materials the term flaws refer to very localized and quite normal discontinuities in structure, such as can be caused by gel particles, by residual catalyst, by transitions from crystallites to amorphous material. Materials that display high resistance to inherent flaws are also materials that offer high resistance to localized stress intensifications that are created by external factors. This observation on the effect of inherent flaws on working strength is in line with the behavior of other thermoplastics, as well as that of traditional materials. For example, if it were not for the presence of naturally occurring flaws the working strength of glass would be many times greater. An objective in the development of an engineering material is to minimize its vulnerability to inherent flaws; that is, to enhance its capacity to perform in the ductile state. This is the other important objective of the validation requirement.

A study conducted by the Plastics Pipe Institute [18] has shown that very good quality longer-term field performance is achieved by pipes that are made of PE materials for which the down turn in its ambient temperature stress-rupture behavior is predicted to occur beyond 100,000hrs. Such pipes have been shown to exhibit high resistance to stress increasing situations. In other words, these pipes have a capacity to continually operate in the ductile state. Based on this study, materials for which a downturn is predicted to occur prior to the 100,000hr intercept are excluded from pressure pipe applications. As discussed earlier in this section, it is important to, once again, emphasize that while the LTHS of a PE pipe material is based on its value at 100,000 hours (11.4 years) this does not define its design life.

The newer high performance PE pipe materials – for example the PE4710 materials – exhibit no downturn prior to the 50-year intercept. Because of this, and also because of a couple of additional performance requirements, these newer materials do not require as large a cushion to compensate for add-on stress and therefore, they can safely operate at a higher hydrostatic design stress. A discussion of this matter is included in Chapter 5.

Methodology for the validation of an LTHS

The validation requirement in ASTM D2837 is predicated on the finding that the kinetics of the slow crack growth process is in line with rate process theory[18, 20, 21, and 27]. In accordance with this theory, which has been found to apply to many naturally occurring chemical and mechanical processes, the rate at which a process proceeds is a function of a driving force (e.g., concentration, pressure or, stress in the case of a fracture process) and temperature (which affects intensity of molecular activity). The following rate process based equation has been found to well model the experimentally established relationship between a pipe's time to failure under the SCG process and the magnitude of the applied stress and the temperature.

(1) $$\text{Log } t = A + B/T + C (\log \delta)/T$$

WHERE
t = time to fail, hrs
T = absolute temperature, °R
δ = circumferential (hoop) stress, psi
A, B, and C = experimentally established coefficients

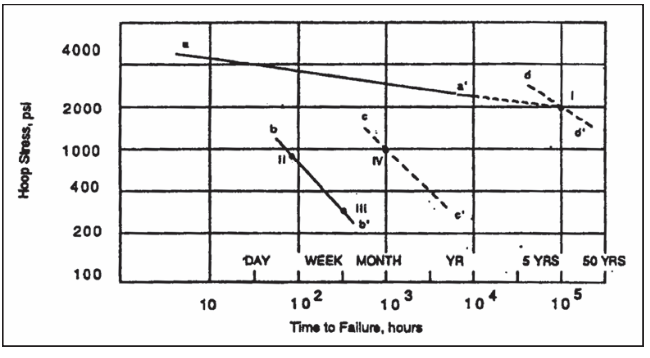

Figure 13 Hoop Stress vs Time to Failure

With reference to Figure 13 the following are the steps that comprise the validation procedure:

1. In accordance with ASTM D2837, evaluate pipe samples of a material of interest at the base temperature of 73.4°F (23°) so as to define the mathematical model that expresses the relationship between hoop stress and time-to-failure (Line a-a'). Then, based on this model compute the predicted value of average hoop stress that results in failure at the 100,000 hour intercept (Point I).

2. At an elevated temperature, but not higher than 194°F (90°C), establish a brittle failure line (line b-b') by the means of the following procedure:

a) Using at least six pipe test specimens, subject each specimen to a hoop stress that results in a brittle-like failure (a crack in the pipe wall with no visible sign of deformation) in the range of 100 to 500hrs. The determination of the best stress/temperature combination may require some preliminary trial and error experimentation. Determine the log average of the results (Point II).

b) Also using not less than six pipe specimens, select a hoop stress that is at least 75psi lower than that used in the above step. Testing under this condition should result in a failure time that ranges from 1,000 to about 2,000hrs. Determine the log average of the results (Point III).

3. Subject at least six pipe samples to the same sustained stress as used under condition 2-a, but conduct the testing at a temperature that is at least 27°F (15°C) lower. Continue this testing until failure of all specimens, or until the log average of the testing times (failures and non-failures) equals or exceeds the time predicted by the requirement that follows (Point IV).

4. To validate that the tested material is in compliance with the D2837 requirement that the straight-line that is depicted by the experimental data shall continue through at least 100,000 hours, the above determined log average failure time (point IV) must at the least equal a value that is predicted by the rate process equation (Equation 1) for which the coefficients A, B and C have been determined based on the experimentally established values of points I, II, and III. PE materials that fail to validate are considered unacceptable for pressure pipe applications.

A challenge in the application of the above method is the high resistance to brittle-like failure that is exhibited by modern PE piping materials. In consequence of this, failure times for these materials at the elevated test temperatures (such as Points III and IV in Figure 13 can be as long as thousands of hours. To achieve a more practical test time an alternate procedure has been established which is based on the Time-Temperature Superposition Principle. This principle is a derivative of the rate process theory. It essentially asserts that a certain stress-rupture performance that is exhibited at an elevated temperature is shifted to a longer time when the temperature is lowered. This shift is exhibited by lines b-b', c-c' and d-d' in Figure 13. Studies show that for PE piping materials of various kinds this shift is adequately represented by means of a common shift factor. Based on this common factor, tables have been established that specify the minimum times to failure at a specified stress and an elevated temperature that ensure the validation of an LTHS for 73.4°F (23°C). These Tables are published in PPI report TR-3.[22]

Substantiation: A Step Beyond Validation

Thanks to modern chemistry, PE piping materials have become available which exhibit outstanding resistance to slow crack growth. In consequence of this property these materials are very highly resistant to brittle-like failure, which results in a straight line stress-rupture behavior at ambient temperature that is predicted to exhibit no downturn prior to the 50-year intercept. This behavior is exhibited by Figure 12. In order to give standard recognition to this very beneficial aspect the substantiation requirement has been established. This requirement is essentially the same as validation, but the difference is that substantiation is the confirmation, also by means of supplementary testing, that the ductile stress-rupture behavior indicated by the experimental data is expected to continue through at least the 50-year intercept.

Compensating for the Effect of Temperature on Working Strength

Many evaluations have been conducted regarding the effect of a sustained temperature on a PE's LTHS. While results show that materials can be affected somewhat differently, they also show that over a range of about 30°F (17°C) above and below the base temperature of 73°F (23°C) the effect is sufficiently similar so that it can be represented by a common set of temperature compensating multipliers. Table A.2 in the Appendix to this chapter lists these common multipliers.

The Appendix also includes guidance for determining a multiplier, for a specific pipe material, for sustained temperatures that are above 100°F (38°C). This determination requires that the PE material from which the pipe is made have a recommended HDB for a temperature above 100°F (38°C), in addition to the universal requirement for pressure pipe applications to have an HDB for the base temperature of 73°F (23°C). This information may be obtained from the pipe supplier or, in the case where the commercial designation of the pipe material is known, it can be obtained by consulting a current copy of PPI Report TR-4. Earlier in this Chapter, the subject of HDB was discussed. For a more thorough discussion of the topic, the interested reader is referred to Chapter 5.

In addition, it is noted in this Appendix that certain standards, codes and manuals that are dedicated to certain applications may list temperature compensating multipliers that are either specific to the PE materials that are covered or, that reflect certain considerations that are unique to the application. For example, in water distribution applications the highest temperature is not sustained all year long. The operating temperature varies with the seasons. Therefore, in AWWA standards and manuals the temperature compensating multipliers apply to a **maximum** operating temperature – as contrasted to a temperature that is sustained – and the values recognize that because of seasonal variations the average operating temperature shall be somewhat below the maximum. Table A.2 in the Appendix presumes that the noted temperature shall be continually sustained. Accordingly, if a standard, code or manual includes a table of temperature de-rating multipliers, those multipliers take precedence over those in Table A.2 in the Appendix.

Compressive Strength

Unlike under the condition of tensile loading, which if excessive can result in a failure, a compressive loading seldom leads to a fracture. Instead, there is a resultant creep in compression, which causes a thickening of the areas resisting the stress, an effect that tends to reduce the true stress. If the stress is excessive failure can occur by yielding (excessive deformation) rather than by a fracture process. For these reasons, it is customary to report compressive strength as the stress required to deform a test sample to a certain strain. Recommended allowable compressive stress values are presented in Table C-1 in the Appendix to this Chapter.

Evaluating the Resistance to Slow Crack Growth (SCG) of a Sharply Notched PE Specimen

As mentioned earlier, a significant value of the validation and the substantiation requirements is that they work to exclude from piping applications those PE materials for which their long-term tensile strength and ductility may be compromised by a lower resistance to the slow crack growth mechanism, as it may be initiated by internal flaws (natural inhomogenities). And, as it was also mentioned earlier, this resistance to the effect of internal flaws is also a recognized index of a PE's resistance to the potentially adverse effect of external flaws. However, indications are that among different kinds of PE's there is not a consistent proportionality between the material's resistance to failure as initiated by internal flaws versus one that is initiated by external flaws. Thus, to more directly determine a PE's resistance to external flaws, ASTM F 1473, "Standard Test Method for Notch Tensile Test to Measure the Resistance to Slow Crack Growth of Polyethylene Pipes and Resins" (5) was developed. In this method a precisely notched specimen is subjected to a constant load in air that is maintained at a constant temperature of 80°C (176°F). This combination of conditions results in a failure time that can be measured in hours. The failure mechanism is at first, and for the greater part of the failure time, that of a slowly growing crack. When this crack reaches a major size it causes the remaining ligament to be subjected to a sufficiently higher stress such that the final break occurs by a ductile tearing. The total time-to-failure that covers both these mechanisms has been shown to be an index of the quality of a PE's resistance to SCG under actual service conditions.

A study sponsored by the Gas Research Institute (GRI) regarding the quality of long-term field performance of PE pipes versus their time-to-fail under test method ASTM F1473 indicates that 50 hours under this test results in an excellent service life. Or, in other words, this minimum time to failure ensures that under proper installation and operating conditions the pipe shall continue to operate in the ductile state. The lowest ASTM F1473 time to failure for current PE piping materials is 100hrs. This is designated by the numeral 6 in the second digit of the PE pipe material designation code (e.g., PE 3608). This minimum 100hr value includes a "safety" margin over the GRI determined "safe" value. However, many current materials qualify for the numeral 7 (e.g., PE4710), which designates a time to failure under this test in excess of 500 hours. This performance indicates a superior capacity for safely tolerating localized stress intensifications, which gives added assurance of a pipe's capability to operate in the ductile state over its intended service life. This is one of the primary requirements that the higher performance PE piping materials must meet in order to qualify for a higher hydrostatic design stress rating. (See Chapter 5 for a discussion on establishing an HDS).

There are materials for which the time-to-fail, when tested under ASTM F1473, is in the thousands of hours. However, it should be kept in mind that under this method, as the time to fail increases, a larger share of this time-to-fail covers the ductile tearing phase, a phase that does not represent resistance to slow crack growth. [36] It also should be kept in mind that the objective of setting a minimum time-to-fail requirement is to achieve the beneficial effect of continued operation in the ductile state. Accordingly, when tested under ASTM F1473,a minimum 500 hour time–to-fail requirement has been established for higher performance PE materials, based on information that indicates materials that meet this requirement exhibit maximum efficacy in tempering potential adverse effects that may be caused by localized stress intensifications.

Resistance to Pressure Surges

As discussed earlier, the pressure rating and pressure class of a PE pipe is established based on the material's long term hydrostatic strength (LTHS), a property that is determined under the condition of a sustained hydrostatic stress. Under actual service conditions pressure surges may occur, which can cause temporary rises in the hydrostatic stress above the sustained working stress. Such rises need to be limited to a value and a total number of occurrences that are safely tolerated by a pipe when it is operating at its working pressure. In the case of some pipe materials, the strength of which is affected by temporary pressure surges, their sustained pressure rating must be appropriately reduced. On the other hand, as evidenced by testing and proven by experience, PE pipe is very tolerant of the effect of pressure surges. Seldom is it necessary to lower a PE pipe's static pressure rating to compensate for the effect of pressure surges.

Temporary rises in operating pressure may lead to either of these events:

1. The total stress that is induced by the combination of the static plus a surge pressure may reach a magnitude that exceeds the pipe's hydrostatic strength thereby, causing the pipe to rupture.

2. A large number of surge pressure events coupled with their magnitude may, after some time, result in fatigue of the pipe material so as to cause a sufficient loss of its long-term hydrostatic strength (LTHS) that can lead to a premature failure.

These two events are distinguished by a major difference. The first event is the simple result of an applied stress that exceeds the pipe material's hydrostatic strength. But, the second one is the result of a gradual degradation of this strength by the effects of fatigue. This essential difference is recognized by the two kinds of allowances for sudden pressure surges for PE pipes that are presented in Chapter 6. One of these allowances is for occasional pressure surges, which do not induce fatiguing and, the other covers frequently occurring pressure surges that may result in fatiguing. PE pipe's reaction to each of these two different events is next discussed.

Reaction to Occasional Pressure Surges

PE's viscoelastic nature, which accounts for its decrease in hydrostatic strength with increased duration of loading also results in the opposite effect, an increased strength under decreased duration of loading. Occasional surge pressure events – such as may be caused by a power failure or other malfunction – result in a maximum hydrostatic stress that lasts for only a few seconds, at their longest. However, it should be noted that the short-term hydrostatic strength of PE pipe is more than twice its LTHS.

An evaluation of PE pipe's stress/strain behavior gives further support to its capacity for safely tolerating occasional pressure surges. When a PE pipe is subjected to an add-on stress of very short duration, the resultant additional strain is relatively small, as predicted by the higher apparent modulus that covers this situation (See previous discussion on apparent modulus). And, essentially all of this strain is elastic, meaning that as soon as the surge pressure is gone the added strain is reversed. Because this temporary strain is fully recovered the minimal pipe expansion that occurs during a short lived surge pressure event has no effect on the longer term creep expansion that occurs under the sustained stress that is induced by a steady operating pressure. In other words, surge pressure events of very short term duration have no adverse effect on a PE's long term hydrostatic strength (LTHS).

The above concepts have been confirmed by various studies and they are the basis for the allowances that are presented in Chapter 6.

Reaction to Frequently Occurring Pressure Surges

To a degree that can vary depending on circumstances, the strength of all materials may be adversely affected by fatigue. Modern PE's that meet current requirements for pressure pipe applications have been shown to exhibit very high resistance to fatigue. The primary parameters that affect the degree and the rate at which a material suffers irreversible damage through fatigue are the frequency and totality of the fatigue events as well as the amplitude of the change in stress that occurs under each event.

In PE, the fatigue mechanism that leads to a loss of long-term strength is that of an initial development of microcracks which under the effect of each cycle event slowly grow into larger cracks. It has been shown by various investigators that PE pipe materials which exhibit a very high resistance to slow crack growth under sustained pressure are also materials that exhibit a very high resistance to crack development and growth when subjected to cyclic stressing. In this regard the studies conducted by Bowman [7] on butt-fused PE piping systems are very informative. They show that even after millions of pressure cycling of substantial magnitude no damage has been detected in the tested systems. And the work by Marshall et al. [17] shows that properly installed pipe made from modern PE piping materials can safely withstand sustained periods of high frequency surging (from 1 to 50 cycles per hour) that result in temporary peak pressure of up to 200 percent of the pipe's static pressure rating with no indication of fatigue and no reduction in long-term serviceability. In a 1999 issue of Water Industry Information and Guidance Note, [35] the UK based Water Research Council concludes that for pipes made from high toughness PE materials (e.g., materials offering very high resistance to slow crack growth), fatigue de-rating is generally not required.

The allowances for frequently occurring pressure surges that are presented in Chapter 6 are conservatively based on the results of studies such as those mentioned in the above paragraph.

Other Engineering Properties

Mechanical Properties

Poisson's Ratio – Any stretching or compressing of a test specimen in one direction, due to uniaxial force (below the yield point) produces an adjustment in the dimensions at right angles to the force. A tensile force in the axial direction causes a small contraction in the lateral direction. The ratio of the decrease in lateral strain to the increase in axial strain is called Poisson's ratio (ν).

Poisson's ratio for PE has been found [10] to vary somewhat depending on the ultimate strain that is achieved, on temperature and on the density of the base resin. However, for typical working stresses, strains, and temperatures, an average value of 0.45 is applicable to all PE pipe materials regardless of their densities, and also for both short- and long-term durations of service. This value is also reported in the Appendix attached to this Chapter.

Impact Strength – The concept of impact strength covers at least two important properties:

1. The magnitude of a suddenly applied energy that causes the initiation and propagation of a crack. This is usually assessed by the results of tests on un-notched or, bluntly notched specimens.
2. The magnitude of a suddenly applied energy that causes a crack to rapidly propagate. This is usually assessed by means of very sharply notched specimens.

The results under the first assessment give an indication of a material's susceptibility to brittle fracture absent a source of localized stress concentration. The second assessment gives an indication of whether a material has useful resistance to shattering by the propagation of an existing crack or flaw. A recognized feature of PE materials is their very high resistance to crack initiation under very rapid loading. Consequently, impact tests on this material are always conducted on notched specimens.

The degree of resistance to impact loading depends on many factors that are not assessed by the impact test. They can include mode of impact loading, strain rate, multi-axiality of the stress field, localized stress concentrations, temperature and environment. However, impact test results have been shown to be of very helpful guidance in the selection of materials that can safely resist the potential adverse effects of impact loading. One of the exceptional features of PE pipe is its excellent impact resistance. This has been proven in the gas distribution application for which PE piping has been shown to resist failure by the rapid crack propagation mechanism.

Impact strength is a measure of the energy absorbed during the fracture or ductile deformation of a specimen of standard dimensions and geometry when subjected to a very rapid (impact) loading at a defined test temperature.

There are several types of impact tests that are used today. The most common one in the United States is the notched Izod test, which is illustrated in Figure 14. Notched specimens are tested as cantilever beams. The pendulum arm strikes the specimen and continues to travel in the same direction, but with less energy due to impact with the specimen. This loss of energy is called the Izod impact strength, measured in foot-pounds per inch of notch of beam thickness (ft-lb/in). Compared to other common true thermoplastic piping materials PE offers the highest Izod impact strengths. At ambient temperatures the resultant values exceed 20ft-lbs/in of notch compared to less than 10 for the other materials. And, many types of PE materials do not fail at all under this test.

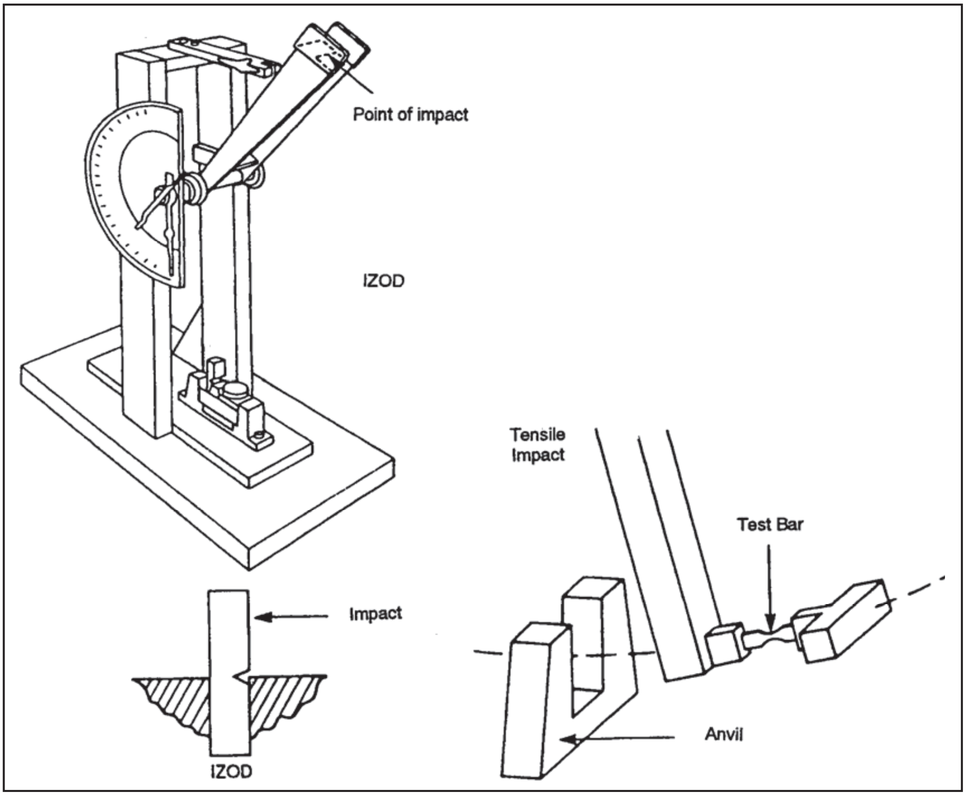

Figure 14 Izod Test

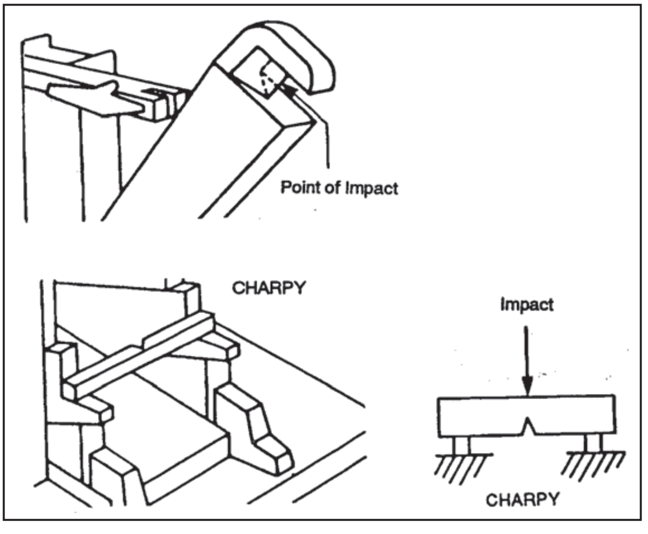

Figure 15 Charpy Test

The Charpy impact test, which is depicted in Figure 15, is widely used in Europe. The specimen is a supported beam, which is then struck with a pendulum. The loss of energy is measured in the same units as in the Izod impact test. At ambient temperature, current PE piping materials also resist failure under this test. ASTM D256, Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics and ASTM D 6110 Standard Test Method for Determining the Charpy Impact Resistance of Notched Specimens of Plastics describe these testing methods.

Resistance to Rapid Crack Propagation

The avoidance of the possibility of the occurrence of a rapid crack propagation (RCP) event in pipe is a very desirable design objective because the consequences of such an event can be very serious, especially when the piping is used for the transport of combustible materials. However, even when transporting an inert material like water an RCP kind of failure can result in a much larger loss of the fluid that is being conveyed as well as in more extensive damage to pipe and fittings. A recognized feature of PE piping is that “it leaks before it breaks”. This feature results from its high ductility and toughness. However, PE’s toughness decreases with decreasing temperature. Other factors that increase the possibility of an RCP event are: the nature of the fluid (compressible versus non-compressible), increasing pipe diameter, increasing wall thickness, and increasing operating pressure. In the case of the conveyance of non-compressible fluids, extensive experience shows that under proper installation and operation of thermally fused PE piping there is very little chance of an RCP event, very much less than with other common thermoplastics piping.

The defining of the exact material requirements and the pipe and operating parameters that will avoid the remote possibility of an RCP event is a complex matter that is still under study [(15)].

Abrasion Resistance

PE pipe is a frequent choice for the transport of granular or slurry solutions, such as sand, fly ash and coal. The advantage of polyethylene in these applications is its wear resistance, which for example when conveying fine grain slurries has been shown in laboratory tests to be three to five times greater than for steel pipe [(37)]. PE pipe has elastic properties that under proper flow conditions allow particles to bounce off its surface. This feature combined with PE’s toughness results in a service life that exceeds that of many metal piping materials.

There are several factors that affect the wear resistance of a pipeline. The concentration, size and shape of the solid materials, along with the pipe diameter and flow velocity, are the major parameters that will affect the life of the pipeline.

The effects of velocity, particle size and solids concentration is discussed in Chapter 6 under the topic of "Pressure Flow of Liquid Slurries". A report by D. Richards [30] covers abrasion resistance factors that apply to dredge pipe applications.

Thermal Properties

Coefficient of Expansion/Contraction

A temperature increase or a decrease can induce a corresponding increase or decrease in the length of a pipe the movement of which is unconstrained. And, in the case of a constrained pipe it can induce the development of a longitudinal tensile or a compressive stress. Both these effects must be given adequate consideration for the proper installation, design and operation of PE piping system. Recommended procedures for dealing with potential reactions that can arise from temperature changes are addressed in various Chapters of this Handbook, but in particular in Chapters 6 (Design of PE Piping Systems), 8 (Above Ground Applications for PE Pipe), and 12 (Horizontal Directional Drilling). These procedures require that two essential properties be adequately defined: the pipe's linear coefficient of expansion/contraction; and, the pipe material's apparent modulus.

A property that distinguishes PE pipe from metallic pipe is that its coefficient of thermal expansion is about 10 times larger. This means a larger thermal expansion/contraction in the case of unconstrained pipe. However, another distinguishing feature is a much lower apparent modulus of elasticity. In the case of constrained pipe this leads to a much lower value of thermally induced longitudinal stresses, which greatly simplifies requirements for supporting and anchoring. The aspect of apparent modulus of elasticity has been covered earlier in this Chapter.

ASTM D696, *Standard Test Method for Coefficient of Linear Expansion of Plastics,* is normally used for the determination of this property. The evaluation is usually conducted on injection molded samples. But, it has been determined that the values that are obtained on samples that are machined from extruded pipe are somewhat smaller. And, it also has been noted that the value representing the diametrical expansion/contraction is about 85 to 90% of that which corresponds to the longitudinal expansion/contraction. This difference is attributed to a small anisotropy that results from the manufacturing process. It also has been noted that the value of this property is affected by resin density, an index of crystallinity. Materials made using resins that have a higher crystalline content (i.e., resins of higher density) have somewhat lower values for coefficient of thermal expansion. It has also been observed that within the practical range of normal operating temperatures there is little change in the value of this coefficient.

The resultant values of this property are presented in Table E.1 in the Appendix to this Chapter.

Thermal Conductivity

The capacity of PE materials to conduct heat is only about one hundredth of that of steel or copper. As reported by the values listed in Table E.1 in the Appendix, this capacity increases with resin density (i.e., with increased crystallinity) and it remains fairly constant over the typical range of working temperatures. [10]

Specific Heat

Over the range of typical working temperatures, the quantity of heat required to produce a unit temperature rise per unit mass of PE pipe material is about 46% of that for water. And, this capacity is little affected by resin density. In terms of traditional units, and as reported in Table E.1 found in the Appendix, the approximate value of the specific heat of PE piping compositions is 0.46 BTU/lb -°F.

Material Classification Properties

As discussed earlier in this Chapter, commercially available PE piping materials offer a range of properties that are tailored for optimizing certain aspects of engineering performance and ease of processing. For purposes of standardization, an identification system has been established which identifies the available PE piping materials based on important physical properties that can be used to distinguish one kind of PE from another.

This is the major objective of ASTM D3350, Standard Specification for Polyethylene Plastic Pipe and Fittings Material, [4] a document that is more fully described in Chapter 5. The discussion that follows focuses on a description of the primary properties that are recognized by this ASTM standard. A listing of these properties is included in the Table that follows. Also included in this table is the location in this Handbook in which a brief description of the subject property is presented. As indicated, two of the more important properties – Hydrostatic Strength Classification and Resistance to Slow Crack Growth – have already been described earlier in this Chapter. A brief description of the other properties is presented below.

TABLE 2
Primary Identification Properties for PE Piping Materials in Accordance with ASTM D3350

Property	Test Method	Where Discussed in this Chapter
Density of PE Resin	ASTM D1505, or D792	Under PE Piping Materials and In this Section
Melt Index	ASTM D1238	In this Section
Flexural Modulus	ASTM D790	In this Section
Tensile Strength at Yield	ASTM D638	In this Section
Resistance to Slow Crack Growth	ASTM F1473, or D1693	Under Structural Properties
Hydrostatic Strength Classification	ASTM D2837	Under Structural Properties
Color	Indicated by code letter	In this Section
UV Stabilizer	Indicated by code letter	In this Section

Density

The crystalline content of a PE resin is reflected by its density. As discussed earlier, the crystalline content exerts a major influence on the properties of a PE resin. This is recognized in the Appendix to this Chapter in which certain properties are somewhat different in accordance with the density of the resin that is used in the PE composition. Generally, as crystalline content increases so do stiffness (apparent modulus), tensile strength, and softening temperature. However, for a given kind of molecular structure there is a corresponding decrease in impact strength, and in low temperature toughness.

The accepted technique for obtaining a measure of a PE resin's crystalline content is to determine its density. A standard method for the measuring of density is ASTM D1505, *Test Method for Density of Plastics by the Density Gradient Technique* (2), or ASTM D792, *Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement* (2).

Melt Index

The melt index is a measure of the flowability of PE materials when in the molten state. This property is an accepted index to two important characteristics of a PE piping material: its processability; and the molecular weight of its primary constituent, the PE resin. A larger melt index denotes a lower melt viscosity, which means the material flows more freely in the molten state. However, a larger melt index also denotes a lower molecular weight, which tends to compromise certain long-term properties. Modern PE's are tailored so that at a resultant molecular weight and molecular weight distribution they remain quite processible while still offering very good long-term properties. Melt index is also important for joining by heat fusion, more information on which can found in PPI TR-33 and TR-41.

The method by which this property is determined is ASTM D1238, *Standard Test Method for Flow Rates of Thermoplastics by Extrusion Plastometer* [(2)]. Under this method the melt index represents the amount of material that passes through a certain size orifice in a given period of time when extruded at a predetermined temperature and under a specified load.

Flexural Modulus

In this test a specimen is supported at both ends and a load is applied in the center at a specified crosshead rate. The flexural modulus is determined at the point when the strain in the outer fiber reaches a value of 2%. The modulus is the ratio of the stress in the outer fiber that results in the 2% strain. It has been determined that the flexural modulus is mainly affected by crystalline content (i.e., resin density) and to a lesser extent by other factors, such as molecular weight and molecular weight distribution, that help to determine size and distribution of crystallites. This property is primarily used for material characterization purposes.

The test method is ASTM D790, *Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials* [(2)]. The particular version of this method that is used for PE materials and the conditions at which the testing is conducted is specified in ASTM D3350.

Tensile Strength at Yield

A traditional means for determining the strength of metals and other materials has been the tensile test, by which the stress/strain behavior of the material of interest is evaluated under a constant rate of straining. For most metals a point of interest is that at which yielding occurs – that is, the point at which there is a transition from elastic (reversible) to plastic (non-reversible) stress/strain response. This is because design with elastic materials seeks to ensure that only elastic deformation will result when a stress is applied.

Because of its viscoelastic nature, PE does not exhibit a true elastic region. As illustrated by Figure 16, although PE exhibits a yield point in the tensile test prior to this point the slope of its stress/strain curve decreases with increased strain. And, prior to yielding there is somewhat less than full reversibility in the strain that results from a certain stress. Also, as is illustrated by this Figure the stress strain curve is significantly affected by the rate of straining. Furthermore, the tensile behavior is also significantly affected by temperature. However, the stress at which yielding commences has been determined to be a useful measure for comparing PE piping materials. Because it has been determined that there is no proportionality between tensile strength at yield and long-term strength this property has limited value for design.

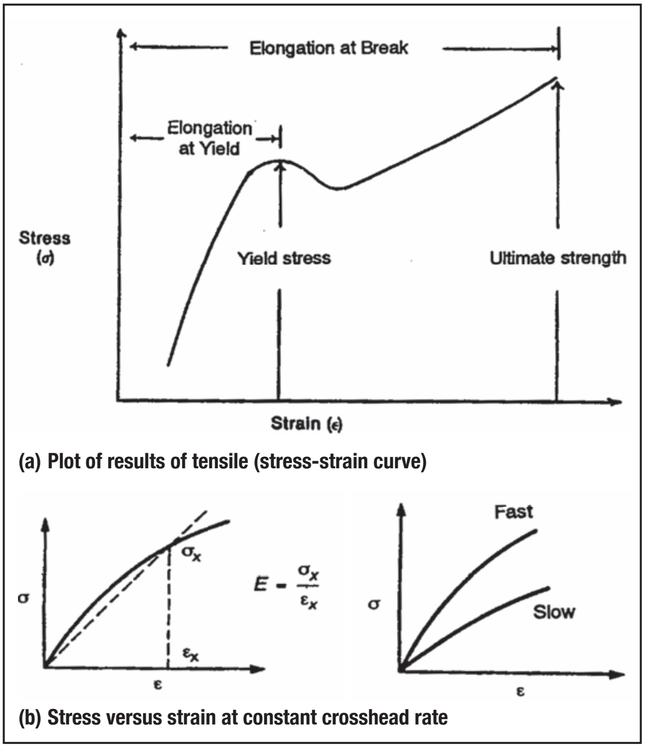

Figure 16 Stress vs Strain Curves Under Specified Conditions

However, it has been also determined that the extent to which a PE deforms in this test prior to failure is an index of the material's ductility under a sustained loading of very long duration. Accordingly, ASTM D3350 requires that all PE materials that are intended for pressure piping have a minimum extension at break of 500%.

The standard test method for determining a PE's tensile strength at yield is ASTM D638, *Standard Test Method for Tensile Properties of Plastics*(2). To provide a uniform basis for comparing different kinds of PE's ASTM D638 specifies the sample preparation procedure and it requires that this test be conducted at 23°C (73.4°F) and at a specified strain rate.

Color and UV Stabilization

ASTM D3350 also includes a code denoting the combination of color – natural, or colored, or black – and ultra violet (UV) stabilizer system that is used in the piping material. The specific requirement for a particular color and effectiveness of UV stabilization (e.g., at least six months of outdoor storage; or, for continuous above ground and outdoor use) is usually specified in the applicable pipe product standard.

Electrical Properties

Metals are very good electrical conductors because their atomic and crystalline structure makes available very many free electrons for participation in the conduction process. PE, along with most other polymers, is a poor conductor of electricity because of the unavailability of a large number of free electrons. Being a poor conductor, PE is a very good electrical insulator and is used as such in wiring and in many other electrical applications. Because it very poorly conducts electricity, PE also does not easily dissipate charges resulting from static electricity. Table F.1 in the Appendix to this Chapter lists the typical electrical properties of PE piping materials. In as much as the exact properties of a particular material can vary, interested readers requiring a more accurate representation should consult the pipe and/or pipe material manufacturer.

Static Charge

Since plastics are good insulators, they also tend to accumulate a static charge. PE pipe can acquire a static charge through friction. Sources of friction can be simply the handling of the pipe in during storage, shipping, or installation. Friction can also result from the flow of gas that contains dust or scale or from the pneumatic transport of dry materials. These charges can be a safety hazard if there is a possibility of a combustible leaking gas or of an explosive atmosphere. Such potential hazard should be dealt with prior to working on the pipeline.

A static charge in PE piping will remain in place until a grounding device discharges it. A ground wire will only discharge the static charge from its point of contact. The most effective method to minimize the hazard of a static electricity discharge is to maintain a conductive path to earth ground by applying a film of electrically conductive liquid (for example, water) to the pipe surface work area prior to handling. So that the conductive liquid does not dry out, cloth coverings that are kept moist with the conductive fluid or conductive films may also be wrapped around the pipe. Please refer to the pipe manufacturer for other suggestions.

Chemical Resistance

As indicated earlier in this Chapter, the standard property requirements for PE piping materials are established in an air or a water environment. When considering the use of a PE piping for the transport of another kind of material, the potential reaction by the piping to that material should first be established. This reaction depends on various factors, particularly the chemical or physical effect of the medium on PE, its concentration, the operating temperature, the period of contact and, the operating stress. PE, being a poor conductor of electricity, is immune to electrolytic corrosion such as can be caused by salts, acids and alkalis. However, strong oxidizing agents can attack the PE molecule directly and lead to a gradual deterioration of properties. Certain organic chemicals can be gradually absorbed by PE, through a process called solvation, causing some swelling, softening and a decrease in long-term strength that largely depends on the chemical configuration of the organic material, but is also affected by other operating variables.

A preliminary measure of the potential effect of a medium on the properties of PE is by means of the so called "soak" or "chemical immersion" test in which the PE is not subjected to any stressing. In this laboratory test, strips of PE material are soaked for different periods of time – generally, not longer than a month – in the medium of interest, which is maintained at a specified temperature. After certain soaking periods, changes are noted in appearance, dimensions, in weight gain or loss, and in strength properties – generally, in tensile strength at yield or elongation at break.

Results obtained by means of an immersion test are a useful guide for applications, such as drainage piping, in which the pipe is subject to only low levels of stressing. However, if the application is a pressurized system, then a more thorough investigation needs to be conducted over and beyond the immersion tests discussed. Please refer to PPI publication TR – 19, Chemical Resistance of Thermoplastics Piping Materials, [26] for more details. In this type of test the immersion period is of limited duration and the effect on strength is only checked by means of a short-term tensile strength test, which is recognized as not a sufficiently reliable indicator of how the tested medium may affect PE's long-term strength. The standard pressure ratings (PR) and standard pressure classes (PC) that are included in PE pipe standards that are issued by ASTM, AWWA and CSA are for the standard condition of water at 73°F. For the transport of other fluids these PR's or PC's may need to be de-rated if the fluid is known to cause a decrease in the pipe material's long-term strength in consequence of a slowly occurring chemical or physical action. Also, an additional de-rating may be applied in cases where a special consideration is in order – usually, when a greater safety margin is considered prudent because of either the nature of the fluid that is being conveyed or by the possible impact of a failure on public safety. The following is a general representation of the effect of different kinds of fluids on the long-term hydrostatic strength of PE pipe materials and the de-ratings, if any, that are normally applied in recognition of this effect:

- **Aqueous solutions of salts, acids and bases** – Because PE is immune to electrolytic attack these solutions have no adverse effect. Consequently, the PR or PC for water is also appropriate for the conveyance of these type materials.
- **Sewage and wastewater** – Normally, these fluids do not include components that affect PE. Therefore, for this case the PR and PC established for water is also appropriate.

- **Surface active agents (e.g., detergents), alcohols and glycols (including anti-freeze solutions)** – If these agents may be present in the fluid a precautionary measure is to specify PE pipe which is made from a material which exhibits very high resistance to slow crack growth (e.g., materials for which the second number in their standard designation code is either 6 or 7, such as PE2708, PE3608, PE3708, PE3710, PE4608, PE4708 and PE4710). For such materials no de-rating is needed.
- **Fluids containing oxidizing agents** – Strong oxidizers can gradually cause damage to PE material. The rate at which this damage occurs depends on the concentration and the chemical activity of the oxidizing agent. If the rate of damage on unprotected PE is low then PE pipe made from material that is adequately stabilized can be used. But, if the rate is high PE pipe may not be the most appropriate choice. Thus, the determination of the suitability of PE pipe and/or the extent to which it needs to be de-rated should be made on a case-by-case basis. For this purpose it is suggested that the reader contact PPI or its member companies for references regarding the known performance of PE pipes in similar applications.
- **Inert gases such as hydrogen, nitrogen and carbon dioxide** – These kinds of gases have no adverse effect and the PR or PC established for water is also appropriate.
- **Hydrocarbon gases of lower molecular weight, such as methane and hydrogen sulfide** – Studies and long-term experience show that the resultant long-term strength is at least equal to that established when using water or air as a test fluid. Therefore, no de-rating is required.
- **Vapors generated by liquefied petroleum gases (LPG)** – These vapors contain hydrocarbon gases of somewhat greater molecular weight, gases which because of their "plasticizing" or, "solvating" effect on PE tend to somewhat reduce PE's long-term hydrostatic strength. To offset this possible reduction, the PR or PC for water is de-rated by the application of a factor of 0.80 or smaller.
- **Common hydrocarbons in the liquid state, such as those in LPG and fuel gas condensates, in crude oil, in fuel oil, in gasoline, in diesels fuels and in kerosene** – Because exposure to these liquids results in a larger "solvating" effect, the practice is either to de-rate PE pipe to a greater extent than for vapors or, if this de-rating is impractical, to use an alternate material. For crude oil application a de-rating factor of 0.50 is typically used.
- **Aromatic hydrocarbons** – Because aromatic hydrocarbons, such as benzene and toluene, have a much greater "solvating" effect, the use of PE should be avoided.

The above information, taken in conjunction with the results of immersion tests as covered in PPI's TR-19 chemical resistance document,[26] is intended to give general guidance regarding the adequacy of a PE piping system for the transport of a specific medium under a particular set of operating conditions. The most reliable guidance is actual service experience under equivalent or similar conditions. PE piping manufacturers, PE material suppliers, and PPI can assist in obtaining this information.

The de-ratings that are mentioned above are only in recognition of the effect of a different fluid than water on the long-term strength of PE pipe. A further de-rating may be called for by a controlling standard or code because of additional considerations, most often for the maximizing of public safety. A designer should comply with the requirements of all applicable codes and standards.

An example of a more conservative de-rating is that by Title 49, Transportation, of the Code of Federal Regulations. The effect of a provision of Part 191 of this code, a part that covers transportation of natural and other fuel gases, is the requirement that the pressure rating of a PE pipe in natural gas service shall be 64% of the pressure rating which would be assigned to that pipe if it conveyed water, provided the water pressure rating is established using an HDS that has been determined based on a design factor (DF) of 0.50. This 64% de-rating is not in response to any adverse effect by natural gas – studies show that similar long-term strengths are obtained when using water or natural gas as the test pressure medium. It is applied mostly in consideration of public safety issues but also in consideration of the minor effect on PE by the small amount of additives that may be contained in fuel gases. There are additional restrictions imposed by this Code, such as the maximum pressure at which a PE pipe may be operated and the acceptable range of operating temperatures.

Another example of a conservative de-rating is that imposed by NFPA/ANSI 58, Standard for the Storage and Handling of Liquefied Petroleum Gases. This standard limits the operating pressure of PE pipe to a maximum of 30psig. The intent of this limitation is to ensure that the LPG gases that are being conveyed are always in the vapor and not in the liquid phase. This is because in the liquid state the constituents of LPG exercise a much more pronounced solvating effect. For further information the reader is referred to PPI publication TR-22, Polyethylene Piping Distribution Systems for Components of Liquid Petroleum Gases.

Permeability

The property of permeability refers to the passage of a substance from one side to the other side of a membrane. Polyethylene has very low permeability to water vapor but it does exhibit some amount of permeability to certain gases and other vapors. As a general rule the larger the vapor molecule or, the more dissimilar in chemical nature to polyethylene, the lower the permeability.

The other factors that affect the rate of permeation include: the difference in concentration, or in the partial pressure of the permeant between the two side of a membrane; the thickness of the membrane (e.g., the wall thickness of a pipe);

temperature; total area available for permeation; and any possible solvating effect by the permeant that can accelerated the rate of permeation.

Depending on the source of a permeant, permeation through a PE pipe can occur from the inside to the outside or, from the outside to the inside. This difference has different potential consequences that need to be recognized and, if significant they also need to be addressed. In the case of possible permeation from the inside the primary concern is the loss of some of the fluid that is flowing through the pipe. Studies show that this is not a problem with liquids. In the case of gases, it has been determined that when conveying methane the loss is so small that there is no problem involving transportation of natural gas. However, as shown in the Table that follows, the permeation rate of hydrogen is several times that of methane. Therefore, if hydrogen is a major constituent of a fuel gas the potential energy loss should be calculated.

The following gases are listed in order of decreasing permeability: sulfur dioxide; carbon dioxide; hydrogen; ethane; oxygen; natural gas; methane; air and nitrogen.

Most of the permeability is through the amorphous regions of the polymer, which is related to density, and to a lesser extent, molecular weight. An increase in density will result in a lower permeability. An increase in molecular weight will also slightly reduce the permeability. Table 3 shows permeation rate of methane and hydrogen through PE as a function of the density of the resin.[1]

TABLE 3
Approximate Gas Permeation Rate Through Polyethylene at Ambient Temperature

Piping Material	Permeation Rate, Ft^3-mil/ft^2-day-atm (The Ft^3 is @ Std. Temp. & Pressure. The Ft^2 refers to the outside surface area of the pipe)	
	Methane	Hydrogen
PE2XXX *	$4.2x10^{-3}$	$21x10^{-3}$
PE3XXX *	$2.4x10^{-3}$	$16x10^{-3}$
PE4XXX *	$1.9x10^{-3}$	$14x10^{-3}$

*PE 2XXX, PE3XXX and PE4XXX denotes all PE's that comply, respectively, to the density cell classification 2, or 3, or 4 in accordance with ASTM D3350

In the case of permeation that originates from the outside, most often it is caused by liquids that tend to permeate at much lower rates than gases, which generally do not cause a problem. However, even a low permeation rate – one that results in a "contamination" of only parts per billion – may affect the quality of the fluid that is being conveyed. This possibility is of concern when the pipe, no matter its type, is transporting potable water, and therefore, the issue is addressed by standards that cover this application. However, it is recognized by authorities that any pipe, as well as an elastomeric gasketed pipe joint, can be subjected to external permeation when the pipeline passes through contaminated soils. Special care should be taken when installing potable water lines through these soils regardless of the pipe material (concrete, clay, plastic, etc.). The Plastics Pipe Institute has issued Statement N – Permeation [28] that should be studied for further details.

Properties Related to Durability

Weatherability

All polymers (resins) are susceptible to gradual degradation when continually exposed to ultraviolet (UV) radiation in sunlight. [25] There are two effective means for protecting a resin against this effect. One is by the addition of a screen that blocks the penetration of UV rays into the material. The other is by the inclusion of a stabilizer that protects the material by chemical means.

For PE piping materials it has been shown that the most effective screen is achieved by the incorporation into the material of 2 to 3 % of finely divided carbon black, which also results in a black color. Experience and studies show that in outdoor applications such a material will retain its original performance properties for periods longer than 50-years. ASTM D3350, *Standard Specification for Polyethylene Plastic Pipe and Fittings Materials*, recognizes these materials by the inclusion of the code letter C in the material's cell classification.

However, in the case of buried and other kinds of applications in which the pipe shall not be exposed to sunlight indefinitely, the UV protection needs only to cover that time period during which the pipe may be handled and stored outdoors. In practice, this period is about two years. Protection for this period, and somewhat longer, is very effectively achieved by the incorporation into the PE material of a UV stabilizer. An advantage of using a stabilizer is that it allows the pipe to have another color than black. For example, yellow is an accepted color for gas distribution applications, blue for water and green for sewer and drain. The choice of a specific kind of colorant follows an evaluation that is intended to ensure that the chosen colorant does not interfere with the efficiency of the UV stabilizer. Standard ASTM D3350 identifies materials that contain both a UV stabilizer and a colorant by means of the code letter E.

Further information on this subject is presented in PPI Technical Report TR-18, *Weatherability of Thermoplastics Piping.* [25]

Stabilization

All PE piping materials include stabilizers in order to achieve two principal objectives. The first is to prevent the degradation of the resin during processing and thermal fusion, when melts are subjected to high temperatures. And the second is to protect the pipe during its service life from any deterioration in performance properties that could occur by gradual oxidation.

Exposure of polymers to high temperatures can induce the development of chemical reactions that can adversely affect performance properties. This degradation process results from the formation of free radicals that continue to react with PE, thereby producing a continuing degradation even after the material has been cooled. To prevent the continuation of this process heat stabilizers are added. These stabilizers work by reacting with initial products of degradation so as to form stable species that are incapable of further action.

At lower working temperatures there exists the possibility of a very slowly acting process of oxidative degradation, a process that can cause gradual degradation in performance properties. To counteract against this possibility antioxidants are added to the composition. These antioxidants can protect in a number of ways. A principal one is by deactivating hydroperoxide sites that are formed by oxidation. Most often, two kinds of antioxidants are used because of a synergism effect that substantially enhances the quality of protection.

There are several tests that have been developed which give a reliable guide on the quality of stabilizer and anti-oxidant protection that is included in a PE piping composition. One of these is the thermal stability test that is included in ASTM D3350. In this test a specimen of defined shape and size is heated in an oven, in air, at a predetermined rate of 10°C (18°F) per minute. Eventually, a point is reached at which the temperature rises much more rapidly than the predetermined rate. This point is called the induction temperature because it denotes the start of an exothermic reaction that results from the exhaustion of stabilizer and anti-oxidant protection. The higher the temperature, the more effective the protection. To qualify for a piping application a PE composition is required to exhibit an induction temperature of not less than 220°C (428°F).

Biological Resistance

Biological attack can be described as degradation caused by the action of microorganisms such as bacteria and fungi. Virtually all plastics are resistant to this type of attack. Once installed, polyethylene pipe will not be affected by microorganisms, such as those found in normal sewer and water systems. PE is not a nutrient medium for bacteria, fungi, spores, etc.

Research has shown that rodents and gnawing insects maintain their teeth in good condition by gnawing on objects. Various materials such as wood, copper, lead, and all plastics would fall prey to this phenomenon if installed in rodent-infested areas.

Termites pose no threat to PE pipe. Several studies have been made where PE pipe was exposed to termites. Some slight damage was observed, but this was due to the fact that the plastic was in the way of the termite's traveling pathway. PPI Technical Report TR-11, Resistance of Thermoplastic Piping Materials to Micro- and Macro-Biological Attack [24] has further information on this matter.

Properties Related to Health and Safety Concerns

Toxicological

Health Effects

The Food and Drug Administration (FDA) issues requirements for materials that may contact food, either directly or indirectly, under the Code of Federal Regulations (CFR) Title 21, parts 170 to 199. Most natural polyethylene resins do comply with these regulations.

Potable water piping materials, fittings, and pipe are currently tested according to the standards developed by the National Sanitation Foundation (NSF). The most recent standard to be written by the NSF is Standard 61, [19] *Drinking Water System Components – Health Effects.* It sets forth toxicological standards not only for plastics piping but also for all potable water system components. Compliance to these standards is a requirement of most States and/or governing authorities that have jurisdiction over water quality.

There are also other certification programs that are operated by independent laboratory and industrial organizations as well as governmental agencies. These are designed to assure compliance with applicable product standards. Amongst other requirements, these programs may include producer qualification, product testing, unannounced plant inspections and authorized use of compliance labels. Products failing to comply are then de-listed or withdrawn from the marketplace.

Flammability

After continuous contact with a flame, PE will ignite unless it contains a flame retardant stabilizer. Burning drips will continue to burn after the ignition source is removed. The flash ignition and self ignition temperatures of polyethylene are 645°F (341°C) and 660°F (349°C) respectively as determined by using ASTM D1929[3], *Standard Test Method for Ignition Properties of Plastics*. The flash point using the Cleveland Open Cup Method, described in ASTM D92[6], Standard Test method for Flash and Fire Points by Cleveland Open Cup, is 430°F (221°C). [9]

During PE pipe production, some fumes may be generated. If present, they can be an irritant and should be properly vented. Specific information and Material Safety Data Sheets (MSDS) are available from the PE resin manufacturer.

Combustion Toxicity

The combustion of organic materials, such as wood, rubber, and plastics, can release toxic gases. The nature and amount of these gases depends upon the conditions of combustion. For further information on combustion gases, refer to *Combustion Gases of Various Building Materials and Combustion Toxicity Testing from the Vinyl Institute.*[33,34]

The combustion products of polyethylene differ greatly from those of polyvinyl chloride (PVC). Polyethylene does not give off any corrosive gases such as hydrochloric acid, since it does not contain any chlorine in its polymer structure.

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Appendix A
Pipe Pressure Rating (PR) And Pressure Class (PC)

A.1 - Standard Pipe Pressure Rating (PR) and Standard Pressure Class (PC) for 73°F (23°C)

Consensus standards for PE pipes intended for pressure applications define PE piping materials in accordance with their recommended hydrostatic design stress (HDS) for water, for the standard base temperature of 73°F (23°C). Most PE pipe standards also identify a pipe's resultant standard pressure rating (PR) or pressure class (PC) for water at 73°F (23°C). As discussed in Chapter 6, this standard PR or PC is determined based on the pipe material's recommended HDS, and the pipe's specified dimension ratio. Pressure ratings for pipes made to common dimension ratios are reproduced in Table A.1 (This is essentially the same Table as Table 6, in Chapter 5).

The pipe's PR or PC may be determined by means of either of the following relationships:

- For pipes made to controlled outside diameters – for which Do/t is defined as the dimension ratio (DR):

$$PR\ or,\ PC = \frac{2\ (HDS)}{\left[\frac{D_o}{t} - 1\right]}$$

- For pipes made to controlled inside diameters – for which Di/t is defined as the inside diameter dimension ratio (IDR):

$$PR\ or,\ PC = \frac{2\ (HDS)}{\left[\frac{D_i}{t} + 1\right]}$$

WHERE

PR **= Pressure Rating, psig (kPa)**
PC **= Pressure Class, psig (kPa)**
HDS **= Hydrostatic Design Stress, psi (kPa) = HDB (Hydrostatic Design Basis) x DF (Design Factor).**
For more details and discussion of each of these terms and the relationship between them, the reader is referred to Chapters 5 and 6.
D_o **= Specified outside pipe diameter, in (mm)**
D_i **= Specified inside pipe diameter, in (mm)**
t **= Specified minimum pipe wall thickness, in (mm)**

TABLE A.1
Standard Pressure Ratings (PR's) and Standard Pressure Classes (PC's), for Water for 73°F (23°C), for PE Pipes Made to Standard Dimension Ratios

Dimension Ratio (see Note 1)		Standard PR and Standard PC as a Function of the Pipe Material's Recommended Hydrostatic Design Stress (HDS) for Water, at 73°F (23°C)					
DR (Ratio = D_0/t (Applies to pipes made to controlled outside diameters- D_o)	**IDR (Ratio = D_i/t)** (Applies to pipes made to controlled inside diameters - D_i)	**HDS = 630psi (4.34MPa)**		**HDS = 800psi (5.52MPa)**		**HDS = 1000psi (6.90MPa)**	
		psig	**kPa**	**Psig**	**kPa**	**psig**	**kPa**
32.5	30.5	40	276	50	345	63	434
26.0	24.0	50	345	63	434	80	552
21.0	19.0	63	434	80	552	100	690
17.0	15.0	80	552	100	690	125	862
13.5	11.5	100	690	125	862	160	1103
11.0	9.0	125	862	160	1103	200	1379
9.0	7.0	160	1103	200	1379	250	1724
7.3	5.3	200	1379	250	1724	320	2206

Note 1: While the term, SDR (Standard Dimension Ratio), is an ANSI term, the pipe industry typically uses the term DR as shown in this table.

A.2 – Values for Other Temperatures

As discussed elsewhere in this and the other chapters of this Handbook (See Chapters 5 and 6), the long-term strength properties of PE pipe materials are significantly affected by temperature. In consequence of this, an operating temperature above the base temperature of 73°F (23°C) results in a decrease in a pipe material's HDS and therefore, in a pipe's PR or PC. Conversely, an operating temperature below the base temperature yields the opposite effect. There are three approaches, as follows, for compensating for the effect of temperature:

1. The application of a temperature compensating factor for operating temperatures that range between 40°F (4°C) and 100°F(38°C).

   While the effect of temperature on long-term strength is not exactly the same among the different commercially offered PE pipe materials, this effect is sufficiently similar over the temperature range covered by Table A.2 to allow for the establishment of the a common table of Temperature Compensation Multipliers. However, because some dissimilarity, though small, may exist, the reader is advised to consult with the pipe manufacturer to determine the most appropriate multiplier to apply in the particular application under consideration.

TABLE A.2
Temperature Compensating Multipliers for Converting a Base Temperature HDS or PR to HDS or PR for Another Temperature Between 40 and 100°F (4 and 38°C)

Maximum Sustained Temperature, °F (°C) (1)	Multiplier (2,3)
40 (4)	1.25
50 (10)	1.17
60 (15)	1.10
73 (23)	1.00
80 (27)	0.94
90 (32)	0.86
100 (38)	0.78

(1) Temporary and relatively minor increases in temperature beyond a sustained temperature have little effect on the long-term strength of a PE pipe material and thus, can be ignored.

(2) The multipliers in this table apply to a PE pipe that is made from a material having at least, an established hydrostatic design stress (HDS) for water, for 73°F (23°C). This HDS is designated by the last two numerals in the PE's standard designation code (e.g., the last two digits in PE4710 designate that the HDS for water, for 73°F (23°C), is 1,000psi – See Introduction and Chapter 5 for a more complete explanation.)

(3) For a temperature of interest that falls within any pair of listed temperatures the reader may apply an interpolation process to determine the appropriate multiplier.

2. In the case of PE pipes that are made from materials that have an established hydrostatic design basis (HDB) for water for both the base temperature of 73°F (23°C) and one higher temperature, the appropriate temperature multiplier for any in-between temperature may be determined by interpolation. Extrapolation above the range bounded by the higher temperature HDB is not recommended.

   Prior to the determination of an HDS, PR or PC for a temperature above 100°F (38°C) it should be first determined by contacting the pipe manufacturer that the pipe material is adequate for the intended application.

   There are many PE pipe materials for which an HDB has also been established for a higher temperature than the base temperature of 73°F (23°C), generally for 140°F (60°C) and, in a few cases for as high as 180°F (82°C). Information on the elevated temperature HDB rating that is held by the PE material from which a pipe is made can be obtained from the pipe supplier. In addition, PPI issues ambient and elevated temperature HDB recommendations for commercially available PE pipe materials. These recommendations are listed in PPI Technical Report TR-4, a copy of which is available via the PPI web site.

   The recognized equation for conducting the interpolation is as follows:

$$F_I = 1 - \frac{HDB_B - HDB_H}{HDB_B} \, \frac{\frac{1}{T_B} - \frac{1}{T_I}}{\frac{1}{T_B} - \frac{1}{T_H}}$$

WHERE
F_I = **Multiplier for the intermediate temperature T_I**
HDB_B = **Hydrostatic Design Basis (HDB) for the base temperature (normally, 73°F or 23°C), psi**
HDB_H =**Hydrostatic Design Basis (HDB) for the higher temperature, psi**
T_B = **Temperature at which the HDB_B has been determined, °Rankin (°F + 460)**
T_H = **Temperature at which the HDB_H has been determined, °Rankin (°F + 460)**
T_I = **Intermediate temperature, °R (°F + 460)**

Examples of the application of this equation are presented at the end of this Section.

3. By regulation. There are certain codes, standards and manuals that cover certain applications (e.g., AWWA water applications and gas distribution piping) that either list temperature compensating multipliers for approved products or, which define rules for their determination. For applications that are regulated by these documents their particular requirements take precedence. For example, AWWA standards C 901 and C 906 and manual M 55 which cover PE pressure class (PC) pipe include an abbreviated table of temperature compensation multipliers that differ slightly from what is presented here. The multipliers in the AWWA tables apply to temperature ranges typical for water applications and are rounded to a single decimal. The interested reader is advised to refer to these documents for more details.

Examples of the Application of the Interpolation Equation

Example – A PE pipe is made from a PE4710 material that has an established HDB of 1600psi for 73°F (533°R) and, an HDB of 1,000psi for 140°F (600°R). What is the temperature compensating multiplier for a sustained operating temperature of 120°F (580°R)?

For this case, $F_{120°F} = 1 - \frac{(1600-1000)}{1600} \frac{\left[\frac{1}{533} - \frac{1}{580}\right]}{\left[\frac{1}{533} - \frac{1}{600}\right]} = 0.73$

Appendix B
Apparent Elastic Modulus

B.1 – Apparent Elastic Modulus for the Condition of Either a Sustained Constant Load or a Sustained Constant Deformation

B.1.1 – Design Values for the Base Temperature of 73°F (23°C)

TABLE B.1.1
Apparent Elastic Modulus for 73°F (23°C)

Duration of Sustained Loading	Design Values For 73°F (23°C) (1,2,3)					
	PE 2XXX		PE3XXX		PE4XXX	
	psi	MPa	psi	MPa	psi	MPa
0.5hr	62,000	428	78,000	538	82,000	565
1hr	59,000	407	74,000	510	78,000	538
2hr	57,000	393	71,000	490	74,000	510
10hr	50,000	345	62,000	428	65,000	448
12hr	48,000	331	60,000	414	63,000	434
24hr	46,000	317	57,000	393	60,000	414
100hr	42,000	290	52,000	359	55,000	379
1,000hr	35,000	241	44,000	303	46,000	317
1 year	30,000	207	38,000	262	40,000	276
10 years	26,000	179	32,000	221	34,000	234
50 years	22,000	152	28,000	193	29,000	200
100 years	21,000	145	27,000	186	28,000	193

(1) Although there are various factors that determine the exact apparent modulus response of a PE, a major factor is its ratio of crystalline to amorphous content – a parameter that is reflected by a PE's density. Hence, the major headings PE2XXX, PE3XXX and, PE4XXX, which are based on PE's Standard Designation Code. The first numeral of this code denotes the PE's density category in accordance with ASTM D3350 (An explanation of this code is presented in Chapter 5).

(2) The values in this table are applicable to both the condition of sustained and constant loading (under which the resultant strain increases with increased duration of loading) and that of constant strain (under which an initially generated stress gradually relaxes with increased time).

(3) The design values in this table are based on results obtained under uni-axial loading, such as occurs in a test bar that is being subjected to a pulling load. When a PE is subjected to multi-axial stressing its strain response is inhibited, which results in a somewhat higher apparent modulus. For example, the apparent modulus of a PE pipe that is subjected to internal hydrostatic pressure – a condition that induces bi-axial stressing – is about 25% greater than that reported by this table. Thus, the Uni-axial condition represents a conservative estimate of the value that is achieved in most applications.

It should also be kept in mind that these values are for the condition of continually sustained loading. If there is an interruption or a decrease in the loading this, effectively, results in a somewhat larger modulus.

In addition, the values in this table apply to a stress intensity ranging up to about 400psi, a value that is seldom exceeded under normal service conditions.

B.1.2 – Values for Other Temperatures

The multipliers listed in Table B.1.2 when applied to the base temperature value (Table B.1.1) yield the value for another temperature.

TABLE B.1.2

Temperature Compensating Multipliers for Determination of the Apparent Modulus of Elasticity at Temperatures Other than at 73°F (23°C)

Equally Applicable to All Stress-Rated PE's (e.g., All PE2xxx's, All PE3xxx's and All PE4xxx's)

Maximum Sustained Temperature of the Pipe °F (°C)	Compensating Multiplier
-20 (-29)	2.54
-10 (-23)	2.36
0 (-18)	2.18
10 (-12)	2.00
20 (-7)	1.81
30 (-1)	1.65
40 (4)	1.49
50 (10)	1.32
60 (16)	1.18
73.4 (23)	1.00
80 (27)	0.93
90 (32)	0.82
100 (38)	0.73
110 (43)	0.64
120 (49)	0.58
130 (54)	0.50
140 (60)	0.43

B.2 – Approximate Values for the Condition of a Rapidly Increasing Stress OR Strain

B.2.1 – Values for the Base Temperature of 73°F (23°C)

TABLE B.2.1

Rate of Increasing Stress	Approximate Values of Apparent Modulus for 73°F (23°C)					
	For Materials Coded PE2XXX (1)		For Materials Coded PE3XXX (1)		For Materials Coded PE4XXX (1)	
	psi	MPa	psi	MPa	psi	MPa
"Short term" (Results Obtained Under Tensile Testing) (2)	100,000	690	125,000	862	130,000	896
"Dynamic" (3)	150,000psi (1,034MPa), For All Designation Codes					

(1) See Chapter 5 for an explanation of the PE Pipe Material Designation Code. The X's designate any numeral that is recognized under this code.

(2) Under ASTM D638, "Standard Test Method for Tensile Properties of Plastics", a dog–bone shaped specimen is subjected to a constant rate of pull. The "apparent modulus" under this method is the ratio of stress to strain that is achieved at a certain defined strain. This apparent modulus is of limited value for engineering design.

(3) The dynamic modulus is the ratio of stress to strain that occurs under instantaneous rate of increasing stress, such as can occur in a water-hammer reaction in a pipeline. This modulus is used as a parameter for the computing of a localized surge pressure that results from a water hammer event.

B.2.2 – Values for Other Temperatures

The values for other temperatures may be determined by applying a multiplier, as follows, to the base temperature value:

- For Short-Term Apparent Modulus – Apply the multipliers in Table B.1.2
- For Dynamic Apparent Modulus – Apply the multipliers in Table B.2.2

TABLE B.2.2
Dynamic Modulus, Temperature Compensating Multipliers

Temperature , °F (°C)	Multiplier
40 (4)	1.78
50 (10)	1.52
60 (16)	1.28
73.4 (23)	1.00
80 (27)	0.86
90 (32)	0.69
100 (38)	0.53
110 (43)	0.40
120 (49)	0.29

Appendix C
Allowable Compressive Stress

Table C.1 lists allowable compressive stress values for 73°F (23°C). Values for allowable compressive stress for other temperatures may be determined by application of the same multipliers that are used for pipe pressure rating (See Table A.2).

TABLE C.1
Allowable Compressive Stress for 73°F (23°C)

<table>
<tr><td rowspan="7"></td><td colspan="6">Pe Pipe Material Designation Code [1]</td></tr>
<tr><td colspan="2">PE 2406</td><td colspan="2">PE3408</td><td colspan="2" rowspan="5">PE 4710</td></tr>
<tr><td colspan="2" rowspan="4">PE 2708</td><td colspan="2">PE 3608</td></tr>
<tr><td colspan="2">PE 3708</td></tr>
<tr><td colspan="2">PE 3710</td></tr>
<tr><td colspan="2">PE 4708</td></tr>
<tr><td>psi</td><td>MPa</td><td>psi</td><td>MPa</td><td>psi</td><td>MPa</td></tr>
<tr><td>Allowable Compressive Stress</td><td>800</td><td>5.52</td><td>1000</td><td>6.90</td><td>1150</td><td>7.93</td></tr>
</table>

(1) See Chapter 5 for an explanation of the PE Pipe Material Designation Code.

Appendix D
Poisson's Ratio

Poisson's Ratio for ambient temperature for all PE pipe materials is approximately 0.45.

This 0.45 value applies both to the condition of tension and compression. While this value increases with temperature, and vice versa, the effect is relatively small over the range of typical working temperatures.

Appendix E
Thermal Properties

TABLE E.1
Approximate Value of Thermal Property for Temperature Range Between 32 and 120°F (0 and 49°C)

Thermal Property	PE Pipe Material Designation Code (1)		
	PE2XXX	PE3XXX	PE4XXX
Coefficient of Thermal Expansion/Contraction (2) (in/in ·°F)	10×10^{-5}	9.0×10^{-5}	8.0×10^{-5}
Specific Heat BTU / LB - °F	0.46		
Thermal Conductivity (BTU · in /hr · sq. ft ·°F)	2.6	3.0	3.1

(1) See Chapter 5 for an explanation of the PE Pipe Material Designation Code. The X's designate any numeral that is recognized under this code.

(2) The thermal expansion coefficients define the approximate value of the longitudinal (axial) expansion/contraction that occurs in PE pipe. Because of a certain anisotropy that results from the extrusion process the diametrical expansion is generally lesser, resulting in a diametrical expansion/contraction coefficient that is about 85 to 90% of the axial value.

Appendix F
Electrical Properties

Table F.1 lists the approximate range of values of electrical properties for ambient temperatures for all commercially available PE pipe materials. The actual value for a particular PE piping material may differ somewhat in consequence, mostly, of the nature and quantity of additives that are included in the formulation. For example, formulations containing small quantities of carbon black – an electrical conductor – may exhibit slightly lower values than those shown in this table.

TABLE F.1
Approximate Range of Electrical Property Values for PE Piping Materials

Electrical Property	Test Method	Range of Property Value	
		Range	Unit
Volume Resistivity	–	$>10^{16}$	Ohms-cm
Surface Resistivity	–	$>10^{13}$	Ohms
Arc Resistance	ASTM D495	200 to 250	Seconds
Dielectric Strength	ASTM D149 (1/8 in thick)	450 to 1,000	Volts/mil
Dielectric Constant	ASTM D150 (60Hz)	2.25 to 2.35	–
Dissipation Factor	ASTM D150 (60Hz)	>0.0005	–

Chapter 4

PE Pipe and Fittings Manufacturing

Introduction

The essential steps of PE pipe and fitting production are to heat, melt, mix and convey the raw material into a particular shape and hold that shape during the cooling process. This is necessary to produce solid wall and profile wall pipe as well as compression and injection molded fittings.

All diameters of solid wall PE pipe are continuously extruded through an annular die. Whereas, for large diameter profile wall pipes, the profile is spirally wound onto a mandrel and heat-fusion sealed along the seams.

Solid wall PE pipe is currently produced in sizes ranging from 1/2 inch to 63 inches in diameter. Spirally wound profile pipe may be made up to 10 feet in diameter or more. PE pipe, both the solid wall type and the profile wall type, are produced in accordance with the requirements of a variety of industry standards and specifications such as ASTM and AWWA. Likewise, the PE fittings that are used with solid wall PE pipe are also produced in accordance with applicable ASTM standards. Refer to Chapter 5 for a list of the commonly used PE pipe standards.

Generally, thermoplastic fittings are injection or compression molded, fabricated using sections of pipe, or machined from molded plates. Injection molding is used to produce fittings up through 12 inches in diameter, and fittings larger than 12 inches are normally fabricated from sections of pipe. Refer to Chapter 5 for a list of the commonly used PE fittings standards.

ASTM F2206 Standard Specification for Fabricated Fittings of Butt-Fused Polyethylene (PE) Plastic Pipe, Fittings, Sheet Stock, Plate Stock, or Block Stock.

All of these pipe and fittings standards specify the type and frequency of quality control tests that are required. There are several steps during the manufacturing process that are closely monitored to ensure that the product complies with these rigorous standards. Some of these steps are discussed in the section of this chapter on quality control and assurance.

Pipe Extrusion

The essential aspects of a solid wall PE pipe manufacturing facility are presented in Figure 1. This section will describe the production of solid wall pipe from raw material handling, extrusion, sizing, cooling, printing, and cutting, through finished product handling. Details concerning profile wall pipe are also discussed in the appropriate sections.

Raw Materials Description

The quality of the starting resin material is closely monitored at the resin manufacturing site. As discussed in the chapter on test methods and codes in this handbook, a battery of tests is used to ensure that the resin is of prime quality. A certification sheet is sent to the pipe and fitting manufacturer documenting important physical properties such as melt index, density, ESCR (environmental stress crack resistance), SCG (slow crack growth), stabilizer tests, amongst others. The resin supplier and pipe manufacturer may agree upon additional tests to be conducted.

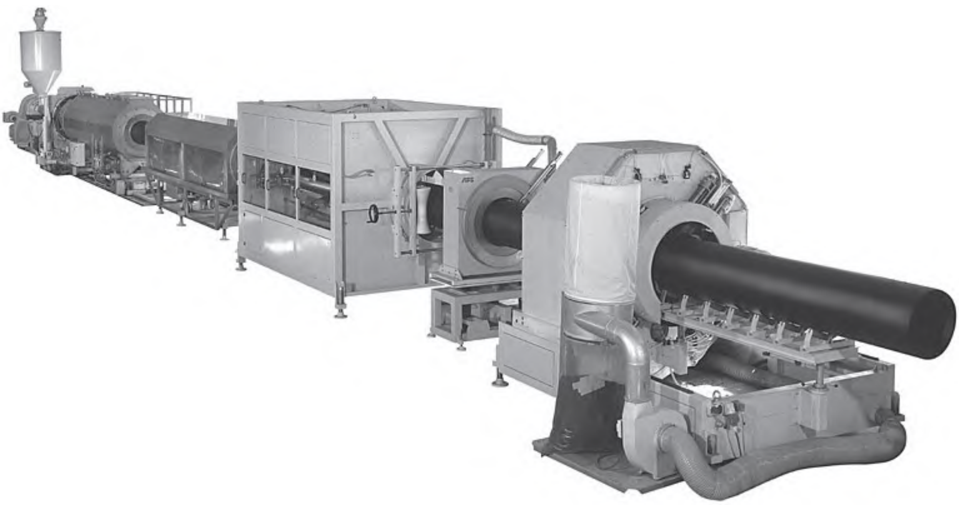

Figure 1 Typical Conventional Extrusion Line

Extrusion Line

The raw material, usually referred to as PE compound, is typically supplied to the pipe producer as non-pigmented pellets. PE pellets are stabilized for both heat and UV protection. Usually, color pigment is added to the pipe at the producer's facility. In North America, the most common colors are black and yellow. The choice of color will depend upon the intended application and the requirements of the pipe purchaser. Carbon black is the most common pigment used for water, industrial, sewer and above-ground uses. Yellow is reserved exclusively for natural gas applications, although black with yellow stripes is also permitted for this application. Other colors are used for telecommunications and other specialty markets.

All ASTM and many other industry standards specify that a PPI-listed compound shall be used to produce pipe and fittings for pressure pipe applications. A compound is defined as the blend of natural resin and color concentrate and the ingredients that make up each of those two materials. The pipe producer may not change any of the ingredients. In a listed compound, such as substituting a different color concentrate that could affect the long-term strength performance of the pipe. Any change to a listed formulation has to be pre-approved. These stringent requirements ensure that only previously tested and approved compounds are being used.

If the resin is supplied as a natural pellet, the pipe producer will blend a color concentrate with the resin prior to extrusion. In order to obtain a PPI Listing, each manufacturer producing pipe in this manner is required to submit data, according to ASTM 2837, to the PPI Hydrostatic Stress Board. A careful review of the data is made according to PPI Policy TR-3 [(5)] to assess the long-term strength characteristics of the in-plant blended compound. When those requirements are met, the compound qualifies for a Dependent listing and is listed as such in the PPI Publication TR-4 [(6)], which lists compounds that have satisfied the requirements of TR-3. Producers of potable water pipe are usually required to have the approval of the NSF International or an equivalent laboratory. NSF conducts un-announced visits during which time they verify that the correct compounds are being used to produce pipe that bears their seal.

Raw Materials Handling

After the material passes the resin manufacturer's quality control tests, it is shipped to the pipe manufacturer's facility in 180,000- to 200,000-pound capacity railcars, 40,000-pound bulk trucks, or 1000- to 1400-pound boxes.

Each pipe producing plant establishes quality control procedures for testing incoming resin against specification requirements. The parameters that are typically tested include: melt flow rate, density, moisture content and checks for contamination. Many resin producers utilize statistical process control (SPC) on certain key physical properties to ensure consistency of the product.

Resin is pneumatically conveyed from the bulk transporters to silos at the plant site. The resin is then transferred from the silos to the pipe extruder by a vacuum transfer system. Pre-colored materials can be moved directly into the hopper above the extruder. If a natural material is used, it must first be mixed homogeneously with a color concentrate. The resin may be mixed with the color concentrate in a central blender remote from the extruder or with an individual blender mounted above the extruder hopper. The blender's efficiency is monitored on a regular basis to ensure that the correct amount of color concentrate is added to the raw material.

Extrusion Basics

The function of the extruder is to heat, melt, mix, and convey the material to the die, where it is shaped into a pipe [8]. The extruder screw design is critical to the performance of the extruder and the quality of the pipe. The mixing sections of the screw are important for producing a homogeneous mix when extruding blends. A typical extruder is shown in Figure 2.

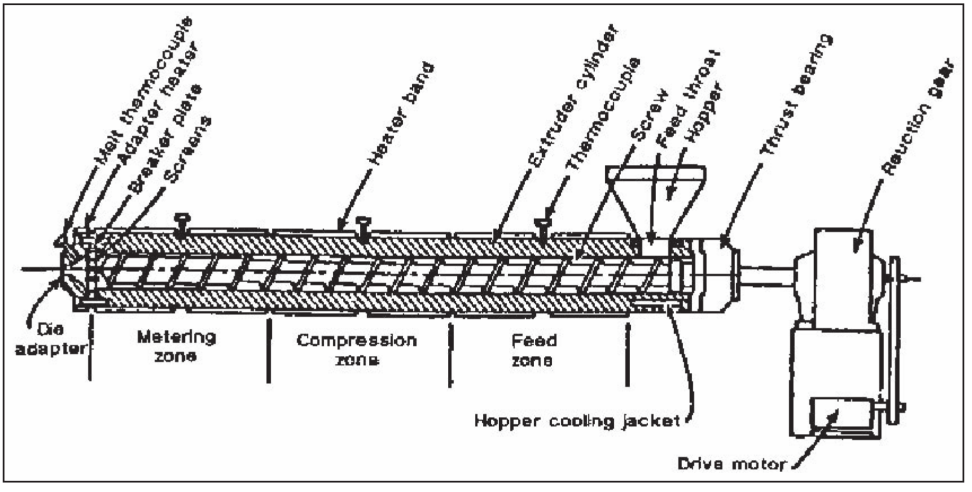

Figure 2 Typical Single-Stage, Single-Screw Extruder (Resin Flow from Right to Left)

There are many different types of screw designs [10], but they all have in common the features shown in Figure 3. Each screw is designed specifically for the type of material being extruded.

The extruder screw operates on the stick/slip principle. The polymer needs to stick to the barrel so that, as the screw rotates, it forces the material in a forward direction.

In the course of doing this, the polymer is subjected to heat, pressure and shear (mechanical heating). The extent to which the material is subjected to these three conditions is the function of the screw speed, the barrel temperature settings and the screw design. The design of the screw is important for the production of high quality pipe.

Figure 3 Typical Extrusion Screw

If a natural resin and concentrate blend is used, the screw will also have to incorporate the colorant into the natural resin. Various mixing devices are used for this purpose as shown in Figure 4. They include mixing rings or pins, fluted or cavity transfer mixers, blister rings, and helix shaped mixers, which are an integral part of the screw.

The pipe extrusion line generally consists of the extruder, die, cooling systems, puller, printer, saw and take-off equipment. Each of these items will be addressed in the following section.

Figure 4 Typical Resin Mixing Devices

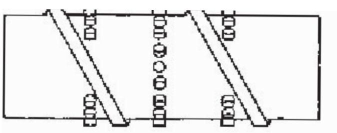

Figure 4.1 Mixing Pins

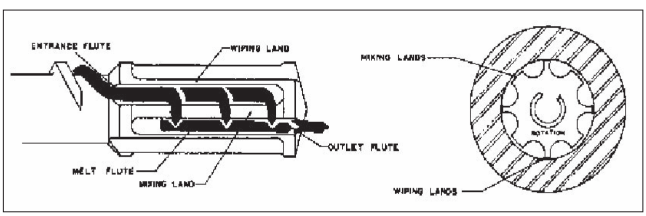

Figure 4.2 Fluted Mixer

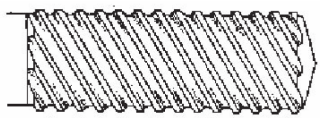

Figure 4.3 Helical Mixer

Extruders

An extruder is usually described by its bore size and barrel length. Pipe extruders typically have an inside diameter of 2 to 6 inches with barrel lengths of 20 to 32 times the bore diameter. The barrel length divided by the inside diameter is referred to as the L/D ratio. An extruder with an L/D ratio of 24:1 or greater provides adequate residence time to produce a homogeneous mixture.

The extruder is used to heat the raw material and then force the resulting melted polymer through the pipe extrusion die. The barrel of the machine has a series of four to six heater bands. The temperature of each band is individually controlled by an instrumented thermocouple. During the manufacturing process, the major portion of the heat supplied to the polymer is the shear energy generated by the screw and motor drive system. This supply of heat can be further controlled by applying cooling or heating to the various barrel zones on the extruder by a series of air or water cooling systems. This is important since the amount of heat that is absorbed by the polymer needs to be closely monitored. The temperature of the extruder melted polymer is usually between 390˚F and 450˚F, and it is also under high pressure (2000 to 4000 psi).

Breaker Plate/Screen Pack

The molten polymer leaves the extruder in the form of two ribbons. It then goes through a screen pack which consists of one or more wire mesh screens, positioned against the breaker plate. The breaker plate is a perforated solid steel plate. Screen packs prevent foreign contaminants from entering the pipe wall and assist in the development of a pressure gradient along the screw. This helps to homogenize the polymer. To assist in the changing of dirty screen packs, many extruders are equipped with an automatic screen changer device. It removes the old pack while it inserts the new pack without removing the die head from the extruder.

Die Design

The pipe extrusion die supports and distributes the homogeneous polymer melt around a solid mandrel, which forms it into an annular shape for solid wall pipe [9]. The production of a profile wall pipe involves extruding the molten polymer through a die which has a certain shaped profile.

The die head is mounted directly behind and downstream of the screen changer unless the extruder splits and serves two offset dies.

There are two common types of die designs for solid wall pipe; the spider die design and the basket die design. They are illustrated in Figure 5. These designs refer to the manner in which the melt is broken and distributed into an annular shape and also the means by which the mandrel is supported.

Figure 5 Typical Pipe Dies

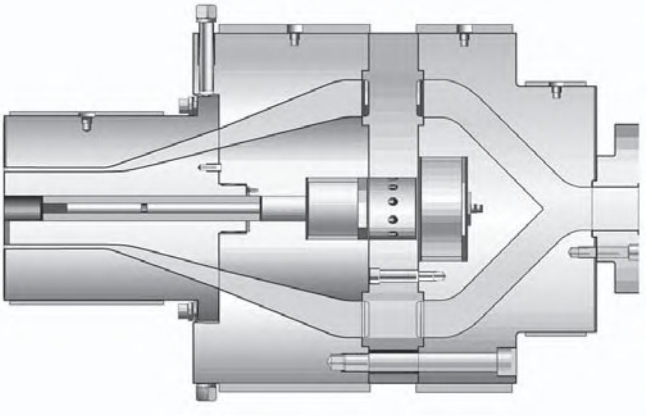

Figure 5.1 Pipe Die with Spider Design

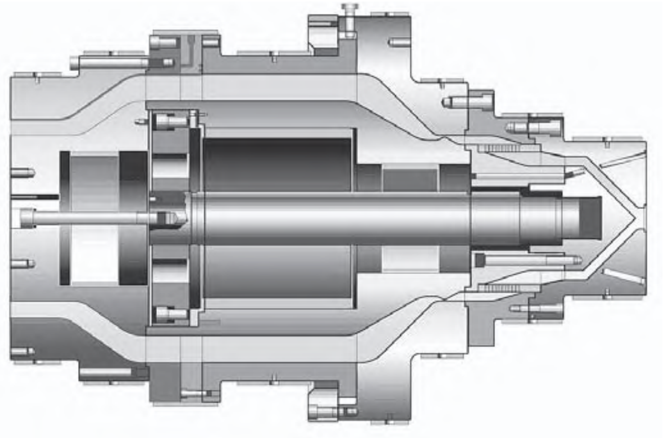

Figure 5.2 Pipe Die with Basket Design

In the spider die (Figure 5.1), the melt stream is distributed around the mandrel by a cone which is supported by a ring of spokes. Since the melt has been split by the spider legs, the flow must be rejoined.

Flow lines caused by mandrel supports should be avoided. This is done by reducing the annular area of the flow channel just after the spider legs to cause a buildup in die pressure and force the melt streams to converge, minimizing weld or spider lines. After the melt is rejoined, the melt moves into the last section of the die, called the land.

The land is the part of the die that has a constant cross-sectional area. It reestablishes a uniform flow and allows the final shaping of the melt and also allows the resin a certain amount of relaxation time. The land can adversely affect the surface finish of the pipe if it is too short in length. Typical land lengths are 15 to 20 times the annular spacing.

The basket design (Figure 5.2) has an advantage over the spider die concerning melt convergence. The molten polymer is forced through a perforated sleeve or plate, which contains hundreds of small holes. Polymer is then rejoined under pressure as a round profile. The perforated sleeve, which is also called a screen basket, eliminates spider leg lines.

Pipe Sizing

The dimensions and tolerances of the pipe are determined and set during the sizing and cooling operation. The sizing operation holds the pipe in its proper dimensions during the cooling of the molten material. For solid wall pipe, the process is accomplished by drawing the hot material from the die through a sizing sleeve and into a cooling tank. Sizing may be accomplished by using either vacuum or pressure techniques. Vacuum sizing is generally the preferred method.

In the vacuum sizing system, molten extrudate is drawn through a sizing tube or rings while its surface is cooled enough to maintain proper dimensions and a circular form. The outside surface of the pipe is held against the sizing sleeve by vacuum. After the pipe exits the vacuum sizing tank, it is moved through a second vacuum tank or a series of spray or immersion cooling tanks.

Figure 6 External Sizing Systems

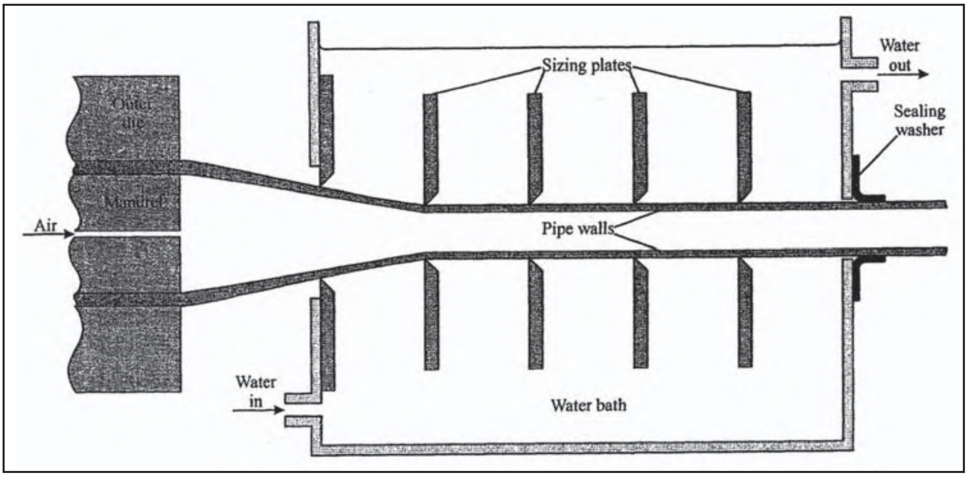

Figure 6.1 Vacuum Tank Sizing [11]

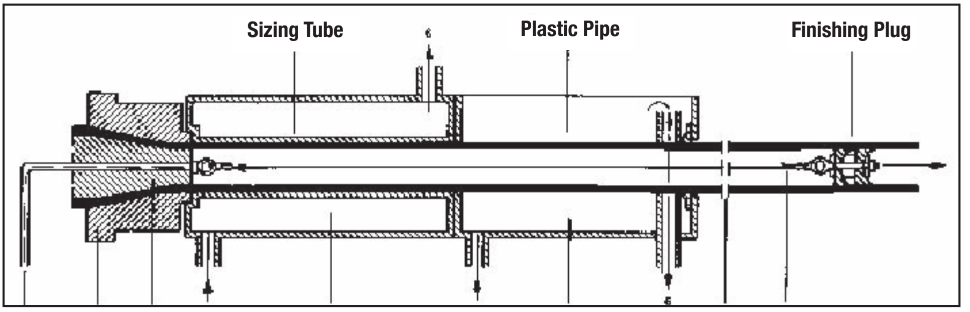

Figure 6.2 Internal (Pressure) Sizing for Small and Medium Pipe Diameters

In the pressure sizing system, a positive pressure is maintained on the inside of the pipe by the use of a plug attached to the die face by a cable or, on very small bore pipe, by closing or pinching off the end of the pipe. The pressure on the outside of the pipe remains at ambient and the melt is forced against the inside of the calibration sleeve with the same results as in the vacuum system.

The production of very large diameter profile pipe, up to 10 feet in diameter, uses mandrel sizing. In one form of this process, the extruded profile is wrapped around a mandrel. As the mandrel rotates, the extruded profile is wrapped such that each turn overlaps the previous turn. In some other techniques, the turns are not overlapped. A typical profile wall PE pipe is shown in Figure 7.

Figure 7 Typical PE Profile Wall Pipe from ASTM Standard F894

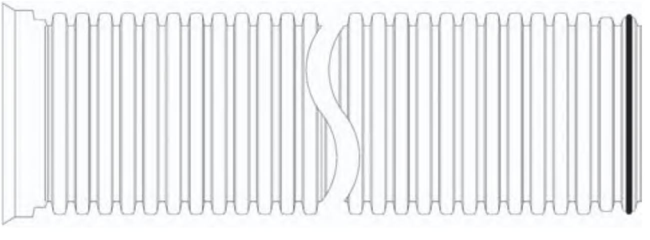

Figure 7.1 Laying Lengths

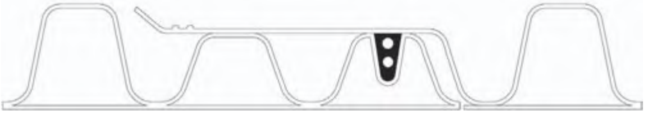

Figure 7.2 Typical Profile Wall Section Showing Bell End (right) and Spigot End (left)

Cooling

For either the vacuum or pressure sizing technique, the pipe must be cool enough so that it maintains its circularity before it exits the cooling tank. Various methods of cooling are utilized to remove the residual heat out of the PE pipe. Depending upon the pipe size, the system may use either total immersion or spray cooling. Spray cooling is usually applied to large diameter pipe where total immersion would be inconvenient. Smaller diameter pipe is usually immersed in a water bath. Cooling water temperatures are typically in the optimum range of 40° to 50°F (4° to 10°C). The total length of the cooling baths must be adequate to cool the pipe below 160°F (71°C) in order to withstand subsequent handling operations.

Residual stresses generated by the cooling process within the pipe wall are minimized by providing annealing zones.[4] These zones are spaces between the cooling baths which allow the heat contained within the inner pipe wall to radiate outward and anneal the entire pipe wall. Proper cooling bath spacing is important in controlling pipe wall stresses. Long-term pipe performance is improved when the internal pipe wall stresses are minimized.

Pullers

The puller must provide the necessary force to pull the pipe through the entire cooling operation. It also maintains the proper wall thickness control by providing a constant pulling rate. The rate at which the pipe is pulled, in combination with the extruder screw speed, determines the wall thickness of the finished pipe. Increasing the puller speed at a constant screw speed reduces the wall thickness, while reducing the puller speed at the same screw speed increases the wall thickness.

Standards of ASTM International and other specifications require that the pipe be marked at frequent intervals. The markings include nominal pipe size, type of plastic, SDR and/or pressure rating, and manufacturer's name or trademark and manufacturing code. The marking is usually ink, applied to the pipe surface by an offset roller. Other marking techniques include hot stamp, ink jet and indent printing. If indent printing is used, the mark should not reduce the wall thickness to less than the minimum value for the pipe or tubing, and the long-term strength of the pipe or tubing must not be affected. The mark should also not allow leakage channels when gasket or compression fittings are used to join the pipe or tubing.

Take-off Equipment

Most pipe four inches or smaller can be coiled for handling and shipping convenience. Some manufacturers have coiled pipe as large as 6 inch. Equipment allows the pipe to be coiled in various lengths. Depending upon the pipe diameter, lengths of up to 10,000 feet are possible. This is advantageous when long uninterrupted lengths of pipe are required - for example, when installing gas and water pipes.

Saw Equipment and Bundling

Pipe four inches or more in diameter is usually cut into specified lengths for storage and shipping. Typical lengths are 40 to 50 feet, which can be shipped easily by rail or truck. The pipe is usually bundled before it is placed on the truck or railcar. Bundling provides ease of handling and safety during loading and unloading.

Fittings Overview

The PE pipe industry has worked diligently to make PE piping systems as comprehensive as possible. As such, various fittings are produced which increase the overall use of the PE piping systems. Some typical fittings are shown in Figure 8.

PE fittings may be injection molded, fabricated or thermoformed. The following section will briefly describe the operations of each technique.

Injection Molded Fittings

Injection molded PE fittings are manufactured in sizes through 12-inch nominal diameter. Typical molded fittings are tees, 45° and 90° elbows, reducers, couplings, caps, flange adapters and stub ends, branch and service saddles, and self-tapping saddle tees. Very large parts may exceed common injection molding equipment capacities, so these are usually fabricated.

Equipment to mold fittings consists of a mold and an injection molding press, as shown in Figure 9. The mold is a split metal block that is machined to form a part-shaped cavity in the block. Hollows in the part are created by core pins shaped into the part cavity. The molded part is created by filling the cavity in the mold block through a filling port, called a gate. The material volume needed to fill the mold cavity is called a shot.

The injection molding press has two parts; a press to open and close the mold block, and an injection extruder to inject material into the mold block cavity. The injection extruder is similar to a conventional extruder except that, in addition to rotating, the extruder screw also moves lengthwise in the barrel. Injection molding is a cyclical process. The mold block is closed and the extruder barrel is moved into contact with the mold gate. The screw is rotated and then drawn back, filling the barrel ahead of the screw with material. Screw rotation is stopped and the screw is rammed forward, injecting molten material into the mold cavity under high pressure. The part in the mold block is cooled by water circulating through the mold block. When the part has solidified, the extruder barrel and mold core pins are retracted, the mold is opened, and the part is ejected.

Typical quality inspections are for knit line strength, voids, dimensions and pressure tests. A knit line is formed when the molten PE material flows around a core pin and joins together on the other side. While molding conditions are set to eliminate the potential for voids, they can occur occasionally in heavier sections due to shrinkage that takes place during cooling. Voids can be detected nondestructively by using x-ray scans. If this is not available, samples can be cut into thin sections and inspected visually.

Figure 8 Typical PE Pipe Fittings

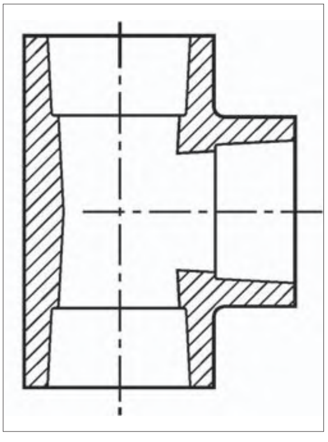

Figure 8.1 Socket Tee

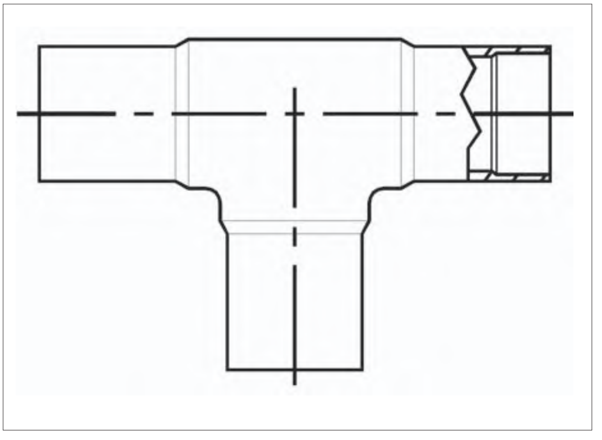

Figure 8.2 Butt Tee

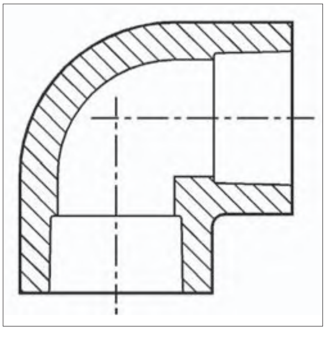

Figure 8.3 90° Socket Elbow

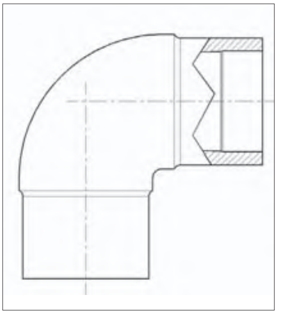

Figure 8.4 90° Butt Elbow

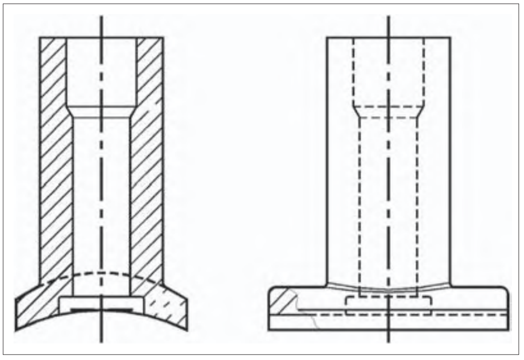

Figure 8.5 Saddle Fusion Fittings

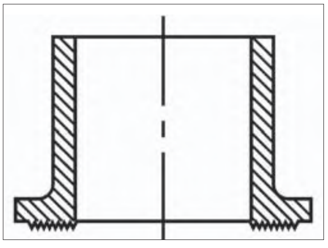

Figure 8.6 Butt Flange Adapter/Stub End

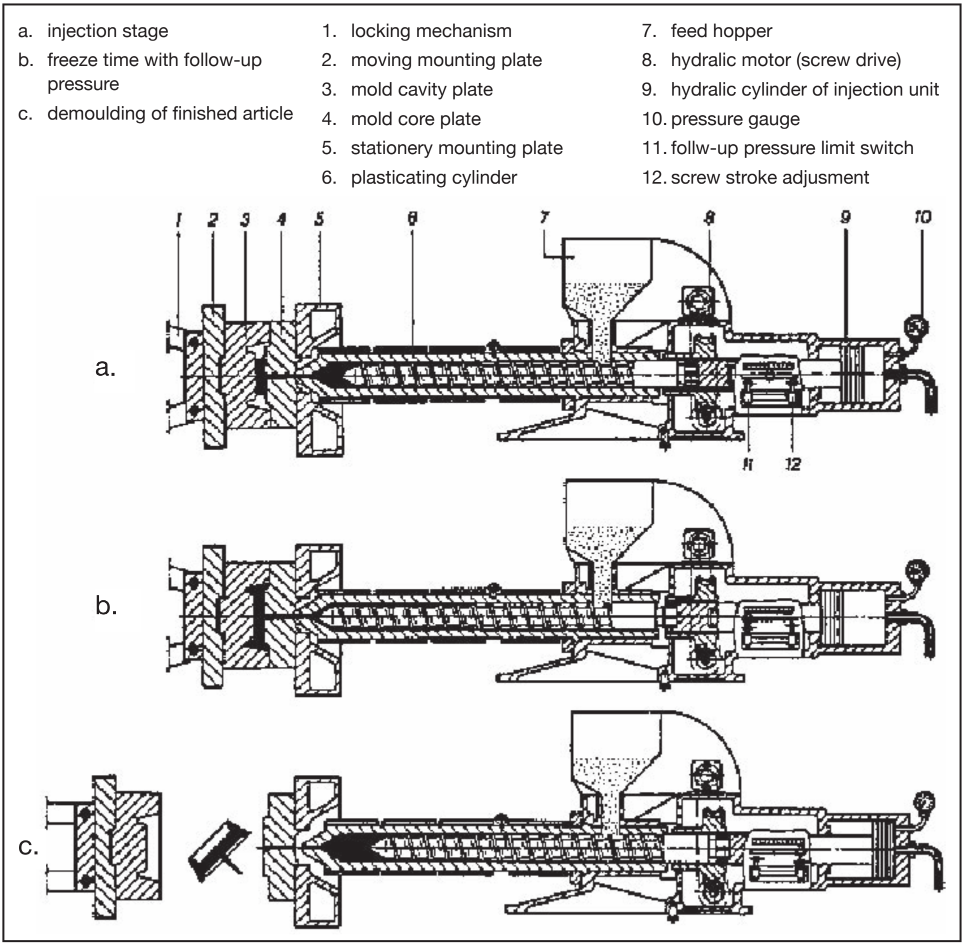

Figure 9 Construction and Mode of Operation of a Reciprocating Screw Injection Unit (Courtesy of Hoechst Celanese Corporation)

Fabricated Fittings

Fully pressure-rated, full bore fabricated fittings are available from select fittings fabricators. Fabricated fittings are constructed by joining sections of pipe, machined blocks, or molded fittings together to produce the desired configuration. Components can be joined by butt or socket heat fusion, electrofusion, hot gas welding or extrusion welding techniques. It is not recommended to use either hot gas or extrusion welding for pressure service fittings since the resultant joint strength is significantly less than that of the other heat fusion joining methods.

Fabricated fittings designed for full pressure service are joined by heat fusion and must be designed with additional material in regions of sharp geometrical changes, regions that are subject to high localized stress. The common commercial practice is to increase wall thickness in high-stress areas by fabricating fittings from heavier wall pipe sections. The increased wall thickness may be added to the OD, which provides for a full-flow ID; or it may be added to the ID, which slightly restricts ID flow. This is similar to molded fittings that are molded with a larger OD, heavier body wall thickness. If heavy-wall pipe sections are not used, the conventional practice is to reduce the pressure rating of the fitting. The lowest-pressure-rated component in a pipeline determines the operating pressure of the piping system.

Various manufacturers address this reduction process in different manners. Reinforced over-wraps are sometimes used to increase the pressure rating of a fitting. Encasement in concrete, with steel reinforcement or rebar, is also used for the same purpose. Contact the fitting manufacturer for specific recommendations.

Very large diameter fittings require special handling during shipping, unloading, and installation. Precautions should be taken to prevent bending moments that could stress the fitting during these periods. Consult the fittings manufacturer for specifics. These fittings are sometimes wrapped with a reinforcement material, such as fiberglass, for protection.

Thermoformed Fittings

Thermoformed fittings are manufactured by heating a section of pipe and then using a forming tool to reshape the heated area. Examples are sweep elbows, swaged reducers, and forged stub ends. The area to be shaped is immersed in a hot liquid bath and heated to make it pliable. It is removed from the heating bath and reshaped in the forming tool. Then the new shape must be held until the part has cooled.

Electrofusion Couplings

Electrofusion couplings and fittings are manufactured by either molding in a similar manner as that previously described for butt and socket fusion fittings or manufactured from pipe stock. A wide variety of couplings and other associated fittings are available from ½" CTS thru 28" IPS. Fittings are also available for ductile iron sized PE pipe. These couplings are rated as high as FM 200.

Electrofusion fittings are manufactured with a coil-like integral heating element. These fittings are installed utilizing a fusion processor, which provides the proper energy to provide a fusion joint stronger than the joined pipe sections. All electrofusion fittings are manufactured to meet the requirements of ASTM F-1055.

Injection Molded Couplings

Some mechanical couplings are manufactured by injection molding in a similar manner as previously described for butt and socket fusion fittings. The external

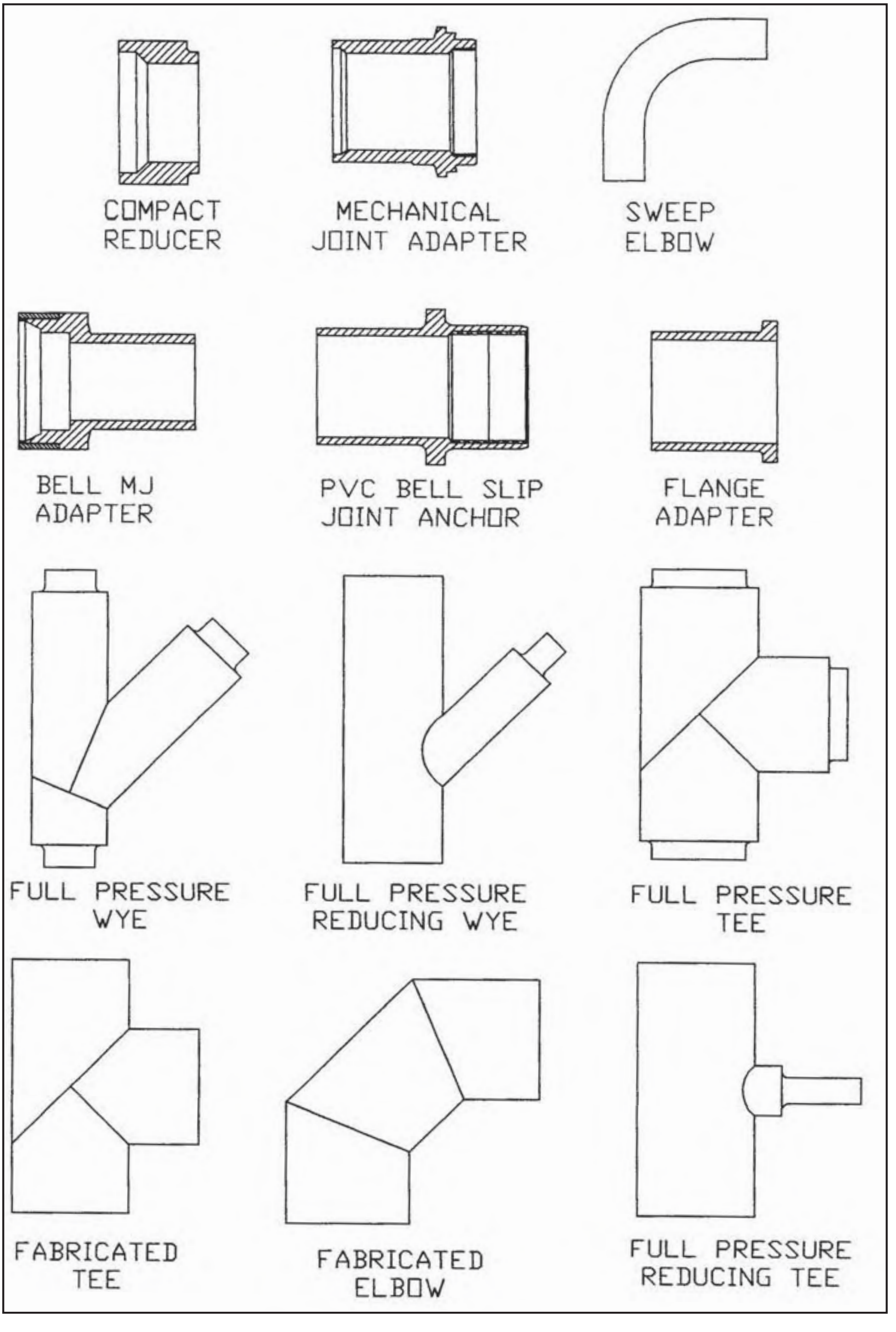

Figure 10 Typical Fabricated Fittings

coupling body is typically injection molded and upon final assembly will include internal components such as steel stiffeners, o-rings, gripping collets, and other components depending upon the design. A wide variety of coupling configurations are available including tees, ells, caps, reducers, and repair couplings. Sizes for joining PE pipe and tubing are typically from ½" CTS through 2" IPS. All injection molded couplings are manufactured to meet the requirements of ASTM D2513.

Quality Control/Quality Assurance Testing

Quality is engineered into the pipe and fitting product during the entire manufacturing process. The three phases of quality control for the pipe manufacturer involve the incoming raw material, the pipe or fitting production and the finished product. The combination of all three areas ensures that the final product will fulfill the requirements of the specification to which it was made.

Testing the incoming resin is the first step in the quality control program. It is usually checked for contamination, melt flow rate and density. Any resin that does not meet the raw material specification is not used for the production of specification-grade pipe or fitting.

During the manufacturing step, the pipe or fitting producer routinely performs quality control tests on samples. This verifies that proper production procedures and controls were implemented during production.

Once the product has been produced, it undergoes a series of quality assurance tests to ensure that it meets the minimum specifications as required by the appropriate standard. (See Handbook Chapter on Test Methods and Codes.)

The manufacturing specifications for piping products list the tests that are required. There are several quality control tests that are common in most ASTM PE standards. For gas service piping systems, refer to PPI Technical Report TR-32 [7] for a typical quality control program for gas system piping, or to the AGA Plastic Pipe Manual for Gas Service [1]. The typical QC/QA tests found in most standards are described below.

Workmanship, Finish, and Appearance

According to ASTM product specifications, the pipe, tubing, and fittings shall be homogeneous throughout and free of visible cracks, holes, foreign inclusions, blisters, and dents or other injurious defects. The pipe tubing and fittings shall be as uniform as commercially practicable in color, opacity, density and other physical properties.

Dimensions

Pipe diameter, wall thickness, ovality, and length are measured on a regular basis to insure compliance with the prevailing specification. All fittings have to comply with the appropriate specification for proper dimensions and tolerances. All measurements are made in accordance with ASTM D2122, Standard Test Method of Determining Dimensions of Thermoplastic Pipe and Fittings [(2)].

Physical Property Tests

Several tests are conducted to ensure that the final pipe product complies to the applicable specification. Depending upon the specification, the type and the frequency of testing will vary. More details about industry standard requirements can be found in the chapter on specifications, test methods and codes in this Handbook.

The following tests, with reference to the applicable ASTM standard [(2)], are generally required in many product specifications such as natural gas service. The following list of tests was taken from the American Gas Association Manual for Plastic Gas Pipe [(1)] to serve as an example of typical tests for gas piping systems.

ASTM TESTS

Sustained Pressure	D1598
Burst Pressure	D1599
Apparent Tensile Strength	D2290

Neither the sustained pressure test or the elevated temperature pressure test are routine quality assurance tests. Rather, they are less frequently applied tests required by the applicable standards to confirm and assure that the established process system and materials being used produce quality product meeting the requirements of the standard.

There are other tests that are used that are not ASTM test methods. They are accepted by the industry since they further ensure product reliability. One such test, required by applicable AWWA Standards, is the Bend-Back Test [(1)] which is used to indicate inside surface brittleness under highly strained test conditions. In this test, a ring of the pipe is cut and then subjected to a reverse 180-degree bend. Any signs of surface embrittlement, such as cracking or crazing, constitute a failure. The presence of this condition is cause for rejection of the pipe.

Quality Assurance Summary

Through the constant updating of industry standards, the quality performance of the PE pipe and fitting industry is continually evolving. Each year, PPI and ASTM work to improve standards on plastic pipe which include the latest test methods and recommended practices. Resin producers, pipe extruders, and fittings manufacturers incorporate these revisions into their own QA/QC practices to insure compliance with these standards. In this way, the exceptional performance and safety record of the PE pipe industry is sustained.

Summary

This chapter provides an overview of the production methods and quality assurance procedures used in the manufacture of PE pipe and fittings. The purpose of this chapter is to create a familiarity with the processes by which these engineered piping products are made. Through a general understanding of these fundamental processes, the reader should be able to develop an appreciation for the utility and integrity of PE piping systems.

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Chapter 5

Standard Specifications, Standard Test Methods and Codes for PE (Polyethylene) Piping Systems

Introduction

The specification, design and use of PE piping systems is addressed by a number of standard specifications, standard test methods and codes including those issued by ASTM International (ASTM), American Water Works Association (AWWA), and Canadian Standards Association (CSA) as well as Technical Reports (TR's) and Technical Notes (TN's) published by the Plastics Pipe Institute (PPI). A listing of the more frequently referenced standards, reports and recommendations is presented in the Appendix to this Chapter.

This Chapter covers topics relating to PE pipe of solid wall or of profile wall construction. These topics include:

1. Material specifications relating to properties and classifications of PE materials for piping applications.

2. Standard requirements relating to pipe pressure rating, dimensions, fittings and joints.

3. Codes, standards and recommended practices governing the application of PE pipe systems in a variety of end uses.

Readers seeking information on PE pipes of corrugated wall construction are invited to visit PPI's web site at http://plasticpipe.org/drainage/index.html

Standard Requirements for PE Piping Materials

As discussed in Chapter 3, polyethylene (PE) is a complex polymer with properties that can be optimized based on the desired end use. Such modifications are effected by choice of catalyst system, polymerization conditions and, the use of a small quantity of co-monomer (a monomer or monomers other than ethylene). All these changes allow PE to be tailor made to a wide range of processing and performance requirements.

For classifying this wide array of property variations that find use in piping applications, ASTM issued standard D 3350, “Standard Specification for Polyethylene Plastic Pipe and Fittings Materials”. This standard recognizes six properties that are considered important in the manufacture of PE piping, in the heat fusion joining of this material and, in defining its long-term performance capabilities. Each property is assigned into a “Cell” and, each cell consists of a number of “Classes”. A cell number covers a narrow range of the larger overall range that is covered by a property “cell”. These D 3350 property cells and classes are identified in Table 1.

TABLE 1

Cell Classification System from ASTM D 3350-06[1,2]

Property	Test Method	0	1	2	3	4	5	6	7	8
Density, g/cm3	D 1505	un-specified	0.925 or lower	>0.925 - 0.940	>0.940 - 0.947	>0.947 - 0.955	>0.955	—	specify value	—
Melt Index	D 1238	un-specified	>1.0	1.0 to 0.4	<0.4 to 0.15	<0.15	A	—	specify value	—
Flexural Modulus, MPa (psi), 2% secant	D 790	un-specified	<138 (<20,000)	138-<276 (20,000 to <40,000)	276-<552 (40,000 to <80,000)	552-<758 (80,000 to <110,000)	758-<1103 (110,000 to <160,000)	>1103 (>160,000)	specify value	—
Tensile strength at yield, MPa (psi)	D638	un-specified	<15 (<2000)	15- < 18 (2200-<2600)	18- <21 (2600-<3000)	21- <24 (3000-<3500)	24- <28 (3500-<4000)	>28 (>4000)	specify value	—
Slow Crack Growth Resistance I. ESCR	D1693	un-specified								
a. Test condition			A	B	C	C	—	—	—	specify value
b. Test duration, hours			48	24	192	600	—	—	—	
c. Failure, max. %			50	50	20	20	—	—	—	
Slow Crack Growth Resistance II. PENT (hours) Molded Plaque, 80˚C, 2.4MPa, notch depth Table 1	F 1473	un-specified	—	—	—	10	30	100	500	specify value
Hydrostatic Strength Classification I. Hydrostatic design basis, MPa, (psi), (23˚C)	D2837	NPR[B]	5.52 (800)	6.89 (1000)	8.62 (1250)	11.03 (1600)	—	—	—	—
Hydrostatic Strength Classification II. Minimum Required Strength, MPa (psi), (20°C)	ISO 12162	—	—	—	—	—	8 (1160)	10 (1450)	—	—

Notes to Table 1-A: Refer to 10.1.4.1 (ASTM D 3350) B: NPR = Not Pressure Rated, 1.) D 3350 is subject to periodic revisions, contact ASTM to obtain the latest version, 2.) The property and density are measured on the PE base resin; all the other property values are measured on the final compound.

In addition, by means of a Code letter, ASTM D3350 designates whether the material includes a colorant and also, the nature of the stabilizer that is included for protecting the material against the potential damaging effects of the ultraviolet (UV) rays in sunlight. Table 2 lists the Code letters that are used in D 3350 and what they reprsent.

TABLE 2

Code Letter Representation

Code Letter	Color and UV Stabilizer
A	Natural
B	Colored
C	Black with 2% minimum carbon black
D	Natural with UV stabilizer
E	Colored with UV stabilizer

For designating a PE material in accordance with ASTM D 3350 the cell number for each cell property is identified, and this is done in the same order as shown in Table 1. This is then followed by an appropriate Code letter to indicate color and stabilization as shown in Table 2. An example of this material designation system is presented in Table 3 for the case of a PE material having designation code PE445574C.

TABLE 3

Properties of a Cell number PE445574 Material

Digit Designating the Applicable Property Cell(1)	Class Number or Code Letter	Corresponding Value of Property (from Table1)
1st Digit – Density of PE base resin, gm/cm^3	4	>0.947 – 0.955
2nd Digit – Melt Index of compound, gm/10 minutes	4	<0.15
3rd Digit – Flexural Modulus of compound, psi (MPa)	5	110,000 - < 160,000 (758 - <1103)
4th Digit – Tensile Strength at Yield of compound, psi (MPa)	5	3,500 - <4,000 (24 - <28)
5th Digit – Resistance to Slow Crack Growth of compound (SCG), hrs.	7	500 minimum based on PENT test
6th Digit – Hydrostatic Design Basis for water at 73°F(23°C), psi of compound (MPa)	4	1600 (11.03)
Code Letter	C	Black with 2% minimum carbon black

(1) The density is that of the PE resin. All the other properties are determined on the final compounded material.

A PE material that complies with the Table 3 cell designation i.e. PE445574C would be a higher density (higher crystallinity), lower melt index (higher molecular weight) material that exhibits exceptionally high resistance to slow crack growth. In addition, it offers a hydrostatic design basis (HDB) for water at 73°F (23°C) of 1600 psi (11.03 MPa). Finally, it would be black and contain a minimum of 2% carbon black.

The cell classification system provides the design engineer with a very useful tool in specifying the requirements of PE materials for piping projects.

Standard PE Piping Material Designation Code

While all PE piping standards specify minimum material requirements based the on the cell requirements of ASTM D3350, a simpler, short-hand, ASTM recognized material designation code is commonly used for quickly identifying the most significant engineering properties of a PE pipe material. An important feature of this designation code is that it identifies the maximum recommended hydrostatic design stress (HDS) for water, at 73°F(23°C). Originally, this designation code was devised to only apply to materials intended for pressure piping. However, there is a recognition that even in non-pressure applications stresses are generated which makes it prudent to use a stress rated material. This has led to the common practice of using this material designation code for quickly identifying all PE piping materials intended for pipes of solid wall or, of profile wall construction.

This code is defined in ASTM F412, "Standard Terminology Relating to Plastic Piping Systems", under the definition for the term code, thermoplastic pipe materials designation. It consists of the ASTM approved abbreviation for the pipe material followed by four digits (e.g., PE4710). The information delivered by this code is as follows:

- The ASTM recognized abbreviation for the piping material. PE, in the case of polyethylene materials.
- The first digit identifies the density range of the base PE resin, in accordance with ASTM D3350, that is used in the material. As discussed in Chapter 3, the density of a PE polymer reflects the polymer's crystallinity which, in turn, is the principal determinant of the final material's strength and stiffness properties.
- The second digit identifies the compound's resistance to slow crack growth (SCG), also in accordance with ASTM D3350. A material's resistance to SCG relates very strongly to its long-term ductility, a property that defines the material's capacity for safely resisting the effects of localized stress intensifications.
- The last two numbers identify the compound's maximum recommended hydrostatic design stress (HDS) category (1) for water, at 73°F(23°C). This recommendation is established in consideration of various factors but, primarily the following: The capacity for safely resisting the relatively well distributed stresses that are generated only by internal pressure, and, the capacity for safely resisting add-on effects caused by localized stress intensifications.(1)

(1) More discussion on these topics later in this Chapter.

The Standard Designation Codes for materials which are recognized as of this writing by current ASTM, AWWA, CSA and other standards are listed in Table 4. This table gives a brief explanation of the significance of the code digits. It should be recognized that a new material may be commercialized which qualifies for a code designation that has not been recognized as of this writing. For a listing of the most current recognized code designations the reader is invited to consult the periodically updated PPI publication TR-4. Contact PPI via their website, www.plasticpipe.org

TABLE 4
Standard Designation Codes for Current Commercially Available PE Piping Compositions

Standard Designation Code	What the Digits in the Code Denote		
	The 1st Digit	The 2nd Digit	The last two Digits(1)
	Cell Number Based on the Density Cell In accordance with ASTM D3350 (See Table 1)	Cell Number Based on the Resistance to SCG Cell In accordance with ASTM D3350 (2) (See Table 1)	Recommended Standard Hydrostatic Design Stress (HDS) Category, for water, at 73°F (23°C) (psi)
PE2406	Cell number 2	Cell number 4	630
PE2708		Cell number 7	800
PE3408	Cell number 3	Cell number 4	800
PE3608		Cell number 6	
PE3708		Cell number 7	800
PE3710			1,000
PE4708	Cell number 4	Cell number 7	800
PE4710			1,000

(1) The last two digits code the Standard HDS Category in units of 100psi. For example, 06 is the code for 630psi and 10 is the code for 1,000psi.

(2) It should be noted that the lowest Cell number for SCG resistance for pipe is 4. Based on research and experience a rating of at least 4 has been determined as sufficient for the safe absorption of localized stresses for properly installed PE pipe.

Standard Equation for Determining the Major Stress Induced in a Pressurized Pipe

There are two major stresses which are induced in the wall of a closed cylindrical vessel, such as a pipe, when it is subjected to internal fluid pressure. One runs along the axis of the vessel, often called the axial (longitudinal) stress, and the other, which is often called the hoop stress, runs along its circumference. Since the magnitude of the hoop stress is about twice that of the axial stress the hoop stress is considered as the significant stress for purposes of pressure pipe design.

The hoop stress is not constant across a pipe's wall thickness. It tends to be larger on the inside than on the outside of a pipe. And, this tendency is heightened in the case of materials having high stiffness and in thicker walled pipes. However, in the case of pipes made from thermoplastics – materials which are characterized by significantly lower stiffness than metals – it has long been accepted that the hoop stress is constant through the pipe's wall thickness. For such case the so called thin-walled hoop stress equation is accepted as satisfactory and it has been adopted by standards which cover thermoplastics pipe. This equation, which more commonly is identified as the ISO (International Organization for Standardization) equation because it has been also adopted for thermoplastic pipes by that organization, is as follows:

(1) $$S = \frac{P}{2}\frac{D_m}{t}$$

WHERE

S **= Hoop stress (psi or, MPa)**

P **= Internal pressure (psi or, MPa)**

D_m **= Mean diameter (in or, mm)**

t **= minimum wall thickness, (in or, mm)**

Because PE pipe is made either to controlled outside diameters or in some cases, to controlled inside diameters the above equation appears in PE pipe standards in one of the following forms:

When the pipe is made to a controlled outside diameter:

(2) $$S = \frac{P}{2}\left[\frac{D_o}{t}-1\right]$$

Where Do is the average outside diameter

When the pipe is made to a controlled inside diameter:

(3) $$S = \frac{P}{2}\left[\frac{D_o}{t}+1\right]$$

Where Di is the average inside diameter

For purposes of pressure pipe design, the pipe's pressure rating (PR) is determined by the hydrostatic design stress (HDS) that is assigned to the material from which the pipe is made. Therefore, Equation (2) can be re-arranged and written in terms of HDS and as follows:

(4) $$PR = \frac{2\,(HDS)}{\left[\frac{D_o}{t}-1\right]}$$

Where PR is the pressure rating (psi or, MPa) and HDS is the hydrostatic design stress (psi or, MPa)

And, Equation (3) becomes:

(5) $$PR = \frac{2\,(HDS)}{\left[\frac{D_t}{t}+1\right]}$$

The term D_o/t is referred to as the *outside diameter dimension ratio* and the term D_i/t as the *inside diameter dimension ratio*. However, the convention in PE pipe standards is to limit these ratios to a standard few. The ASTM terms and abbreviations for these preferences are:

- *Standard Dimension Ratio (SDR)*, for a standard D_o/t dimension ratio
- *Standard Inside Diameter Ratio (SIDR)*, for a standard D_i/t dimension ratio

Standard Diameters

Standard specifications for PE pipe allow the pipe to be made to either controlled inside diameters or, to controlled outside diameters. The inside diameter system, applicable to small diameter sizes only, is intended for use with insert type fittings for which the pipe must have a predicable inside diameter, independent of pipe wall thickness. And the outside diameter systems are intended for use with fittings that require a predictable outside diameter, also independent of wall thickness.

There is but one standard inside diameter sizing convention, SIDR , and this system is based on the inside diameters of the Schedule 40 series of iron pipe sizes (IPS). But there are four standard outside diameter sizing conventions and these are as follows:

- The outside diameters specified for iron pipe sized (IPS) pipe
- The outside diameters specified for ductile iron pipe sizes (DIPS)
- The outside diameters specified for copper tubing sizes (CTS)
- The outside diameters specified by the International Standards Organization (ISO 161/1)

The scope of a consensus standard usually identifies the sizing convention system that is covered by that standard.

PE Pipe Standards are Simplified by the Use of Preferred Values

The most widely accepted standards for PE pipes are those that define pipes which when made to the same Dimension Ratio and from the same kind of material are able to offer the same pressure rating independent of pipe size (See Equations 4 and 5). These standards are commonly referred to as Dimension Ratio/Pressure Rated (DR-PR) so as to distinguish them from other standards, such as those based on Schedule 40 and 80 dimensioning, in which the Dimension Ratio varies from one size to the next.

For the purpose of limiting standard pressure ratings (PR) in DR-PR standards to just those few which adequately satisfy common application requirements these standards require that the Dimension Ratios be one of certain series of established preferred numbers. They also require that the pipe's pressure rating be determined based on a recognized HDS category that is also expressed in terms of a preferred number (See previous discussion on PE pipe material designation code). The preferred numbers for both are derived from the ANSI Preferred Numbers, Series 10. The Series 10 numbers get that name because ten specified steps are required to affect a rise from one power of ten to the next one. Each ascending step represents an increase of about 25% over the previous value. For example, the following are the ANSI specified steps between 10 and 100: are 10; 12.5; 16.0; 20.0; 25.0; 31.5; 40.0; 50.0; 63.0; 80.0; 100.

A beneficial feature of the use of preferred numbers is that when a preferred number is multiplied or, is divided by another preferred number the result is always a preferred number.

The table that follows lists the Standard Dimension Ratios, all based on preferred numbers, which appear in the various ASTM, AWWA and CSA DR-PR based standards for PE pipe.

TABLE 5
Standard Dimension Ratios (SDRs)

Based on Mean Diameter (D_m/t) (Same numerical value as ANSI Preferred Number, Series 10)	Based on Outside Diameter SDR = (D_o/t (Series 10 Number + 1)	Based on Inside Diameter SIDR = (D_i/t) (Series 10 Number – 1)
5.0	6.0	4.0
6.3	7.3	5.3
8.0	9.0	7.0
10.0	11.0	9.0
12.5	13.5	11.5
16.0	17.0	15.0
20.0	21.0	19.0
25.0	26.0	24.0
31.5	32.5	30.5
40.0	41.0	39.0
50.0	51.0	49.0
63.0	64.0	62.0

The recognized standard HDS categories for water, at 73°F (23°C), are: 630 psi (4.34 MPa); 800 psi (5.52 MPa); and 1,000psi (6.90 MPa) (See discussion under the heading, Standard PE Piping Material Designation Code).

And, the standard pressure ratings for water, at 73°F (23°C), which are commonly recognized by DR-PR standard specifications for PE pipe are as follows: 250; 200; 160; 125; 100; 80; 63; 50; and 40 psig. However, individual standards generally only cover a selected portion of this broad range.

The result of the use of these standard preferred number values is that a pipe's standard pressure rating (PR) is a consistent result, independent of pipe size, which simply depends on its standard dimension ratio and the standard HDS of the material from which the pipe was made. This relationship is shown in Table 6, as follows.

TABLE 6
Standard Pressure Ratings for Water, at 73°F (23°C), for SDR-PR Pipes, psig (1)

Standard Dimension Ratio		Standard Pressure Rating (psig) as a function of a Material's HDS for Water, at 73°F (23°C), psi		
SDR (In the Case of Pipes Made to Standard OD's)	SIDR (In the Case of Pipes Made to Standard ID's)	HDS = 630psi (4.34 MPa)	HDS = 800psi (5.52 MPa)	HDS = 1000psi (6.90 MPa)
32.5	30.5	40	50	63
26.0	24.0	50	63	80
21.0	19.0	63	80	100
17.0	15.0	80	100	125
13.5	11.5	100	125	160
11.0	9.0	125	160	200
9.0	7.0	160	200	250

(1) Note: The Standard Pressure Ratings are the calculated values using equations (4) and (5) but with a slight rounding-off so that they conform to a preferred number.

Although the adoption of preferred numbers by the ASTM, CSA and AWWA DR-PR based standards is very widespread, there are a few exceptions. In some DR-PR standards a non-preferred Diameter Ratio has been included so as to define pipes which offer a pressure rating that more closely meets a particular application requirement. In addition, where existing system conditions or special requirements may be better served by other than standard diameters or Standard Dimension Ratios many standards allow for the manufacture of custom sized pipe provided all the performance and quality control requirements of the standard are satisfied and also, provided the proposed changes are restricted to pipe dimensions and that these changes are mutually agreed upon by the manufacturer and the purchaser.

Determining a PE's Appropriate Hydrostatic Design Stress (HDS) Category

As stated earlier, the last two digits of the PE pipe material designation code indicate the material's maximum allowable HDS for water, at 73°F (23°C). This value of HDS is then used for the determining of a pipe's pressure rating. This practice of using an allowable stress, instead of basing design on a particular measure of strength that is reduced by a specified "factor of safety", is recognized by many standards and codes that cover other kinds of pipes and materials. One reason for avoiding the specifying of a factor of safety is that it is misleading because it implies a greater degree of safety than actually exists. This is because a particular laboratory measure of strength only defines a material's reaction to a certain kind of a major test stress whereas, in an actual installation a material can also be subjected to other add-on stresses which can have a significant effect on ultimate performance. To provide a satisfactory cushion against the effect of these add-on stresses the chosen measure of strength is reduced by an appropriate strength reduction factor. But, as can be appreciated, the magnitude of this factor needs to be greater than the resultant true factor of safety.

As discussed in Chapter 3, it is recognized that a very significant strength of PE pressure pipe is its long-term hoop strength based on which it resists the effects of sustained internal hydrostatic pressure. The manner by which this long-term hydrostatic strength (LTHS) is forecast and, the reduction of the resultant LTHS into one of a limited hydrostatic design basis (HDB) strength categories is also described in Chapter 3. As implied by its name, the HDB is a design basis the limitations of which need to be recognized when using it for the establishment of a hydrostatic design stress (HDS). This is done by the choice of an appropriate strength reduction factor. This factor has many functions, but one of the more important ones is the providing of a suitable cushion for the safe absorption of all stresses the pipe may see in actual service, not just the stresses upon which the material's HDB has been determined.

So as not to mistake this strength reduction factor for a true factor of safety it has been designated as a design factor (DF). Furthermore, this factor is a multiplier, having a value of less than 1.0, as compared to a factor of safety which normally is a divisor having a value greater than 1.0. For consistency in design, the DF's are also expressed in terms of a preferred number. Therefore, when an HDB – which is expressed in terms of a preferred number – is reduced by a DF – also, a preferred number – it yields an HDS that is always a preferred number. The resultant value of this HDS becomes part of the standard PE material code designation.

Determining the Appropriate Value of HDS

As explained in Chapter 3, HDB of a PE pipe material is determined on the basis of PE pipe samples that are only subjected to the relatively well distributed stresses that are generated by internal pressure. This test model does not expose the test pipe to other stresses, in particular to the very localized stresses that are intensified by external causes such as by stone impingement or, by scratches and gouges or, by geometric effects inherent in fittings and joints. Extensive field experience and studies indicate that in the case of certain older generation PE materials which have been shown to exhibit low resistance to slow crack growth (SCG) localized stress intensifications can initiate and then, propagate the growth of slowly growing cracks. After some time, when these cracks grow to a size where they span through a pipe's entire wall thickness the end result is a localized fracture. As is the case for traditional piping materials, and as it has been demonstrated to be also the case for plastics, the potential damaging effect of a localized stress intensification depends strongly on the material's ability to safely deform locally and thereby, blunt a nascent crack, a reaction that reduces the magnitude of the localized stress. A feature of modern high performance PE materials is that they offer this ability to a significantly high degree.

To avoid the chance of a failure by the slow crack mechanism a three-fold approach has proven to be very successful:

1. PE pipe, and for that matter, pipe made from any material needs to be handled, joined and installed so as to minimize the development of excessive localized stress intensifications. Requirements for proper handling, joining and installing of PE piping – which are not at all onerous – are covered by standards, guides and manuals issued by ASTM, AWWA and other organizations. They are also described in this Handbook.
2. PE piping materials need to offer adequate resistance to slow crack growth (SCG). All Current commercially available materials meet not less than Cell number 4 of the requirement for resistance to SCG Cell that is specified by ASTM D3350. However, the newer generation of high performance materials have far superior resistance to slow crack growth and therefore, qualify for the Cell number 7 requirement for this property(See Table 1).
3. The design factor (DF) based on which an HDB (hydrostatic design basis) is reduced to and HDS (hydrostatic design stress) needs to leave sufficient cushion for the safe absorption of stresses that are in addition to those upon which the HDB has been established. While the DF has many roles, this is one of the more important ones.

Over 40 years of actual experience and many studies regarding the fracture mechanics behavior of PE pipe materials have shown that when the first two approaches are in play – a principal objective of standards for PE piping – the establishment of an HDS by the reduction of an HDB by means of a DF = 0.50 results in a very reliable and very durable field performance. However, more recent developments in the manufacture of PE resin have resulted in the availability of higher performance PE's that offer exceptional resistance to SCG. These materials, which exceed the requirements for Cell number 7 of the SCG cell in ASTM 3350, have demonstrated that they have a significantly greater capacity for safely shedding-off localized stress intensifications. Consequently, the HDS for these materials does not need to provide the same cushion against localized stress intensifications as established for the traditional materials. It has been determined that for such high performance materials a DF of 0.63 is proven to be reliable.

For a PE pipe material to qualify as a high performance material it must be experimentally demonstrated that it meets the following three requirements:

1. By means of supplementary elevated temperature stress-rupture testing followed by a Rate Process Analysis of the test results it must be demonstrated that at 73°F (23°C) the slope of the stress regression line shall remain linear out to at least 50 years. This means that the failure mode of test samples remains in the ductile region for at least this same time period. This test protocol is referred to as the Substantiation requirement (See Chapter 3 for a discussion of Rate Process and Substantiation methodologies). Such performance at the higher test stresses is an indicator of a PE's very high resistance to SCG at the lower operating stresses.

2. The resistance to SCG of the composition must qualify it for Cell number 7 of the Slow Crack Growth Resistance Cell of ASTM D3350. To qualify, the failure time must exceed 500 hrs when the material is evaluated in accordance with method ASTM F1473. This is a fracture mechanics based method (Described in Chapter 3) which yields an index – one that has been calibrated against actual quality of longer-term field experience – of a PE's capacity for resisting localized stress intensifications that are caused by external (i.e., non-pressure) causes.

3. The LCL (lower confidence limit) ratio of the stress rupture data for these high performance materials has been raised to a minimum of 90 percent. This ratio represents the amount of scatter in the data; it means that the minimum predicted value of the LTS (long term strength) based on statistical analysis of the data shall not be less than 90 percent of it's average predicted value.

A PE material which qualifies for the second of these three requirements is identified by the number 7 as the second numeral in the PE pipe material designation code (For example, PE4710 and PE2708).

It should be evident from the above discussion that the HDS of a PE pipe material is not solely determined by its HDB, a measure of the material's capacity for resisting stresses induced by internal hydrostatic pressure. The HDS that is established needs also to reflect the material's capacity for safely shedding off add-on stresses. Thus, even if two PE pipe materials have the same HDB their allowable HDS's can be different. For this reason PE pipe standards designate a PE by its pipe material designation code, a code which both identifies the material's resistance to SCG and its recommended HDS (See Table 4). The pipe's pressure rating for the standard condition of water and 73°F (23°C) is derived from this HDS. Table A.2 in Chapter 3 (Appendix) lists factors for the determining of a pipe's pressure rating for other temperatures.

As pointed out in Item 3 under this Section's introductory paragraph, the DF has other important roles than just that of allowing for the safe absorption of other than the stresses that are induced by hydrostatic pressure. Included among these roles are the following:

- The hydrostatic design basis (HDB), upon which a DF is applied, is but a design basis that has been established based on a forecast of the average value of the material's hydrostatic strength at a loading that is continually sustained for 100,000hrs (11.4yrs). The DF must give recognition to the fact that a PE's minimum strength is actually somewhat below its predicted average and that the resultant HDS is intended for a loading duration that shall be substantially longer than 11.4 years.
- The forecasted value of a material's long-term hydrostatic strength (LTHS) is established using "perfect" test pipes that have not been subjected to the normal effects of handling and installation and that include no typical components of a piping system.
- The minimum value of material's long-term strength may somewhat vary due to normal variabilities in the processes that are used both in the manufacture of the pipe material and the pipe.
- The forecasted value of a material's LTHS has been established under conditions of constant pressure and temperature whereas in actual service these can vary.

A Widely Recognized Source of HDS Recommendations

Most PE pipe standards that are issued by ASTM establish PE pipe pressure ratings based on the HDS's that are recommended by the Hydrostatic Stress Board (HSB) of the Plastics Pipe Institute. This group has been issuing HDS recommendations for commercial grade materials since the early 1960's. The membership of the HSB is constituted of persons who are recognized experts in the technology of thermoplastic pressure pipe. These experts include representatives from material and pipe producers, testing laboratories, trade associations, a regulatory agency and private consultants. And, all major thermoplastic pipe materials are represented, including polyvinyl chloride (PVC), chlorinated PVC (CPVC), polyethylene (PE), and cross-linked PE (PEX).

The HDS recommendations that are issued by the HSB are based upon a close review of detailed longer-term stress rupture data and they take into account the various factors, as above discussed, that need to be considered when establishing an HDS. The HSB's policies regarding data requirements are presented in PPI publication TR-3, "Policies and Procedures for Developing Hydrostatic Design Basis (HDB), Hydrostatic Design Stresses (HDS), Pressure Design Basis (PDB), Strength Design Basis, and Minimum Required Strength (MRS) Ratings for Thermoplastic Pipe

Materials or Pipe". A listing of HDS recommendations is offered in the periodically updated publication TR-4, "PPI Listing of Hydrostatic Design Basis (HDB), Hydrostatic Design Stress (HDS), Strength Design Basis (SDB), Pressure Design Basis (PDB) and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials".

A current edition of both TR-2 and TR-4 can be found at the PPI website www.plasticpipe.org. Also available at this website are other reports, recommendations, notes and model specifications intended to assist users and designers in the optimum use of PE pipe. Each of these publications may be downloaded from this website.

Standard Specifications for Fittings and Joints

One of the best attributes of PE pipe is its ability to be joined by heat fusion (butt, socket and saddle). Butt fusion is performed by heating the ends of the pipe and/or fitting with an electrically heated plate at about 400°F until the ends are molten. The ends are then forced together at a controlled rate and pressure, and held until cooled. Performed properly, this results in a joint that is integral with the pipe itself, is totally leak-proof, and is typically stronger than the pipe itself. Heat fusion joining can also be used for connecting service lines to mains using saddle fittings — even while the main line is in service. Another type of heat fusion is electrofusion. The main difference between conventional heat fusion and electrofusion is the method by which heat is supplied. More complete details of the fusion joining procedure and other methods of joining PE pipe can be found in Chapter 9, "PE Pipe Joining Procedures".

While heat fusion is a good method for joining PE pipe and fittings, mechanical fittings are another option. Mechanical fittings consist of compression fittings, flanges, or other types of manufactured transition fittings. There are many types and styles of fittings available from which the user may choose. Each offers its particular advantages and limitations for each joining situation the user may encounter.

The chapter on joining polyethylene pipe within this Handbook provides more detailed information on these procedures. It should be noted that, at this time, there are no known adhesives or solvent cements that are suitable for joining polyethylene pipes.

Joining of polyethylene pipe can be done by either mechanical fittings or by heat fusion. All joints and fittings must be designed at the same high level of performance and integrity as the rest of the piping system. For gas distribution systems, the installation of a plastic pipe system must provide that joining techniques comply with Department of Transportation 49 CFR 192 subpart F-Joining of Materials Other Than by Welding. The general requirements for this subpart are:

General

a. The pipeline must be designed and installed so that each joint will sustain the longitudinal pullout or thrust forces caused by contraction or expansion of the piping or by anticipated external or internal loading.

b. Each joint must be made in accordance with written procedures that have been proven by test or experience to produce strong, gas-tight joints.

c. Each joint must be inspected to ensure compliance with this subpart. Within 49 CFR 192 subpart F, 192.281 specifies selected requirements for plastic joints; 192.282 specifies requirements for qualifying joining procedures; 192.285 specifies qualifying persons to make joints; and 192.287 specifies inspection of joints.

Since PE fittings are also subjected to stresses they must also be produced from stress rated PE materials. However, since the geometry of the fittings is different from the pipe, the stress fields induced by internal pressure and by external causes are more complex. Because of this, there are no simple equations that can be used for the design of pressure rated fittings. The practice is to establish fitting pressure ratings by means of testing. Typically, the fitting will be rated to handle the same pressure as the pipe to which it is designed to be joined. If there is a question about the pressure rating of the fitting, the reader is advised to contact the manufacturer.

Specifications for socket, butt fusion, and electrofusion fittings that have been developed and issued by ASTM include:

- D 2683 "Standard Specification for Socket-Type Polyethylene Fittings for Outside Diameter-Controlled Polyethylene Pipe and Fittings."
- D 3261 "Standard Specification for Butt Heat Fusion Polyethylene (PE) Plastic Fittings for Polyethylene Plastic Pipe and Tubing."
- F 1055 "Electrofusion Type Polyethylene Fittings for Outside Diameter Controlled Polyethylene Pipe and Tubing."
- D 2657 "Standard Practice for Heat Fusion Joining of Polyolefin Pipe and Fittings."

Generic fusion procedures for PE pipe products have also been published by the Plastic Pipe Institute (PPI). They include, TR 33 " Generic Butt Fusion Joining Procedure for Polyethylene Gas Pipe" and TR 41 "Generic Saddle Fusion Joining Procedure for Polyethylene Gas Pipe." In addition to these standards and procedures, each manufacturer will have published joining procedures for their pipe and/or fittings. Some of the relevant standards that pertain to fitting performance or joining practices are listed in the Appendix.

Codes, Standards and Recommended Practices for PE Piping Systems

There are a large number of codes, standards and practices that apply to the use of PE piping. These consensus documents cover a broad range of applications for PE pipe and fittings. Some standards pertain to the product performance requirements for a specific application, while other standards are guidelines and practices detailing how a certain type of activity is to be performed. Some are test methods that define exactly how a particular test is to be run so that a direct comparison can be made between results. There are several organizations that issue standards, codes of practice, manuals, guides, and recommendations that deal with the manufacture, testing, performance, and use of PE pipe and fittings. Some of the major ones are discussed below. A more inclusive listing can be found in the Appendix of this chapter.

Plastics Pipe Institute (PPI)

The Plastics Pipe Institute is a trade association dedicated to promoting the proper and effective use of plastics piping systems. The assignment of a recommended hydrostatic design basis for a thermoplastic material falls under the jurisdiction of the Hydrostatic Stress Board - HSB - of the Plastics Pipe Institute. The Hydrostatic Stress Board has the responsibility of developing policies and procedures for the recommendation of the estimated long-term strength for commercial thermoplastic piping materials. The document most widely used for this is Technical Report-3, TR-3 "Policies and Procedures for Developing Hydrostatic Design Bases (HDB), Pressure Design Bases (PDB), Strength Design Bases (SDB), and Minimum Required Strengths (MRS) for Thermoplastic Piping Materials or Pipe." The material stress ratings themselves are published in TR-4, "PPI Listing of Hydrostatic Design Bases (HDB), Strength Design Bases (SDB), Pressure Design Bases (PDB) and Minimum Required Strengths (MRS) Ratings for Thermoplastic Piping Materials or Pipe." There are many other publications pertaining to various aspects of polyethylene pipe available from PPI such as: TN's - Technical Notes, TR's - Technical Reports, Model Specifications, and White Papers on specific positions addressed by the industry. Check the website www.plasticpipe.org for up-to-date publications.

It should be noted that while the Hydrostatic Stress Board (HSB) is a division of the Plastics Pipe Institute, involved in the development and issuance of policies, procedures, and listings of stress and pressure ratings for all thermoplastic pipe materials, PPI itself is an industry association focused on the promotion and effective and proper use of pipe primarily made from polyethylene (PE), cross linked polyethylene (PEX), and polyamide (POM) materials.

ASTM

ASTM International is a consensus standards writing organization, and has published standards for a multitude of materials, products, practices and applications. Those pertaining to polyethylene pipe are found in Volume 8.04 "Plastic Pipe and Building Products." ASTM employees do not write these standards; rather they are written by interested parties and experts within the industry who are members of ASTM. Most anyone can be a member of ASTM and participate in the standard writing process. Other standards, pertaining to plastics in general are found in other books within Volume 8 - 8.01, 8.02, or 8.03.

ASTM Standards pertaining to PE pipe can be a Standard Specification that defines the product requirements and performance for a specific application. It can also be a Standard Practice, which defines how a particular activity is to be performed, or a Standard Test Method, which defines how a particular test on PE pipe, fittings, or materials is to be done. While ASTM standards are mainly used in North America, many are also approved by the American National Standards Institute (ANSI) for international recognition, or are equivalent to an International Standards Organization (ISO) standard. When a manufacturer prints the ASTM Standard on a product, the manufacturer is certifying that the product meets all of the requirements of that standard.

The typical sections included in an ASTM Product Standard are:

Scope – what products and applications are covered under this standard.

Referenced Documents – what other standards or specifications are referenced in this standard.

Terminology – lists definitions that are specific to this standard.

Materials – defines material requirements for products that conform to this standard.

Requirements – details the performance requirements that the product must meet. This section will also contain dimensions.

Test Methods – details how the testing is to be performed to determine conformance to the performance requirements.

Marking – details the print that must be on the product. Includes the standard number, manufacturer's name, size, date of manufacture, and possibly the application such as "water." There may be other wording added to the print as the purchaser requires.

This is only a typical example of sections that may be included. While ASTM has defined protocol for product standards, each one may contain sections unique to that standard. Each standard should be reviewed individually for its requirements.

A listing of major ASTM standards pertaining to PE pipe and fittings is in the Appendix. Current publications of these standards can be found at the website www.astm.org.

ISO

The International Organization for Standardization (ISO) is a network of national standards institutes from 140 countries working in partnership with international organizations, governments, industry, business and consumer representatives.

The ISO committee having jurisdiction for development of plastics pipe standards is Technical Committee 138. The committee's stated scope is: Standardization of pipes, fittings, valves and auxiliary equipment intended for the transport of fluids and made from all types of plastic materials, including all types of reinforced plastics. Metal fittings used with plastics pipes are also included. The main committee has seven subcommittees devoted to specific issues.

TC 138 has 35 participating countries, including the United States and Canada, and 27 observer countries. For ISO matters the United States is represented by the American National Standards Institute (ANSI). Canadian representation is through the Standards Council of Canada (SCC). The United States representation has been passed through ANSI who had delegated it down to ASTM and, who in turn, had delegated it to the Plastics Pipe Institute.

NSF International

NSF International plays a vital role in the use of pipe and fittings for potable water and plumbing applications. NSF is an independent, not-for-profit organization of scientists, engineers, educators and analysts. It is a trusted neutral agency, serving government, industry and consumers in achieving solutions to problems relating to public health and the environment. NSF has three essential missions, as follows:

1. To issue standards that establish the necessary public health and safety requirements for thermoplastic piping materials and for piping products intended for use in the transport of potable water and for drainage and venting systems in plumbing applications.
2. To establish the appropriate test methods by which these requirements are evaluated.
3. To offer a certification program which affirms that a particular product which carries an NSF seal is in compliance with the applicable NSF requirements

NSF standards are developed with the active participation of public health and other regulatory officials, users and industry. The standards specify the requirements for the products, and may include requirements relating to materials, design, construction, and performance.

There are two NSF Standards that are of particular importance to the polyethylene pipe and fittings industry: Standard 14, "Plastic Piping components and Related Materials" and Standard 61, "Drinking Water System Components-Health Effects." Standard 14 includes both performance requirements from product standards and provisions for health effects covered in Standard 61. NSF Standard 14 does not contain performance requirements itself, but rather NSF will certify that a product conforms to a certain ASTM, AWWA, etc... product performance standard. In order to be certified for potable water applications under Standard 14, the product must also satisfy the toxicological requirements of Standard 61.

For products intended for potable water applications, it is also an option to be certified under Standard 61 only, without certifying the performance aspects of the product. In the early 1990's NSF separated the toxicological sections of Standard 14 into a new Standard 61. This was done for several reasons, but mainly to make it easier to bring new, innovative products to market without undue expense and time, while continuing to keep the public safe. This was a great benefit to the industry. Now manufacturers have a choice of staying with Standard 14 or switching to Standard 61. Many manufacturers who have in-house quality programs and the ability to perform the necessary tests switched to this new potable water certification option.

AWWA

The American Water Works Association (AWWA) is a leader in the development of water resource technology. These AWWA standards describe minimum requirements and do not contain all of the engineering and administrative information normally contained in a specification that is written for a particular project. AWWA standards usually contain options that must be evaluated by the user of the standard. Until each optional feature is specified by the user, the product or service is not fully defined. The use of AWWA standards is entirely voluntary. They are intended to represent a consensus of the water supply industry that the product described will provide satisfactory service.

There are currently two AWWA standards that pertain to polyethylene pipe: AWWA C901, "Polyethylene (PE) Pressure Pipe and Tubing, 1/2 inch through 3 inch, for Water Service" and AWWA C906, "Polyethylene (PE) Pressure Pipe and Fittings, 4 inch through 63 inches, for Water Distribution." Standard C901 addresses PE pressure pipe and tubing for use primarily as potable water service lines in the construction of underground distribution systems. It includes dimensions for pipe and tubing made to pressure classes of 80 psi, 100 psi, 125 psi, 160 psi and 250 psi.

This standard covers PE pipe in nominal sizes from ½ inch through 3 inch that are made to controlled outside-diameters based on iron pipe sizes i.e. (OD based IPS size) and also to controlled inside-diameter based on iron pipe sizes i.e. (ID based IPS size). It also covers tubing, ranging in size from ½ inch through 2 inch that conforms to the outside-diameter dimensions of copper tubing sizes (CTS). There are also sections on materials, testing and marking requirements; inspection and testing by manufacturer; and in-plant inspection by purchaser.

AWWA Standard C906 addresses larger diameter PE pressure pipe. The pipe is primarily intended for use in transporting potable water in either buried or above-ground installations. The standard covers 10 standard dimension ratios (SDR's) for nominal pipe sizes ranging from 4 inch through 63 inch. The available pipe sizes are limited by a maximum wall thickness of 3 inch. Pipe outside diameters (OD's) conform to the outside diameter dimensions of iron pipe sizes (IPS), ductile iron pipe size (DIPS), or those established by the International Standards Organization (ISO). Pressure class ratings range from 40 to 250 psig.

AWWA has also published a manual M55, "PE Pipe-Design and Installation". This manual is a design and installation guide for the use of polyethylene pipe in potable water applications. The manual supplements C901 and C906 and provides specific design recommendations as it relates to the use of PE pipe in potable water systems.

Standard Plumbing Codes

Piping systems used in buildings must meet standards that are recognized by the plumbing code adopted by the jurisdiction in which the building is to be located. Within the United States there are several "model" codes, any one of which can be used as the basis for a local jurisdiction's code. Most widely used model codes include the International Plumbing Code (IPC), produced by the International Code Council (ICC) and the Uniform Plumbing Code (UPC), produced by the International Association of Plumbing and Mechanical Officials (IAPMO). One of the model codes may be adopted in its entirety or modified by the jurisdiction. Some states adopt a statewide code which municipalities may or may not be allowed to amend based on state law. Both designers and contractors need to be familiar with the code that applies to a particular project with a specific jurisdiction.

ASME B31.3, Chemical Plant and Petroleum Refinery Piping Code

The proper and safe usage of plastics piping in industrial applications demands that close attention be paid in the design, selection and installation of such piping. Safe design rules and guidelines are set forth in the ASME B31.3 Piping Code. In this code the requirements for plastics piping, including those for PE, are placed in a separate Chapter V1, titled "Nonmetallic Piping and Piping Lined with Nonmetals".

Other Codes and Standards

There are several other codes and standards writing organizations which pertain to polyethylene pipe. These groups usually have a type of certification program for products to be used in a certain industry or application, and may or may not write their own performance standards. If they do not write their own standards, they will certify products to an existing standard such as ASTM, AWWA, etc. The certification process will normally consist of an initial application stating what specific products are requesting certification, an on-site inspection of the production facilities, and testing of the product to assure performance to the relevant product specification. This is followed up by annual random inspections and product testing.

The Canadian Standards Association (CSA) provides a good example of the type of compliance certification program that relates to the use of polyethylene pipe in both water (CSA B137.1) and gas distribution (C137.4) applications. CSA's certification of compliance to the standards to which a particular polyethylene pipe is made allows the producer of that product to place the CSA mark on the product. The presence of the mark assures the purchaser that the product has met the requirements of the CSA certification program and insures that the product meets the appropriate product specifications as determined by the audits and inspections conducted by the Canadian Standards Association.

Factory Mutual

Factory Mutual Research (FM), an affiliate of FM Global, is a non-profit organization that specializes in property loss prevention knowledge. The area that pertains to PE pipe is the FM Standard "Plastic Pipe and Fittings for Underground Fire Protection Service." Certification to this standard may be required by an insurance company for any PE pipe and fittings being used in a fire water system. FM Global requires an initial inspection and audit of production facilities to be assured that the facility has the proper quality systems in place similar to ISO 9000 requirements. Then testing of the pipe must be witnessed by an FM representative. This testing must pass the requirements set forth in the FM Standard for PE pipe. After initial certification, unannounced audits are performed on at least an annual basis. More information can be found at their website www.fmglobal.com, or by calling at (401) 275-3000.

Conclusion

PE resins are produced to cover a very broad range of applications. The physical performance properties of these various formulations of PE vary significantly making each grade suitable for a specific range of applications. To that end, the PE pipe industry has worked diligently to establish effective standards and codes which will assist the designer in the selection and specification of piping systems produced from PE materials which lend themselves to the type of service life sought. As such, the discussion which has been presented here should assist the designer and/or installer in his understanding of these standards and their significance relative to the use of these unique plastic piping materials.

Extensive reference has been made throughout the preceding discussion to standards writing or certifying organizations such as ASTM, AWWA, NSF, etc. The standards setting process is dynamic, as is the research and development that continues within the PE pipe industry. As such, new standards and revisions of existing standards are developed on an ongoing basis. For this reason, the reader is encouraged to obtain copies of the most recent standards available from these various standards organizations.

References

1. ASTM Annual Book of Standards, Volume 8.03 Plastics, (III): D 3100 - Latest, American Society for Testing and Materials, West Conshohocken, PA.
2. ASTM Annual Book of Standards, Volume 8.04 Plastic Pipe and Building Products, American Society for Testing and Materials, West Conshohocken, PA.
3. Plastics Pipe Institute, Various Technical Reports, Technical Notes, Model Specifications, Irving, TX.
4. NSF Standard 14, Plastic Piping Components and Related Materials , NSF International, Ann Arbor, MI.
5. NSF Standard 61, Drinking Water System Components - Health Effects, NSF International, Ann Arbor, MI.

Appendix 1
Major Standards, Codes and Practices

General

ASTM

D 3350	Polyethylene Plastics Pipe and Fittings Materials
D 1598	Time-to-Failure of Plastic Pipe Under Constant Internal Pressure
D 1599	Short-Time Hydraulic Failure Pressure of Plastic Pipe, Tubing and Fittings
D 2122	Determining Dimensions of Thermoplastic Pipe and Fittings
D 2837	Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials
D 2488	Description and Identification of Soils (Visual-Manual Procedure)
D 2657	Heat-Joining Polyolefin Pipe and Fittings
D 2683	Socket Type Polyethylene Fittings for Outside Diameter Controlled Polyethylene Pipe and Tubing
F 412	Terminology Relating to Plastic Piping Systems
F 480	Thermoplastic Well Casing Pipe and Couplings Made in Standard Dimension Ratios (SDRs), SCH 40, and SCH 80
F 948	Time-to-Failure of Plastic Piping Systems and Components Under Constant Internal Pressure With Flow
F 1055	Electrofusion Type Polyethylene Fittings for Outside Diameter Controlled Polyethylene Pipe and Tubing
F 1248	Test Method for Determination of Environmental Stress Crack Resistance (ESCR) of Polyethylene Pipe
F1290	Electrofusion Joining Polyolefin Pipe and Fittings
F 1473	Notch Tensile Test to Measure the Resistance to Slow Crack Growth of Polyethylene Pipes and Resins
F 1533	Deformed Polyethylene (PE) Liner
F 1901	Polyethylene (PE) Pipe and Fittings for Roof Drain Systems
F 1962	Standard Guide for Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossing
F 2164	Standard Practice for Field Leak Testing of Polyethylene (PE) Pressure Piping Systems Using Hydrostatic Pressure
F 2231	Standard Test Method for Charpy Impact Test on Thin Specimens of Polyethylene Used in Pressurized Pipes
F 2263	Standard Test Method for Evaluating the Oxidative Resistance of Polyethylene (PE) Pipe to Chlorinated Water
F 2620	Standard Practice for Heat Fusion Joining of Polyethylene Pipe and Fittings

PPI TECHNICAL REPORTS

TR-3	Policies and Procedures for Developing Hydrostatic Design Bases (HDB), Pressure Design Bases (PDB), Strength Design Bases (SDB), and Minimum Required Strengths (MRS) Ratings for Thermoplastic Piping Materials for Pipe
TR-4	PPI Listing of Hydrostatic Design Bases (HDB), Strength Design Bases (SDB), Pressure Design Bases (PDB) and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials or Pipe
TR-7	Recommended Methods for Calculation of Nominal Weight of Solid Wall Plastic Pipe
TR-9	Recommended Design Factors for Pressure Applications of Thermoplastic Pipe Materials
TR-11	Resistance of Thermoplastic Piping Materials to Micro- and Macro-Biological Attack
TR-14	Water Flow Characteristics of Thermoplastic Pipe
TR-18	Weatherability of Thermoplastic Piping Systems
TR-19	Thermoplastic Piping for the Transport of Chemicals
TR-21	Thermal Expansion and Contraction in Plastics Piping Systems
TR-30	Investigation of Maximum Temperatures Attained by Plastic Fuel Gas Pipe Inside Service Risers
TR-33	Generic Butt Fusion Joining Procedure for Polyethylene Gas Pipe
TR-34	Disinfection of Newly Constructed Polyethylene Water Mains
TR-35	Chemical & Abrasion Resistance of Corrugated Polyethylene Pipe
TR-36	Hydraulic Considerations for Corrugated Polyethylene Pipe
TR-37	CPPA Standard Specification (100-99) for Corrugated Polyethylene (PE) Pipe for Storm Sewer Applications
TR-38	Structural Design Method for Corrugated Polyethylene Pipe
TR-39	Structural Integrity of Non-Pressure Corrugated Polyethylene Pipe
TR-41	Generic Saddle Fusion Joining Procedure for Polyethylene Gas Piping

PPI TECHNICAL NOTES

TN-4	Odorants in Plastic Fuel Gas Distribution Systems
TN-5	Equipment used in the Testing of Plastic Piping Components and Materials
TN-6	Polyethylene (PE) Coil Dimensions
TN-7	Nature of Hydrostatic Stress Rupture Curves
TN-11	Suggested Temperature Limits for the Operation and Installation of Thermoplastic Piping in Non-Pressure Applications
TN-13	General Guidelines for Butt, Saddle and Socket Fusion of Unlike Polyethylene Pipes and Fittings
TN-14	Plastic Pipe in Solar Heating Systems
TN-15	Resistance of Solid Wall Polyethylene Pipe to a Sanitary Sewage Environment
TN-16	Rate Process Method for Projecting Performance of Polyethylene Piping Components
TN-17	Cross-linked Polyethylene (PEX) Tubing
TN-18	Long-Term Strength (LTHS) by Temperature Interpolation.
TN-19	Pipe Stiffness for Buried Gravity Flow Pipes
TN-20	Special Precautions for Fusing Saddle Fittings to Live PE Fuel Gas Mains Pressurized on the Basis of a 0.40 Design Factor
TN-21	PPI PENT test investigation
TN-22	PPI Guidelines for Qualification Testing of Mechanical Couplings for PE Pipes in Pressurized Water or Sewer Service
TN-23	Guidelines for Establishing the Pressure Rating for Multilayer and Coextruded Plastic Pipes
TN-35	General Guidelines for Repairing Buried HDPE Potable Water Pressure Pipes
TN-36	General Guidelines for Connecting HDPE Potable Water pressure Pipes to DI and PVC piping Systems
TN-38	Bolt Torque for Polyethylene Flanged Joints
TN-41	High Performance PE Material for Water Piping Applications

Gas Pipe, Tubing and Fittings

ASTM

D 2513	Thermoplastic Gas Pressure Pipe, Tubing and Fittings
F 689	Determination of the Temperature of Above-Ground Plastic Gas Pressure Pipe Within Metallic Castings
F 1025	Selection and Use of Full-Encirclement-Type Band Clamps for Reinforcement or Repair of Punctures or Holes in Polyethylene Gas Pressure Pipe
F 1041	Squeeze-Off of Polyolefin Gas Pressure Pipe and Tubing
F 1563	Tools to Squeeze Off Polyethylene (PE) Gas Pipe or Tubing
F 1734	Practice for Qualification of a Combination of Squeeze Tool, Pipe, and Squeeze-Off Procedure to Avoid Long-Term Damage in Polyethylene (PE) Gas Pipe
F 1924	Plastic Mechanical Fittings for Use on Outside Diameter Controlled Polyethylene Gas Distribution Pipe and Tubing
F 1948	Metallic Mechanical Fittings for Use on Outside Diameter Controlled Thermoplastic Gas Distribution Pipe and Tubing
F 1973	Factory Assembled Anodeless Risers and Transition Fittings in Polyethylene (PE) Fuel Gas Distribution Systems
F 2138	Standard Specification for Excess Flow Valves for Natural Gas Service

PPI

TR-22	Polyethylene Plastic Piping Distribution Systems for Components of Liquid Petroleum Gase
MS-2	Model Specification for Polyethylene Plastic Pipe, Tubing and Fittings for Natural Gas Distribution

OTHER STANDARDS FOR GAS PIPING APPLICATIONS

Title 49, CFR part 192	Transportation of Natural Gas and Other Gas by Pipe Line
AGA	AGA Plastic Pipe Manual for Gas Service (American Gas Association)
API	API Spec 15LE Specification for Polyethylene Line Pipe (American Petroleum Institute)

Water Pipe, Tubing and Fittings and Relatd Practices

ASTM

D 2104	Polyethylene (PE) Plastic Pipe, Schedule 40
D 2239	Polyethylene (PE) Plastic Pipe (SIDR-PR) Based on Controlled Inside Diameter
D 2447	Polyethylene (PE) Plastic Pipe, Schedules 40 to 80, Based on Outside Diameter
D 2609	Plastic Insert Fittings for Polyethylene (PE) Plastic Pipe
D 2683	Socket-Type Polyethylene Fittings for Outside Diameter-Controlled Polyethylene Pipe and Tubing
D 2737	Polyethylene (PE) Plastic Tubing
D 3035	Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Controlled Outside Diameter
D 3261	Butt Heat Fusion Polyethylene (PE) Plastic Fittings for Polyethylene (PE) Plastic Pipe and Tubing
F 405	Corrugated Polyethylene (PE) Tubing and Fittings
F 667	Large Diameter Corrugated Polyethylene (PE) Tubing and Fittings
F 714	Polyethylene (PE) Plastic Pipe (SIDR-PR) Based on Controlled Outside Diameter
F 771	Polyethylene (PE) Thermoplastic High-Pressure Irrigation Pipeline Systems
F 810	Smooth Wall Polyethylene (PE Pipe for Use in Drainage and Waste Disposal Absorption Fields
F 982	Polyethylene (PE) Corrugated Pipe with a Smooth Interior and Fittings
F 894	Polyethylene (PE) Large Diameter Profile Wall Sewer and Drain Pipe
F 905	Qualification of Polyethylene Saddle Fusion Joints
F 1055	Electrofusion Type Polyethylene Fittings for Outside Diameter Controlled Polyethylene Pipe and Tubing
F 1056	Socket Fusion Tools for Use in Socket Fusion Joining Polyethylene Pipe or Tubing and Fittings
F 1759	Standard Practice for Design of High-Density Polyethylene (HDPE) Manholes for Subsurface Applications
F 2206	Standard Specification for Fabricated Fittings of Butt-Fused Polyethylene (PE) Plastic Pipe, Fittings, Sheet Stock, Plate Stock, or Block Stock

PPI

MS-3	Model Specification for Polyethylene Plastic Pipe, Tubing and Fittings for Water Mains and Distribution

AWWA

C 901	Polyethylene (PE) Pressure Pipe, Tubing, and Fittings, 1/2 inch through 3 inch for Water Service
C 906	Polyethylene (PE) Pressure Pipe and Fittings, 4 inch through 63 inch for Water Distribution
M 55	AWWA Manual 55: PE Pipe - Design and Installation

CSA

B 137.1	Polyethylene Pipe, Tubing and Fittings for Cold Water Pressure Services
B137.4	Polyethylene Piping Systems for Gas Services (Canadian Standards Association)

Installation

ASTM

D 2321	Underground Installation of Flexible Thermoplastic Sewer Pipe
D 2774	Underground Installation of Thermoplastic Pressure Piping
F 449	Subsurface Installation of Corrugated Thermoplastic Tubing for Agricultural Drainage or Water Table Control
F 481	Installation of Thermoplastic Pipe and Corrugated Tubing in Septic Tank Leach Fields
F 585	Insertion of Flexible Polyethylene Pipe into Existing Sewers
F 645	Selection, Design and Installation of Thermoplastic Water Pressure Pipe System
F 690	Underground Installation of Thermoplastic Pressure Piping Irrigation Systems
F 1176	Design and Installation of Thermoplastic Irrigation Systems with Maximum Working Pressure of 63 psi
F 1417	Test Method for Installation Acceptance of Plastic Gravity Sewer Lines Using Low-Pressure Air
F 1606	Standard Practice for Rehabilitation of Existing Sewers and Conduits with Deformed Polyethylene (PE) Liner
F 1668	Guide for Construction Procedures for Buried Plastic Pipe
F 1759	Standard Practice for Design of High-Density Polyethylene (HDPE) Manholes for Subsurface Applications
F 1743	Qualification of a Combination of Squeeze Tool, Pipe, and Squeeze-Off Procedures to Avoid Long-Term Damage in Polyethylene (PE) Gas Pipe
F 1804	Determine Allowable Tensile Load For Polyethylene (PE) Gas Pipe During Pull-in Installation
F 1962	Guide for Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe of Conduit Under Obstacles, Including River Crossings
F 2164	Standard Practice for Field Leak Testing of Polyethylene (PE) Pressure Piping Systems Using Hydrostatic Pressure

CONDUIT

F 2160	Standard Specification for Solid Wall High Density Polyethylene (HDPE) Conduit Based on Controlled Outside Diameter (OD)
F 2176	Standard Specification for Mechanical Couplings Used on Polyethylene Conduit, Duct, and Innerduct

AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

S376.1	Design, Installation and Performance of Underground, Thermoplastic Irrigation Pipelines

Chapter 6

Design of PE Piping Systems

Introduction

Design of a PE piping system is essentially no different than the design undertaken with any ductile and flexible piping material. The design equations and relationships are well-established in the literature, and they can be employed in concert with the distinct performance properties of this material to create a piping system which will provide very many years of durable and reliable service for the intended application.

In the pages which follow, the basic design methods covering the use of PE pipe in a variety of applications are discussed. The material is divided into four distinct sections as follows:

Section 1 covers Design based on Working Pressure Requirements. Procedures are included for dealing with the effects of temperature, surge pressures, and the nature of the fluid being conveyed, on the sustained pressure capacity of the PE pipe.

Section 2 deals with the hydraulic design of PE piping. It covers flow considerations for both pressure and non-pressure pipe.

Section 3 focuses on burial design and flexible pipeline design theory. From this discussion, the designer will develop a clear understanding of the nature of pipe/soil interaction and the relative importance of trench design as it relates to the use of a flexible piping material.

Finally, **Section 4** deals with the response of PE pipe to temperature change. As with any construction material, PE expands and contracts in response to changes in temperature. Specific design methodologies will be presented in this section to address this very important aspect of pipeline design as it relates to the use of PE pipe.

This chapter concludes with a fairly extensive appendix which details the engineering and physical properties of the PE material as well as pertinent pipe characteristics such as dimensions of product produced in accordance with the various industry standards.

Section 1
Design Based on Required Pressure Capacity

Pressure Rating

The methodology for arriving at the standard pressure rating, PR, for PE pipe is discussed in detail in Chapter 5. The terms pressure rating (PR), pressure class (PC), are used in various consensus standards from ASTM, AWWA, CSA and others to denote the pipe's capacity for safely resisting sustained pressure, and typically is inclusive of the capacity to resist momentary pressure increases from pressure surges such as from sudden changes in water flow velocity. Consensus standards may treat pressure surge capacity or allowances differently. That treatment may vary from the information presented in this handbook. The reader is referred to the standards for that specific information.

Equations 1-1 and 1-2 utilize the Hydrostatic Design Stress, HDS, at 73ºF (23ºC) to establish the performance capability of the pipe at that temperature. HDS's for various PE pipe materials are published in PPI TR-4, "PPI Listing of Hydrostatic Design Basis (HDB), Hydrostatic Design Stress (HDS), Strength Design Basis (SDB), Pressure Design Basis (PDB) and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials". Materials that are suitable for use at temperatures above 100ºF (38ºC) will also have elevated temperature Hydrostatic Design Basis ratings that are published in PPI TR-4.

The PR for a particular application can vary from the standard PR for water service. PR is reduced for pipelines operating above the base design temperatures, for pipelines transporting fluids that are known to have some adverse effect on PE, for pipelines operating under Codes or Regulations, or for unusual conditions. The PR may be reduced by application of a factor to the standard PR. For elevated temperature applications the PR is multiplied by a temperature factor, F_T. For special fluids such as hydrocarbons, or regulated natural gas, an environmental application factor, A_F, is applied. See Tables 1-2 and Appendix, Chapter 3.

The reader is alerted to the fact that the form of the ISO equation presented in Equations 1-1 and 1-2 has changed from the form of the ISO equation published in the previous edition of the PPI PE Handbook. The change is to employ HDS rather than HDB, and is necessitated by the additional ratings available for high performance materials. In the earlier form of the ISO equation, PR is given as a function of the HDB, not the HDS as in Equations 1-1 and 1-2. This difference is significant and can result in considerable error if the reader uses the Environmental Applications Factors given in Table 1-2 as the "Design Factor" in the HDB form of the ISO equation.

(1-1)
$$PR = \frac{2\ HDS\ F_T\ A_F}{(DR\text{-}1)}$$

(1-2)
$$PR = \frac{2\ HDS\ F_T\ A_F}{(IDR+1)}$$

WHERE

PR **= Pressure rating, psi**

HDS **= Hydrostatic Design Stress, psi (Table 1-1)**

A_F **= Environmental Application Factor (Table 1-2)**

NOTE: The environmental application factors given in Table 1-2 are not to be confused with the Design Factor, DF, used in previous editions of the PPI Handbook and in older standards.

F_T **= Service Temperature Design Factor (See Appendix to Chapter 3)**

DR **= OD -Controlled Pipe Dimension Ratio**

(1-3)
$$DR = \frac{D_O}{t}$$

D_O **= OD-Controlled Pipe Outside Diameter, in.**

t **= Pipe Minimum Wall Thickness, in.**

IDR **= ID -Controlled Pipe Dimension Ratio**

(1-4)
$$IDR = \frac{D_I}{t}$$

D_I **= ID-Controlled Pipe Inside Diameter, in.**

TABLE 1-1
Hydrostatic Design Stress and Service Temperatures

Property	Standard	PE 2606, PE2706	PE 2708, PE 3608, PE 3708, PE 4608	PE 3710, PE 4710
Hydrostatic Design Stress, HDS at 73°F (23°C)	ASTM D2837 & PPI TR-3	630 psi (4.6 MPa)	800 psi (5.5 MPa)	1000 psi (6.9 MPa)
Maximum recommended operating temperature for Pressure Service*	-	140°F (60°C)	140°F (60°C)	140°F (60°C)
Maximum recommended operating temperature for Non-Pressure Service	-	180°F (82°C)	180°F (82°C)	180°F (82°C)

* Some PE piping materials are stress rated at temperatures as high as 180°F. For more information regarding these materials and their use, the reader is referred to PPI, TR-4.

The Hydrostatic Design Stress, HDS, is the safe long-term circumferential stress that PE pipe can withstand. It is derived by applying an appropriate design factor, DF, to the Hydrostatic Design Basis, HDB. The method for establishing the Hydrostatic Design Stress for PE pipe is described in Chapters 3 and 5.

At the time of this printing, AWWA is in the process of revising AWWA C906 to incorporate PE4710 material and to use the HDS values in Table 1-1. The version in effect at the time of this printing, AWWA C906-07, limits the maximum Hydrostatic Design Stress to 800 psi for HDPE and to 630 psi for MDPE. AWWA C901-08 has been revised to incorporate the materials listed in Table 1-1.

The Environmental Application Factor is used to adjust the pressure rating of the pipe in environments where specific chemicals are known to have an effect on PE and therefore require derating as described in Chapter 3. Table 1-2 gives Environmental Applications Factors, A_F, which should only be applied to pressure equations (see Equations 1-1 and 1-2) based on the HDS, not the HDB.

TABLE 1-2
PE Pipe Environmental Application Factors (A_F)*

Pipe Environment	Environmental Application Factor (A_F) at 73ºF (23ºC)
Water: Aqueous solutions of salts, acids and bases; Sewage; Wastewater; Alcohols; Glycols (anti-freeze solutions)	1.0
Nitrogen; Carbon dioxide; Methane; Hydrogen sulfide; Non-Federally regulated applications involving dry natural gas or other non-reactive gases	1.0
Fluids such as solvating/permeating chemicals in pipe or soil (typically hydrocarbons) in 2% or greater concentration, natural or other fuel-gas liquids condensates, crude oil, fuel oil, gasoline, diesel, kerosene, hydrocarbon fuels, wet gas gathering, multiphase oilfield fluids, LVP liquid hydrocarbons, oilfield water containing >2% hydrocarbons.	0.5

* Certain codes and standards include prohibitions and/or strength reduction factors relating to the presence of certain constituents in the fluid being transported. In a code controlled application the designer must ensure compliance with all code requirements.

When choosing the environmental applications factor (A_F), consideration must be given to Codes and Regulations, the fluid being transported, the external environment, and the uncertainty associated with the design conditions of internal pressure and external loads.

The pressure rating (PR) for PE pipe in water at 73ºF over the range of typical DR's is given in Tables 1-3 A and 1-3 B in this chapter.

Pressure Rating for Fuel Gas Pipe

Compared to other common thermoplastic pipes, PE pipe can be used over a broader temperature range. For pressure applications, it has been successfully used from -40ºF (-40ºC) to 140ºF (60ºC). In the case of buried non-pressure applications it has been used for conveying fluids that are at temperatures as high as 180°F (82°C). See Table 1-1. For pressure applications above 80ºF (27ºC) the Service Temperature Design Factor is applied to determine the pressure rating. See Table A.2 in the Appendix to Chapter 3.

The pressure rating for gas distribution and transmission pipe in US federally regulated applications is determined by Title 49, Transportation, of The Code of Federal Regulations. Part 192 of this code, which covers the transportation of natural and other gases, requires that the maximum pressure rating (PR) of a PE pipe be determined based on an HDS that is equal to the material's HDB times a DF of 0.32. (See Chapter 5 for a discussion of the Design Factor, DF.) This is the equivalent of saying that for high density PE pipe meeting the requirements of ASTM D2513 the HDS is 500 psi at 73ºF and for medium density PE pipe meeting D2513 the HDS is 400 psi at 73ºF. There are additional restrictions imposed by this Code, such as the maximum pressure at which a PE pipe may be operated (which at the time of this writing is 125 psi for pipe 12-in and smaller and 100 psi for pipe larger than 12-in through 24-in.) and the acceptable range of operating temperatures. The temperature design factors for federally regulated pipes are different than those given in Table A.2 in the Appendix to Chapter 3. Consult with the Federal Regulations to obtain the correct temperature design factor for gas distribution piping.

At the time of this writing, there is an effort underway to amend the US federal code to reflect changes already incorporated in ASTM F714 and D3035. When amended, these changes will increase the pressure rating (PR) of pipe made with high performance PR resins - those that meet the higher performance criteria listed in Chapter 5 (see "Determining the Appropriate Value of HDS"), to be 25% greater than pressure ratings of pipe made with 'traditional' resins.

In Canada gas distribution pipe is regulated per CSA Z662-07. CSA allows a design factor of 0.4 to be applied to the HDB to obtain the HDS for gas distribution pipe.

PE pipe meeting the requirements of ASTM D2513 may be used for the regulated distribution and transmission of liquefied petroleum gas (LPG). NFPA/ANSI 58 recommends a maximum operating pressure of 30 psig for LPG gas applications involving polyethylene pipe. This design limit is established in recognition of the higher condensation temperature for LPG as compared to that of natural gas and, thus, the maximum operating pressure is recommended to ensure that plastic pipe is not subjected to excessive exposure to LPG condensates. The Environmental Application Factor for LP Gas Vapors (propane, propylene, and butane) is 0.8 with a maximum HDS of 800 psi at 73°F for HDPE and 630 psi for MDPE. For further information the reader is referred to PPI's TR-22, Polyethylene Piping Distribution Systems for Components of Liquid Petroleum Gases.

The pressure rating for PE gas gathering lines in the US may differ depending upon the class location (population density) of the gathering line. Gas gathering lines in Class 2, 3 and 4 locations are regulated applications and subject to US federal codes the same as gas distribution and transmission lines. Gas gathering lines in Class 1 locations are not regulated in accordance with US federal codes, and may be operated at service pressures determined using Equation 1-1. Non-regulated gas gathering lines may use PE pipe meeting ASTM F2619 or API 15LE, and may be larger than 24" diameter. PE pipe meeting ASTM D2513 is not required for non-regulated gas gathering lines.

In Canada, PE gas gathering lines are regulated in accordance with CSA Z662 Clause 13.3 and are required to meet API 15LE. PE gas gathering lines may be operated at service pressures equivalent to those determined using Equation 1-1.

Pressure Rating for Liquid Flow Surge Pressure

Surge pressure events, which give rise to a rapid and temporary increase in pressure in excess of the steady state condition, are the result of a very rapid change in velocity of a flowing liquid. Generally, it is the fast closing of valves and uncontrolled pump shutdowns that cause the most severe changes and oscillations in fluid velocity and, consequently in temporary major pressure oscillations. Sudden changes in demand can also lead to lesser but more frequent pressure oscillations. For many pipe materials repeated and frequent pressure oscillations can cause gradual and cumulative fatigue damage which necessitate specifying higher pressure class pipes than determined solely based on sustained pressure requirements. And, for those pipe materials a higher pressure class may also be required for avoiding pipe rupture under the effect of occasional but more severe high-pressure peaks. Two properties distinguish PE pipes from these other kinds of pipes. The first is that because of their lower stiffness the peak value of a surge pressures that is generated by a sudden change in velocity is significantly lower than for higher stiffness pipes such as metallic pipes. And, the second is that a higher pressure rating (PR), or pressure class (PC), is generally not required to cope with the effects of pressure surges. Research, backed by extensive actual experience, indicates that PE pipes can safely tolerate the commonly observed maximum peak temporary surge pressure of twice the steady state condition. Furthermore, the long-term strength of PE pipes is not adversely affected by repeated cyclic loading – that is, PE pipes are very fatigue resistant.

In the design of PE pipe, pressure surges are generally classified as Occasional pressure surges, Recurring pressure surges, and Negative pressures.

- Occasional surge pressures are caused by emergency operations such as fire flow or as a result of a malfunction, such as a power failure or system component failure, which includes pump seize-up, valve stem failure and pressure relief valve failure.
- Recurring surge pressures are inherent to the design and operation of a system. Recurring surge pressures can be caused by normal pump start up or shut down, normal valve opening and closing, and/or "background" pressure fluctuations associated with normal pipe operation.
- Negative pressure may be created by a surge event and cause a localized collapse by buckling. (Negative pressure may also occur inside flowing pipelines due to improper hydraulic design.)

In recognition of the performance behavior of PE pipes the following design principles have been adopted by AWWA for all PE pressure class (PC) rated pipes. These design principles, which are as follows, are also applicable to PE water pipes that are pressure rated (PR) in accordance with ASTM and CSA standards:

1. Resistance to Occasional Pressure Surges:

- The resultant total pressure – sustained plus surge – must not exceed 2.0 times the pipe's temperature compensated pressure rating (PR). See Tables 1-3 A and 1-3 B for standard surge allowances when the pipe is operated at its full rated pressure.
- In the rare case where the resultant total pressure exceeds 2.0 times the pipe's temperature adjusted PR, the pipe must be operated at a reduced pressure so that the above criterion is satisfied. In this event the pipe's reduced pressure rating is sometimes referred to as the pipe's "working pressure rating" (WPR), meaning that for a specific set of operating conditions (temperature, velocity, and surge) this is the pipe's pressure rating. AWWA uses the term WPR not just for a reduced pressure rating but for any pressure rating based on application specific conditions. Where the total pressure during surge does not exceed the standard allowance of 2.0 (occasional) and 1.5 (recurring) the WPR equals the temperature adjusted PR.
- The maximum sustained pressure must never exceed the pipe's temperature adjusted pressure rating (PR).

Example:

A PE pipe has a DR = 17 and is made from a PE4710 material. Accordingly, its standard pressure rating (PR) for water, at 73°F is 125 psi (See Table A.1 in Appendix to Chapter 3). The maximum sustained water temperature shall remain below 73°F. Accordingly, no temperature compensation is required and therefore, the pipe's initial WPR is equal to its standard PR or, 125 psi.

Let us first assume that the maximum occasional surge pressure shall never exceed 120 psi. Since a WPR of 125 psi plus a surge of 120 psi is less than 2 times 125 psi the pipe's initial WPR of 125 psi remains at that value.

Now let us assume a second case in which the maximum occasional surge pressure can be as high as 150 psi. This pressure plus the pipe's initial WPR of 125 psi result in a total momentary pressure of 275 psi, which is 25 psi above the limit of 2 x 125 psi = 250 psi. To accommodate this 25 psi excess it is necessary to reduce the pipe's initial WPR of 125 to a final WPR of 100 psi.

2. Resistance to Recurring Pressure Surges:

- The resultant total momentary pressure – sustained plus surge – must not exceed 1.5 times the pipe's temperature adjusted pressure rating (PR). See Tables 1-3 A and 1-3 B for standard surge allowance when the pipe is operated at its full rated pressure.
- In the rare case where the resultant total pressure exceeds 1.5 times the pipe's temperature adjusted PR the pressure rating must be reduced to the pipe's WPR so that the above criterion is satisfied.
- The maximum sustained pressure must never exceed the pipe's temperature adjusted PR.

3. Resistance to Localized Buckling When Subjected to a Negative Pressure Generated by a Surge Event

A buried pipe's resistance to localized buckling while under the combined effect of external pressure and a very temporary full vacuum should provide an adequate margin of safety. The design for achieving this objective is discussed in a later section of this chapter. It has been shown that a DR21 pipe can withstand a recurring negative pressure surge equal to a full vacuum at 73°F. Higher DR pipes may also be able to withstand a recurring negative surge equal to full vacuum if they are properly installed and have soil support. Their resistance may be calculated using Luscher's Equation presented later in this chapter.

Estimating the Magnitude of Pressure Surges

Regardless of the type of pipe being used surge or water hammer problems can be complex especially in interconnected water networks and they are best evaluated by conducting a formal surge analysis (See References 25 and 32). For all water networks, rising mains, trunk mains and special pump/valve circumstances a detailed surge analysis provides the best way of anticipating and designing for surge.

Absent a formal surge analysis, an estimate of the magnitude of a surge pressure can be made by evaluating the surge pressure that results from an anticipated sudden change in velocity in the water flowing inside a PE pipe.

An abrupt change in the velocity of a flowing liquid in a pipe generates a pressure wave. The velocity of the wave may be determined using Equation 1-5.

(1-5)

$$a = \frac{4660}{\sqrt{1 + \frac{K_{BULK}}{E_d}(DR - 2)}}$$

WHERE

a = Wave velocity (celerity), ft/sec

K_{BULK} = Bulk modulus of fluid at working temperature (typically 300,000 psi for water at 73°F)

E_d = Dynamic instantaneous effective modulus of pipe material (typically 150,000 psi for all PE pipe at 73°F (23°C)); see Appendix to Chapter 3

DR = Pipe dimension ratio

The resultant transient surge pressure, Ps, may be calculated from the wave velocity, a, and the sudden change in fluid velocity, ΔV.

(1-6)

$$P_s = a\left(\frac{\Delta V}{2.31g}\right)$$

WHERE

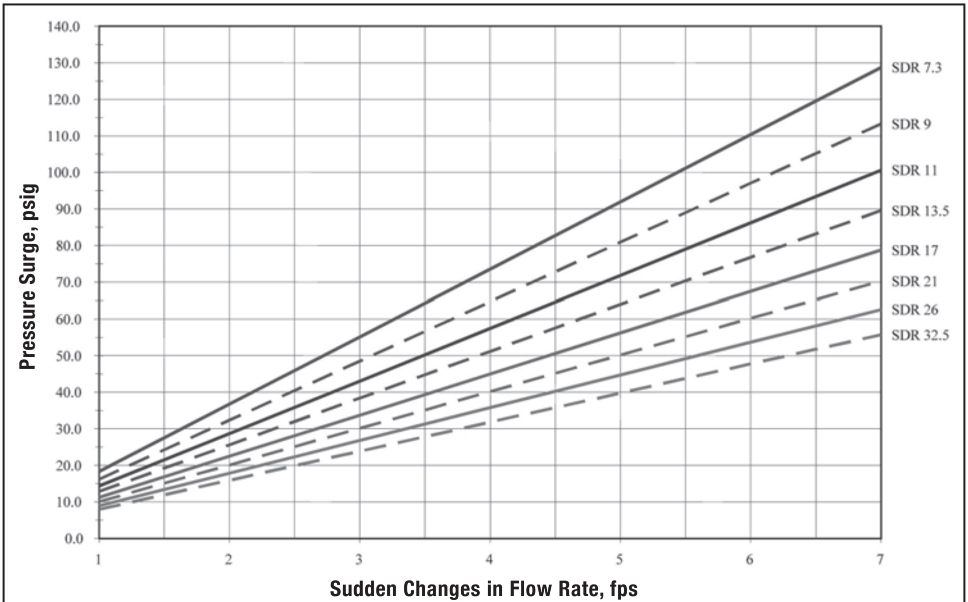
P_S = Transient surge pressure, psig

a = Wave velocity (celerity), ft/sec

ΔV = Sudden velocity change, ft/sec

g = Constant of gravitational acceleration, 32.2 ft/sec^2

Figure 1-1 represents the pressure surge curves for all PE pipes as calculated using Equations 1-5 and 1-6 for Standard Dimension Ratios (SDR's).



* A value of 150,000 psi and 300,000 psi were used for E_d and K, respectively.

** Calculated surge pressure values applicable to water at temperatures not exceeding 80°F (27°C).

Figure 1-1 Sudden Velocity Change vs. Pressure Surge for All PE Pipes

The surge pressure values in Figure 1-1 are based on a sudden change in velocity, which may more often be the case for events like a sudden pump shut-down or a rapid valve closure. A sudden shut-down or a rapid closure occurs faster than the "critical time" (the time it takes a pressure wave initiated at the beginning of a valve closing to return again to the valve). Under ordinary operations, during which valve closings and pump shut-downs are slower than the "critical time", the actual pressure surge is smaller than that in Figure 1-1. The "critical time" is determined by means of the following relationship:

(1-7) $$T_{CR} = 2L/a$$

WHERE

T_{CR} = **critical time, seconds**

L = **distance within the pipeline that the pressure wave moves before it is reflected back by a boundary condition, ft**

a = **wave velocity (celerity) of pressure wave for the particular pipe, ft/s. (See Equation 1-5)**

Generally, PE pipe's capacity for safely tolerating occasional and frequently occurring surges is such that seldom are surge pressures large enough to require a de-rating of the pipe's static pressure rating. Tables 1-3 A and 1-3 B show the maximum allowable sudden changes in water flow velocity (ΔV) that are safely tolerated without the need to de-rate the pressure rating (PR) or, the pressure class (PC), of a PE pipe. If sudden changes in velocity are expected to be greater than the values shown in these Tables, they then must be accommodated by lowering the pipe's static pressure rating. As previously discussed, the new rating is called the working pressure rating (WPR).The procedure for establishing a WPR has been discussed earlier in this Section.

TABLE 1-3A

Allowances for Momentary Surge Pressures Above PR or PC for Pipes Made From PE4710 and PE3710 Materials[1].

Pipe Standard Diameter Ratio (SDR)	Standard Static Pressure Rating (PR) or, Standard Pressure Class (PC) for water @ 73°F, psig	Standard Allowance for Momentary Surge Pressure Above the Pipe's PR or PC			
		Allowance for Recurring Surge		Allowance for Occasional Surge	
		Allowable Surge Pressure, psig	Resultant Allowable Sudden Change in Velocity, fps	Allowable Surge Pressure, psig	Resultant Allowable Sudden Change in Velocity, fps
32.5	63	32	4.0	63	8.0
26	80	40	4.5	80	9.0
21	100	50	5.0	100	10.0
17	125	63	5.6	125	11.2
13.5	160	80	6.2	160	12.4
11	200	100	7.0	200	14.0
9	250	125	7.7	250	15.4
7.3	320	160	8.7	320	17.4

1. AWWA C906-07 limits the maximum Pressure Class of PE pipe to the values shown in Table B. At the time of this printing C906 is being revised to allow PC values in Table A to be used for PE3710 and PE4710 materials. Check the latest version of C906

TABLE 1-3 B

Allowances for Momentary Surge Pressures Above PR or PC for Pipes Made from PE 2708, PE3408, PE3608, PE3708 and PE4708 Materials.

Pipe Standard Diameter Ratio (SDR)	Standard Static Pressure Rating (PR) or, Standard Pressure Class (PC), for Water @ 73°F, psig	Standard Allowance for Momentary Surge Pressure Above the Pipe's PR or PC			
		Allowance for Recurring Surge		Allowance for Occasional Surge	
		Allowable Surge Pressure, psig	Resultant Allowable Sudden Change in Velocity, fps	Allowable Surge Pressure, psig	Resultant Allowable Sudden Change in Velocity, fps
32.5	50	25	3.1	50	6.2
26	63	32	3.6	63	7.2
21	80	40	4.0	80	8.0
17	100	50	4.4	100	8.8
13.5	125	63	4.9	125	9.8
11	160	80	5.6	160	11.2
9	200	100	6.2	200	12.4
7.3	250	125	6.8	250	13.6

The surge pressure allowance in Table 1-3 A and 1-3 B are not the maximum surge limits that the pipe can safely withstand. Higher surge pressures can be tolerated in pipe where the working pressure rating (WPR) of the pipe is limited to a pressure less than the pressure rating (PR). This works because the combined total pressure for surge and for pumping pressure is limited to 1.5 times the PR (or PC) for recurring surge and 2.0 times the PR (or PC) for occasional surge. If the pumping pressure is less than the PR (or PC) then a higher surge than the standard allowance given in Table A and B is permitted. The maximum permitted surge pressure is equal to 1.5 x PR – WP for recurring surge and 2.0 x PR – WP for occasional surge, where WP is the pumping or working pressure of the pipeline. For example a DR21 PE4710 pipe with an operating pressure of 80 psi can tolerate a recurring surge pressure of 1.5 x 100 psi – 80 psi = 70 psi. Note that in all cases WP must be equal or less than PR.

Controlling Surge Pressure Reactions

Reducing the rate at which a change in flow velocity occurs is the major means by which surge pressure rises can be minimized. Although PE pipe is very tolerant of such rises, other non-PE components may not be as surge tolerant; therefore, the prudent approach is to minimize the magnitude of surge pressures by taking reasonable precautions to minimize shock. Hydrants, large valves, pumps, and all other hydraulic appurtenances that may suddenly change the velocity of a column of water should be operated slowly, particularly during the portion of travel near valve closing which has the larger effect on rate of flow. If the cause of a major surge can be attributable to pump performance – especially, in the case of an emergency stoppage – then, proper pressure relief mechanisms should be included. These can include traditional solutions such as by providing flywheels or by allowing the pumps to run backwards.

In hilly regions, a liquid flow may separate at high points and cause surge pressures when the flow is suddenly rejoined. In such cases measures should be taken to keep the pipeline full at all times. These can consist of the reducing of the flow rate, of the use at high points of vacuum breakers or, of air relief valve.

Also, potential surge pressure problems should be investigated in the design of pumping station piping, force mains, and long transmission lines. Proven and suitable means should be provided to reduce the effect of surges to a minimum that is practicable and economical. Although PE pipe is much more tolerant of the effect of sudden pressure increases traditional measures should be employed for the minimizing of the occurrence of such increases.

Section 2
Hydraulic Design of PE Pipe

This section provides design information for determining the required flow diameter for PE pipe. It also covers the following topics: general fluid flows in pipe and fittings, liquid (water and water slurry) flow under pressure, non-pressure(gravity) liquid flow, and compressible gas flow under pressure. Network flow analysis and design is not addressed. [1,2]

The procedure for piping system design is frequently an iterative process. For pressure liquid flows, initial choice of pipe flow diameter and resultant combinations of sustained internal pressure, surge pressure, and head loss pressure can affect pipe selection. For non-pressure systems, piping design typically requires selecting a pipe size that provides adequate reserve flow capacity and a wall thickness or profile design that sufficiently resists anticipated static and dynamic earthloads. This trial pipe is evaluated to determine if it is appropriate for the design requirements of the application. Evaluation may show that a different size or external load capacity may be required and, if so, a different pipe is selected then reevaluated. The Appendix to Chapter 3 provides engineering data for PE pipes made to industry standards that are discussed in this chapter and throughout this handbook.

Pipe ID for Flow Calculations

Thermoplastic pipes are generally produced in accordance with a dimension ratio (DR) system. The dimension ratio, DR or IDR, is the ratio of the pipe diameter to the respective minimum wall thickness, either OD or ID, respectively. As the diameter changes, the pressure rating remains constant for the same material, dimension ratio and application. The exception to this practice is production of thermoplastic pipe in accordance with the industry established SCH 40 and SCH 80 dimensions such as referenced in ASTM D 2447.

Flow Diameter for Outside Diameter Controlled Pipe

OD-controlled pipe is dimensioned by outside diameter and wall thickness. Several sizing systems are used including IPS, which specifies the same OD's as iron pipe sized (IPS) pipe: DIPS pipe which specifies the same OD's as ductile iron pipe; and CTS, which specifies the same OD's as copper tubing sizes. For flow calculations, inside diameter is calculated by deducting twice the average wall thickness from the specified outside diameter. OD-controlled pipe standards include ASTM D2513, ASTM D2737, ASTM D2447, ASTM D3035, ASTM F714, AWWA C901, AWWA C906 and API 15LE.[3,4,5,6,7,8,9,10] The Appendix to this chapter provides specific dimensional information for outside diameter controlled PE pipe and tubing that is made to dimension ratio (DR) requirements in accordance with a number of different ASTM, AWWA, CSA and API standards.

The average inside diameter for such pipes has been calculated using Equation 2-1. Typically, wall thickness is specified as a minimum dimension, and a plus 12% tolerance is applied. In this equation, the average ID is determined by deducting twice the average wall thickness (minimum wall thickness plus a tolerance of 6%) from the average outside diameter.

(2-1)
$$D_I = D_O - 2.12\left(\frac{D_O}{DR}\right)$$

WHERE
D_I **= pipe average inside diameter, in**
D_O **= specified average value of pipe outside diameter, in**
DR **= dimension ratio**

(2-2)
$$DR = \frac{D_O}{t}$$

t = pipe minimum wall thickness, in

Pipe Diameter for ID Controlled Pipe

Standards for inside diameter controlled pipes provide average dimensions for the pipe inside diameter that are used for flow calculations. ID-controlled pipe standards include ASTM D2104, ASTM D2239, ASTM F894 and AWWA C901. [11,12,13]

The terms "DR" and "IDR" identify the diameter to wall thickness dimension ratios for outside diameter controlled and inside diameter controlled pipe, respectively. When those ratios comply with standard values they are called "standard dimension ratios", that is SDR or SIDR. A discussion of standard dimension ratios is included in Chapter 5.

Fluid Flow in PE Piping

Head Loss in Pipes – Darcy-Weisbach/Colebrook/Moody

Viscous shear stresses within the liquid and friction along the pipe walls create resistance to flow within a pipe. This resistance results in a pressure drop, or loss of head in the piping system.

The Darcy-Weisbach formula, Equation 2-3., and the Colebrook formula, Equation 2-6, are generally accepted methods for calculating friction losses due to liquids flowing in full pipes.[15,16] These formulas recognize dependence on pipe bore and pipe surface characteristics, liquid viscosity and flow velocity.

The Darcy-Weisbach formula is:

(2-3)
$$h_f = f \frac{L V^2}{d' 2g}$$

WHERE

h_f = **friction (head) loss, ft. of liquid**

L = **pipeline length, ft.**

d' = **pipe inside diameter, ft.**

V = **flow velocity, ft/sec.**

f = **friction factor (dimensionless, but dependent upon pipe surface roughness and Reynolds number)**

g = **constant of gravitational acceleration (32.2ft/sec^2)**

The flow velocity may be computed by means of the following equation

(2-4)
$$V = \frac{0.4085 \ Q}{D_1^{\ 2}}$$

WHERE

Q = **flow rate, gpm**

D_I = **pipe inside diameter, in**

Liquid flow in pipes will assume one of three flow regimes. The flow regime may be laminar, turbulent or in transition between laminar and turbulent. In laminar flow (Reynolds number, Re, below 2000), the pipe's surface roughness has no effect and is considered negligible. As such, the friction factor, *f*, is calculated using Equation 2-5.

(2-5)
$$f = \frac{64}{\text{Re}}$$

WHERE

Re = **Reynolds number, dimensionless = < 2000 for laminar flow, see Equation 2-7**

> 4000 for turbulent flow, see Figure 2-1

For turbulent flow (Reynolds number, Re, above 4000), the friction factor, *f*, is dependent on two factors, the Reynolds number and pipe surface roughness. The resultant friction factor may be determined from Figure 2-1, the Moody Diagram. This factor applies to all kinds of PE's and to all pipe sizes[17]. In the Moody Diagram, relative roughness, ε/d (see Table 2-1 for ε) is used which is the ratio of absolute roughness to the pipe inside diameter. The friction factor may also be determined using the Colebrook formula. The friction factor can also be read from the Moody diagram with enough accuracy for calculation.

The Colebrook formula is:

(2-6)
$$\frac{1}{\sqrt{f}} = -2\log_{10}\left\{\frac{\varepsilon}{3.7d'} + \frac{2.51}{\mathrm{Re}\sqrt{f}}\right\}$$

For Formulas 2-5 and 2-6, terms are as previously defined, and:

ε = absolute roughness, ft. (see Table 2-1)

R_e = Reynolds number, dimensionless (see Equation 2-5)

Liquid flow in a pipe occurs in one of three flow regimes. It can be laminar, turbulent or in transition between laminar and turbulent. The nature of the flow depends on the pipe diameter, the density and viscosity of the flowing fluid, and the velocity of flow. The numerical value of a dimensionless combination of these parameters is known as the Reynolds number and the resultant value of this number is a predictor of the nature of the flow. One form of the equation for the computing of this number is as follows:

(2-7)
$$Re = \frac{3160\,Q}{k\,Di}$$

WHERE

Q = rate of flow, gallons per minute

k = kinematic viscosity, in centistokes (See Table 2-3 for values for water)

Di = internal diameter of pipe, in

When the friction loss through one size pipe is known, the friction loss through another pipe of different size may be found by:

(2-8)
$$h_{f2} = h_{f1}\left(\frac{d'_1}{d'_2}\right)^5$$

The subscripts 1 and 2 refer to the known and unknown pipes. Both pipes must have the same surface roughness, and the fluid must be the same viscosity and have the same flow rate.

TABLE 2-1
Surface Roughness for Various New Pipes

Type of Pipe	'Ɛ' Absolute Roughness of Surface, ft		
	Values for New Pipe Reported by Reference (18)	Values for New Pipe and Recommended Design Values Reported by Reference (19)	
		Mean Value	Recommended Design Value
Riveted steel	0.03 - 0.003	–	–
Concrete	0.01 – 0.001	–	–
Wood stave	0.0003 – 0.0006	–	–
Cast Iron – Uncoated	0.00085	0.00074	0.00083
Cast Iron – Coated	–	0.00033	0.00042
Galvanized Iron	0.00050	0.00033	0.00042
Cast Iron – Asphalt Dipped	0.0004	–	–
Commercial Steel or Wrought Iron	0.00015	–	–
Drawn Tubing	0.000005 corresponds to "smooth pipe"	–	–
Uncoated Stee	–	0.00009	0.00013
Coated Steel	–	0.00018	0.00018
Uncoated Asbestos – Cement	–		
Cement Mortar Relined Pipes (Tate Process)	–	0.00167	0.00167
Smooth Pipes (PE and other thermoplastics, Brass, Glass and Lead)	–	"smooth pipe" (0.000005 feet) (See Note)	"smooth pipe" (0.000005) (See Note)

Note: Pipes that have absolute roughness equal to or less than 0.000005 feet are considered to exhibit "smooth pipe" characteristics.

Pipe Deflection Effects

Pipe flow formulas generally assume round pipe. Because of its flexibility, buried PE pipe will deform slightly under earth and other loads to assume somewhat of an elliptical shape having a slightly increased lateral diameter and a correspondingly reduced vertical diameter. Elliptical deformation slightly reduces the pipe's flow area. Practically speaking, this phenomenon can be considered negligible as it relates to pipe flow capacity. Calculations reveal that an elliptical deformation which reduces the pipe's vertical diameter by 7% results in a flow reduction of approximately 1%.

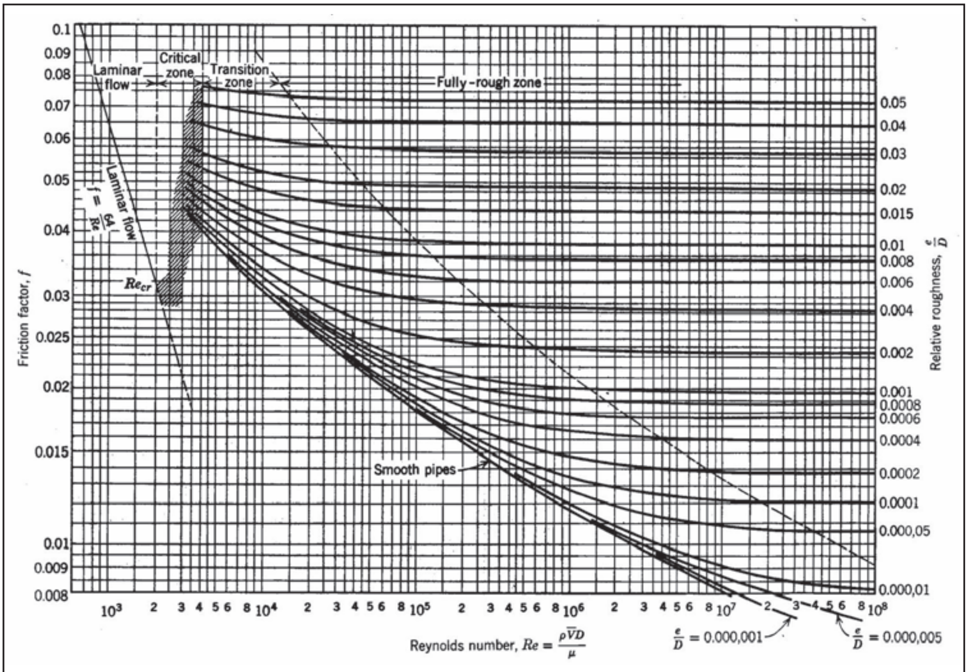


Figure 2-1 The Moody Diagram

Head Loss in Fittings

Fluids flowing through a fitting or valve will experience a friction loss that can be directly expressed using a resistance coefficient, K', which represents the loss in terms of an equivalent length of pipe of the same diameter.[20] As shown in the discussion that follows, this allows the loss through a fitting to be conveniently added into the system flow calculations. Table 2-2 presents K' factors for various fittings.

Where a pipeline contains a large number of fittings in close proximity to each other, this simplified method of predicting flow loss may not be adequate due to the cumulative systems effect. Where this is a design consideration, the designer should consider an additional frictional loss allowance, or a more thorough treatment of the fluid mechanics.

The equivalent length of pipe to be used to estimate the friction loss due to fittings may be obtained by Eq. 2-9 where L_{EFF} = Effective Pipeline length, ft; D is pipe bore diameter in ft.; and K' is obtained from Table 2-2.

(2-9) $$L_{EFF} = K'D$$

TABLE 2-2
Representative Fittings Factor, K', To Determine Equivalent Length of Pipe

Piping Component	K'
90° Molded Elbow	40
45° Molded elbow	21
15° Molded Elbow	6
90° Fabricated Elbow (3 or more miters)	24
90° Fabricated Elbow (2 miters)	30
90° Fabricated Elbow (1 miters)	60
60° Fabricated Elbow (2 or more miters)	25
60° Fabricated Elbow (1 miters)	16
45° Fabricated Elbow (2 or more miters)	15
45° Fabricated Elbow (1 miters)	12
30° Fabricated Elbow (2 or more miters)	8
30° Fabricated Elbow (1 miters)	8
15° Fabricated Elbow (1 miters)	6
Equal Outlet Tee, Run/Branch	60
Equal Outlet Tee, Run/Run	20
Globe Valve, Conventional, Fully Open	340
Angle Valve, Conventional, Fully Open	145
Butterfly Valve, >8", Fully Open	40
Check Valve, Conventional Swing	135

- K values are based on Crane Technical Paper No 410-C
- K value for Molded Elbows is based on a radius that is 1.5 times the diameter.
- K value for Fabricated Elbows is based on a radius that is approximately 3 times the diameter.

Head Loss Due to Elevation Change

Line pressure may be lost or gained from a change in elevation. For liquids, the pressure for a given elevation change is given by:

(2-10) $$h_E = h_2 - h_1$$

WHERE

h_E = Elevation head, ft of liquid

h_1 = Pipeline elevation at point 1, ft

h_2 = Pipeline elevation at point 2, ft

If a pipeline is subject to a uniform elevation rise or fall along its length, the two points would be the elevations at each end of the line. However, some pipelines may have several elevation changes as they traverse rolling or mountainous terrain. These pipelines may be evaluated by choosing appropriate points where the pipeline slope changes, then summing the individual elevation heads for an overall pipeline elevation head.

In a pipeline conveying liquids and running full, pressure in the pipe due to elevation exists whether or not liquid is flowing. At any low point in the line, internal pressure will be equal to the height of the liquid above the point multiplied by the specific weight of the liquid. If liquid is flowing in the line, elevation head and head loss due to liquid flow in the pipe are added to determine the pressure in the pipe at a given point in the pipeline.

Pressure Flow of Water – Hazen-Williams Equation

The Darcy-Weisbach method of flow resistance calculation may be applied to liquid and gases, but its solution can be complex. For many applications, empirical formulas are available and, when used within their limitations, reliable results are obtained with greater convenience. For example, Hazen and Williams developed an empirical formula for the flow of water in pipes at 60° F.

The Hazen-Williams formula for water at 60° F (16°C) can be applied to water and other liquids having the same kinematic viscosity of 1.130 centistokes which equals 0.00001211 ft^2/sec or 31.5 SSU (Saybolt Second Universal). The viscosity of water varies with temperature, so some error can occur at temperatures other than 60°F (16°C).

Hazen-Williams formula for friction (head) loss in feet of water head:

(2-11)

$$h_f = \frac{0.002083\,L}{{D_I}^{4.8655}}\left(\frac{100\,Q}{C}\right)^{1.85}$$

Hazen-Williams formula for friction (head) loss in psi:

(2-12)

$$p_f = \frac{0.0009015\mathrm{L}}{{D_I}^{4.8655}}\left(\frac{100\,Q}{C}\right)^{1.85}$$

Terms are as previously defined, and:

h_f = **friction (head) loss, ft. of water.**

p_f = **friction (head) loss, psi**

D_I = **pipe inside diameter, in**

C = **Hazen-Williams Friction Factor, dimensionless c = 150-155 for PE , (not related to Darcy-Weisbach friction factor, *ƒ*)**

Q = **flow rate, gpm**

The Hazen-Williams Friction Factor, C, for PE pipe was determined in a hydraulics laboratory using heat fusion joined lengths of pipe with the inner bead present. Other forms of these equations are prevalent throughout the literature.[21] The reader is referred to the references at the end of this chapter.

TABLE 2-3
Properties of Water

Temperature, °F/°C	Specific Weight, lb/ft^3	Kinematic Viscosity, Centistokes
32 / 0	62.41	1.79
60 / 15.6	62.37	1.13
75 / 23.9	62.27	0.90
100 / 37.8	62.00	0.69
120 / 48.9	61.71	0.57
140 / 60	61.38	0.47

Water flow through pipes having different Hazen-Williams factors and different flow diameters may be determined using the following equations:

(2-13)

$$\%\,flow = 100\left(\frac{D_{I2}}{D_{I1}}\right)^{2.63}\left(\frac{C_2}{C_1}\right)$$

Where the subscripts 1 and 2 refer to the designated properties for two separate pipe profiles, in this case, the pipe inside diameter (D_I in inches) of the one pipe (1) versus that of the second pipe (2) and the Hazen-Williams factor for each respective profile.

Pipe Flow Design Example

A PE pipeline conveying water at 60°F is 15,000 feet long and is laid on a uniform grade that rises 150 feet. What is the friction head loss in 4" IPS DR 17 PE 3408 pipe for a 50 gpm flow? What is the elevation head? What is the internal pressure at the bottom of the pipe when water is flowing uphill? When flowing downhill? When full but not flowing?

Using equation 2-12 and C = 150

$$p_f = \frac{0.0009015(15000)}{3.938^{4.8655}}\left(\frac{100(50)}{150}\right)^{1.85} = 11.3\ psi$$

To determine the elevation head, assume point 1 is at the bottom of the elevation, and point 2 is at the top. Using Equation 2-10,

$$h_E = 150 - 0 = 150\ ft\ of\ water$$

The specific weight of water at 60°F is 62.37 lb/ft^3 (see Table 2-3), which, for each foot of head exerts a pressure of 62.37 lb over a 1 ft square area, or a pressure of 62.37/144 = 0.43 lb/in^2. Therefore, for a 150 ft. head,

$$h_E = (150 - 0)0.43 = 64.5\ psig$$

When water is flowing, elevation head and the friction head are added. The maximum friction head acts at the source point, and the maximum elevation head at the lowest point. Therefore, when flowing uphill, the pressure, P, at the bottom is elevation head plus the friction head because the flow is from the bottom to the top.

$$P = h_E + p_f = 64.5 + 11.3 = 75.8\, psig$$

When flowing downhill, water flows from the top to the bottom. Friction head applies from the source point at the top, so the pressure developed from the downhill flow is applied in the opposite direction as the elevation head. Therefore,

$$P = h_E - p_f = 64.5 - 11.3 = 53.2\, psig$$

When the pipe is full, but water is not flowing, no friction head develops.

$$P = h_E + p_f = 64.5 + 0 = 64.5\, psig$$

Pressure Flow of Liquid Slurries

Liquid slurry piping systems transport solid particles entrained in a liquid carrier. Water is typically used as a liquid carrier, and solid particles are commonly granular materials such as sand, fly-ash or coal. Key design considerations involve the nature of the solid material, it's particle size and the carrier liquid.

Turbulent flow is preferred to ensure that particles are suspended in the liquid. Turbulent flow also reduces pipeline wear because particles suspended in the carrier liquid will bounce off the pipe inside surface. PE pipe has viscoelastic properties that combine with high molecular weight toughness to provide service life that can significantly exceed many metal piping materials. Flow velocity that is too low to maintain fully turbulent flow for a given particle size can allow solids to drift to the bottom of the pipe and slide along the surface. However, compared to metals, PE is a softer material. Under sliding bed and direct impingement conditions, PE may wear appreciably. PE directional fittings are generally unsuitable for slurry applications because the change of flow direction in the fitting results in direct impingement. Directional fittings in liquid slurry applications should employ hard materials that are resistant to wear from direct impingement.

Particle Size

As a general recommendation, particle size should not exceed about 0.2 in (5 mm), but larger particles are occasionally acceptable if they are a small percentage of the solids in the slurry. With larger particle slurries such as fine sand and coarser particles, the viscosity of the slurry mixture will be approximately that of the carrying liquid. However, if particle size is very small, about 15 microns or less, the slurry viscosity will increase above that of the carrying liquid alone. The rheology of fine particle slurries should be analyzed for viscosity and specific gravity before determining flow friction losses. Inaccurate assumptions of a fluid's rheological properties can lead to significant errors in flow resistance analysis. Examples of fine particle slurries are water slurries of fine silt, clay and kaolin clay.

Slurries frequently do not have uniform particle size, and some particle size non-uniformity can aid in transporting larger particles. In slurries having a large proportion of smaller particles, the fine particle mixture acts as a more viscous carrying fluid that helps suspend larger particles. Flow analysis of non-uniform particle size slurries should include a rheological characterization of the fine particle mixture.

Solids Concentration and Specific Gravity

Equations 2-14 through 2-17 are useful in determining solids concentrations and mixture specific gravity. Tables 2-4, 2-5, and 2-6 provide information about specific gravity and particle size of some slurries.

(2-14)
$$C_V = \frac{S_M - S_L}{S_S - S_L}$$

(2-15)
$$C_W = \frac{C_V S_S}{S_M}$$

(2-16)
$$S_M = C_V \left(S_S - S_L \right) + S_L$$

(2-17)
$$S_M = \frac{S_L}{1 - \frac{C_W \left(S_S - S_L \right)}{S_S}}$$

WHERE

S_L **= carrier liquid specific gravity**

S_S **= solids specific gravity**

S_M **= slurry mixture specific gravity**

C_V **= percent solids concentration by volume**

C_W **= percent solids concentration by weight**

Critical Velocity

As pointed out above, turbulent flow is preferred to maintain particle suspension. A turbulent flow regime avoids the formation of a sliding bed of solids, excessive pipeline wear and possible clogging. Reynolds numbers above 4000 will generally insure turbulent flow.

Maintaining the flow velocity of a slurry at about 30% above the critical settlement velocity is a good practice. This insures that the particles will remain in suspension thereby avoiding the potential for excessive pipeline wear. For horizontal pipes, critical velocity may be estimated using Equation 2-18.

Individual experience with this equation varies. Other relationships are offered in the literature. See Thompson and Aude [26]. A test section may be installed to verify applicability of this equation for specific projects.

(2-18)
$$V_C = F_L \sqrt{2gd' \left(S_S - 1\right)}$$

Where terms are previously defined and

V_C **= critical settlement velocity, ft/sec**

F_L **= velocity coefficient (Tables 2-7 and 2-8)**

d' **= pipe inside diameter, ft**

An approximate minimum velocity for fine particle slurries (below 50 microns, 0.05 mm) is 4 to 7 ft/sec, provided turbulent flow is maintained. A guideline minimum velocity for larger particle slurries (over 150 microns, 0.15 mm) is provided by Equation 2-19.

(2-19)
$$V_{min} = 14\sqrt{d'}$$

WHERE

V_{min} **= approximate minimum velocity, ft/sec**

Critical settlement velocity and minimum velocity for turbulent flow increases with increasing pipe bore. The relationship in Equation 2-20 is derived from the Darcy-Weisbach equation. (Equation 2-3)

(2-20)
$$V_2 = \frac{\sqrt{d'_2}}{\sqrt{d'_1}} V_1$$

The subscripts 1 and 2 are for the two pipe diameters.

TABLE 2-4
Scale of Particle Sizes

Tyler Screen Mesh	U.S. Standard Mesh	Inches	Microns	Class
–	–	1.3 – 2.5	33,000 – 63,500	Very coarse gravel
–	–	0.6 – 1.3	15,200 – 32,000	Coarse gravel
2.5	–	0.321	8,000	Medium gravel
5	5	0.157	4,000	Fine gravel
9	10	0.079	2,000	Very fine gravel
16	18	0.039	1,000	Very coarse sand
32	35	0.0197	500	Coarse sand
60	60	0.0098	250	Medium sand
115	120	0.0049	125	Fine sand
250	230	0.0024	62	Very fine sand
400	–	0.0015	37	Coarse silt
–	–	0.0006 – 0.0012	16 – 31	Medium silt
–	–	–	8 – 13	Fine silt
–	–	-	4 – 8	Very fine silt
–	–	–	2 – 4	Coarse clay
–	–	–	1 – 2	Medium clay
–	–	–	0.5 - 1	Fine clay

TABLE 2-5
Typical Specific Gravity and Slurry Solids Concentration (Water Slurries)

Material	Specific Gravity	Typical Solids Concentration	
		% by Weight	% by Volume
Gilsonite	1.05	40 –45	39 – 44
Coal	1.40	45 – 55	37 – 47
Sand	2.65	43 – 43	23 – 30
Limestone	2.70	60 – 65	36 – 41
Copper Concentrate	4.30	60 – 65	26 – 30
Iron Ore	4.90	–	–
Iron Sands	1.90	–	–
Magnetite	4.90	60 - 65	23 - 27

TABLE 2-6
Water-Base Slurry Specific Gravities

Concentration by Weight Percent, C_W	Solid Specific Gravity, S_S									
	1.4	1.8	2.2	2.6	3.0	3.4	3.8	4.2	4.6	5.0
5	1.01	1.02	1.03	1.03	1.03	1.04	1.04	1.04	1.04	1.04
10	1.03	1.05	1.06	1.07	1.07	1.08	1.08	1.08	1.08	1.09
15	1.04	1.07	1.09	1.10	1.11	1.12	1.12	1.13	1.13	1.14
20	1.05	1.10	1.12	1.14	1.15	1.16	1.17	1.18	1.19	1.19
25	1.08	1.13	1.16	1.18	1.20	1.21	1.23	1.24	1.24	1.25
30	1.09	1.15	1.20	1.23	1.25	1.27	1.28	1.30	1.31	1.32
35	1.11	1.18	1.24	1.27	1.30	1.33	1.35	1.36	1.38	1.39
40	1.13	1.22	1.28	1.33	1.36	1.39	1.42	1.44	1.46	1.47
45	1.15	1.25	1.33	1.38	1.43	1.47	1.50	1.52	1.54	1.56
50	1.17	1.29	1.38	1.44	1.50	1.55	1.58	1.62	1.64	1.67
55	1.19	1.32	1.43	1.51	1.58	1.63	1.69	1.72	1.76	1.79
60	1.21	1.36	1.49	1.59	1.67	1.73	1.79	1.84	1.89	1.92
65	1.23	1.41	1.55	1.67	1.76	1.85	1.92	1.98	2.04	2.08
70	1.25	1.45	1.62	1.76	1.88	1.98	2.07	2.14	2.21	2.27

TABLE 2-7
Velocity Coefficient, F_L (Uniform Particle Size)

Particle Size, mm	Velocity Coefficient, F_L			
	C_V = 2%	C_V = 5%	C_V = 10%	C_V = 15%
0.1	.76	0.92	0.94	0.96
0.2	0.94	1.08	1.20	1.28
0.4	1.08	1.26	1.41	1.46
0.6	1.15	1.35	1.46	1.50
0.8	1.21	1.39	1.45	1.48
1.0	1.24	1.04	1.42	1.44
1.2	1.27	1.38	1.40	1.40
1.4	1.29	1.36	1.67	1.37
1.6	1.30	1.35	1.35	1.35
1.8	1.32	1.34	1.34	1.34
2.0	1.33	1.34	1.34	1.34
2.2	1.34	1.34	1.34	1.34
2.4	1.34	1.34	1.34	1.34
2.6	1.35	1.35	1.35	1.35
2.8	1.36	1.36	1.36	1.36
≥ 3.0	1.36	1.36	1.36	1.36

TABLE 2-8
Velocity Coefficient, F_L (50% Passing Particle Size)

Particle Size, mm	Velocity Coefficient, F_L			
	C_V = 5%	C_V = 10%	C_V = 20%	C_V = 30%
0.01	0.48	0.48	0.48	0.48
0.02	0.58	0.59	0.60	0.61
0.04	0.70	0.72	0.74	0.76
0.06	0.77	0.79	0.81	0.83
0.08	0.83	0.86	0.86	0.91
0.10	0.85	0.88	0.92	0.95
0.20	0.97	1.00	1.05	1.08
0.40	1.09	1.13	1.18	1.23
0.60	1.15	1.21	1.26	1.30
0.80	1.21	1.25	1.31	1.33
1.0	1.24	1.29	1.33	1.35
2.0	1.33	1.36	1.38	1.40
3.0	1.36	1.38	1.39	1.40

Equation 2-3, Darcy-Weisbach, and Equations 2-11 and 2-12, Hazen-Williams, may be used to determine friction head loss for pressure slurry flows provided the viscosity limitations of the equations are taken into account. Elevation head loss is increased by the specific gravity of the slurry mixture.

(2-21)
$$h_E = S_M\left(h_2 - h_1\right)$$

Compressible Gas Flow

Flow equations for smooth pipe may be used to estimate compressible gas flow through PE pipe.

Empirical Equations for High Pressure Gas Flow

Equations 2-22 through 2-25 are empirical equations used in industry for pressure greater than 1 psig. Calculated results may vary due to the assumptions inherent in the derivation of the equation.

Mueller Equation

(2-22)
$$Q_h = \frac{2826\,D_I^{\,2.725}}{S_g^{\,0.425}}\left(\frac{p_1^{\,2} - p_2^{\,2}}{L}\right)^{0.575}$$

Weymouth Equation

(2-23)
$$Q_h = \frac{2034\,D_I^{\,2.667}}{S_g^{\,0.5}}\left(\frac{p_1^{\,2} - p_2^{\,2}}{L}\right)^{0.5}$$

IGT Distribution Equation

(2-24)

$$Q_h = \frac{2679\, D_I^{\ 2.667}}{S_g^{\ 0.444}} \left(\frac{p_1^{\ 2} - p_2^{\ 2}}{L} \right)^{0.555}$$

Spitzglass Equation

(2-25)

$$Q_h = \frac{3410}{S_g^{\ 0.5}} \left(\frac{p_1^{\ 2} - p_2^{\ 2}}{L} \right)^{0.5} \left(\frac{D_I^{\ 5}}{1 + \frac{3.6}{D_I} + 0.03\, D_I} \right)^{0.5}$$

WHERE

(Equations 2-22 through 2-25)

Q_h **= flow, standard ft^3/hour**

S_g **= gas specific gravity**

p_1 **= inlet pressure, lb/in^2 absolute**

p_2 **= outlet pressure, lb/in^2 absolute**

L **= length, ft**

D_I **= pipe inside diameter, in**

Empirical Equations for Low Pressure Gas Flow

For applications where internal pressures are less than 1 psig, such as landfill gas gathering or wastewater odor control, Equations 2-26 or 2-27 may be used.

Mueller Equation

(2-26)

$$Q_h = \frac{2971\, D_I^{\ 2.725}}{S_g^{\ 0.425}} \left(\frac{h_1 - h_2}{L} \right)^{0.575}$$

Spitzglass Equation

(2-27)

$$Q_h = \frac{3350}{S_g^{\ 0.5}} \left(\frac{h_1 - h_2}{L} \right)^{0.5} \left(\frac{D_I^{\ 5}}{1 + \frac{3.6}{D_I} + 0.03\, D_I} \right)^{0.5}$$

Where terms are previously defined, and

h_1 **= inlet pressure, in H_2O**

h_2 **= outlet pressure, in H_2O**

Gas Permeation

Long distance pipelines carrying compressed gasses may deliver slightly less gas due to gas permeation through the pipe wall. Permeation losses are small, but it may be necessary to distinguish between permeation losses and possible leakage. Equation 2-28 may be used to determine the volume of a gas that will permeate through PE pipe of a given wall thickness:

(2-28)

$$q_P = \frac{K_P A_s \Theta P_A}{t'}$$

WHERE

q_P = **volume of gas permeated, cm^3 (gas at standard temperature and pressure)**

K_P = **permeability constant (Table 2-9);** units: $\frac{\text{Cm}^3 \text{ mil}}{100 \text{ in}^2 \text{ atm day}}$

A_s = **pipe outside wall area in units of 100 square inches**

P_A = **pipe internal pressure, atmospheres (1 atmosphere = 14.7 lb/in^2)**

Θ = **elapsed time, days**

t' = **wall thickness, mils**

TABLE 2-9
Permeability Constants [28]

Gas	K_P
Methane	85
Carbon Monoxide	80
Hydrogen	425

TABLE 2-10
Physical Properties of Gases (Approx. Values at 14.7 psi & 68ºF)

Gas	Chemical Formula	Molecular Weight	Weight Density, lb/ft^3	Specific Gravity, (Relative to Air) S_g
Acetylene (ethylene)	C_2H_2	26.0	0.0682	0.907
Air	–	29.0	0.0752	1.000
Ammonia	NH_3	17.0	0.0448	0.596
Argon	A	39.9	0.1037	1.379
Butane	C_4H_{10}	58.1	0.1554	2.067
Carbon Dioxide	CO_2	44.0	0.1150	1.529
Carbon Monoxide	CO	28.0	0.0727	0.967
Ethane	C_2H_6	30.0	0.0789	1.049
Ethylene	C_2H_4	28.0	0.0733	0.975
Helium	H_e	4.0	0.0104	0.138
Hydrogen Chloride	HCl	36.5	0.0954	1.286
Hydrogen	H	2.0	0.0052	0.070
Hydrogen Sulphide	H_2S	34.1	0.0895	1.190
Methane	CH_4	16.0	0.0417	0.554
Methyl Chloride	CH_3Cl	50.5	0.1342	1.785
Natural Gas	–	19.5	0.0502	0.667
Nitric Oxide	NO	30.0	0.0708	1.037
Nitrogen	N_2	28.0	0.0727	0.967
Nitrous Oxide	N_2O	44.0	0.1151	1.530
Oxygen	O_2	32.0	0.0831	1.105
Propane	C_3H_8	44.1	0.1175	1.562
Propene (Propylene)	C_3H_6	42.1	0.1091	1.451
Sulfur Dioxide	SO_2	64.1	0.1703	2.264
Landfill Gas (approx. value)	–	–	–	1.00
Carbureted Water Gas	–	–	–	0.63
Coal Gas	–	–	–	0.42
Coke-Oven Gas	–	–	–	0.44
Refinery Oil Gas	–	–	–	0.99
Oil Gas (Pacific Coast)	–	–	–	0.47
“Wet” Gas (approximate value)	–	–	–	0.75

Gravity Flow of Liquids

In a pressure pipeline, a pump of some sort, generally provides the energy required to move the fluid through the pipeline. Such pipelines can transport fluids across a level surface, uphill or downhill. Gravity flow lines, on the other hand, utilize the energy associated with the placement of the pipeline discharge below the inlet. Like pressure flow pipelines, friction loss in a gravity flow pipeline depends on viscous shear stresses within the liquid and friction along the wetted surface of the pipe bore.

Some gravity flow piping systems may become very complex, especially if the pipeline grade varies, because friction loss will vary along with the varying grade. Sections of the pipeline may develop internal pressure, or vacuum, and may have varying liquid levels in the pipe bore.

Manning Flow Equation

For open channel water flow under conditions of constant grade, and uniform channel cross section, the Manning equation may be used.[29,30] Open channel flow exists in a pipe when it runs partially full. Like the Hazen-Williams formula, the Manning equation is applicable to water or liquids with a kinematic viscosity equal to water.

Manning Equation

(2-29)
$$V = \frac{1.486}{n} r_H^{2/3} S_H^{1/2}$$

WHERE

V **= flow velocity, ft/sec**

n **= roughness coefficient, dimensionless**

r_H **= hydraulic radius, ft**

S_H **= hydraulic slope, ft/ft**

(2-30)
$$r_H = \frac{A_C}{P_W}$$

A_C **= cross-sectional area of flow bore, ft²**

P_W **= perimeter wetted by flow, ft**

(2-31)
$$S_H = \frac{h_U - h_D}{L} = \frac{h_f}{L}$$

h_U **= upstream pipe elevation, ft**

h_D **= downstream pipe elevation, ft**

h_f **= friction (head) loss, ft of liquid**

L **= length, ft**

It is convenient to combine the Manning equation with

(2-32)
$$Q = A_C V$$

To obtain

(2-33)
$$Q = \frac{1.486\, A_C}{n} r_H^{2/3} S_H^{1/2}$$

Where terms are as defined above, and

Q = flow, ft³/sec

When a circular pipe is running full or half-full,

(2-34)

$$r_H = \frac{d'}{4} = \frac{D_I}{48}$$

WHERE

d' = pipe inside diameter, ft

D_I = pipe inside diameter, in

Full pipe flow in ft³ per second may be estimated using:

(2-35)

$$Q_{FPS} = \left(6.136 \times 10^{-4}\right) \frac{D_I^{\;8/3} S_H^{\;1/2}}{n}$$

Full pipe flow in gallons per minute may be estimated using:

(2-36)

$$Q' = 0.275 \frac{D_I^{\;8/3} S_H^{\;1/2}}{n}$$

Nearly full circular pipes will carry more liquid than a completely full pipe. When slightly less than full, the perimeter wetted by flow is reduced, but the actual flow area is only slightly lessened. This results in a larger hydraulic radius than when the pipe is running full. Maximum flow is achieved at about 93% of full pipe flow, and maximum velocity at about 78% of full pipe flow. Manning's n is often assumed to be constant with flow depth. Actually, n has been found to be slightly larger in non-full flow.

TABLE 2-11
Values of n for Use with Manning Equation

Surface	n, typical design
PE pipe	0.009
Uncoated cast or ductile iron pipe	0.013
Corrugated steel pipe	0.024
Concrete pipe	0.013
Vitrified clay pipe	0.013
Brick and cement mortar sewers	0.015
Wood stave	0.011
Rubble masonry	0.021

Note: The n-value of 0.009 for PE pipe is for clear water applications.
An n-value of 0.010 is typically utilized for applications such as sanitary sewer, etc.

Comparative Flows for Slipliners

Deteriorated gravity flow pipes may be rehabilitated by sliplining with PE pipe. This process involves the installation of a PE liner inside of the deteriorated original pipe as described in subsequent chapters within this manual. For conventional sliplining, clearance between the liner outside diameter and the existing pipe bore is required to install the liner; thus after rehabilitation, the flow channel is smaller than that of the original pipe. However, it is often possible to rehabilitate with a PE slipliner, and regain all or most of the original flow capacity due to the extremely smooth inside surface of the PE pipe and its resistance to deposition or build-up. Because PE pipe is mostly joined by means of butt-fusion, this results in no effective reduction of flow diameter at joint locations Comparative flow capacities of circular pipes may be determined by the following:

(2-37)

$$\%\ flow = 100\frac{Q_1}{Q_2} = 100\frac{\left(\dfrac{{D_{I1}}^{8/3}}{n_1}\right)}{\left(\dfrac{{D_{I2}}^{8/3}}{n_2}\right)}$$

Table 2-12 was developed using Equation 2-36 where D_{I1} = the inside diameter (ID) of the liner, and D_{I2} = the original inside diameter of the deteriorated host pipe.

TABLE 2-12
Comparative Flows for Slipliners

Existing Sewer ID, in	Liner OD, in.	Liner DR 32.5			Liner DR 26			Liner DR 21			Liner DR 17		
		Liner ID, in.†	% flow vs. concrete	% flow vs. clay	Liner ID, in.†	% flow vs. concrete	% flow vs. clay	Liner ID, in.†	% flow vs. concrete	% flow vs. clay	Liner ID, in.†	% flow vs. concrete	% flow vs. clay
4	3.500	3.272	97.5%	84.5%	3.215	93.0%	80.6%	3.147	87.9%	76.2%	3.064	81.8%	70.9%
6	4.500	4.206	64.6%	56.0%	4.133	61.7%	53.5%	4.046	58.3%	50.5%	3.939	54.3%	47.0%
6	5.375	5.024	103.8%	90.0%	4.937	99.1%	85.9%	4.832	93.6%	81.1%	4.705	87.1%	75.5%
8	6.625	6.193	84.2%	73.0%	6.085	80.3%	69.6%	5.956	75.9%	65.8%	5.799	70.7%	61.2%
8	7.125	6.660	102.2%	88.6%	6.544	97.5%	84.5%	6.406	92.1%	79.9%	6.236	85.8%	74.4%
10	8.625	8.062	93.8%	81.3%	7.922	89.5%	77.6%	7.754	84.6%	73.3%	7.549	78.8%	68.3%
12	10.750	10.049	103.8%	90.0%	9.873	99.1%	85.9%	9.665	93.6%	81.1%	9.409	87.1%	75.5%
15	12.750	11.918	90.3%	78.2%	11.710	86.1%	74.6%	11.463	81.4%	70.5%	11.160	75.7%	65.6%
15	13.375	12.503	102.5%	88.9%	12.284	97.8%	84.8%	12.025	92.4%	80.1%	11.707	86.1%	74.6%
16	14.000	13.087	97.5%	84.5%	2.858	93.0%	80.6%	12.587	87.9%	76.2%	12.254	81.8%	70.9%
18	16.000	14.956	101.7%	88.1%	14.695	97.0%	84.1%	14.385	91.7%	79.4%	14.005	85.3%	74.0%
21	18.000	16.826	92.3%	80.0%	16.532	88.1%	76.3%	16.183	83.2%	72.1%	15.755	77.5%	67.1%
24	20.000	18.695	85.6%	74.2%	18.369	81.7%	70.8%	17.981	77.2%	66.9%	17.506	71.9%	62.3%
24	22.000	20.565	110.4%	95.7%	20.206	105.3%	91.3%	19.779	99.5%	86.2%	19.256	92.6%	80.3%
27	24.000	22.434	101.7%	88.1%	22.043	97.0%	84.1%	21.577	91.7%	79.4%	21.007	85.3%	74.0%
30	28.000	26.174	115.8%	100.4%	25.717	110.5%	95.8%	25.173	104.4%	90.5%	24.508	97.2%	84.2%
33	30.000	28.043	108.0%	93.6%	27.554	103.0%	89.3%	26.971	97.3%	84.3%	26.259	90.6%	78.5%
36	32.000	29.913	101.7%	88.1%	29.391	97.0%	84.1%	28.770	91.7%	79.4%	28.009	85.3%	74.0%
36	34.000	31.782	119.5%	103.6%	31.228	114.1%	98.9%	30.568	107.7%	93.4%	29.760	100.3%	86.9%
42	36.000	33.652	92.3%	80.0%	33.065	88.1%	76.3%	32.366	83.2%	72.1%	31.511	77.5%	67.1%
48	42.000	39.260	97.5%	84.5%	38.575	93.0%	80.6%	37.760	87.9%	76.2%	36.762	81.8%	70.9%
54	48.000	44.869	101.7%	88.1%	44.086	97.0%	84.1%	43.154	91.7%	79.4%	42.014	85.3%	74.0%
60	54.000	50.478	105.1%	91.1%	49.597	100.3%	86.9%	48.549	94.8%	82.1%	47.266	88.2%	76.5%

† Liner ID calculated per Equation 2-1.

Flow Velocity

Acceptable flow velocities in PE pipe depend on the specific details of the system. For water systems operating at rated pressures, velocities may be limited by surge allowance requirements. See Tables 1-3A and 1-3B. Where surge effects are reduced, higher velocities are acceptable, and if surge is not possible, such as in many gravity flow systems, water flow velocities exceeding 25 feet per second may be acceptable.

Liquid flow velocity may be limited by the capabilities of pumps or elevation head to overcome friction (head) loss and deliver the flow and pressure required for the application. PE pipe is not eroded by water flow. Liquid slurry pipelines may be subject to critical minimum velocities that ensure turbulent flow and maintain particle suspension in the slurry.

Gravity liquid flows of 2 fps (0.6 m/s) and higher can help prevent or reduce solids deposition in sewer lines. When running full, gravity flow pipelines are subject to the same velocity considerations as pressure pipelines.

Flow velocity in compressible gas lines tends to be self-limiting. Compressible gas flows in PE pipes are typically laminar or transitional. Fully turbulent flows are possible in short pipelines, but difficult to achieve in longer transmission and distribution lines because the pressure ratings for PE pipe automatically limit flow capacity and, therefore, flow velocity.

Pipe Surface Condition, Aging

Aging acts to increase pipe surface roughness in most piping systems. This in turn increases flow resistance. PE pipe resists typical aging effects because PE does not rust, rot, corrode, tuberculate, or support biological growth, and it resists the adherence of scale and deposits. In some cases, moderate flow velocities are sufficient to prevent deposition, and where low velocities predominate, occasional high velocity flows will help to remove sediment and deposits. As a result, the initial design capabilities for pressure and gravity flow pipelines are retained as the pipeline ages.

Where cleaning is needed to remove depositions in low flow rate gravity flow pipelines, water-jet cleaning or forcing a “soft” (plastic foam) pig through the pipeline are effective cleaning methods. Bucket, wire and scraper-type cleaning methods will damage PE pipe and must not be used.

Section 3
Buried PE Pipe Design

Introduction

This section covers basic engineering information for calculating earth and live-load pressures on PE pipe, for finding the pipe's response to these pressures taking into account the interaction between the pipe and its surrounding soil, and for judging that an adequate safety factor exists for a given application.

Soil pressure results from the combination of soil weight and surface loads. As backfill is placed around and over a PE pipe, the soil pressure increases and the pipe deflects vertically and expands laterally into the surrounding soil. The lateral expansion mobilizes passive resistance in the soil which, in combination with the pipe's inherent stiffness, resists further lateral expansion and consequently further vertical deflection.

During backfilling, ring (or hoop) stress develops within the pipe wall. Ring bending stresses (tensile and compressive) occur as a consequence of deflection, and ring compressive stress occurs as a consequence of the compressive thrust created by soil compression around the pipe's circumference. Except for shallow pipe subject to live load, the combined ring stress from bending and compression results in a net compressive stress.

The magnitude of the deflection and the stress depends not only on the pipe's properties but also on the properties of the surrounding soil. The magnitude of deflection and stress must be kept safely within PE pipe's performance limits. Excessive deflection may cause loss of stability and flow restriction, while excessive compressive stress may cause wall crushing or ring buckling. Performance limits for PE pipe are given in Watkins, Szpak, and Allman[1] *and illustrated in Figure 3-1.*

The design and construction requirements can vary somewhat, depending on whether the installation is for pressure or non-pressure service. These differences will be addressed later in this chapter and in Chapter 7, "Underground Installation of PE Pipe."

Calculations

Section 3 describes how to calculate the soil pressure acting on PE pipe due to soil weight and surface loads, how to determine the resulting deflection based on pipe and soil properties, and how to calculate the allowable (safe) soil pressure for wall compression (crushing) and ring buckling for PE pipe.

Detailed calculations are not always necessary to determine the suitability of a particular PE pipe for an application. Pressure pipes that fall within the Design Window given in AWWA M-55 "PE Pipe – Design and Installation" regarding pipe DR, installation, and burial depth meet specified deflection limits for PE pipe, have a safety factor of at least 2 against buckling, and do not exceed the allowable material compressive stress for PE. Thus, the designer need not perform extensive calculations for pipes that are sized and installed in accordance with the Design Window.

AWWA M-55 Design Window

AWWA M-55, "PE Pipe – Design and Installation", describes a Design Window. Applications that fall within this window require no calculations other than constrained buckling per Equation 3-15. It turns out that if pipe is limited to DR 21 or lower as in Table 3-1, the constrained buckling calculation has a safety factor of at least 2, and no calculations are required.

The design protocol under these circumstances (those that fall within the AWWA Design Window) is thereby greatly simplified. The designer may choose to proceed with detailed analysis of the burial design and utilize the AWWA Design Window guidelines as a means of validation for his design calculations and commensurate safety factors. Alternatively, he may proceed with confidence that the burial design for these circumstances (those outlined within the AWWA Design Window) has already been analyzed in accordance with the guidelines presented in this chapter.

The Design Window specifications are:

- Pipe made from stress-rated PE material.
- Essentially no dead surface load imposed over the pipe, no ground water above the surface, and provisions for preventing flotation of shallow cover pipe have been provided.
- The embedment materials are coarse-grained, compacted to at least 85% Standard Proctor Density and have an E′ of at least 1000 psi. The native soil must be stable; in other words the native soil must have an E′ of at least 1000 psi. See Table 3-7.
- The unit weight of the native soil does not exceed 120 pcf.
- The pipe is installed in accordance with manufacturer's recommendations for controlling shear and bending loads and minimum bending radius, and installed

in accordance with ASTM D2774 for pressure pipes or ASTM D2321 for non-pressure pipes.

- Minimum depth of cover is 2 ft (0.61 m); except when subject to AASHTO H20 truck loadings, in which case the minimum depth of cover is the greater of 3 ft (0.9 m) or one pipe diameter.
- Maximum depth of cover is 25 ft (7.62 m).

TABLE 3-1
AWWA M-55 Design Window Maximum and Minimum Depth of Cover Requiring No Calculations

DR	Min. Depth of Cover With H20 Load	Min. Depth of Cover Without H20 Load	Maximum Depth of Cover
7.3	3 ft	2 ft	25 ft
9	3 ft	2 ft	25 ft
11	3 ft	2 ft	25 ft
13.5	3 ft	2 ft	25 ft
17	3 ft	2 ft	25 ft
21	3 ft	2 ft	25 ft

* Limiting depths where no calculations are required. Pipes are suitable for deeper depth provided a sufficient E' (1,000 psi or more) is accomplished during installations. Calculations would be required for depth greater than 25 ft.

Installation Categories

For the purpose of calculation, buried installations of PE pipe can be separated into four categories depending on the depth of cover, surface loading, groundwater level and pipe diameter. Each category involves slightly different equations for determining the load on the pipe and the pipe's response to the load. The boundaries between the categories are not definite, and engineering judgment is required to select the most appropriate category for a specific installation. The categories are:

1. **Standard Installation-Trench or Embankment** installation with a maximum cover of 50 ft with or without traffic, rail, or surcharge loading. To be in this category, where live loads are present the pipe must have a minimum cover of at least one diameter or 18″ whichever is greater. Earth pressure applied to the pipe is found using the prism load (geostatic soil stress). The Modified Iowa Formula is used for calculating deflection. Crush and buckling are performance limits as well. The Standard Installation section also presents the AWWA "Design Window."

2. **Shallow Cover Vehicular Loading Installation** applies to pipes buried at a depth of at least 18″ but less than one pipe diameter. This installation category

uses the same equations as the Standard Installation but with an additional equation relating wheel load to the pipe's bending resistance and the soil's supporting strength.

3. **Deep Fill Installation** applies to embankments with depths exceeding 50 ft. The soil pressure calculation may be used for profile pipe in trenches less than 50 ft. The Deep Fill Installation equations differ from the Standard Installation equations by considering soil pressure based on armored, calculating deflection from the Watkins-Gaube Graph, and calculating buckling with the Moore-Selig Equation.

4. **Shallow Cover Flotation Effects** applies to applications where insufficient cover is available to either prevent flotation or hydrostatic collapse. Hydrostatic buckling is introduced in this chapter because of its use in subsurface design.

Section 3 of the Design Chapter is limited to the design of PE pipes buried in trenches or embankments. The load and pipe reaction calculations presented may not apply to pipes installed using trenchless technologies such as pipe bursting and directional drilling. These pipes may not develop the same soil support as pipe installed in a trench. The purveyor of the trenchless technology should be consulted for piping design information. See the Chapter on "PE Pipe for Horizontal Directional Drilling" and ASTM F1962, *Use of Maxi-Horizontal Directional Drilling (HDD) for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossings* for additional information on design of piping installed using directional drilling.

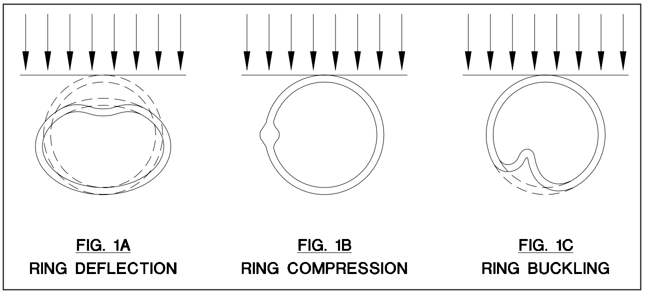


Figure 3-1 Performance Limits for Buried PE Pipe

Design Process

The interaction between pipe and soil, the variety of field-site soil conditions, and the range of available pipe Dimension Ratios make the design of buried pipe seem challenging. This section of the Design Chapter has been written with the intent of easing the designer's task. While some very sophisticated design approaches for buried pipe systems may be justified in certain applications, the simpler, empirical methodologies presented herein have been proven by experience to provide reliable results for virtually all PE pipe installations.

The design process consists of the following steps:

1. Determine the **vertical soil pressure** acting at the crown of the pipe due to earth, live, and surcharge loads.

2. Select a **trial pipe**, which means selecting a **trial dimension ratio (DR)** or, in the case of profile pipe, a **trial profile**.

3. Select an embedment material and degree of compaction. As will be described later, soil type and compaction are relatable to a specific **modulus of soil reaction value (E')** (Table 3-8). (As deflection is proportional to the combination of pipe and soil stiffness, pipe properties and embedment stiffness can be traded off to obtain an optimum design.)

4. For the trial pipe and trial modulus of soil reaction, **calculate** the deflection due to the vertical soil pressure. **Compare** the pipe deflection to the deflection limit. If deflection exceeds the limit, it is generally best to look at increasing the modulus of soil reaction rather than reducing the DR or changing to a heavier profile. Repeat step 4 for the new E' and/or new trial pipe.

5. For the trial pipe and trial modulus of soil reaction, **calculate** the allowable soil pressure for wall crushing and for wall buckling. **Compare** the allowable soil pressure to the applied vertical pressure. If the allowable pressure is equal to or higher than the applied vertical pressure, the design is complete. If not, select a different pipe DR or heavier profile or different E', and repeat step 5.

Since design begins with calculating vertical soil pressure, it seems appropriate to discuss the different methods for finding the vertical soil pressure on a buried pipe before discussing the pipe's response to load within the four installation categories.

Earth, Live, and Surcharge Loads on Buried Pipe

Vertical Soil Pressure

The weight of the earth, as well as surface loads above the pipe, produce soil pressure on the pipe. The weight of the earth or "earth load" is often considered to be a "dead-load" whereas surface loads are referred to as "surcharge loads" and may be temporary or permanent. When surcharge loads are of short duration they are usually referred to as "live loads." The most common live load is vehicular load. Other common surcharge loads include light structures, equipment, and piles of stored materials or debris. This section gives formulas for calculating the vertical soil pressure due to both earth and surcharge loads. The soil pressures are normally calculated at the depth of the pipe crown. The soil pressures for earth load and each surcharge load are added together to obtain the total vertical soil pressure which is then used for calculating deflection and for comparison with wall crush and wall buckling performance limits.

Earth Load

In a uniform, homogeneous soil mass, the soil load acting on a horizontal plane within the mass is equal to the weight of the soil directly above the plane. If the mass contains areas of varying stiffness, the weight of the mass will redistribute itself toward the stiffer areas due to internal shear resistance, and arching will occur. Arching results in a reduction in load on the less stiff areas. Flexible pipes including PE pipes are normally not as stiff as the surrounding soil, so the resulting earth pressure acting on PE pipe is reduced by arching and is less than the weight of soil above the pipe. (One minor exception to this is shallow cover pipe under dynamic loads.) For simplicity, engineers often ignore arching and assume that the earth load on the pipe is equal to the weight of soil above the pipe, which is referred to as the "prism load" or "geostatic stress." Practically speaking, the prism load is a conservative loading for PE pipes. It may be safely used in virtually all designs. Equation 3-1 gives the vertical soil pressure due to the prism load. The depth of cover is the depth from the ground surface to the pipe crown.

(3-1) $$P_E = \mathrm{w}H$$

WHERE

P_E **= vertical soil pressure due to earth load, psf**

w **= unit weight of soil, pcf**

H **= depth of cover, ft**

UNITS CONVENTION: To facilitate calculations for PE pipes, the convention used with rigid pipes for taking the load on the pipe as a line load along the longitudinal axis in units of **lbs/lineal-ft** of pipe length is not used here. Rather, the load is treated as a soil pressure acting on a horizontal plane at the pipe crown and is given in units of **lbs/ft^2 or psf.**

Soil weight can vary substantially from site to site and within a site depending on composition, density and load history. Soil weights are often found in the construction site geotechnical report. The saturated unit weight of the soil is used when the pipe is below the groundwater level. For design purposes, the unit weight of dry soil is commonly assumed to be 120 pcf, when site-specific information is not available.

Generally, the soil pressure on profile pipe and on DR pipe in deep fills is significantly less than the prism load due to arching. For these applications, soil pressure is best calculated using the calculations that account for arching in the "Deep Fill Installation" section.

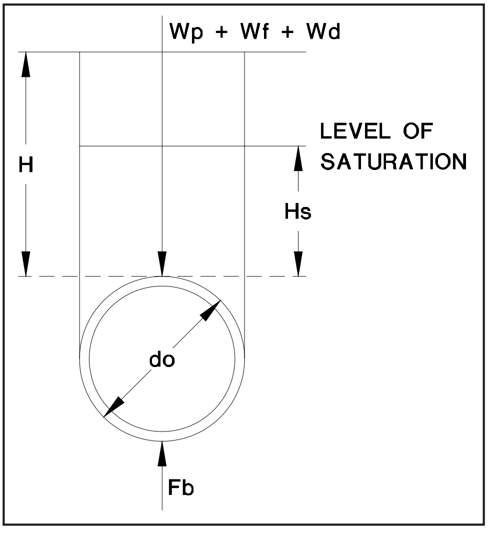


Figure 3-2 Prism Load

Live Load

Even though wheel loadings from cars and other light vehicles may be frequent, these loads generally have little impact on subsurface piping compared to the less frequent but significantly heavier loads from trucks, trains, or other heavy vehicles. For design of pipes under streets and highways, only the loadings from these heavier vehicles are considered. The pressure transmitted to a pipe by a vehicle depends on the pipe's depth, the vehicle's weight, the tire pressure and size, vehicle speed, surface smoothness, the amount and type of paving, the soil, and the distance from the pipe to the point of loading. For the more common cases, such as AASHTO, H20 HS20 truck traffic on paved roads and E-80 rail loading, this information has been simplified and put into Table 3-3, 3-4, and 3-5 to aid the designer. For special cases, such as mine trucks, cranes, or off-road vehicles, Equations 3-2 and 3-4 may be used.

The maximum load under a wheel occurs at the surface and diminishes with depth. PE pipes should be installed a minimum of one diameter or 18", whichever is greater, beneath the road surface. At this depth, the pipe is far enough below the wheel load to significantly reduce soil pressure and the pipe can fully utilize the embedment soil for load resistance. Where design considerations do not permit installation with at least one diameter of cover, additional calculations are required and are given in the section discussing "Shallow Cover Vehicular Loading Installation." State highway departments often regulate minimum cover depth and may require 2.5 ft to 5 ft of cover depending on the particular roadway.

During construction, both permanent and temporary underground pipelines may be subjected to heavy vehicle loading from construction equipment. It may be advisable to provide a designated vehicle crossing with special measures such as temporary pavement or concrete encasement, as well as vehicle speed controls to limit impact loads.

The following information on AASHTO Loading and Impact Factor is not needed to use Tables 3-3 and 3-4. It is included to give the designer an understanding of the surface loads encountered and typical impact factors. If the designer decides to use Equations 3-2 or 3-4 rather than the tables, the information will be useful.

AASHTO Vehicular Loading

Vehicular loads are typically based on The American Association of State Highway and Transportation Officials (AASHTO) standard truck loadings. For calculating the soil pressure on flexible pipe, the loading is normally assumed to be an H20 (HS20) truck. A standard H20 truck has a total weight of 40,000 lbs (20 tons). The weight is distributed with 8,000 lbs on the front axle and 32,000 lbs on the rear axle. The HS20 truck is a tractor and trailer unit having the same axle loadings as the H20 truck but with two rear axles. See Figure 3-3. For these trucks, the maximum wheel load is found at the rear axle(s) and equals 40 percent of the total weight of the truck. The maximum wheel load may be used to represent the static load applied by either a single axle or tandem axles. Some states permit heavier loads. The heaviest tandem axle loads normally encountered on highways are around 40,000 lbs (20,000 lbs per wheel). Occasionally, vehicles may be permitted with loads up to 50 percent higher.

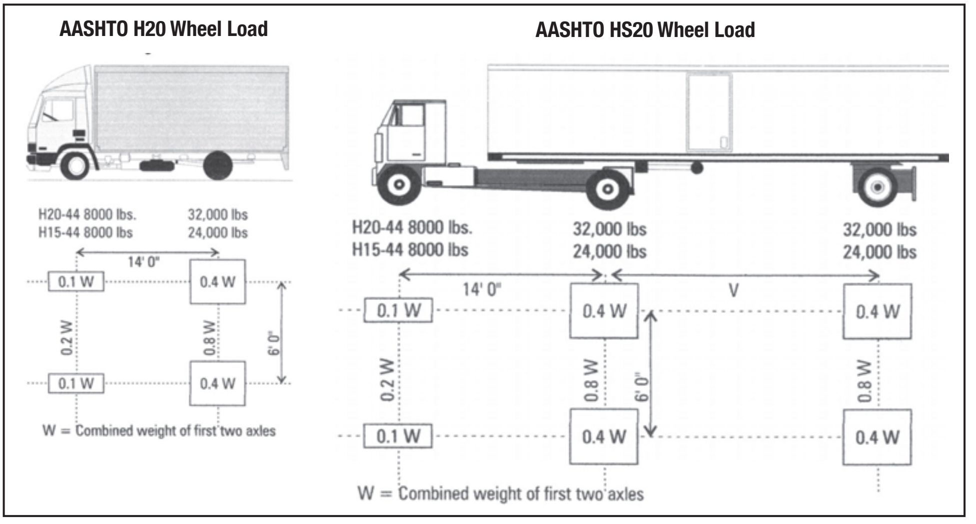


Figure 3-3 AASHTO H20 and HS20 Vehicle Loads

Impact Factor

Road surfaces are rarely smooth or perfectly even. When vehicles strike bumps in the road, the impact causes an instantaneous increase in wheel loading. Impact load may be found by multiplying the static wheel load by an impact factor. The factor varies with depth. Table 3-2 gives impact factors for vehicles on paved roads. For unpaved roads, impact factors of 2.0 or higher may occur, depending on the road surface.

TABLE 3-2
Typical Impact Factors for Paved Roads

Cover Depth, ft	Impact Factor, I_f
1	1.35
2	1.30
3	1.25
4	1.20
6	1.10
8	1.00

Derived from Illinois DOT dynamic load formula (1996).

Vehicle Loading through Highway Pavement (Rigid)

Pavement reduces the live load pressure reaching a pipe. A stiff, rigid pavement spreads load out over a large subgrade area thus significantly reducing the vertical soil pressure. Table 3-3 gives the vertical soil pressure underneath an H20 (HS20) truck traveling on a paved highway (12-inch thick concrete). An impact factor is incorporated. For use with heavier trucks, the pressures in Table 3-3 can be adjusted proportionally to the increased weight as long as the truck has the same tire area as an HS20 truck.

TABLE 3-3
Soil Pressure under H20 Load (12" Thick Pavement)

Depth of cover, ft.	Soil Pressure, lb/ft^2
1	1800
1.5	1400
2	800
3	600
4	400
5	250
6	200
7	175
8	100
Over 8	Neglect

Note: For reference see ASTM F7906. Based on axle load equally distributed over two 18 by 20 inch areas, spaced 72 inches apart. Impact factor included.

Vehicle Loading through Flexible Pavement or Unpaved Surface

Flexible pavements (or unpaved surfaces) do not have the bridging ability of rigid pavement and thus transmit more pressure through the soil to the pipe than given by Table 3-3. In many cases, the wheel loads from two vehicles passing combine to create a higher soil pressure than a single dual-tire wheel load. The maximum pressure may occur directly under the wheels of one vehicle or somewhere in between the wheels of the two vehicles depending on the cover depth. Table 3-4 gives the largest of the maximum pressure for two passing H20 trucks on an unpaved surface. No impact factor is included. The loading in Table 3-3 is conservative and about 10% higher than loads found by the method given in AASHTO Section 3, LRFD Bridge Specifications Manual based on assuming a single dual-tire contact area of 20 x 10 inches and using the equivalent area method of load distribution.

TABLE 3-4
Soil Pressure Under H20 Load (Unpaved or Flexible Pavement)

Depth of cover, ft.	Soil Pressure, lb/ft^2
1.5	2000
2.0	1340
2.5	1000
3.0	710
3.5	560
4.0	500
6.0	310
8.0	200
10.0	140

Note: Based on integrating the Boussinesq equation for two H20 loads spaced 4 feet apart or one H20 load centered over pipe. No pavement effects or impact factor included.

Off-Highway Vehicles

Off-highway vehicles such as mine trucks and construction equipment may be considerably heavier than H20 trucks. These vehicles frequently operate on unpaved construction or mine roads which may have very uneven surfaces. Thus, except for slow traffic, an impact factor of 2.0 to 3.0 should be considered. For off-highway vehicles, it is generally necessary to calculate live load pressure from information supplied by the vehicle manufacturer regarding the vehicle weight or wheel load, tire footprint (contact area) and wheel spacing.

The location of the vehicle's wheels relative to the pipe is also an important factor in determining how much load is transmitted to the pipe. Soil pressure under a point load at the surface is dispersed through the soil in both depth and expanse. Wheel loads not located directly above a pipe may apply pressure to the pipe, and this pressure can be significant. The load from two wheels straddling a pipe may produce a higher pressure on a pipe than from a single wheel directly above it.

For pipe installed within a few feet of the surface, the maximum soil pressure will occur when a single wheel (single or dual tire) is directly over the pipe. For deeper pipes, the maximum case often occurs when vehicles traveling above the pipe pass within a few feet of each other while straddling the pipe, or in the case of off-highway vehicles when they have closely space axles. The minimum spacing between the centerlines of the wheel loads of passing vehicles is assumed to be four feet. At this spacing for H20 loading, the pressure on a pipe centered midway between the two passing vehicles is greater than a single wheel load on a pipe at or below a depth of about four feet.

For design, the soil pressure on the pipe is calculated based on the vehicle location (wheel load locations) relative to the pipe that produces the maximum pressure. This generally involves comparing the pressure under a single wheel with that occurring with two wheels straddling the pipe. The Timoshenko Equation can be used to find the pressure directly under a single wheel load, whereas the Boussinesq Equation can be used to find the pressure from wheels not directly above the pipe.

Timoshenko's Equation

The Timoshenko Equation gives the soil pressure at a point directly under a distributed surface load, neglecting any pavement.

(3-2)

$$P_L = \frac{I_f W_w}{a_C}\left(1 - \frac{H^3}{(r_T^{\,2} + H^2)^{1.5}}\right)$$

WHERE

P_L = vertical soil pressure due to live load, lb/ft^2

I_f = impact factor

W_W = wheel load, lb

a_C = contact area, ft^2

r_T = equivalent radius, ft

H = depth of cover, ft

The equivalent radius is given by:

(3-3)

$$r_T = \sqrt{\frac{a_C}{\pi}}$$

For standard H2O and HS20 highway vehicle loading, the contact area is normally taken for dual wheels, that is, 16,000 lb over a 10 in. by 20 in. area.

Timoshenko Example Calculation

Find the vertical pressure on a 24" PE pipe buried 3 ft beneath an unpaved road when an R-50 off-road truck is over the pipe. The manufacturer lists the truck with a gross weight of 183,540 lbs on 21X35 E3 tires, each having a 30,590 lb load over an imprint area of 370 in^2.

SOLUTION: Use Equations 3-2 and 3-3. Since the vehicle is operating on an unpaved road, an impact factor of 2.0 is appropriate.

$$r_T = \sqrt{\frac{370/144}{\pi}} = 0.90ft \qquad P_L = \frac{(2.0)(30{,}590)}{\frac{370}{144}}\left(1 - \frac{3^3}{(0.90^2 + 3^2)^{1.5}}\right)$$

$$P_L = 2890 lb/ft^2$$

Boussinesq Equation

The Boussinesq Equation gives the pressure at any point in a soil mass under a concentrated surface load. The Boussinesq Equation may be used to find the pressure transmitted from a wheel load to a point that is not along the line of action of the load. Pavement effects are neglected.

(3-4)
$$P_L = \frac{3I_f W_w H^3}{2\pi r^5}$$

WHERE

P_L = vertical soil pressure due to live load lb/ft²

W_W = wheel load, lb

H = vertical depth to pipe crown, ft

I_f = impact factor

r = distance from the point of load application to pipe crown, ft

(3-5)
$$r = \sqrt{X^2 + H^2}$$

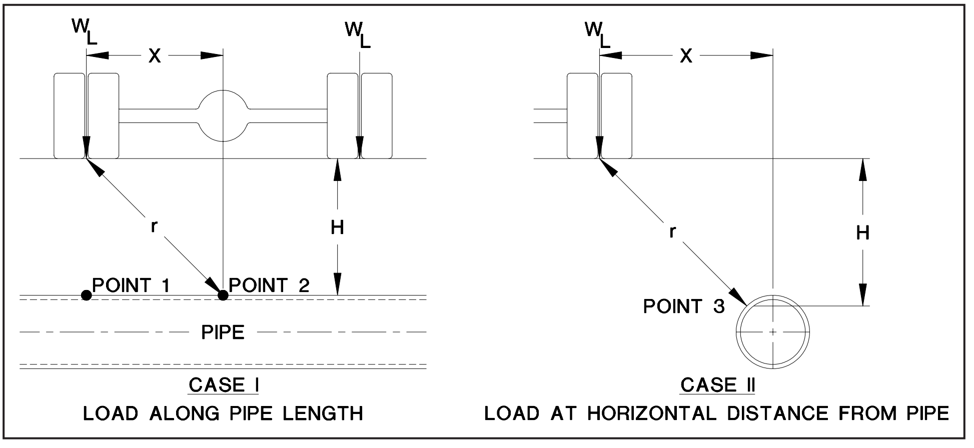


Figure 3-4 Illustration of Boussinesq Point Loading

Example Using Boussinesq Point Loading Technique

Determine the vertical soil pressure applied to a 12″ pipe located 4 ft deep under a dirt road when two vehicles traveling over the pipe and in opposite lanes pass each other. Assume center lines of wheel loads are at a distance of 4 feet. Assume a wheel load of 16,000 lb.

SOLUTION: Use Equation 3-4, and since the wheels are traveling, a 2.0 impact factor is applied. The maximum load will be at the center between the two wheels, so X = 2.0 ft. Determine r from Equation 3-5.

$$r = \sqrt{4^2 + 2.0^2} = 4.47\ ft$$

Then solve Equation 3-4 for PL, the load due to a single wheel.

$$P_L = \frac{3(2.0)(16{,}000)(4)^3}{2\pi(4.47)^5}$$

$$P_L = 548\ lb/ft^2$$

The load on the pipe crown is from both wheels, so

$$2P_L = 2(548) = 1096\ lb/ft^2$$

The load calculated in this example is higher than that given in Table 3-4 for a comparable depth even after correcting for the impact factor. Both the Timoshenko and Boussinesq Equations give the pressure applied at a point in the soil. In solving for pipe reactions it is assumed that this point pressure is applied across the entire surface of a unit length of pipe, whereas the actual applied pressure decreases away from the line of action of the wheel load. Methods that integrate this pressure over the pipe surface such as used in deriving Table 3-4 gives more accurate loading values. However, the error in the point pressure equations is slight and conservative, so they are still effective equations for design.

Railroad Loads

The live loading configuration used for pipes under railroads is the Cooper E-80 loading, which is an 80,000 lb load that is uniformly applied over three 2 ft by 8 ft areas on 5 ft centers. The area represents the 8 ft width of standard railroad ties and the standard spacing between locomotive drive wheels. Live loads are based on the axle weight exerted on the track by two locomotives and their tenders coupled together in doubleheader fashion. See Table 3-5. Commercial railroads frequently require casings for pressure pipes if they are within 25 feet of the tracks, primarily for safety reasons in the event of a washout. Based upon design and permitting requirements, the designer should determine whether or not a casing is required.

TABLE 3-5
Live Load Pressure for E-80 Railroad Loading

Depth of cover, ft.	Soil Pressure*, lb/ft^2
2.0	3800
5.0	2400
8.0	1600
10.0	1100
12.0	800
15.0	600
20.0	300
30.0	100
Over 30.0	Neglect

For referecne see ASTM A796. *The values shown for soil pressure include impact.

Surcharge Load

Surcharge loads may be distributed loads, such as a footing, foundation, or an ash pile, or may be concentrated loads, such as vehicle wheels. The load will be dispersed through the soil such that there is a reduction in pressure with an increase in depth or horizontal distance from the surcharged area. Surcharge loads not directly over the pipe may exert pressure on the pipe as well. The pressure at a point beneath a surcharge load depends on the load magnitude and the surface area over which the surcharge is applied. Methods for calculating vertical pressure on a pipe either located directly beneath a surcharge or located near a surcharge are given below.

Pipe Directly Beneath a Surcharge Load

This design method is for finding the vertical soil pressure under a rectangular area with a uniformly distributed surcharge load. This may be used in place of Tables 3-3 to 3-5 and Equations 3-3 and 3-5 to calculate vertical soil pressure due to wheel loads. This requires knowledge of the tire imprint area and impact factor.

The point pressure on the pipe at depth, H, is found by dividing the rectangular surcharge area (ABCD) into four sub-area rectangles (a, b, c, and d) which have a common corner, E, in the surcharge area, and over the pipe. The surcharge pressure, P_L, at a point directly under E is the sum of the pressure due to each of the four sub-area loads. Refer to Figure 3-5 A.

The pressure due to each sub-area is calculated by multiplying the surcharge pressure at the surface by an Influence Value, I_V. Influence Values are proportionality constants that measure what portion of a surface load reaches the subsurface point in question. They were derived using the Boussinesq Equation and are given in Table 3-6.

(3-6) $$P_L = p_a + p_b + p_c + p_d$$

WHERE
P_L = vertical soil pressure due to surcharge pressure, lb/ft^2
p_a = pressure due to sub-area a, lb/ft^2
p_b = pressure due to sub-area b, lb/ft^2
p_c = pressure due to sub-area c, lb/ft^2
p_d = pressure due to sub-area d, lb/ft^2

Pressure due to the surcharge applied to the i-th sub-area equals:

(3-7) $$p_i = I_V \; w_S$$

WHERE
I_V = Influence Value from Table 3-6
w_S = distributed pressure of surcharge load at ground surface, lb/ft^2

If the four sub-areas are equivalent, then Equation 3-7 may be simplified to:

(3-8) $$P_L = 4I_V \; w_S$$

The influence value is dependent upon the dimensions of the rectangular area and upon the depth to the pipe crown, H. Table 3-6 Influence Value terms depicted in Figure 3-6, are defined as:

H = depth of cover, ft
M = horizontal distance, normal to the pipe centerline, from the center of the load to the load edge, ft
N = horizontal distance, parallel to the pipe centerline, from the center of the load to the load edge, ft

Interpolation may be used to find values not given in Table 3-6. The influence value gives the portion (or influence) of the load that reaches a given depth beneath the corner of the loaded area.

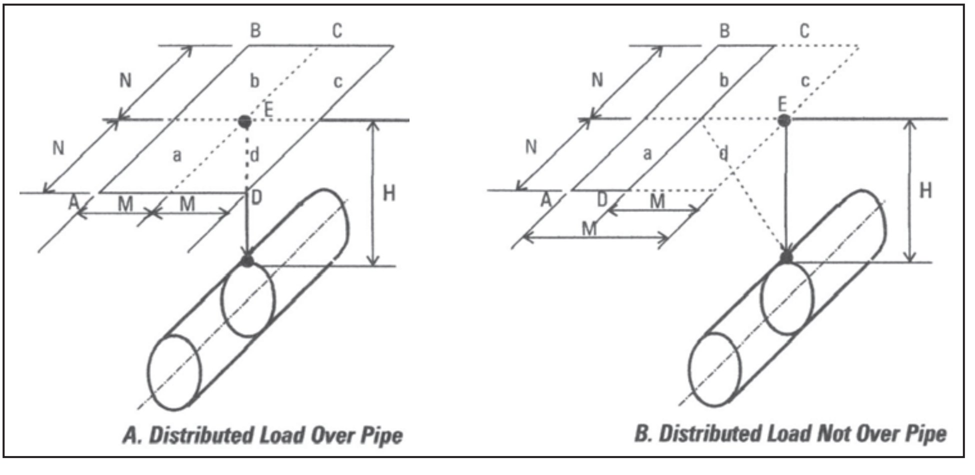


Figure 3-5 Illustration of Distributed Loads

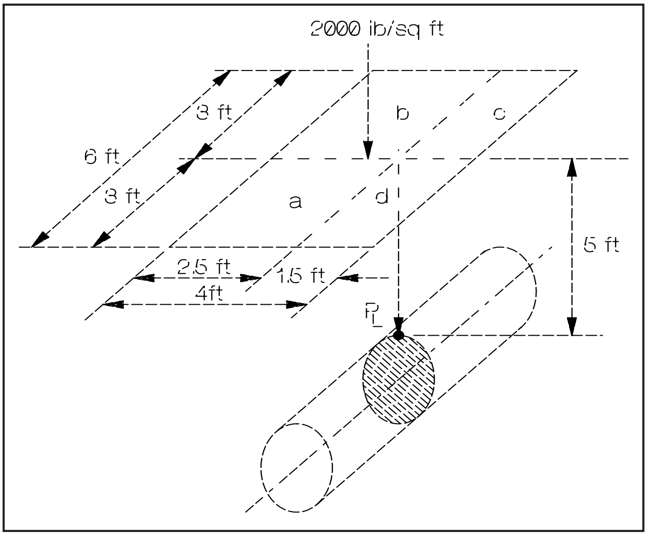
TABLE 3-6
Influence Values, I_V for Distributed Loads*

	N/H													
M/H	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**	**1.2**	**1.5**	**2.0**	∞
0.1	0.005	0.009	0.013	0.017	0.020	0.022	0.024	0.026	0.027	0.028	0.029	0.030	0.031	0.032
0.2	0.009	0.018	0.026	0.033	0.039	0.043	0.047	0.050	0.053	0.055	0.057	0.060	0.061	0.062
0.3	0.013	0.026	0.037	0.047	0.056	0.063	0.069	0.073	0.077	0.079	0.083	0.086	0.089	0.090
0.4	0.017	0.033	0.047	0.060	0.071	0.080	0.087	0.093	0.098	0.101	0.106	0.110	0.113	0.115
0.5	0.020	0.039	0.056	0.071	0.084	0.095	0.103	0.110	0.116	0.120	0.126	0.131	0.135	0.137
0.6	0.022	0.043	0.063	0.080	0.095	0.107	0.117	0.125	0.131	0.136	0.143	0.149	0.153	0.156
0.7	0.024	0.047	0.069	0.087	0.103	0.117	0.128	0.137	0.144	0.149	0.157	0.164	0.169	0.172
0.8	0.026	0.050	0.073	0.093	0.110	0.125	0.137	0.146	0.154	0.160	0.168	0.176	0.181	0.185
0.9	0.027	0.053	0.077	0.098	0.116	0.131	0.144	0.154	0.162	0.168	0.178	0.186	0.192	0.196
1.0	0.028	0.055	0.079	0.101	0.120	0.136	0.149	0.160	0.168	0.175	0.185	0.194	0.200	0.205
1.2	0.029	0.057	0.083	0.106	0.126	0.143	0.157	0.168	0.178	0.185	0.196	0.205	0.209	0.212
1.5	0.030	0.060	0.086	0.110	0.131	0.149	0.164	0.176	0.186	0.194	0.205	0.211	0.216	0.223
2.0	0.031	0.061	0.088	0.113	0.135	0.153	0.169	0.181	0.192	0.200	0.209	0.216	0.232	0.240
∞	0.032	0.062	0.089	0.116	0.137	0.156	0.172	0.185	0.196	0.205	0.212	0.223	0.240	0.250

* H, M, and N are per Figure 3-5.

Vertical Surcharge Example # 1

Find the vertical surcharge load for the 4′ x 6′, 2000 lb/ft2 footing shown below.



SOLUTION: Use equations 3-6 and 3-7, Table 3-6, and Figure 3-5. The 4 ft x 6 ft footing is divided into four sub-areas, such that the common corner of the sub-areas is directly over the pipe. Since the pipe is not centered under the load, sub-areas a and b have dimensions of 3 ft x 2.5 ft, and sub-areas c and d have dimensions of 3 ft x 1.5 ft.

Determine sub-area dimensions for M, N, and H, then calculate M/H and N/H. Find the Influence Value from Table 3-6, then solve for each sub area, p_a, p_b, p_c, p_d, and sum for P_L.

	Sub-area			
	a	b	c	d
M	2.5	2.5	1.5	1.5
N	3.0	3.0	3.0	3.0
M/H	0.5	0.5	0.3	0.3
N/H	0.6	0.6	0.6	0.6
I_V	0.095	0.095	0.063	0.063
p_i	190	190	126	126

Therefore: P_L = 632 lbs/ft^2

Pipe Adjacent to, but Not Directly Beneath, a Surcharge Load

This design method may be used to find the surcharge load on buried pipes near, but not directly below, uniformly distributed loads such as concrete slabs, footings and floors, or other rectangular area loads, including wheel loads that are not directly over the pipe.

The vertical pressure is found by first adding an imaginary loaded area that covers the pipe, then determining the surcharge pressure due to the overall load (actual and imaginary) based on the previous section, and finally by deducting the pressure due to the imaginary load from that due to the overall load.

Refer to Figure 3-5 B. Since there is no surcharge directly above the pipe centerline, an imaginary surcharge load, having the same pressure per unit area as the actual load, is applied to sub-areas c and d. The surcharge pressure for sub-areas a+d and b+c are determined, then the surcharge loads from the imaginary areas c and d are deducted to determine the surcharge pressure on the pipe.

(3-9) $$P_L = p_{a+d} + p_{b+c} - p_d - p_c$$

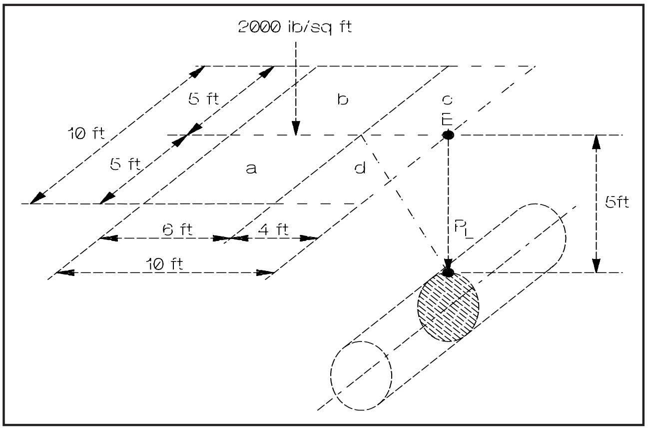
Where terms are as previously defined above, and

P_{a+d} **= surcharge load of combined sub-areas a and d, lb/ft^2**

P_{b+c} **= surcharge load of combined sub-areas b and c, lb/ft^2**

Vertical Surcharge Example # 2

Find the vertical surcharge pressure for the 6' x 10', 2000 lb/ft² slab shown below.



SOLUTION: Use Equations 3-7 and 3-9, Table 3-6, and Figure 3-5 B. The surcharge area is divided into two sub-areas, a and b. The area between the surcharge and the line of the pipe crown is divided into two sub-areas, c and d, as well. The imaginary load is applied to sub-areas c and d. Next, the four sub-areas are treated as a single surcharge area. Unlike the previous example, the pipe is located under the edge of the surcharge area rather than the center. So, the surcharge pressures for the combined sub-areas a+d and b+c are determined, and then for the sub-areas c and d. The surcharge pressure is the sum of the surcharge pressure due to the surcharge acting on sub-areas a+d and b+c, less the imaginary pressure due to the imaginary surcharge acting on sub-areas c and d.

	Sub-area			
	a + d	**b + c**	**c**	**d**
M	10	10	4	4
N	5	5	5	5
M/H	2.0	2.0	0.8	0.8
N/H	1.0	1.0	1.0	1.0
I_V	0.200	0.200	0.160	0.160
p_i	400	400	(320)	(320)

Therefore P_L = 160 lb/ft²

Installation Category 1: Standard Installation - Trench or Embankment

Pipe Reaction to Earth, Live, and Surcharge Loads

Now might be a good time to review the "Design Process" that appeared earlier in Section 3. After calculating the vertical pressure applied to the pipe the next design step is to choose a trial pipe (DR or profile). Then, based on the Installation Category and the selected embedment and compaction, calculate the anticipated deflection and resistance to crush and buckling.

The Standard Installation category applies to pipes that are installed between 18 inches and 50 feet of cover. Where surcharge, traffic, or rail load may occur, the pipe must have at least one full diameter of cover. If such cover is not available, then the application design must also consider limitations under the Shallow Cover Vehicular Loading Installation category. Where the cover depth exceeds 50 ft an alternate treatment for dead loads is given under the Deep Fill Installation category. Where ground water occurs above the pipe's invert and the pipe has less than two diameters of cover, the potential for the occurrence of flotation or upward movement of the pipe may exist. See Shallow Cover Flotation Effects.

While the Standard Installation is suitable for up to 50 feet of cover, it may be used for more cover. The 50 feet limit is based on A. Howard's [(3)] recommended limit for use of E' values. Above 50 feet, the E' values given in Table B.1.1 in Chapter 3 Appendix are generally thought to be overly conservative as they are not corrected for the increase in embedment stiffness that occurs with depth as a result of the higher confinement pressure within the soil mass. In addition, significant arching occurs at depths greater than 50 feet.

The Standard Installation, as well as the other design categories for buried PE pipe, looks at a ring or circumferential cross-section of pipe and neglects longitudinal loading, which is normally insignificant. They also ignore the re-rounding effect of internal pressurization. Since re-rounding reduces deflection and stress in the pipe, ignoring it is conservative.

Ring Deflection

Ring deflection is the normal response of flexible pipes to soil pressure. It is also a beneficial response in that it leads to the redistribution of soil stress and the initiation of arching. Ring deflection can be controlled within acceptable limits by the selection of appropriate pipe embedment materials, compaction levels, trench width and, in some cases, the pipe itself.

The magnitude of ring deflection is inversely proportional to the combined stiffness of the pipe and the embedment soil. M. Spangler [(4)] characterized this relationship in the Iowa Formula in 1941. R. Watkins [5] modified this equation to allow a simpler approach for soil characterization, thus developing the Modified Iowa Formula. In 1964, Burns and Richards [6] published a closed-form solution for ring deflection and pipe stress based on classical linear elasticity. In 1976 M. Katona et. al. [7] developed a finite element program called CANDE (Culvert Analysis and Design) which is now available in a PC version and can be used to predict pipe deflection and stresses.

The more recent solutions may make better predictions than the Iowa Formula, but they require detailed information on soil and pipe properties, e.g. more soil lab testing. Often the improvement in precision is all but lost in construction variability. Therefore, the Modified Iowa Formula remains the most frequently used method of determining ring deflection.

Spangler's Modified Iowa Formula can be written for use with solid wall PE pipe as:

(3-10)

$$\frac{\Delta X}{D_M} = \frac{1}{144}\left(\frac{K_{BED}\, L_{DL} P_E + K_{BED} P_L}{\frac{2E}{3}\left(\frac{1}{DR - 1}\right)^3 + 0.061 F_S E'}\right)$$

and for use with ASTM F894 profile wall pipe as:

(3-11)

$$\frac{\Delta X}{D_I} = \frac{P}{144}\left(\frac{K_{BED} L_{DL}}{\frac{1.24(RSC)}{D_M} + 0.061 F_S E'}\right)$$

WHERE

ΔX = Horizontal deflection, in

K_{BED} = Bedding factor, typically 0.1

L_{DL} = Deflection lag factor

P_E = Vertical soil pressure due to earth load, psf

P_L = Vertical soil pressure due to live load, psf

E = Apparent modulus of elasticity of pipe material, lb/in^2

E' =Modulus of Soil reaction, psi

F_S = Soil Support Factor

RSC = Ring Stiffness Constant, lb/ft

DR = Dimension Ratio, OD/t

D_M = Mean diameter (D_I+2z or D_O-t), in

z = Centroid of wall section, in

t = Minimum wall thickness, in

D_I = pipe inside diameter, in

D_O = pipe outside diameter, in

Deflection is reported as a percent of the diameter which can be found by multiplying 100 times $\Delta X/D_M$ or $\Delta X/D_I$. (When using RSC, the units of conversion are accounted for in Equation 3-11.)

Apparent Modulus of Elasticity for Pipe Material, E

The apparent modulus of PE is dependent on load-rate or, duration of laoding and temperature.Apparent elastic modulus values for high and medium density PE may be found in Table B.1.1 in Chapter 3 Appendix. These values can be used in Spangler's Iowa Formula. It has long been an industry practice to use the short-term modulus in the Iowa Formula for thermoplastic pipe. This is based on the idea that, in granular embedment soil, deformation is a series of instantaneous deformations consisting of rearrangement and fracturing of grains while the bending stress in the pipe wall is decreasing due to stress relaxation. Use of the short-term modulus has proven effective and reliable for corrugated and profile wall pipes. These pipes typically have pipe stiffness values of 46 psi or less when measured per ASTM D2412. Conventional DR pipes starting with DR17 or lower have significantly higher stiffness and therefore they may carry a greater proportion of the earth and live load than corrugated or profile pipe; so it is conservative to use the 50-year modulus for DR pipes that have low DR values when determining deflection due to earth load.

Vehicle loads are generally met with a higher modulus than earth loads, as load duration may be nearly instantaneous for moving vehicles. The deflection due to a combination of vehicle or temporary loads and earth load may be found by separately calculating the deflection due to each load using the modulus appropriate for the expected load duration, then adding the resulting deflections together to get the total deflection. When doing the deflection calculation for vehicle load, the Lag Factor will be one. An alternate, but conservative, method for finding deflection for combined vehicle and earth load is to do one calculation using the 50-year modulus, but separate the vertical soil pressure into an earth load component and a live load component and apply the Lag Factor only to the earth load component.

Ring Stiffness Constant, RSC

Profile wall pipes manufactured to ASTM F894, "Standard Specification for Polyethylene (PE) Large Diameter Profile Wall Sewer and Drain Pipe," are classified on the basis of their Ring Stiffness Constant (RSC). Equation 3-12 gives the RSC.

(3-12)
$$RSC = \frac{6.44\ EI}{D_M^2}$$

WHERE

E = **Apparent modulus of elasticity of pipe material @73°F (See Chapter 3 Appendix)**

I = **Pipe wall moment of inertia, in^4/in ($t^3/12$, if solid wall construction)**

z = **Pipe wall centroid in**

DI = **Pipe inside diameter in**

D_M = **Mean diameter (DI + 2z or D_O-t), in**

t = **Minimum wall thickness, in**

Modulus of Soil Reaction, E'

The soil reaction modulus is proportional to the embedment soil's resistance to the lateral expansion of the pipe. There are no convenient laboratory tests to determine the soil reaction modulus for a given soil. A. Howard [8] determined E' values empirically from numerous field deflection measurements by substituting site parameters (i.e. depth of cover, soil weight) into Spangler's equation and "back-calculating" E'. Howard developed a table for the Bureau of Reclamation relating E' values to soil types and compaction efforts. See Table 3-7. In back-calculating E', Howard assumed the prism load was applied to the pipe. Therefore, Table 3-7 E' values indirectly include load reduction due to arching and are suitable for use only with the prism load. In 2006, Howard published a paper reviewing his original 1977 publication from which Table 3-7 is taken. For the most part the recent work indicates that the E' values in Table 3-7 are conservative.

Due to differences in construction procedures, soil texture and density, pipe placement, and insitu soil characteristics, pipe deflection varies along the length of a pipeline. Petroff [9] has shown that deflection measurements along a pipeline typically fit the Normal Distribution curve. To determine the anticipated maximum deflection using Eq. 3-10 or 3-11, variability may be accommodated by reducing the Table 3-7 E' value by 25%, or by adding to the calculated deflection percentage the correction for 'accuracy' percentage given in Table 3-7.

In shallow installations, the full value of the E' given in Table 3-7 may not develop. This is due to the lack of "soil confining pressure" to hold individual soil grains tightly together and stiffen the embedment. Increased weight or equivalently, depth, increases the confining pressure and, thus, the E'. J. Hartley and J. Duncan [10] published recommended E' values based on depth of cover. See Table 3-8. These are particularly useful for shallow installations.

Chapter 7, "Underground Installation of PE Pipe" covers soil classification for pipe embedment materials and preferred methods of compaction and installation for selected embedment materials. Some of the materials shown in Table 3-7 may not be appropriate for all pipe installation. One example would be fine-grained soils in wet ground, which would not be appropriate embedment, under most circumstances, for either profile pipe or pipes with high DR's. Such limitations are discussed in Chapter 7.

TABLE 3-7
Values of E' for Pipe Embedment (See Howard [(8)])

Soil Type-pipe Embedment Material (Unified Classification System)[1]	E' for Degree of Embedment Compaction, lb/in^2			
	Dumped	Slight, <85% Proctor, <40% Relative Density	Moderate, 85%-95% Proctor, 40%-70% Relative Density	High, >95% Proctor, >70% Relative Density
Fine-grained Soils (LL > 50)[2] Soils with medium to high plasticity; CH, MH, CH-MH	No data available: consult a competent soils engineer, otherwise, use E' = 0.			
Fine-grained Soils (LL < 50) Soils with medium to no plasticity, CL, ML, ML-CL, with less than 25% coarse grained particles.	50	200	400	1000
Fine-grained Soils (LL < 50) Soils with medium to no plasticity, CL, ML, ML-CL, with more than 25% coarse grained particles; Coarse-grained Soils with Fines, GM, GC, SM, SC[3] containing more than 12% fines.	100	400	1000	2000
Coarse-grained soils with Little or No Fines GW, GP, SW, SP[3] containing less than 12% fines	200	1000	2000	3000
Crushed Rock	1000	3000	3000	3000
Accuracy in Terms of Percentage Deflection[4]	±2%	±2%	±1%	±0.5%

[1] ASTM D-2487, USBR Designation E-3
[2] LL = Liquid Limit
[3] Or any borderline soil beginning with one of these symbols (i.e., GM-GC, GC-SC).
[4] For ±1% accuracy and predicted deflection of 3%, actual deflection would be between 2% and 4%.

Note: Values applicable only for fills less than 50 ft (15 m). Table does not include any safety factor. For use in predicting initial deflections only; appropriate Deflection Lag Factor must be applied for long-term deflections. If embedment falls on the borderline between two compaction categories, select lower E' value, or average the two values. Percentage Proctor based on laboratory maximum dry density from test standards using 12,500 ft-lb/cu ft (598,000 J/m^2) (ASTM D-698, AASHTO T-99, USBR Designation E-11). 1 psi = 6.9 KPa.

TABLE 3-8
Values of E' for Pipe Embedment (See Duncan and Hartley[10])

Type of Soil	Depth of Cover, ft	E' for Standard AASHTO Relative Compaction, lb/in²			
		85%	90%	95%	100%
Fine-grained soils with less than 25% sand content (CL, ML, CL-ML)	0-5	500	700	1000	1500
	5-10	600	1000	1400	2000
	10-15	700	1200	1600	2300
	15-20	800	1300	1800	2600
Coarse-grained soils with fines (SM, SC)	0-5	600	1000	1200	1900
	5-10	900	1400	1800	2700
	10-15	1000	1500	2100	3200
	15-20	1100	1600	2400	3700
Coarse-grained soils with little or no fines (SP, SW, GP, GW)	0-5	700	1000	1600	2500
	5-10	1000	1500	2200	3300
	10-15	1050	1600	2400	3600
	15-20	1100	1700	2500	3800

Soil Support Factor, F_S

Ring deflection and the accompanying horizontal diameter expansion create lateral earth pressure which is transmitted through the embedment soil and into the trench sidewall. This may cause the sidewall soil to compress. If the compression is significant, the embedment can move laterally, resulting in an increase in pipe deflection. Sidewall soil compression is of particular concern when the insitu soil is loose, soft, or highly compressible, such as marsh clay, peat, saturated organic soil, etc. The net effect of sidewall compressibility is a reduction in the soil-pipe system's stiffness. The reverse case may occur as well if the insitu soil is stiffer than the embedment soil; e.g. the insitu soil may enhance the embedment giving it more resistance to deflection. The Soil Support Factor, F_S, is a factor that may be applied to E' to correct for the difference in stiffness between the insitu and embedment soils. Where the insitu soil is less stiff than the embedment, F_S is a reduction factor. Where it is stiffer, F_S is an enhancement factor, i.e. greater than one.

The Soil Support Factor, F_S, may be obtained from Tables 3-9 and 3-10 as follows:

- Determine the ratio B_d/D_O, where B_d equals the trench width at the pipe springline (inches), and D_O equals the pipe outside diameter (inches).
- Based on the native insitu soil properties, find the soil reaction modulus for the insitu soil, E'_N in Table 3-9.
- Determine the ratio E'_N/E'.
- Enter Table 3-10 with the ratios B_d/D_O and E'_N/E' and find F_S.

TABLE 3-9
Values of E'_N, Native Soil Modulus of Soil Reaction, Howard [3]

Native In Situ Soils				
Granular		Cohesive		E'_N (psi)
Std. Pentration ASTM D1586 Blows/ft	Description	Unconfined Compressive Strength (TSF)	Description	
> 0 - 1	very, very loose	> 0 - 0.125	very, very soft	50
1 - 2	very loose	0.125 - 0.25	very soft	200
2 - 4	very loose	0.25 - 0.50	soft	700
4 - 8	loose	0.50 - 1.00	medium	1,500
8 - 15	slightly compact	1.00 - 2.00	stiff	3,000
15 - 30	compact	2.00 - 4.00	very stiff	5,000
30 - 50	dense	4.00 - 6.00	hard	10,000
> 50	very dense	> 6.00	very hard	20,000
Rock	–	–	–	50,000

TABLE 3-10
Soil Support Factor, F_S

E'_N/E'	B_d/D_O 1.5	B_d/D_O 2.0	B_d/D_O 2.5	B_d/D_O 3.0	B_d/D_O 4.0	B_d/D_O 5.0
0.1	0.15	0.30	0.60	0.80	0.90	1.00
0.2	0.30	0.45	0.70	0.85	0.92	1.00
0.4	0.50	0.60	0.80	0.90	0.95	1.00
0.6	0.70	0.80	0.90	0.95	1.00	1.00
0.8	0.85	0.90	0.95	0.98	1.00	1.00
1.0	1.00	1.00	1.00	1.00	1.00	1.00
1.5	1.30	1.15	1.10	1.05	1.00	1.00
2.0	1.50	1.30	1.15	1.10	1.05	1.00
3.0	1.75	1.45	1.30	1.20	1.08	1.00
5.0	2.00	1.60	1.40	1.25	1.10	1.00

Lag Factor and Long-Term Deflection

Spangler observed an increase in ring deflection with time. Settlement of the backfill and consolidation of the embedment under the lateral pressure from the pipe continue to occur after initial installation. To account for this, he recommended applying a lag factor to the Iowa Formula in the range of from 1.25 to 1.5. Lag occurs in installations of both plastic and metal pipes. Howard [3, 11] has shown that the lag factor varies with the type of embedment and the degree of compaction. Many plastic pipe designers use a Lag Factor of 1.0 when using the prism load as it accounts for backfill settlement. This makes even more sense when the Soil Support Factor is included in the calculation.

Vertical Deflection Example

Estimate the vertical deflection of a 24" diameter DR 26 pipe produced from a PE4710 material that is installed under 18 feet of cover. The embedment material is a well-graded sandy gravel, compacted to a minimum 90 percent of Standard Proctor density, and the native ground is a saturated, soft clayey soil. The anticipated trench width is 42".

SOLUTION: Use the prism load, Equation 3-1, Tables 3-7, 3-9, and 3-10, and Equation 3-10. Table 3-7 gives an E′ for a compacted sandy gravel or GW-SW soil as 2000 lb/in^2. The Short-Term Apparent Modulus of Elasticity for PE 4710 material obtained from Table B.2.1 equals 130,000 psi. To estimate maximum deflection due to variability, this value will be reduced by 25%, or to 1500 lb/in^2. Table 3-9 gives an E'_N of 700 psi for soft clay. Since B_d/D equals 1.75 and E'_N/E' equals 0.47, F_S is obtained by interpolation and equal 0.60.

The prism load on the pipe is equal to:

$$P_E = (120)(18) = 2160 lb / ft^2$$

Substituting these values into Equation 3-10 gives:

$$\frac{\Delta X}{D_M} = \frac{2160}{144}\left(\frac{(0.1)(1.0)}{\frac{2(130{,}000)}{3}\left(\frac{1}{26-1}\right)^3 + (0.061)(0.60)(1500)}\right)$$

$$\frac{\Delta X}{D_M} = 0.025 = 2.5\,\%$$

Deflection Limits

The designer limits ring deflection in order to control geometric stability of the pipe, wall bending strain, pipeline hydraulic capacity and compatibility with cleaning equipment, and, for bell-and-spigot jointed pipe, its sealing capability. Only the limits for geometric stability and bending strain will be discussed here. Hydraulic capacity is not impaired at deflections less than 7.5%.

Geometric stability is lost when the pipe crown flattens and loses its ability to support earth load. Crown flattening occurs with excessive deflection as the increase in horizontal diameter reduces crown curvature. At 25% to 30% deflection, the crown may completely reverse its curvature inward and collapse. See Figure 3-1A. A deflection limit of 7.5% provides at least a 3 to 1 safety factor against reverse curvature.

Bending strain occurs in the pipe wall as a result of ring deflection—outer-fiber tensile strain at the pipe springline and outer-fiber compressive strain at the crown and invert. While strain limits of 5% have been proposed, Jansen [12] reported that, on tests of PE pipe manufactured from pressure-rated resins and subjected to soil pressure only, "no upper limit from a practical design point of view seems to exist for the bending strain." In other words, as deflection increases, the pipe's performance limit will not be overstraining but reverse curvature collapse.

Thus, for non-pressure applications, a 7.5 percent deflection limit provides a large safety factor against instability and strain and is considered a safe design deflection. Some engineers will design profile wall pipe and other non-pressure pipe applications to a 5% deflection limit, but allow spot deflections up to 7.5% during field inspection.

The deflection limits for pressurized pipe are generally lower than for non-pressurized pipe. This is primarily due to strain considerations. Hoop strain from pressurization adds to the outer-fiber tensile strain. But the internal pressure acts to reround the pipe and, therefore, Eq. 3-10 overpredicts the actual long-term deflection for pressurized pipe. Safe allowable deflections for pressurized pipe are given in Table 3-11. Spangler and Handy [13] give equations for correcting deflection to account for rerounding.

TABLE 3-11
Safe Deflection Limits for Pressurized Pipe

DR or SDR	Safe Deflection as % of Diameter
32.5	7.5
26	7.5
21	7.5
17	6.0
13.5	6.0
11	5.0
9	4.0
7.3	3.0

* Based on Long-Term Design Deflection of Buried Pressurized Pipe given in ASTM F1962.

Compressive Ring Thrust

Earth pressure exerts a radial-directed force around the circumference of a pipe that results in a compressive ring thrust in the pipe wall. (This thrust is exactly opposite to the tensile hoop thrust induced when a pipe is pressurized.) See Figure 3-1B. Excessive ring compressive thrust may lead to two different performance limits: crushing of the material or buckling (loss of stability) of the pipe wall. See Figure 3-1C. This section will discuss crushing, and the next section will discuss buckling.

As is often the case, the radial soil pressure causing the stress is not uniform around the pipe's circumference. However, for calculation purposes it is assumed uniform and equal to the vertical soil pressure at the pipe crown.

Pressure pipes often have internal pressure higher than the radial pressure applied by the soil. As long as there is pressure in the pipe that exceeds the external pressure, the net thrust in the pipe wall is tensile rather than compressive, and wall crush or buckling checks are not necessary. Whether one needs to check this or not can be quickly determined by simply comparing the internal pressure with the vertical soil pressure.

Crushing occurs when the compressive stress in the wall exceeds the compressive yield stress of the pipe material. Equations 3-13 and 3-14 give the compressive stress resulting from earth and live load pressure for conventional extruded DR pipe and for ASTM F894 profile wall PE Pipe:

(3-13)

$$S = \frac{(P_E + P_L)\,DR}{288}$$

(3-14)

$$S = \frac{(P_E + P_L)\,D_O}{288A}$$

WHERE

P_E **= vertical soil pressure due to earth load, psf**

P_L **= vertical soil pressure due to live-load, psf**

S **= pipe wall compressive stress, lb/in^2**

DR **= Dimension Ratio, D_O/t**

D_O **= pipe outside diameter (for profile pipe $D_O = D_I + 2H_P$), in**

D_I **= pipe inside diameter, in**

H_P **= profile wall height, in**

A **= profile wall average cross-sectional area, in^2/in**
(Obtain the profile wall area from the manufacturer of the profile pipe.)

(Note: These equations contain a factor of 144 in the denominator for correct units conversions.)

Equation 3-14 may overstate the wall stress in profile pipe. Ring deflection in profile wall pipe induces arching. The "Deep Fill Installation" section of this chapter discusses arching and gives equations for calculating the earth pressure resulting from arching, P_{RD}. P_{RD} is given by Equation 3-23 and may be substituted for PE to determine the wall compressive stress when arching occurs.

The compressive stress in the pipe wall can be compared to the pipe material allowable compressive stress. If the calculated compressive stress exceeds the allowable stress, then a lower DR (heavier wall thickness) or heavier profile wall is required.

Allowable Compressive Stress

Allowable long-term compressive stress values for the several PE material designation codes can be found in Appendix, Chapter 3.

The long-term compressive stress value should be reduced for elevated temperature pipeline operation. Temperature design factors used for hydrostatic pressure may be used. See temperature re-rating or adjustment factors in the Appendix, Chapter 3.

Ring Compression Example

Find the pipe wall compressive ring stress in a DR 32.5 PE4710 pipe buried under 46 ft of cover. The ground water level is at the surface, the saturated weight of the insitu silty-clay soil is 120 lbs/ft3.

SOLUTION: Find the vertical earth pressure acting on the pipe. Use Equation 3-1.

Although the net soil pressure is equal to the buoyant weight of the soil, the water pressure is also acting on the pipe. Therefore the total pressure (water and earth load) can be found using the saturated unit weight of the soil.

Next, solve for the compressive stress.

$$P_E = (120\ pcf)(46\ ft) = 5520\ psf$$

$$S = \frac{(5520\ lb/\ ft^2)(32.5)}{288} = 623\ lb/inch^2$$

The compressive stress is well below the allowable limit of 1150 psi for the PE4710 material given in the Appendix, Chapter 3.

Constrained (Buried) Pipe Wall Buckling

Excessive compressive stress (or thrust) may cause the pipe wall to become unstable and buckle. Buckling from ring compressive stress initiates locally as a large "dimple," and then grows to reverse curvature followed by structural collapse. Resistance to buckling is proportional to the wall thickness divided by the diameter raised to a power. Therefore the lower the DR, the higher the resistance. Buried pipe has an added resistance due to support (or constraint) from the surrounding soil.

Non-pressurized pipes or gravity flow pipes are most likely to have a net compressive stress in the pipe wall and, therefore, the allowable buckling pressure should be calculated and compared to the total (soil and ground water) pressure. For most pressure pipe applications, the fluid pressure in the pipe exceeds the external pressure, and the net stress in the pipe wall is tensile. Buckling needs only be considered for that time the pipe is not under pressure, such as during and immediately after construction and during system shut-downs and, in cases in which a surge pressure event can produce a temporary negative internal pressure. Under these circumstances the pipe will react much stiffer to buckling as its modulus is higher under short term loading. When designing, select a modulus appropriate for the duration of the negative external pressure. For pipe that are subjected to negative pressure due to surge, consideration should be given to selecting a DR that gives the pipe sufficient unconstrained collapse strength to resist the full applied negative pressure without support for the soil. This is to insure against construction affects that result in the embedment material not developing its full design strength.

This chapter gives two equations for calculating buckling. The modified Luscher Equation is for buried pipes that are beneath the ground water level, subject to vacuum pressure, or under live load with a shallow cover. These forces act to increase even the slightest eccentricity in the pipe wall by following deformation inward. While soil pressure alone can create instability, soil is less likely to follow deformation inward, particularly if it is granular. So, dry ground buckling is only considered for deep applications and is given by the Moore-Selig Equation found in the section, "Buckling of Pipes in Deep, Dry Fills".

Luscher Equation for Constrained Buckling Below Ground Water Level

For pipes below the ground water level, operating under a full or partial vacuum, or subject to live load, Luscher's equation may be used to determine the allowable constrained buckling pressure. Equation 3-15 and 3-16 are for DR and profile pipe respectively.

(3-15)

$$P_{WC} = \frac{5.65}{N}\sqrt{RB'E'\frac{E}{12(DR-1)^3}}$$

(3-16)

$$P_{WC} = \frac{5.65}{N}\sqrt{RB'E'\frac{EI}{D_M{}^3}}$$

WHERE

P_{WC} = allowable constrained buckling pressure, lb/in^2

N = safety factor

(3-17)
$$R = 1 - 0.33\frac{H_{GW}}{H}$$

WHERE

R = buoyancy reduction factor

H_{GW} = height of ground water above pipe, ft

H = depth of cover, ft

(3-18)
$$B' = \frac{1}{1 + 4e^{(-0.065H)}}$$

WHERE

e = natural log base number, 2.71828

E' = soil reaction modulus, psi

E = apparent modulus of elasticity, psi

DR = Dimension Ratio

I = pipe wall moment of inertia, in^4/in ($t^3/12$, if solid wall construction)

D_M = Mean diameter (D_I + 2z or D_O – t), in

Although buckling occurs rapidly, long-term external pressure can gradually deform the pipe to the point of instability. This behavior is considered viscoelastic and can be accounted for in Equations 3-15 and 3-16 by using the apparent modulus of elasticity value for the appropriate time and temperature of the loading. For instance, a vacuum event is resisted by the short-term value of the modulus whereas continuous ground water pressure would be resisted by the 50 year value. For modulus values see Appendix, Chapter 3.

For pipes buried with less than 4 ft or a full diameter of cover, Equations 3-15 and 3-16 may have limited applicability. In this case the designer may want to use Equations 3-39 and 3-40.

The designer should apply a safety factor commensurate with the application. A safety factor of 2.0 has been used for thermoplastic pipe.

The allowable constrained buckling pressure should be compared to the total vertical stress acting on the pipe crown from the combined load of soil, and ground water or floodwater. It is prudent to check buckling resistance against a ground water level for a 100-year-flood. In this calculation the total vertical stress is typically taken as the prism load pressure for saturated soil, plus the fluid pressure of any floodwater above the ground surface.

For DR pipes operating under a vacuum, it is customary to use Equation 3-15 to check the combined pressure from soil, ground water, and vacuum, and then to use the unconstrained buckling equation, Equation 3-39, to verify that the pipe can operate with the vacuum independent of any soil support or soil load, in case construction does not develop the full soil support. Where vacuum load is short-term, such as during water hammer events two calculations with Equation 3-14 are necessary. First determine if the pipe is sufficient for the ground water and soil pressure using a long-term modulus; then determine if the pipe is sufficient for the combined ground water, soil pressure and vacuum loading using the short-term modulus.

Constrained Buckling Example

Does a 36" SDR 26 PE4710 pipe have satisfactory resistance to constrained buckling when installed with 18 ft of cover in a compacted soil embedment? Assume ground water to the surface and an E' of 1500 lb/in^2.

SOLUTION: Solve Equation 3-15. Since this is a long-term loading condition, the 50 year stress relaxation modulus for PE4710 material is given in the Appendix to Chapter 3 as 29,000 psi. Soil cover, H, and ground water height, H_{GW}, are both 18 feet. Therefore, the soil support factor, B', is found as follows;

$$B' = \frac{1}{1+4e^{-(0.065)(18)}} = 0.446$$

and the bouyancy reduction factor, R, is found as follows:

$$R = 1 - 0.33\frac{18}{18} = 0.67$$

Solve Equation 3-15 for the allowable long-term constrained buckling pressure:

$$P_{WC} = \frac{5.65}{2}\sqrt{\frac{0.67(0.446)1500(29{,}000)}{12(26-1)^3}}$$

$$P_{WC} = 23.5\ psi = 3387\ psf$$

The earth pressure and ground water pressure applied to the pipe is found using Equation 3-1 (prism load) with a saturated soil weight. The saturated soil weight being the net weight of both soil and water.

$$P_E = (120)(18) = 2160\frac{lb}{ft^2}$$

Compare this with the constrained buckling pressure. Since P_{WC} exceeds P_E, DR 26 has satisfactory resistance to constrained pipe buckling.

Installation Category #2: Shallow Cover Vehicular Loading

The Standard Installation methodology assumes that the pipe behaves primarily as a "membrane" structure, that is, the pipe is almost perfectly flexible with little ability to resist bending. At shallow cover depths, especially those less than one pipe diameter, membrane action may not fully develop, and surcharge or live loads place a bending load on the pipe crown. In this case the pipe's flexural stiffness carries part of the load and prevents the pipe crown from dimpling inward under the load. Equation 3-19, published by Watkins [14] gives the soil pressure that can be supported at the pipe crown by the combination of the pipe's flexural stiffness (bending resistance) and the soil's internal resistance against heaving upward. In addition to checking Watkins' formula, the designer should check deflection using Equations 3-10 or 3-11, pipe wall compressive stress using Equations 3-13 or 3-14, and pipe wall buckling using Equations 3-15 or 3-16.

Watkins' equation is recommended only where the depth of cover is greater than one-half of the pipe diameter and the pipe is installed at least 18 inches below the road surface. In other words, it is recommended that the pipe regardless of diameter always be at least 18" beneath the road surface where there are live loads present; more may be required depending on the properties of the pipe and installation. In some cases, lesser cover depths may be sufficient where there is a reinforced concrete cap or a reinforced concrete pavement slab over the pipe. Equation 3-19 may be used for both DR pipe and profile pipe. See definition of "A" below.

(3-19)

$$P_{WAT} = \frac{12w(KH)^2}{N_S D_O} + \frac{7387(I)}{N_S D_O^2 c}\left(S_{MAT} - \frac{w D_O H}{288A}\right)$$

WHERE

P_{WAT} = allowable live load pressure at pipe crown for pipes with one diameter or less of cover, psf

w = unit weight of soil, lb/ft^3

D_O = pipe outside diameter, in

H = depth of cover, ft

I = pipe wall moment of inertia ($t^3/12$ for DR pipe), in^4/in

A = profile wall average cross-sectional area, in^2/in, for profile pipe or wall thickness (in) for DR pipe (obtain the profile from the manufacturer of the profile pipe.)

c = outer fiber to wall centroid, in

$c = H_P - z$ for profile pipe and $c = 0.5t$ for DR pipe, in

H_P = profile wall height, in

z = pipe wall centroid, in

S_{MAT} = material yield strength, lb/in^2, Use 3000 PSI for PE3408

N_S = safety factor

K = passive earth pressure coefficient

(3-20)
$$K = \frac{1 + \mathrm{SIN}(\phi)}{1 - \mathrm{SIN}(\phi)}$$

ϕ = angle of internal friction, deg

Equation 3-19 is for a point load applied to the pipe crown. Wheel loads should be determined using a point load method such as given by Equations 3-2 (Timoshenko) or 3-4 (Boussinesq).

When a pipe is installed with shallow cover below an unpaved surface, rutting can occur which will not only reduce cover depth, but also increase the impact factor.

Shallow Cover Example

Determine the safety factor against flexural failure of the pipe accompanied by soil heave, for a 36" RSC 100 F894 profile pipe 3.0 feet beneath an H20 wheel load. Assume an asphalt surface with granular embedment.

SOLUTION: The live load pressure acting at the crown of the pipe can be found using Equation 3-4, the Boussinesq point load equation. At 3.0 feet of cover the highest live load pressure occurs directly under a single wheel and equals:

$$P_L = \frac{(3)(2.0)(16000)(3.0)^3}{2\pi(3.0)^5} = 1697\ psf$$

WHERE

I_f = 2.0

W = 16,000 lbs

H = 3.0 ft

w = 120 pcf

The live load pressure is to be compared with the value in Equation 3-19. To solve Equation 3-19, the following parameters are required:

I = 0.171 in^4/in

A = 0.470 in^2/in

H_P = 2.02 in (Profile Wall Height)

D_O = D_I+2*h = 36.00+2*2.02 = 40.04 in

Z = 0.58 in

C = h-z = 1.44 in

S = 3000 psi

ϕ = 30 deg.

Determine the earth pressure coefficient:

$$K = \frac{1+\sin(30)}{1-\sin(30)} = \frac{1+0.5}{1-0.5} = 3.0$$

The live load pressure incipient to failure equals:

$$P_{WAT} = \frac{(12)120(3.0*3.0)^2}{40.04} + \frac{7387*0.171}{40.04^2(1.44)}(3000 - \frac{120(40.04)3.0}{288*0.470})$$

$$P_{WAT} = 2904 + 1584 = 4498\ psf$$

The resulting safety factor equals:

$$N = \frac{P_{WAT}}{p_L} = \frac{4498}{1697} = 2.65$$

Installation Category #3: Deep Fill Installation

The performance limits for pipes in a deep fill are the same as for any buried pipe. They include:

1. Compressive ring thrust stress
2. Ring deflection
3. Constrained pipe wall buckling

The suggested calculation method for pipe in deep fill applications involves the introduction of design routines for each performance limit that are different than those previously given.

Compressive ring thrust is calculated using soil arching. The arching calculation may also be used for profile pipe designs in standard trench applications. Profile pipes are relatively low stiffness pipes where significant arching may occur at relatively shallow depths of cover.

At a depth of around 50 feet or so it becomes impractical to use Spangler's equation as published in this chapter because it neglects the significant load reduction due to arching and the inherent stiffening of the embedment and consequential increase in E′ due to the increased lateral earth pressure applied to the embedment. This section gives an alternate deflection equation for use with PE pipes. It was first introduced by Watkins et al. (1) for metal pipes, but later Gaube extended its use to include PE pipes. (15)

Where deep fill applications are in dry soil, Luscher's equation (Eq. 3-15 or 3-16) may often be too conservative for design as it considers a radial driving force from ground water or vacuum. Moore and Selig[17] developed a constrained pipe wall buckling equation suitable for pipes in dry soils, which is given in a following section.

Considerable care should be taken in the design of deeply buried pipes whose failure may cause slope failure in earthen structures, or refuse piles or whose failure may have severe environmental or economical impact. These cases normally justify the use of methods beyond those given in this Chapter, including finite element analysis and field testing, along with considerable professional design review.

Compressive Ring Thrust and the Vertical Arching Factor

The combined horizontal and vertical earth load acting on a buried pipe creates a radially-directed compressive load acting around the pipe's circumference. When a PE pipe is subjected to ring compression, thrust stress develops around the pipe hoop, and the pipe's circumference will ever so slightly shorten. The shortening permits "thrust arching," that is, the pipe hoop thrust stiffness is less than the soil hoop thrust stiffness and, as the pipe deforms, less load follows the pipe. This occurs much like the vertical arching described by Marston.[18] Viscoelasticity enhances this effect. McGrath[19] has shown thrust arching to be the predominant form of arching with PE pipes.

Burns and Richard[6] have published equations that give the resulting stress occurring in a pipe due to arching. As discussed above, the arching is usually considered when calculating the ring compressive stress in profile pipes. For deeply buried pipes McGrath [19] has simplified the Burns and Richard's equations to derive a vertical arching factor as given by Equation 3-21.

(3-21)

$$VAF = 0.88 - 0.71 \frac{S_A - 1}{S_A + 2.5}$$

WHERE

VAF **= Vertical Arching Factor**

S_A **= Hoop Thrust Stiffness Ratio**

(3-22)

$$S_A = \frac{1.43\, M_S\, r_{CENT}}{EA}$$

WHERE

r_{CENT} **= radius to centroidal axis of pipe, in**

M_S**= one-dimensional modulus of soil, psi**

E **= apparent modulus of elasticity of pipe material, psi (See Appendix, Chapter 3)**

A**= profile wall average cross-sectional area, in^2/in, or wall thickness (in) for DR pipe**

One-dimensional modulus values for soil can be obtained from soil testing, geotechnical texts, or Table 3-12 which gives typical values. The typical values in Table 3-12 were obtained by converting values from McGrath [20].

TABLE 3-12
Typical Values of M_S, One-Dimensional Modulus of Soil

Vertical Soil Stress[1] (psi)	Gravelly Sand/Gravels 95% Std. Proctor (psi)	Gravelly Sand/Gravels 90% Std. Proctor (psi)	Gravelly Sand/Gravels 85% Std. Proctor (psi)
10	3000	1600	550
20	3500	1800	650
40	4200	2100	800
60	5000	2500	1000
80	6000	2900	1300
100	6500	3200	1450

* Adapted and extended from values given by McGrath[20]. For depths not shown in McGrath[20], the MS values were approximated using the hyperbolic soil model with appropriate values for K and n where n=0.4 and K=200, K=100, and K=45 for 95% Proctor, 90% Proctor, and 85% Proctor, respectively.

[1] Vertical Soil Stress (psi) = [soil depth (ft) x soil density (pcf)]/144

The radial directed earth pressure can be found by multiplying the prism load (pressure) by the vertical arching factor as shown in Eq. 3-23.

(3-23) $$P_{RD} = (VAF)wH$$

WHERE

P_{RD} **= radial directed earth pressure, lb/ft²**

w **= unit weight of soil, pcf**

H **= depth of cover, ft**

The ring compressive stress in the pipe wall can be found by substituting P_{RD} from Equation 3-23 for P_E in Equation 3-13 for DR pipe and Equation 3-14 for profile wall pipe.

Earth Pressure Example

Determine the earth pressure acting on a 36" profile wall pipe buried 30 feet deep. The following properties are for one unique 36" profile pipe made from PE3608 material. Other 36" profile pipe may have different properties. The pipe's cross-sectional area, A, equals 0.470 inches^2/inch, its radius to the centroidal axis is 18.00 inches plus 0.58 inches, and its apparent modulus is 27,000 psi. Its wall height is 2.02 in and its D_O equals 36 in +2 (2.02 in) or 40.04 in. Assume the pipe is installed in a clean granular soil compacted to 90% Standard Proctor (Ms = 1875 psi), the insitu soil is as stiff as the embedment, and the backfill weighs 120 pcf. (Where the excavation is in a stable trench, the stiffness of the insitu soil can generally be ignored in this calculation.) The following series of equations calculates the hoop compressive stress, S, in the pipe wall due to the earth pressure applied by the soil above the pipe. The earth pressure is reduced from the prism load by the vertical arching factor.

(From Equation 3-22)

$$S_A = \frac{1.43(1875\frac{lbs}{inch^2})(18.58\,inch)}{(28250\frac{lbs}{inch^2})(0.470\frac{inch^2}{inch})} = 3.93$$

(From Equation 3-21)

$$VAF = 0.88 - 0.71\frac{3.75-1}{3.75+2.5} = 0.56$$

(From Equation 3-23)

$$P_{RD} = 0.57(120\ pcf)(30\ ft) = 2016\frac{lb}{ft^2}$$

(From Equation 3-14)

$$S = \frac{P_{RD} D_O}{288A} = \frac{2052\ psf\,(40.04\,in)}{288\,(0.470\,in^2/in)} = 596\ psi \leq 1000\ psi$$

(Allowable compressive stress per Table C.1, Appendix to Chapter 3)

Ring Deflection of Pipes Using Watkins-Gaube Graph

R. Watkins[1] developed an extremely straight-forward approach to calculating pipe deflection in a fill that does not rely on E′. It is based on the concept that the deflection of a pipe embedded in a layer of soil is proportional to the compression or settlement of the soil layer and that the constant of proportionality is a function of the relative stiffness between the pipe and soil. Watkins used laboratory testing to establish and graph proportionality constants, called Deformation Factors, D_F , for the stiffness ranges of metal pipes. Gaube[15, 16] extended Watkins' work by testing to include PE pipes. In order to predict deflection, the designer first determines the amount of compression in the layer of soil in which the pipe is installed using conventional geotechnical equations. Then, deflection equals the soil compression multiplied by the D_F factor. This bypasses some of the inherent problems associated with using the soil reaction modulus, E′, values. The designer using the Watkins-Gaube Graph (Figure 3-6) should select conservative soil modulus values to accommodate variance due to installation. Two other factors to consider when using this method is that it assumes a constant Deformation Factor independent of depth of cover and it does not address the effect of the presence of ground water on the Deformation Factor.

To use the Watkins-Gaube Graph, the designer first determines the relative stiffness between pipe and soil, which is given by the Rigidity Factor, R_F. Equation 3-24 and 3-25 are for DR pipe and for profile pipe respectively:

(3-24)
$$R_F = \frac{12\,E_S\,(DR-1)^3}{E}$$

(3-25)
$$R_F = \frac{E_S D_m^{\;3}}{EI}$$

WHERE

DR = **Dimension Ratio**

E_S = **Secant modulus of the soil, psi**

E = **Apparent modulus of elasticity of pipe material, psi**

I = **Pipe wall moment of inertia of pipe, in^4/in**

D_m = **Mean diameter (D_I + 2z or D_O – t), in**

The secant modulus of the soil may be obtained from testing or from a geotechnical engineer's evaluation. In lieu of a precise determination, the soil modulus may be related to the one-dimensional modulus, M_S, from Table 3-12 by the following equation where μ is the soil's Poisson ratio.

(3-26)
$$E_S = M_S\frac{(1+\mu)(1-2\mu)}{(1-\mu)}$$

TABLE 3-13
Typical range of Poisson's Ratio for Soil (Bowles [21])

Soil Type	Poisson's Ratio, μ
Saturated Clay	0.4-0.5
Unsaturated Clay	0.1-0.3
Sandy Clay	0.2-0.3
Silt	0.3-0.35
Sand (Dense)	0.2-0.4
Coarse Sand (Void Ratio 0.4-0.7)	0.15
Fine-grained Sand (Void Ratio 0.4-0.7)	0.25

Next, the designer determines the Deformation Factor, D_F , by entering the Watkins-Gaube Graph with the Rigidity Factor. See Fig. 3-6. The Deformation Factor is the proportionality constant between vertical deflection (compression) of the soil layer containing the pipe and the deflection of the pipe. Thus, pipe deflection can be obtained by multiplying the proportionality constant D_F times the soil settlement. If D_F is less than 1.0 in Fig. 3-6, use 1.0.

The soil layer surrounding the pipe bears the entire load of the overburden above it without arching. Therefore, settlement (compression) of the soil layer is proportional to the prism load and not the radial directed earth pressure. Soil strain, ε_S, may be determined from geotechnical analysis or from the following equation:

(3-27)

$$\varepsilon_S = \frac{wH}{144E_S}$$

WHERE

w **= unit weight of soil, pcf**

H **= depth of cover (height of fill above pipe crown), ft**

E_S **= secant modulus of the soil, psi**

The designer can find the pipe deflection as a percent of the diameter by multiplying the soil strain, in percent, by the deformation factor:

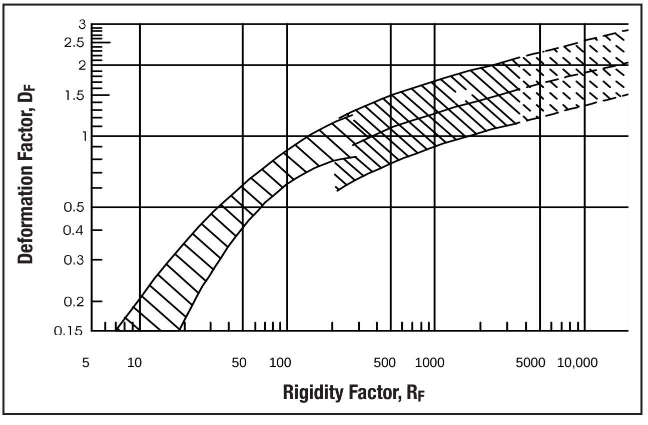


Figure 3-6 Watkins-Gaube Graph

(3-28)

$$\frac{\Delta X}{D_M}(100) = D_F \varepsilon_S$$

WHERE

$\Delta X/D_M$ **multiplied by 100 gives percent deflection.**

Example of the Application of the Watkins-Gaube Calculation Technique

Find the deflection of a 6″ SDR 11 pipe made from PE4710 materials under 140 ft of fill with granular embedment containing 12% or less fines, compacted at 90% of standard proctor. The fill weighs 75 pcf.

SOLUTION: First, calculate the vertical soil pressure equation, Eq. 3-1.

Eq. 3-1: $P_E = wH$

P_E **= (75lb/ft³)(140 ft)**

P_E **= 10,500 lb/ft² or 72.9 psi**

The M_S is obtained by interpolation from Table 3-12 and equals 2700. The secant modulus can be found assuming a Poisson's Ratio of 0.30.

$$E_S = \frac{2700\ psi\,(1+0.30)(1-2(0.30))}{(1-0.30)} = 2005\ psi$$

The rigidity factor is obtained from Equation 3-24.

$$R_F = \frac{12\,(2005)\,(11-1)^3}{29{,}000} = 830$$

Using Figure 3-6, the average value of the deformation factor is found to be 1.2. The soil strain is calculated by Equation 3-27.

$$\varepsilon_S = \frac{75pcf * 140ft}{144 * 2005\dfrac{lbs}{inch^2}} * 100 = 3.6\%$$

The deflection is found by multiplying the soil strain by the deformation factor:

$$\frac{\Delta X}{D_M}(100) = 1.2*3.6 = 4.4\%$$

Moore-Selig Equation for Constrained Buckling in Dry Ground

As discussed previously, a compressive thrust stress exists in buried pipe. When this thrust stress approaches a critical value, the pipe can experience a local instability or large deformation and collapse. In an earlier section of this chapter, Luscher's equation was given for constrained buckling under ground water. Moore and Selig(17) have used an alternate approach called the continuum theory to develop design equations for contrained buckling due to soil pressure (buckling of embedded pipes). The particular version of their equations given below is more appropriate for dry applications than Luscher's equation. Where ground water is present, Luscher's equation should be used.

The Moore-Selig Equation for critical buckling pressure follows: (Critical buckling pressure is the pressure at which buckling will occur. A safety factor should be provided.)

(3-29)
$$P_{CR} = \frac{2.4\,\varphi\,R_H}{D_M}(EI)^{\frac{1}{3}}(E_S^*)^{\frac{2}{3}}$$

WHERE

P_{CR} = **Critical constrained buckling pressure, psi**

φ = **Calibration Factor, 0.55 for granular soils**

R_H = **Geometry Factor**

E = **Apparent modulus of elasticity of pipe material, psi**

I = **Pipe wall moment of Inertia, in^4/in (t^3/12, if solid wall construction)**

E_S^* = **E_S /(1-μ)**

E_S = **Secant modulus of the soil, psi**

μ_S = **Poisson's Ratio of Soil (Consult a textbook on soil for values. Bowles (1982) gives typical values for sand and rock ranging from 0.1 to 0.4.)**

The geometry factor is dependent on the depth of burial and the relative stiffness between the embedment soil and the insitu soil. Moore has shown that for deep burials in uniform fills, R_H equals 1.0.

Critical Buckling Example

Determine the critical buckling pressure and safety factor against buckling for the 6″ SDR 11 pipe (5.987″ mean diameter) in the previous example.

SOLUTION:

$$E_S^* = \frac{2000}{(1-0.3)} = 2860\ \frac{lbs}{inch^2}$$

$$P_{CR} = \frac{2.4*0.55*1.0}{5.987}(29000*0.018)^{\frac{1}{3}}(2860)^{\frac{2}{3}} = 358\ \frac{lbs}{in^2}$$

Determine the Safety Factor against buckling:

$$S.F. = \frac{P_{CR}}{P_E} = \frac{358*144}{140*75} = 4.9$$

Installation Category #4: Shallow Cover Flotation Effects

Shallow cover presents some special considerations for flexible pipes. As already discussed, full soil structure interaction (membrane effect) may not occur, and live loads are carried in part by the bending stiffness of the pipe. Even if the pipe has sufficient strength to carry live load, the cover depth may not be sufficient to prevent the pipe from floating upward or buckling if the ground becomes saturated with ground water. This section addresses:

- Minimum soil cover requirements to prevent flotation
- Hydrostatic buckling (unconstrained)

Design Considerations for Ground Water Flotation

High ground water can float buried pipe, causing upward movement off-grade as well as catastrophic upheaval. This is not an issue for plastic pipes alone. Flotation of metal or concrete pipes may occur at shallow cover when the pipes are empty.

Flotation occurs when the ground water surrounding the pipe produces a buoyant force greater than the sum of the downward forces provided by the soil weight, soil friction, the weight of the pipe, and the weight of its contents. In addition to the disruption occurring due to off-grade movements, flotation may also cause significant reduction of soil support around the pipe and allow the pipe to buckle from the external hydrostatic pressure.

Flotation is generally not a design consideration for buried pipe where the pipeline runs full or nearly full of liquid or where ground water is always below the pipe invert. Where these conditions are not met, a quick “rule of thumb” is that pipe buried in soil having a saturated unit weight of at least 120 lb/ft^3 with at least 1½ pipe diameters of cover will not float. However, if burial is in lighter weight soils or with lesser cover, ground water flotation should be checked.

Mathematically the relationship between the buoyant force and the downward forces is given in Equation 3-30. Refer to Figure 3-7. For an empty pipe, flotation will occur if:

(3-30) $$F_B > W_P + W_S + W_D + W_L$$

WHERE

F_B = buoyant force, lb/ft of pipe

W_P = pipe weight, lb/ft of pipe

W_S = weight of saturated soil above pipe, lb/ft of pipe

W_D = weight of dry soil above pipe, lb/ft of pipe

W_L = weight of liquid contents, lb/ft of pipe

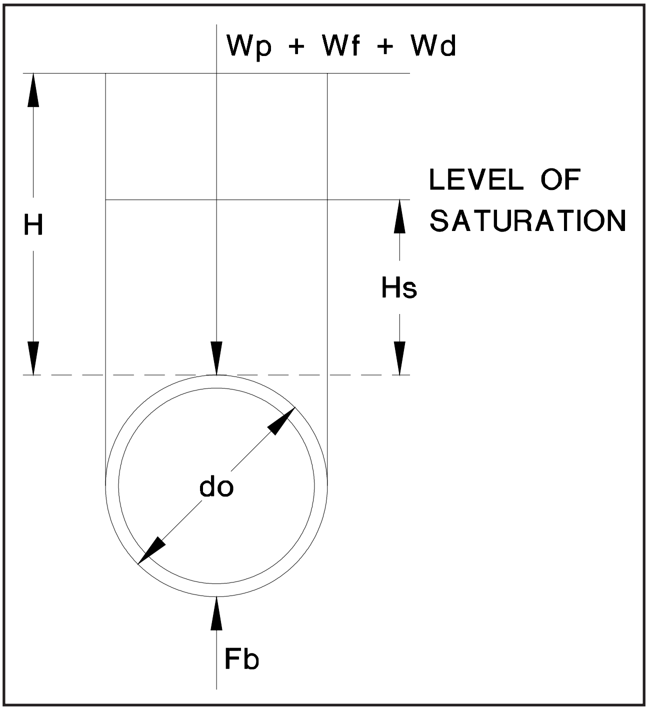


Figure 3-7 Schematic of Ground Water Flotation Forces

For a 1 ft length of pipe running empty and submerged, the upward buoyant force is:

(3-31)
$$F_B = \omega_G \frac{\pi}{4} d_O^{\ 2}$$

WHERE

d_O = pipe outside diameter, ft

ω_G = specific weight of ground water

(fresh water = 62.4 lb/ft³)

(sea water = 64.0 lb/ft³)

The average pipe weight, W_P in lbs/ft may be obtained from manufacturers' literature or from Equation 3-32 or from the Table of Weights in the Appendix to this Chapter. This calculation is based on the use of a pipe material density of 0.955 gm/cc.

(3-32)
$$W_P = \pi d_O^{\ 2} \frac{(1.06\,DR - 1.12)}{DR^2} 59.6$$

Equation 3-33 gives the weight of soil per lineal foot of pipe.

(3-33) $$W_D = \omega_d (H - H_S) d_O$$

WHERE

ω_d = **unit weight of dry soil, pcf (See Table 3-14 for typical values.)**

H = **depth of cover, ft**

H_S = **level of ground water saturation above pipe, ft**

TABLE 3-14
Saturated and Dry Soil Unit Weight

Soil Type	Unit Weight, lb/ft^3	
	Saturated, unit weight of ground water, pcf ω_S	Dry, the weight of saturated soil above the pipe, lbs per foot of pipe ω_d
Sands & Gravel	118-150	93-144
Silts & Clays	87-131	37-112
Glacial Till	131-150	106-144
Crushed Rock	119-137	94-125
Organic Silts & Clay	81-112	31-94

(3-34) $$W_S = (\omega_S - \omega_G)\left(\frac{d_O^{\,2}(4-\pi)}{8} + d_O H_S\right)$$

WHERE

ω_S = **saturated unit weight of soil, pcf**

When an area is submerged, the soil particles are buoyed by their immersion in the ground water. The effective weight of submerged soil, (W_S – W_G), is the soil's saturated unit weight less the density of the ground water. For example, a soil of 120 pcf saturated unit weight has an effective weight of 57.6 pcf when completely immersed in water (120 - 62.4 = 57.6 pcf).

Equation 3-35 gives the weight per lineal foot of the liquid in a full pipe.

(3-35) $$W_L = \omega_L \frac{\pi d'^2}{4}$$

WHERE

W_L = **weight of the liquid in the pipe, lb/ft**

ω_L = **unit weight of liquid in the pipe, pcf**

and if half-full, the liquid weight is

(3-36)

$$W_L = \omega_L \frac{\pi d'^2}{8}$$

WHERE

ω_L **= unit weight of the liquid in the pipe, lb/ft3**

d' **= pipe inside diameter, ft**

For liquid levels between empty and half-full (0% to 50%), or between half-full and full (50% to 100%), the following formulas provide an approximate liquid weight with an accuracy of about ±10%. Please refer to Figure 3-8.

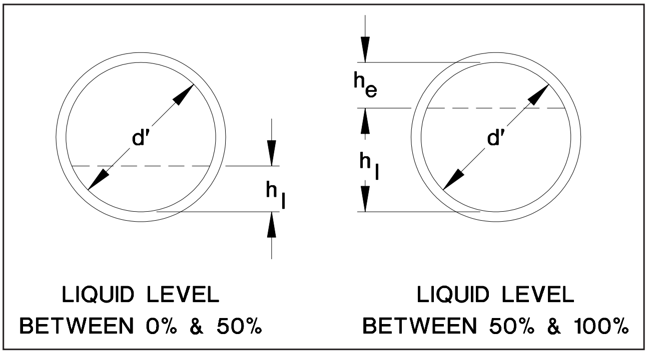


Figure 3-8 Flotation and Internal Liquid Levels

For a liquid level between empty and half-full, the weight of the liquid in the pipe is approximately

(3-37)

$$W_L = \omega_L \frac{4 h_l^3}{3} \sqrt{\frac{d' - h_l}{h_l} + 0.392}$$

WHERE

hl **= liquid level in pipe, ft**

For a liquid level between half-full and full, the weight of the liquid in the pipe is approximately

(3-38)

$$W_L = \omega_L \left(\frac{\pi d'^2}{4} - 1.573 h_e \right)$$

WHERE

$h_e = d' - h_l$

Unconstrained Pipe Wall Buckling (Hydrostatic Buckling)

The equation for buckling given in this section is here to provide assistance when designing shallow cover applications. However, it may be used to calculate the buckling resistance of above grade pipes subject to external air pressure due to an internal vacuum, for submerged pipes in lakes or ponds, and for pipes placed in casings without grout encasement.

Unconstrained pipe are pipes that are not constrained by soil embedment or concrete encasement. Above ground pipes are unconstrained, as are pipes placed in a casing prior to grouting. Buried pipe may be considered essentially unconstrained where the surrounding soil does not significantly increase its buckling resistance beyond its unconstrained strength. This can happen where the depth of cover is insufficient to prevent the pipe from floating slightly upward and breaking contact with the embedment below its springline. Ground water, flooding, or vacuum can cause buckling of unconstrained pipe.

A special case of unconstrained buckling referred to as "upward" buckling may happen for shallow buried pipe. Upward buckling occurs when lateral pressure due to ground water or vacuum pushes the sides of the pipe inward while forcing the pipe crown and the soil above it upward. (Collapse looks like pipe deflection rotated 90 degrees.) A pipe is susceptible to upward buckling where the cover depth is insufficient to restrain upward crown movement. It has been suggested that a minimum cover of four feet is required before soil support contributes to averting upward buckling; however, larger diameter pipe may require as much as a diameter and a half to develop full support.

A conservative design for shallow cover buckling is to assume no soil support, and to design the pipe using the unconstrained pipe wall buckling equation. In lieu of this, a concrete cap, sufficient to resist upward deflection, may also be placed over the pipe and then the pipe may be designed using Luscher's equation for constrained buckling.

Equations 3-39 and 3-40 give the allowable unconstrained pipe wall buckling pressure for DR pipe and profile pipe, respectively.

(3-39)

$$P_{WU} = \frac{f_O}{N_S} \frac{2E}{(1-\mu^2)} \left(\frac{1}{DR-1} \right)^3$$

(3-40)
$$P_{WU} = \frac{f_O}{N_S} \frac{24EI}{(1-\mu^2)D_M^3}$$

WHERE

P_{WU} **= allowable unconstrained pipe wall buckling pressure, psi**

DR **= Dimension Ratio**

E **= apparent modulus of elasticity of pipe material, psi**

f_O **= Ovality Correction Factor, Figure 3-9**

N_S **= safety factor**

I **= Pipe wall moment of inertia, in4/in**

μ **= Poisson's ratio**

D_M **= Mean diameter, (DI + 2z or DO -t), in**

D_I **= pipe inside diameter, in**

z **= wall-section centroidal distance from inner fiber of pipe, in (obtain from pipe producer)**

Although buckling occurs rapidly, long-term external pressure can gradually deform the pipe to the point of instability. This behavior is considered viscoelastic and can be accounted for in Equations 3-39 and 3-40 by using the apparent modulus of elasticity value for the appropriate time and temperature of the specific application as given in the Appendix, Chapter 3. For Poisson's ratio, use a value of 0.45 for all PE pipe materials.

Ovality or deflection of the pipe diameter increases the local radius of curvature of the pipe wall and thus reduces buckling resistance. Ovality is typically reported as the percentage reduction in pipe diameter or:

(3-41)
$$\%DEFLECTION = 100\left(\frac{D_I - D_{MIN}}{D_I}\right)$$

WHERE

D_I **= pipe inside diameter, in**

D_{MIN} **= pipe minimum inside diameter, in**

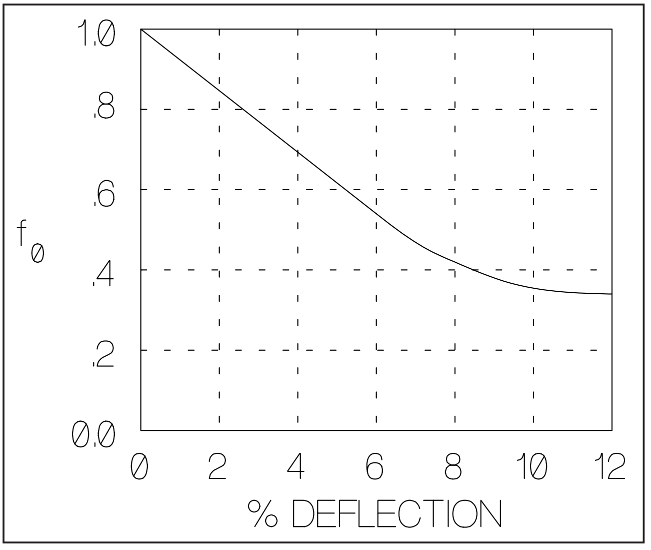


Figure 3-9 Ovality Compensation Factor, $f_{\emptyset}$

The designer should compare the critical buckling pressure with the actual anticipated pressure, and apply a safety factor commensurate with their assessment of the application. A safety factor of 2.5 is common, but specific circumstances may warrant a higher or lower safety factor. For large-diameter submerged pipe, the anticipated pressure may be conservatively calculated by determining the height of water from the pipe invert rather than from the pipe crown.

Ground Water Flotation Example

Find the allowable flood water level above a 10" DR 26 PE4710 pipe installed with only 2 ft of cover. Assume the pipe has 3 percent ovality due to shipping, handling, and installation loads.

SOLUTION: Use Equation 3-39. The pipe wall buckling pressure depends upon the duration of the water level above the pipe. If the water level is long lasting, then a long-term value of the stress relaxation modulus should be used, but if the water level rises only occasionally, a shorter term elastic modulus may be applied.

Case (a): For the long lasting water above the pipe, the stress relaxation modulus at 50 year, 73°F is approximately 29,000 lb/in^2 for a typical PE4710 material. Assuming 3% ovality (f_O equals 0.76) and a 2.5 to 1 safety factor, the allowable long-term pressure, P_{WU} is given by:

$$P_{WU} = \frac{(0.76)}{2.5}\frac{2\,(29{,}000)}{(1-0.45^2)}\left(\frac{1}{26-1}\right)^3 = 1.4\ psig\ (3.2\ ft\text{-}hd)$$

Case (b): Flooding conditions are occasional happenings, usually lasting a few days to a week or so. However, ground water elevations may remain high for several weeks following a flood. The 1000 hour elastic modulus value has been used to approximate the expected flood duration.

$$P_{WU} = \frac{(0.76)}{2.5}\frac{2(46{,}000)}{(1-0.45^2)}\left(\frac{1}{26-1}\right)^3 = 2.2\ psi = 5.2\ ft.\ (of\ head)$$

Section 4
Thermal Design Considerations

Introduction

Similar to all thermoplastics, the engineering behavior of PE can be significantly affected by temperature. An increase in temperature causes a decrease in strength and in apparent modulus. A decrease in temperature results in opposite effects. For effective pipeline design these effects must be adequately recognized.

In the case of pressure pipe the highest operating temperature is limited by the practical consideration of retaining sufficient long-term strength or maintaining the pressure rating that is sufficient for the intended application. That maximum temperature is generally 140°F (60°C). De-rating factors for up to 140°F are presented in the Appendix to Chapter 3. If higher temperatures are being considered, the pipe supplier should be consulted for additional information.

In the case of buried applications of non-pressure pipe, in which the embedment material provides a significant support against pipe deformation, the highest operating temperature can be higher –sometimes, as high 180°F (~82°C). The temperature re-rating factors for apparent modulus of elasticity, which are presented in the Appendix, Chapter 3, can be used for the re-rating of a pipe's 73°F pipe stiffness for any other temperature between -20 to 140°F (-29 to 60°C). For temperatures above 140°F the effect is more material dependent and the pipe supplier should be consulted.

A beneficial feature of PE pipe is that it retains much of its toughness even at low temperatures. It can be safely handled, installed and operated even in sub-freezing conditions. The formation of ice in the pipe will restrict or, stop flow but not cause pipe breakage. Although under sub-freezing conditions PE pipe is somewhat less tough it is still much tougher that most other pipe materials.

Strength and Stress/Strain Behavior

As discussed earlier in this Handbook, the engineering properties of PE material are affected by the magnitude of a load, the duration of loading, the environment and the operating temperature. And, also as discussed earlier, the standard convention is to report the engineering properties of PE piping materials based on a standard environment – which is water – and, a standard temperature – which is 73°F (23°C). A design for a condition that departs from this convention requires that an appropriate accommodation be made. This Section addresses the issue of the effect of a different temperature than that of the base temperature.

To properly consider the affect of temperature on strength and, on stress/strain properties this must be done based on actually observed long-term strength behavior. Tables which are presented in an Appendix to Chapter 3, list temperature adjustment factors that have been determined based on long-term evaluations.

Thermal Expansion/Contraction Effects

Fused PE pipe joints are fully restrained. The pipe and the fused joints can easily accommodate the stress induced by changes in temperature. In general thrust restraints and mechanical expansion joints are not required in a fully fused PE piping system. However, thrust restraint may be necessary where PE pipe is connection to other 'bell and spigot' end pipe. Design for this condition is addressed later in this chapter and in PPI's TN-36.

Because the coefficient of thermal expansion for PE is significantly larger than that of non-plastics, considerations relating to the potential effects of thermal expansion/contraction may include:

- Piping that is installed when it is warm may cool sufficiently after installation to generate significant tensile forces. Thus, the final connection should be made after the pipe has equilibrated to its operating temperature.
- Unrestrained pipe may shrink enough so that it pulls out from a mechanical joint that does not provide sufficient pull-out resistance. Methods used to connect PE pipe should provide restraint against pull-out that is either inherent to the joint design or additional mechanical restraint. See Chapter 9. (Note –specially designed thrust blocks may be needed to restrain movement when mechanical joints are in line with PE pipes.)
- Unrestrained pipe that is exposed to significant temperature swings will in some combination, expand and contract, deflect laterally, or apply compressive or tensile loads to constraints or supports.

A mitigating factor is PE's relatively low modulus of elasticity, which greatly reduces the thrust that is generated by a restrained expansion/contraction. This thrust imposes no problem on thermal fusion connections.

See Chapter 8 for additional information on designing above grade pipelines for thermal effects.

Unrestrained Thermal Effects

The theoretical change in length for an unrestrained pipe placed on a frictionless surface can be determined from Equation 4-1.

(4-1) $$\Delta L = L \alpha \Delta T$$

WHERE

ΔL = pipeline length change, ft

L = pipe length, ft

α = thermal expansion coefficient, in/in/°F

ΔT = temperature change,°F

The coefficient of thermal expansion for PE pipe material is approximately 1 x 10^{-4} in/in/°F. As a "rule of thumb," temperature change for *unrestrained* PE pipe is about "1/10/100," that is, 1 inch for each 10°F temperature change for each 100 foot of pipe. A temperature rise results in a length increase while a temperature drop results in a length decrease.

End Restrained Thermal Effects

A length of pipe that is restrained or anchored on both ends and one placed on a frictionless surface will exhibit a substantially different reaction to temperature change than the unrestrained pipe discussed above. If the pipe is restrained in a straight line between two points and the temperature decreases, the pipe will attempt to decrease in length. Because the ends are restrained or anchored, length change cannot occur, so a longitudinal tensile stress is created along the pipe. The magnitude of this stress can be determined using Equation 4-2.

(4-2) $$\sigma = E\,\alpha\,\Delta T$$

Where terms are as defined above, and

σ = longitudinal stress in pipe, psi

E = apparent modulus elasticity of pipe material, psi

The value of the apparent modulus of elasticity of the pipe material has a large impact on the calculated stress. As with all thermoplastic materials, PE's modulus, and therefore its stiffness, is dependent on temperature and the duration of the applied load. Therefore, the appropriate elastic modulus should be selected based on these two variables. When determining the appropriate time interval, it is important to consider that heat transfer occurs at relatively slow rates through the wall of PE pipe; therefore temperature changes do not occur rapidly. Because the temperature change does not happen rapidly, the average temperature is often chosen for the modulus selection.

(4-3) $$F = \sigma\,A_P$$

Where terms are as defined above, and

F = end thrust, lb

A_P = area of pipe cross section,$(\pi/4)(DO^2 - Di^2)$ in^2

Equations 4-2 and 4-3 can also be used to determine the compressive stress and thrust (respectively) from a temperature increase.

Although the length change of PE pipe during temperature changes is greater than many other materials, the amount of force required to restrain the movement is less because of its lower modulus of elasticity.

As pipeline temperature decreases from weather or operating conditions, a longitudinal tensile stress develops along the pipe that can be determined using Equation 4-2. The allowable tensile stress for pipe operating at its pressure rating is determined by the HDS for that temperature. The HDS is that of the pipe material for the base temperature at 73°F (23°C) times the temperature adjustment factor listed in Appendix, Chapter 3.

(4-4) $$\sigma_{allow} = HDS \ x \ F_T$$

WHERE

HDS **= Hydrostatic Design Stress, psi (Table 1-1)**

F_T **= Temperature factor (See Appendix, Chapter 3)**

Equation 4-3 is used to determine the thrust load applied to structural anchoring devices.

During temperature increase, the pipeline attempts to increase in length, but is restrained by mechanical guides that direct longitudinal compressive thrust to structural anchors that prevent length increase. This in turn creates a longitudinal compressive stress in the pipe and a thrust load against the structural anchors. The compressive stress that develops in the pipe and is resisted by the structural anchors is determined using Equation 4-2. Compressive stress should not exceed the allowable compressive stress per the Appendix in Chapter 3.

Above Ground Piping Systems

The design considerations for PE piping systems installed above ground are extensive and, therefore, are addressed separately in the Handbook chapter on above ground applications for PE pipe.

Buried Piping Systems

A buried pipe is generally well restrained by soil loads and will experience very little lateral movement. However, longitudinal end loads may result that need to be addressed.

Transitions to other pipe materials that use the bell and spigot assembly technique will need to be calculated using the thrust load as delivered by the pressure plus the potential of the load due to temperature changes. Merely fixing the end of the PE to the mating material may result in up stream joints pulling apart unless those connections are restrained. The number of joints that need to be restrained to prevent bell and spigot pull out may be calculated using techniques as recommended by the manufacturer of the alternate piping material. Equation 4-3 may be used to calculate the total thrust load due to temperature change.

Low thrust capacity connections to manholes or other piping systems as will be present in many no pressure gravity flow systems may be addressed via a longitudinal thrust anchor such as shown in Fig. 4-1. The size of the thrust block will vary depending on soil conditions and the thrust load as calculated via Equation 4-3.

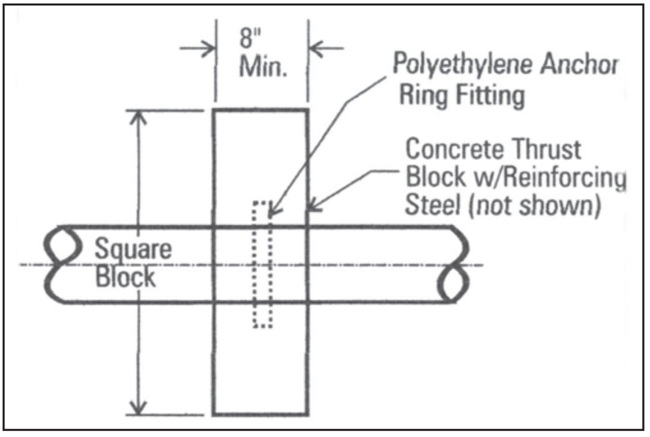


Figure 4-1 Longitudinal Thrust Anchor

Conclusion

The durability and visco-elastic nature of modern PE piping materials makes these products ideally suited for a broad array of piping applications such as: potable water mains and service lines, natural gas distribution, oil and gas gathering, force main sewers, gravity flow lines, industrial and various mining piping. To this end, fundamental design considerations such as fluid flow, burial design and thermal response were presented within this chapter in an effort to provide guidance to the piping system designer on the use of these tough piping materials in the full array of potential piping applications.

For the benefit of the pipeline designer, a considerable amount of background information and/or theory has been provided within this chapter. However, the designer should also keep in mind that the majority of pipeline installations fall within the criteria for the AWWA Design Window approach presented in Section 3 of this chapter. Pipeline installations that fall within the guidelines for the AWWA Window, may be greatly simplified in matters relating to the design and use of flexible PE piping systems.

While every effort has been made to be as thorough as possible in this discussion, it also should be recognized that these guidelines should be considered in light of specific project, installation and/or service needs. For this reason, this chapter on pipeline design should be utilized in conjunction with the other chapters of this Handbook to provide a more thorough understanding of the design considerations that may be specific to a particular project or application using PE piping systems. The reader is also referred to the extensive list of references for this chapter as additional resources for project and or system analysis and design.

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Appendix A.1

PIPE WEIGHTS AND DIMENSIONS (DIPS)
(Black)

OD			Pipe inside diameter (d)	Minimum Wall Thickness (t)	Weight (w)
Nominal in.	Actual in.	DR*	in.	in.	lb. per foot
		7	2.76	0.566	2.621
		9	3.03	0.440	2.119
		11	3.20	0.360	1.776
		13.5	3.34	0.293	1.476
3	3.960	15.5	3.42	0.255	1.299
		17	3.47	0.233	1.192
		21	3.56	0.189	0.978
		26	3.64	0.152	0.798
		32.5	3.70	0.122	0.644
		7	3.35	0.686	3.851
		9	3.67	0.533	3.114
		11	3.87	0.436	2.609
		13.5	4.05	0.356	2.168
4	4.800	15.5	4.14	0.310	1.909
		17	4.20	0.282	1.752
		21	4.32	0.229	1.436
		26	4.41	0.185	1.172
		32.5	4.49	0.148	0.946
		7	4.81	0.986	7.957
		9	5.27	0.767	6.434
		11	5.57	0.627	5.392
		13.5	5.82	0.511	4.480
6	6.900	15.5	5.96	0.445	3.945
		17	6.04	0.406	3.620
		21	6.20	0.329	2.968
		26	6.34	0.265	2.422
		32.5	6.45	0.212	1.954

OD			Pipe inside diameter (d)	Minimum Wall Thickness (t)	Weight (w)
Nominal in.	Actual in.	DR*	in.	in.	lb. per foot
		7	6.31	1.293	13.689
		9	6.92	1.006	11.069
		11	7.31	0.823	9.276
		13.5	7.63	0.670	7.708
8	9.050	15.5	7.81	0.584	6.787
		17	7.92	0.532	6.228
		21	8.14	0.431	5.106
		26	8.31	0.348	4.166
		32.5	8.46	0.278	3.361
		7	7.74	1.586	20.593
		9	8.49	1.233	16.652
		11	8.96	1.009	13.955
		13.5	9.36	0.822	11.595
10	11.100	15.5	9.58	0.716	10.210
		17	9.72	0.653	9.369
		21	9.98	0.529	7.681
		26	10.19	0.427	6.267
		32.5	10.38	0.342	5.056
		7	9.20	1.886	29.121
		9	10.09	1.467	23.548
		11	10.66	1.200	19.734
		13.5	11.13	0.978	16.397
12	13.200	15.5	11.39	0.852	14.439
		17	11.55	0.776	13.250
		21	11.87	0.629	10.862
		26	12.12	0.508	8.863
		32.5	12.34	0.406	7.151
		7	10.67	2.186	39.124
		9	11.70	1.700	31.637
		11	12.35	1.391	26.513
		13.5	12.90	1.133	22.030
14	15.300	15.5	13.21	0.987	19.398
		17	13.39	0.900	17.801
		21	13.76	0.729	14.593
		26	14.05	0.588	11.907
		32.5	14.30	0.471	9.607

OD			Pipe inside diameter (d)	Minimum Wall Thickness (t)	Weight (w)
Nominal in.	Actual in.	DR*	in.	in.	lb. per foot
		7	12.13	2.486	50.601
		9	13.30	1.933	40.917
		11	14.05	1.582	34.290
		13.5	14.67	1.289	28.492
16	17.400	15.5	15.02	1.123	25.089
		17	15.23	1.024	23.023
		21	15.64	0.829	18.874
		26	15.98	0.669	15.400
		32.5	16.26	0.535	12.425
		7	13.59	2.786	63.553
		9	14.91	2.167	51.390
		11	15.74	1.773	43.067
		13.5	16.44	1.444	35.785
18	19.500	15.5	16.83	1.258	31.510
		17	17.07	1.147	28.916
		21	17.53	0.929	23.704
		26	17.91	0.750	19.342
		32.5	18.23	0.600	15.605
		7	15.06	3.086	77.978
		9	16.51	2.400	63.055
		11	17.44	1.964	52.842
		13.5	18.21	1.600	43.907
20	21.600	15.5	18.65	1.394	38.662
		17	18.91	1.271	35.479
		21	19.42	1.029	29.085
		26	19.84	0.831	23.732
		32.5	20.19	0.665	19.147
		11	20.83	2.345	75.390
		13.5	21.75	1.911	62.642
		15.5	22.27	1.665	55.159
24	25.800	17	22.58	1.518	50.618
		21	23.20	1.229	41.495
		26	23.70	0.992	33.858
		32.5	24.12	0.794	27.317

OD			Pipe inside diameter (d)	Minimum Wall Thickness (t)	Weight (w)
Nominal in.	Actual in.	DR*	in.	in.	lb. per foot
		13.5	26.97	2.370	96.367
		15.5	27.62	2.065	84.855
30	32.000	17	28.01	1.882	77.869
		21	28.77	1.524	63.835
		26	29.39	1.231	52.086
		32.5	29.91	0.985	42.023

* These DRs (7.3, 9, 11, 13.5, 17, 21, 26, 32.5) are from the standard dimension ratio (SDR) series established by ASTM F 412.51

Appendix A.2

PIPE WEIGHTS AND DIMENSIONS (IPS)
(BLACK)

OD			Pipe inside diameter (d)	Minimum Wall Thickness (t)	Weight (w)
Nominal in.	Actual in.	DR	in.	in.	lb. per foot
		7	0.59	0.120	0.118
		7.3	0.60	0.115	0.114
1/2	0.840	9	0.64	0.093	0.095
		9.3	0.65	0.090	0.093
		11	0.68	0.076	0.080
		11.5	0.69	0.073	0.077
		7	0.73	0.150	0.184
		7.3	0.75	0.144	0.178
3/4	1.050	9	0.80	0.117	0.149
		9.3	0.81	0.113	0.145
		11	0.85	0.095	0.125
		11.5	0.86	0.091	0.120
		7	0.92	0.188	0.289
		7.3	0.93	0.180	0.279
1	1.315	9	1.01	0.146	0.234
		9.3	1.02	0.141	0.227
		11	1.06	0.120	0.196
		11.5	1.07	0.114	0.188
		7	1.16	0.237	0.461
		7.3	1.18	0.227	0.445
		9	1.27	0.184	0.372
1 1/4	1.660	9.3	1.28	0.178	0.362
		11	1.34	0.151	0.312
		11.5	1.35	0.144	0.300
		13.5	1.40	0.123	0.259

OD			Pipe inside diameter (d)	Minimum Wall Thickness (t)	Weight (w)
Nominal in.	Actual in.	DR	in.	in.	lb. per foot
		7	1.32	0.271	0.603
		7.3	1.35	0.260	0.583
		9	1.45	0.211	0.488
1 1/2	1.900	9.3	1.47	0.204	0.474
		11	1.53	0.173	0.409
		11.5	1.55	0.165	0.393
		13.5	1.60	0.141	0.340
		15.5	1.64	0.123	0.299
		7	1.66	0.339	0.943
		7.3	1.69	0.325	0.911
		9	1.82	0.264	0.762
		9.3	1.83	0.255	0.741
2	2.375	11	1.92	0.216	0.639
		11.5	1.94	0.207	0.614
		13.5	2.00	0.176	0.531
		15.5	2.05	0.153	0.467
		17	2.08	0.140	0.429
		7	2.44	0.500	2.047
		7.3	2.48	0.479	1.978
		9	2.68	0.389	1.656
		9.3	2.70	0.376	1.609
		11	2.83	0.318	1.387
3	3.500	11.5	2.85	0.304	1.333
		13.5	2.95	0.259	1.153
		15.5	3.02	0.226	1.015
		17	3.06	0.206	0.932
		21	3.15	0.167	0.764
		26	3.21	0.135	0.623

OD			Pipe inside diameter (d)	Minimum Wall Thickness (t)	Weight (w)
Nominal in.	Actual in.	DR	in.	in.	lb. per foot
		7	3.14	0.643	3.384
		7.3	3.19	0.616	3.269
		9	3.44	0.500	2.737
		9.3	3.47	0.484	2.660
		11	3.63	0.409	2.294
4	4.500	11.5	3.67	0.391	2.204
		13.5	3.79	0.333	1.906
		15.5	3.88	0.290	1.678
		17	3.94	0.265	1.540
		21	4.05	0.214	1.262
		26	4.13	0.173	1.030
		32.5	4.21	0.138	0.831
		7	3.88	0.795	5.172
		7.3	3.95	0.762	4.996
		9	4.25	0.618	4.182
		9.3	4.29	0.598	4.065
		11	4.49	0.506	3.505
5	5.563	11.5	4.54	0.484	3.368
		13.5	4.69	0.412	2.912
		15.5	4.80	0.359	2.564
		17	4.87	0.327	2.353
		21	5.00	0.265	1.929
		26	5.11	0.214	1.574
		32.5	5.20	0.171	1.270
		7	4.62	0.946	7.336
		7.3	4.70	0.908	7.086
		9	5.06	0.736	5.932
		9.3	5.11	0.712	5.765
		11	5.35	0.602	4.971
6	6.625	11.5	5.40	0.576	4.777
		13.5	5.58	0.491	4.130
		15.5	5.72	0.427	3.637
		17	5.80	0.390	3.338
		21	5.96	0.315	2.736
		26	6.08	0.255	2.233
		32.5	6.19	0.204	1.801

OD			Pipe inside diameter (d)	Minimum Wall Thickness (t)	Weight (w)
Nominal in.	Actual in.	DR	in.	in.	lb. per foot
		7	6.01	1.232	12.433
		7.3	6.12	1.182	12.010
		9	6.59	0.958	10.054
		9.3	6.66	0.927	9.771
		11	6.96	0.784	8.425
8	8.625	11.5	7.04	0.750	8.096
		13.5	7.27	0.639	7.001
		15.5	7.45	0.556	6.164
		17	7.55	0.507	5.657
		21	7.75	0.411	4.637
		26	7.92	0.332	3.784
		7	7.49	1.536	19.314
		7.3	7.63	1.473	18.656
		9	8.22	1.194	15.618
		9.3	8.30	1.156	15.179
		11	8.68	0.977	13.089
10	10.750	11.5	8.77	0.935	12.578
		13.5	9.06	0.796	10.875
		15.5	9.28	0.694	9.576
		17	9.41	0.632	8.788
		21	9.66	0.512	7.204
		26	9.87	0.413	5.878
		32.5	10.05	0.331	4.742
		7	8.89	1.821	27.170
		7.3	9.05	1.747	26.244
		9	9.75	1.417	21.970
		9.3	9.84	1.371	21.353
		11	10.29	1.159	18.412
12	12.750	11.5	10.40	1.109	17.693
		13.5	10.75	0.944	15.298
		15.5	11.01	0.823	13.471
		17	11.16	0.750	12.362
		21	11.46	0.607	10.134
		26	11.71	0.490	8.269
		32.5	11.92	0.392	6.671

OD			Pipe inside diameter (d)	Minimum Wall Thickness (t)	Weight (w)
Nominal in.	Actual in.	DR	in.	in.	lb. per foot
		7	9.76	2.000	32.758
		7.3	9.93	1.918	31.642
		9	10.70	1.556	26.489
		9.3	10.81	1.505	25.745
		11	11.30	1.273	22.199
14	14.000	11.5	11.42	1.217	21.332
		13.5	11.80	1.037	18.445
		15.5	12.09	0.903	16.242
		17	12.25	0.824	14.905
		21	12.59	0.667	12.218
		26	12.86	0.538	9.970
		32.5	13.09	0.431	8.044
		7	11.15	2.286	42.786
		7.3	11.35	2.192	41.329
		9	12.23	1.778	34.598
		9.3	12.35	1.720	33.626
		11	12.92	1.455	28.994
16	16.000	11.5	13.05	1.391	27.862
		13.5	13.49	1.185	24.092
		15.5	13.81	1.032	21.214
		17	14.00	0.941	19.467
		21	14.38	0.762	15.959
		26	14.70	0.615	13.022
		7	12.55	2.571	54.151
		7.3	12.77	2.466	52.307
		9	13.76	2.000	43.788
		9.3	13.90	1.935	42.558
		11	14.53	1.636	36.696
18	18.000	11.5	14.68	1.565	35.263
		13.5	15.17	1.333	30.491
		15.5	15.54	1.161	26.849
		17	15.76	1.059	24.638
		21	16.18	0.857	20.198
		26	16.53	0.692	16.480
		32.5	16.83	0.554	13.296

OD			Pipe inside diameter (d)	Minimum Wall Thickness (t)	Weight (w)
Nominal in.	Actual in.	DR	in.	in.	lb. per foot
		7	13.94	2.857	66.853
		7.3	14.19	2.740	64.576
		9	15.29	2.222	54.059
		9.3	15.44	2.151	52.541
		11	16.15	1.818	45.304
20	20.000	11.5	16.31	1.739	43.535
		13.5	16.86	1.481	37.643
		15.5	17.26	1.290	33.146
		17	17.51	1.176	30.418
		21	17.98	0.952	24.936
		26	18.37	0.769	20.346
		32.5	18.70	0.615	16.415
		9	16.82	2.444	65.412
		9.3	16.98	2.366	63.574
		11	17.76	2.000	54.818
		11.5	17.94	1.913	52.677
22	22.000	13.5	18.55	1.630	45.548
		15.5	18.99	1.419	40.107
		17	19.26	1.294	36.805
		21	19.78	1.048	30.172
		26	20.21	0.846	24.619
		32.5	20.56	0.677	19.863
		9	18.35	2.667	77.845
		9.3	18.53	2.581	75.658
		11	19.37	2.182	65.237
		11.5	19.58	2.087	62.690
24	24.000	13.5	20.23	1.778	54.206
		15.5	20.72	1.548	47.731
		17	21.01	1.412	43.801
		21	21.58	1.143	35.907
		26	22.04	0.923	29.299
		32.5	22.43	0.738	23.638

OD			Pipe inside diameter (d)	Minimum Wall Thickness (t)	Weight (w)
Nominal in.	Actual in.	DR	in.	in.	lb. per foot
		11	22.60	2.545	88.795
		11.5	22.84	2.435	85.329
		13.5	23.60	2.074	73.781
		15.5	24.17	1.806	64.967
28	28.000	17	24.51	1.647	59.618
		21	25.17	1.333	48.874
		26	25.72	1.077	39.879
		32.5	26.17	0.862	32.174
		11	24.22	2.727	101.934
		11.5	24.47	2.609	97.954
		13.5	25.29	2.222	84.697
		15.5	25.90	1.935	74.580
30	30.000	17	26.26	1.765	68.439
		21	26.97	1.429	56.105
		26	27.55	1.154	45.779
		32.5	28.04	0.923	36.934
		13.5	26.97	2.370	96.367
		15.5	27.62	2.065	84.855
32	32.000	17	28.01	1.882	77.869
		21	28.77	1.524	63.835
		26	29.39	1.231	52.086
		32.5	29.91	0.985	42.023
		15.5	31.08	2.323	107.395
		17	31.51	2.118	98.553
36	36.000	21	32.37	1.714	80.791
		26	33.06	1.385	65.922
		32.5	33.65	1.108	53.186
		15.5	36.26	2.710	146.176
		17	36.76	2.471	134.141
42	42.000	21	37.76	2.000	109.966
		26	38.58	1.615	89.727
		32.5	39.26	1.292	72.392

OD			Pipe inside diameter (d)	Minimum Wall Thickness (t)	Weight (w)
Nominal in.	Actual in.	DR	in.	in.	lb. per foot
		17	42.01	2.824	175.205
48	48.000	21	43.15	2.286	143.629
		26	44.09	1.846	117.194
		32.5	44.87	1.477	94.552
		21	48.55	2.571	181.781
54	54.000	26	49.60	2.077	148.324
		32.5	50.48	1.662	119.668

Appendix A.3

List of Design Chapter Variables

υ	=	kinematic viscosity, ft^2/sec
ρ	=	fluid density, lb/ft^3
μ	=	dynamic viscosity, $lb\text{-}sec/ft^2$
Δv	=	Sudden velocity change, ft/sec
a	=	Wave velocity (celerity), ft/sec
A_C	=	Cross-sectional area of pipe bore, ft^2
a_c	=	contact area, ft^2
A	=	profile wall average cross-sectional area, in^2/in, for profile pipe or wall thickness (in) for DR pipe
A_S	=	Area of pipe cross-section or $(\prod/4)(D_O^2 - D_i^2)$, in^2
A_P	=	area of the outside wall of the pipe, 100 in^2
C	=	Hazen-Williams Friction Factor, dimensionless ,see table 1-7.
c	=	outer fiber to wall centroid, in
C_V	=	percent solids concentration by volume
C_W	=	percent solids concentration by weight
D_A	=	pipe average inside diameter, in
DF	=	Design Factor, from Table 1-2
d'	=	Pipe inside diameter, ft
D_I	=	Pipe inside diameter, in
D_M	=	Mean diameter ($DI+2z$ or D_O-t), in
D_{MIN}	=	pipe minimum inside diameter, in
D_o	=	pipe outside diameter, in
d_O	=	pipe outside diameter, ft
DR	=	Dimension Ratio, D_O/t
E	=	Apparent modulus of elasticity for pipe material, psi
e	=	natural log base number, 2.71828
E'	=	Modulus of soil reaction, psi
E_d	=	Dynamic instantaneous effective modulus of pipe material (typically 150,000 psi for PE pipe)
E_N	=	Native soil modulus of soil reaction, psi
E_S	=	Secant modulus of the soil, psi
E_S*	=	$E_S/(1-\mu)$
f	=	friction factor (dimensionless, but dependent upon pipe surface roughness and Reynolds number)
F	=	end thrust, lb
F_B	=	buoyant force, lb/ft
F_L	=	velocity coefficient (Tables 1-14 and 1-15)
f_O	=	Ovality Correction Factor, Figure 2-9
F_S	=	Soil Support Factor
F_T	=	Service Temperature Design Factor, from Table 1-11
g	=	Constant gravitational acceleration, 32.2 ft/sec^2
H_P	=	profile wall height, in
H	=	height of cover, ft
h_l	=	liquid level in the pipe, ft
H_{GW}	=	ground water height above pipe, ft
h_1	=	pipeline elevation at point 1, ft

h_1	=	inlet pressure, in H_2O
h_U	=	upstream pipe elevation, ft
h_2	=	pipeline elevation at point 2, ft
h_2	=	outlet pressure, in H_2O
d_D	=	downstream pipe elevation, ft
HDB	=	Hydrostatic Design Basis, psi
h_E	=	Elevation head, ft of liquid
h_f	=	friction (head) loss, ft. of liquid
H_S	=	level of ground water saturation above pipe, ft
I_V	=	Influence Value from Table 2-5
I	=	Pipe wall moment of inertia, in^4/in
IDR	=	ID -Controlled Pipe Dimension Ratio
I_f		impact factor
k	=	kinematic viscosity, centistokes
K_{BULK}	=	Bulk modulus of fluid at working temperature
K_{BED}	=	Bedding factor, typically 0.1
K	=	passive earth pressure coefficient
K’	=	Fittings Factor, Table 1-5
K_P	=	permeability constant (Table 1-13)
L_{EFF}	=	Effective Pipeline length, ft.
L	=	Pipeline length, ft
L_{DL}	=	Deflection lag factor
ΔL	=	pipeline length change, in
M	=	horizontal distance, normal to the pipe centerline, from the center of the load to the load edge, ft
M_s	=	one-dimensional modulus of soil, psi
n	=	roughness coefficient, dimensionless
N	=	horizontal distance, parallel to the pipe centerline, from the center of the load to the load edge, ft
N_S	=	safety factor
P	=	Internal Pressure, psi
P_W	=	perimeter wetted by flow, ft
p_1	=	inlet pressure, lb/in^2 absolute
p_2	=	outlet pressure, lb/in^2 absolute
P_A	=	pipe internal pressure, atmospheres (1 atmosphere = 14.7 lb/in^2)
PC	=	Pressure Class
P_{CR}	=	Critical constrained buckling pressure, psi
P_E	=	vertical soil pressure due to earth load, psf
P_f	=	friction (head) loss, psi
P_L	=	vertical soil pressure due to live load, psf
P_{OS}	=	Occasional Surge Pressure
P_{RD}	=	radial directed earth pressure, lb/ft^2
P_{RS}	=	Recurring Surge Pressure
P_s	=	Transient surge pressure, psig
P_{WAT}	=	Allowable live load pressure at pipe crowm for pipes with one diameter or less of cover, psf
P_{WC}	=	allowable constrained buckling pressure, lb/in^2
P_{WU}	=	allowable unconstrained pipe wall buckling pressure, psi

p_i	=	Pressure due to sub-area *i* lb/ft^2
Q	=	flow rate, gpm
Q_{FPS}	=	flow, ft^3/sec
Q_h	=	flow, standard ft^3/hour
q_P	=	volume of gas permeated, cm^3 (gas at standard temperature and pressure)
r_H	=	hydraulic radius, ft
r	=	distance from the point of load application to pipe crown, ft
R	=	buoyancy reduction factor
r_{CENT}	=	radius to centroidal axis of pipe, in
Re	=	Reynolds number, dimensionless
R_H	=	Geometry Factor
RSC	=	Ring Stiffness Constant, lb/ft
r_T	=	equivalent radius, ft
RF	=	Rigidity factor, dimensions
s	=	liquid density, gm/cm^3
S_H	=	hydraulic slope, ft/ft
S	=	pipe wall compressive stress, lb/in^2
S_{MAT}	=	material yield strength, lb/in^2
S_A	=	Hoop Thrust Stiffness Ratio
S_g	=	gas specific gravity
S_L	=	carrier liquid specific gravity
S_M	=	slurry mixture specific gravity
S_S	=	solids specific gravity
t	=	minimum wall thickness, in
t'	=	wall thickness, mils
T_{CR}	=	Critical time, seconds
V	=	flow velocity, ft/sec
VAF	=	Vertical Arching Factor
V_C	=	critical settlement velocity, ft/sec
ν	=	kinematic viscosity. ft^2/sec
V_{Min}	=	approximate minimum velocity, ft/sec
w	=	unit weight of soil, pcf
w	=	unit weight of soil, lb/ft^3
W_D	=	weight of dry soil above pipe, lb/ft of pipe
W_w	=	wheel load, lb
W_L	=	weight of liquid contents, lb/ft of pipe
W_L	=	weight of the liquid in contacts, lb/ft of pipe
WP	=	Working Pressure, psi
W_P	=	pipe weight, lb/ft of pipe
WPR	=	Working Pressure Rating, psi
w_S	=	distributed surcharge pressure acting over ground surface, lb/ft^2
W_S	=	weight of saturated soil above pipe, lb/ft of pipe
ζ	=	dynamic viscosity, centipoises
Z	=	Centroid of wall section, in
Z	=	Pipe wall centroid, in
Z_i	=	wall-section centroidal distance from inner fiber of pipe, in
α	=	thermal expansion coefficient, in/in/°F

ΔL	=	length change, in
ΔT	=	temperature change, °F
ΔX	=	Horizontal deflection, in
ΔV	=	Sudden velocity change., ft/sec
ε	=	absolute roughness, ft.
ε_S	=	Soil strain
Θ	=	elapsed time, days
μ_s	=	Poisson's Ratio of Soil
μ	=	Poisson's ratio
σ	=	longitudinal stress in pipe, psi
σ_{allow}	=	Allowable tensile stress at 73°F, lb/in
φ	=	Calibration Factor, 0.55 for granular soils change in psi
ω_D	=	unit weight of dry soil,lb/ft^3 (See Table 2-16 for typical values.)
ω_G	=	unit weight of groundwater lb/ft^3
ω_L	=	unit weight of liquid in the pipe, lb/ft^3
ω_S	=	unit weight of saturated soil, pcf lb/ft^3
ϕ	=	angle of internal friction, deg
Γ	=	Dynamic viscosity, lb-sec/ft^2

Chapter 7

Underground Installation of PE Piping

Introduction

Piping systems are prevalent throughout our everyday world. Most of us think of piping systems as underground structures used to convey liquids of one sort or another. To the novice, the concept of pipeline installation underground sounds relatively straight forward: a) dig a trench, b) lay the pipe in the trench, and c) fill the trench back in.

While this simplified perspective of pipeline construction may be appealing, it does not begin to address the engineering concepts involved in the underground installation of a pipeline. This chapter is written to assist in the development of a comprehensive understanding of the engineering principles utilized in the underground installation of PE pipe.

In the pages which follow, the reader will be introduced to the concept of a pipe soil system and the importance that the soil and the design and preparation of the back-fill materials play in the long-term performance of a buried pipe structure. Specific terminology and design concepts relating to the underground installation of PE pipe will be fully discussed. This will include fundamental guidelines regarding trench design and the placement and subsequent backfill of the PE pipe.

This chapter is intended to assist the pipeline designer in the underground installation of PE piping materials. This chapter is not intended as a substitute for the judgement of a professional engineer. Rather, it is felt that a comprehensive presentation of these design and installation principles may assist the engineer or designer in utilizing PE pipe in a range of applications that require that it be buried beneath the earth.

Flexible Pipe Installation Theory

PE piping is considered "flexible" pipe. Flexible pipes can deflect up to their allowable deflection limit without damage. Most PE pipes can withstand large amounts of deflection without damage but for practical purposes PE pipes are limited to 7.5% deflection or less depending on the DR and application. For PE pipes, flexibility is directly proportional to the Dimension Ratio (DR). Low DR pipes such as DR 7.3 have high resistance to deflection because their flexibility is very low, or conversely their stiffness is high. DR 7.3 has a Pipe Stiffness (PS) per ASTM D2412 of about 1600 psi. On the other hand DR 32.5 pipe has a PS of about 12.5 psi. Such a wide range in flexibility across a product line means different installation requirements for different DR's may be necessary to achieve successful and economical installations. The depth of cover and anticipated surface loads also affect the particular installation requirements. Therefore the engineer has to make an assessment of the application and site conditions to determine the best and most economical installation design. Guidelines for doing this are given in Chapter 6.

In general there are two objectives to achieve in an installation. The first is to provide an envelope of embedment to protect the pipe from mechanical damage from impact or hard objects (cobbles, boulders) in the soil. The second is to provide support against earth and live load pressures, where this is required. The envelope surrounding the pipe is referred to as the "embedment". See Figure 1. The earth and live loads are supported by the combination of the pipe's stiffness and the embedment's stiffness. Lower DR pipes will carry more of the load and require less support from the soil. When support from the embedment is needed by the pipe to resist earth and live loads, the embedment material is often compacted. The trench backfill placed on top of the embedment material may also be compacted. Compaction of trench backfill immediately above the pipe facilitates the redistribution of some of the load away from the pipe and into the side-fill soil.

Terminology of Pipe Embedment Materials

The materials enveloping a buried pipe are generally identified, as shown by their function or location (see Figure 1).

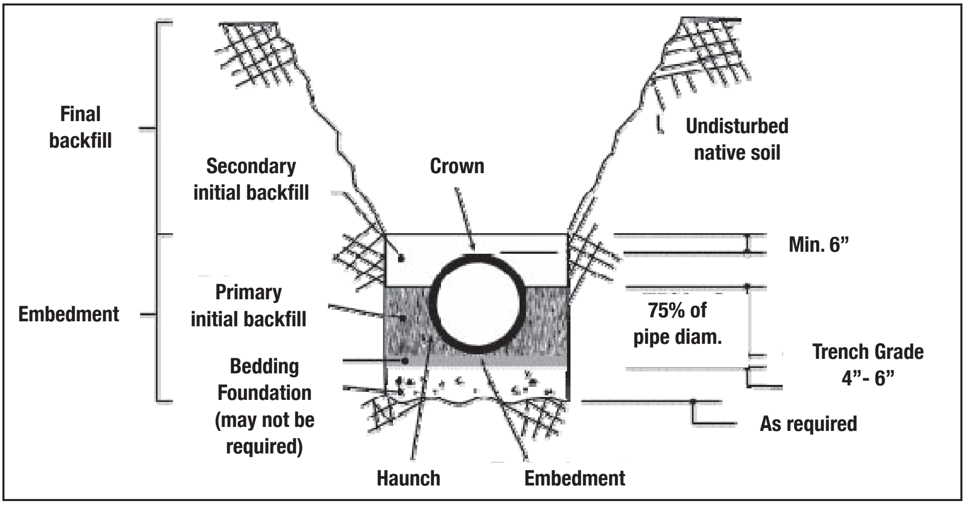

Figure 1 Pipe Trench

Note: When groundwater levels are expected to reach above the pipe, the secondary initial backfill should be a continuation of the primary initial backfill in order to provide optimum pipe support. Minimum trench width will depend on site conditions and embedment materials.

Foundation - A foundation is required only when the native trench bottom does not provide a firm working platform for placement of the pipe bedding material.

Initial Backfill - This is the critical zone of embedment soil surrounding the pipe from the foundation to at least 6 inches over the pipe. The pipe's ability to support loads and resist deflection is determined by the quality of the embedment material and the quality of its placement. Within the initial backfill zone are bedding, haunching, primary, and secondary zones.

Bedding - In addition to bringing the trench bottom to required grade, the bedding levels out any irregularities and ensures uniform support along the length of the pipe.

Haunching - The backfill under the lower half of the pipe (haunches) distributes the superimposed loadings. The nature of the haunching material and the quality of its placement are one of the most important factors in limiting the deformation of PE pipe.

Primary Initial Backfill - This zone of backfill provides the primary support against lateral pipe deformation. To ensure such support is available, this zone should extend from trench grade up to at least 75 percent of the pipe diameter. Under some conditions, such as when the pipe will be permanently below the ground water table, the primary initial backfill should extend to at least 6 inches over the pipe.

Secondary Initial Backfill - The basic function of the material in this zone is to distribute overhead loads and to isolate the pipe from any adverse effects of the placement of the final backfill.

Final Backfill - As the final backfill is not an embedment material, its nature and quality of compaction has a lesser effect on the flexible pipe. However, arching and thus a load reduction on the pipe is promoted by a stiff backfill. To preclude the possibility of impact or concentrated loadings on the pipe, both during and after backfilling, the final backfill should be free of large rocks, organic material, and debris. The material and compaction requirements for the final backfill should reflect sound construction practices and satisfy local ordinances and sidewalk, road building, or other applicable regulations.

Engineered and Simplified Installation Guidelines for PE Pipe

The engineer must evaluate the site conditions, the subsurface conditions, and the application objectives to determine the extent of support the pipe may need from the surrounding soil. Where the pipe burial depth is relatively deep, where subsurface soil conditions are not supportive of pipe, where surface loads or live loads are present, or where the pipe DR is high, the engineer will generally want to prepare a specific installation specification. Guidelines for what to include in that specification are given in later sections of this chapter. On the other hand there are many applications that meet the criterion below for using Simplified Installation Guidelines. These applications would include many rural transmission and distribution water lines, many force main sewer lines, and many process water lines. Typically these lines contain pressure pipes installed at shallow depths which are sufficiently stiff to resist the minimal earth load. In some cases a pipeline may contain sections that require specific engineering such as a section that crosses a road.

Simplified Installation Guidelines for Pressure Pipe

(Small diameter pressure pipes usually have adequate stiffness and are usually installed in such shallow depths that it is unnecessary to make an internal inspection of the pipe for deflection.)

A quality job can be achieved for most installations following the simple steps that are listed below. These guidelines apply where the following conditions are met:

1. Pipe Diameter of 24-inch or less

2. SDR equal to or less than 26

3. Depth of Cover between 2. 5 feet and 16 feet

4. Groundwater elevation never higher than 2 feet below the surface

5. The route of the pipeline is through stable soil

Stable soil is an arbitrary definition referring to soil that can be cut vertically or nearly vertically without significant sloughing, or soil that is granular but dry (or de-watered) that can stand vertical to at least the height of the pipe. These soils must also possess good bearing strength. (Quantitatively, good bearing capacity is defined as a minimum unconfined compressive strength of 1000 psf for cohesive soils or a minimum standard penetration resistance of 10 blows per ft for coarse grained soils.) Examples of soils that normally do not possess adequate stability for this method are mucky, organic, or loose and wet soils.

Where the above conditions are met, the specifier can write installation specifications from the following steps. The specifier should insure that all OSHA, state and local safety regulations are met.

The following are general guidelines for the installation of PE pipe. Other satisfactory methods or specifications may be available. This information should not be substituted for the judgment of a professional engineer in achieving specific requirements.

Simplfied Step-by-Step Installation

Trenching

Trench collapses can occur in any soil and account for a large number of worker deaths each year. In unbraced or unsupported excavations, proper attention should be paid to sloping the trench wall to a safe angle. Consult the local codes. All trench shoring and bracing must be kept above the pipe. (If this is not possible, consult the more detailed installation recommendations.) The length of open trench required for fused pipe sections should be such that bending and lowering the pipe into the ditch does not exceed the manufacturer's minimum recommended bend radius and result in kinking. The trench width at pipe grade should be equal to the pipe outer diameter (O. D.) plus 12 inches.

De-watering

For safe and proper construction the groundwater level in the trench should be kept below the pipe invert. This can be accomplished by deep wells, well points or sump pumps placed in the trench.

Bedding

Where the trench bottom soil can be cut and graded without difficulty, pressure pipe may be installed directly on the prepared trench bottom. For pressure pipe, the trench bottom may undulate, but must support the pipe smoothly and be free of ridges, hollows, and lumps. In other situations, bedding may be prepared from the excavated material if it is rock free and well broken up during excavation. The trench bottom should be relatively smooth and free of rock. When rocks, boulders, or large stones are encountered which may cause point loading on the pipe, they should be removed and the trench bottom padded with 4 to 6 inches of tamped bedding material. Bedding should consist of free-flowing material such as gravel, sand, silty sand, or clayey sand that is free of stones or hard particles larger than one-half inch.

Placing Pipe in Trench

PE pressure pipe up to about 8" in diameter and weighing roughly 6 lbs per ft or less can usually be placed in the trench by hand. Heavier, larger diameter pipe will require handling equipment to lift, move, and lower the pipe into the trench. Pipe must not be dumped, dropped, pushed, or rolled into the trench. Appropriate safety precautions must be observed whenever persons are in or near the trench

Pipe Embedment

The embedment material should be a coarse grained soil, such as gravel or sand, or a coarse grained soil containing fines, such as a silty sand or clayey sand. The particle size should not exceed one-half inch for 2 to 4-inch pipe, three-quarter inch for 6 to 8-inch pipe and one inch for all other sizes. Where the embedment is angular, crushed stone may be placed around the pipe by dumping and slicing with a shovel. Where the embedment is naturally occurring gravels, sands and mixtures with fines, the embedment should be placed in lifts, not exceeding 6 inches in thickness, and then tamped. Tamping should be accomplished by using a mechanical tamper. Compact to at least 85 percent Standard Proctor density as defined in ASTM D698, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort, (12 400 ft-lbf/ft^3 (600 kN-m/m^3))." Under streets and roads, increase compaction to 95 percent Standard Proctor density.

Leak Testing

If a leak test is required, it should be conducted in accordance with the procedure in Chapter 2 after the embedment material is placed.

Trench Backfill

The final backfill may consist of the excavated material, provided it is free from unsuitable matter such as large lumps of clay, organic material, boulders or stones larger than 8 inches, or construction debris. Where the pipe is located beneath a road, place the final backfill in lifts as mentioned earlier and compact to 95 percent Standard Proctor Density.

Engineered Installation Guidelines for PE Pipe

There will be applications where the engineer will want to prepare a specific embedment specification. These applications would most likely include gravity flow pipes that are relatively deep, shallow cover applications where the pipe is subject to vehicular or train loading, pipes placed in unstable, soft, or wet soils, high DR pipes, and pipes in deep applications such as landfills and embankments. The Simplified Installation Guidelines do not cover these applications. What all of these applications have in common is that the soil provides a relatively significant portion of the support against the overburden soil and surface loads. Or, to say this differently, the soil provides a relatively significant portion of the deflection resistance of the pipe. In these cases, detailed attention must be paid to the native (in-situ) soil, the embedment soil, and the placement of the embedment soil. The objective of installation is to minimize pipe deflection. Profile wall pipes such as pipes manufactured to ASTM F894 are normally inspected for deflection after installation. These pipes are normally limited to gravity flow applications and very low pressure systems. Conventionally-extruded, solid wall pipes such as “DR” classified pipes that are joined by heat fusion are normally not inspected for deflection. For instance AWWA standards C901 and C906 and manual M-55 do not call for field deflection testing of “DR” classified PE pipes.

Deflection Control

The load carrying capability of a PE pipe, particularly a pipe with a high DR, can be greatly increased by the soil in which it is embedded. When the pipe is loaded, load is transferred from the pipe to the soil by a horizontal outward movement of the pipe wall (see Figure 2). This enhances contact between pipe and soil and mobilizes the passive resistance of the soil. This resistance aids in preventing further pipe deformation and contributes to the support for the vertical loads. The amount of resistance found in the embedment soil is a direct consequence of the installation procedure. The stiffer the embedment materials are, the less deflection occurs. Because of this, the combination of embedment and pipe is often referred to as a pipe-soil system.

The key objective of a PE pipe installation is to limit or control deflection. (In this chapter the term “deflection” will mean a change in vertical diameter of the pipe, unless otherwise stated.) The deflection of a PE pipe is the sum total of two major components: the “installation deflection,” which reflects the technique and care by which the pipe is handled and installed; and the “service deflection,” which reflects the accommodation of the constructed pipe-soil system to the subsequent earth loading and other loadings.

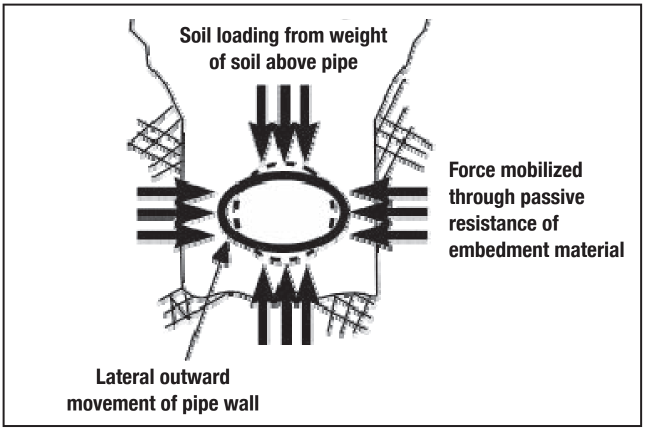

Figure 2 Mobilization of Enveloping Soil through Pipe Deformation

The "service deflection," which is usually a decrease in vertical pipe diameter, may be predicted by a number of reasonably well documented relationships, including those of Watkins and Spangler [1,2], or by use of a finite element analysis such as CANDE [1,2].

The "installation deflection" may be either an increase or decrease in vertical pipe diameter. An increase in vertical pipe diameter is referred to as "rise" and is usually a result of the forces acting on the pipe during compaction of the embedment beside it. Moderately stiff pipes such as DR17 and DR21 and stiffer pipes are usually unaffected by "rise" due to normal construction technique. Up to a point this may be beneficial in offsetting service deflection. Installation deflection is not predictable by any mathematical formula, although there are empirical methods for accounting for it [3].

Installation deflection is subject to control by the care used in the placement and compaction of the pipe embedment material in relation to the pipe's ring stiffness. For instance, compaction forces from hand operated air or gasoline tampers normally cause little rise, even when obtaining densities of 95 percent, but driving heavy loading equipment or driven compactors on the embedment while it is being placed beside the pipe may cause severe rise even in DR17 and stiffer pipes.

Commonly, deflection varies along the length of the pipeline due to variations in construction technique, soil type and loading. Field measurements illustrating this variability have been made by the U. S. Bureau of Reclamation and have been published by Howard[3]. Typically, this variation runs around ±2 percent.

Deflection Limit

Designing buried pipe to control deflection is discussed in Chapter 6. Field inspection of the installation procedure is generally adequate for controlling deflection of most PE fusion joined pipes. Very large diameter pipes (man entry) and gasketed jointed PE pipes are sometimes inspected for vertical deflection. Typically deflection measurements are made only after the backfill has been placed on the pipe for at least 30 days. The engineer will specify an acceptance deflection. Commonly a limit of 5 percent is used. This provides an additional safety factor as most gravity flow PE pipe can withstand higher deflection without damage. See Chapter 6.

Pipe Embedment Materials

The embedment is the material immediately surrounding the pipe. This material may be imported, such as a crushed stone, or it may be the material excavated from the trench to make room for the pipe. In this case, it is referred to as native soil.

The embedment material should provide adequate strength, stiffness, uniformity of contact and stability to minimize deformation of the pipe due to earth pressures. The earth pressure acting on the pipe varies around the pipe's circumference. The pressure on the crown or top will typically be less than the free field stress as is the pressure at the invert or bottom of the pipe. Often, the highest pressure may be acting horizontally at the springline of the pipe, due to mobilization of passive pressure and arching.

Because the earth pressure is acting around the circumference, it is important to completely envelop the pipe in embedment. (This may vary to a greater or lesser extent depending on the earth pressure, burial depth, and SDR.) To ensure that the embedment function should always be carried out under the anticipated job conditions, the design engineer will specify the permissible pipe embedment materials and their minimum acceptable density (compaction).

The properties of the in-situ (or native) soil into which the pipe is placed need not be as demanding as those for the embedment materials (unless it is used as the embedment material). The native soil may experience additional compression and deformation due to the horizontal pressure exerted by the pipe and transferred through the embedment material. This is usually a minor effect, but in some cases it can result in additional pipe deflection. This is most likely to occur where native soils are wet and loose, soft, or where native soil sloughs into the trench during excavation and is not removed. This effect is attenuated as the trench width (or width of embedment material) increases. Therefore, consideration must be given to the in-situ soil to ensure that it has adequate strength to permanently contain the embedment system. This is also discussed in a following section.

Classification and Supporting Strength of Pipe Embedment Materials

The burial of PE pipe for gravity flow applications is covered by ASTM D2321 "*Standard Practice for Underground Installation of Thermoplastic Pipe for Sewer and Other Gravity-Flow Applications*." ASTM 2774, "*Standard Practice for Underground Installation of Thermoplastic Pressure Piping*," covers water pipe and force mains.

Strength of Embedment Soil

When selecting embedment material, consideration should be given to how the grain size, shape, and distribution will affect its supporting strength. The following will help guide the designer or installer in making a choice. In general, soils with large grains such as gravel have the highest stiffness and thus provide the most supporting strengths. Rounded grains tend to roll easier than angular, or sharp grains, which tend to interlock, and resist shear better. Well graded mixtures of soils (GW, SW), which contain a good representation of grains from a wide range of sizes, tend to offer more resistance than uniform graded soils (GP, SP).

Aside from the grain characteristics, the density has the greatest effect on the embedment's stiffness. For instance, in a dense soil there is considerable interlocking of grains and a high degree of grain-to-grain contact. Movement within the soil mass is restricted as the volume of the soil along the surface of sliding must expand for the grains to displace. This requires a high degree of energy. In a loose soil, movement causes the grains to roll or to slide, which requires far less energy. Thus, loose soil has a lower resistance to movement. Loose soil will permit more deflection of pipe for a given load than a dense soil.

Embedment Classification Per ASTM D-2321

Pipe embedment materials have been grouped by ASTM D-2321, "*Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity –Flow Applications*" into five embedment classes according to their suitability for that use. **See Appendix 1 for embedment soil descriptions, classifications, and soil group symbols referred to in the following paragraphs.**

Class I and Class II

Class I and II soils are granular and tend to provide the maximum embedment support as illustrated by the high E' values that can be achieved with them. See Chapter 6 Table 2-7 for the relationship between soil types and E' values. Class I material is generally manufactured aggregate, such as crushed stone. Class II materials consist of clean sands and gravels and are more likely to be naturally occurring soils such as river deposits. Class I and Class II materials can be blended together to obtain materials that resist migration of finer soils into the embedment zone (as will be explained below.) In addition, Class I and II materials can be placed and compacted over a wide range of moisture content more easily than can other materials. This tends to minimize pipe deflection during installation. The high permeability of open-graded Class I and II materials aids in de-watering trenches, making these materials desirable in situations such as rock cuts where water problems may be encountered. This favorable combination of characteristics leads many designers to select these materials over others when they are readily and economically available.

Maximum aggregate size of Class I and Class II materials when used next to the pipe (i. e. , bedding, haunching and initial backfill) should not be larger than those given in Table 1 below. (Larger stones up to 1½ inches have been successfully used, but they are difficult to shovel slice and compact.) The smaller the rock size, the easier it is to place in the haunches. Maximum size for the foundation material is not restricted except that it should be graded to prevent the bedding stone from migrating into it.

TABLE 1
Maximum Particle Size vs. Pipe Size

Nominal Pipe Size (in.)	Maximum Particle Size (in.)
2 to 4	½
6 to 8	¾
10 to 15	1
16 and larger	1 ½

Migration

When the pipe is located beneath the ground water level, consideration must be given to the possibility of loss of side support through soil migration (the conveying by ground water of finer particle soils into void spaces of coarser soils). Generally, migration can occur where the void spaces in the embedment material are sufficiently large to allow the intrusion of eroded fines from the trench side walls.

For migration to occur, the in-situ soil must be erodible. Normally, erodible soils are fine sand and silts and special clays known as dispersive clays. (Most clays have good resistance to dispersion.) This situation is exacerbated where a significant gradient exists in the ground water from outside of the trench toward the inside of the trench; i. e. , the trench must act as a drain. (Seasonal fluctuations of the ground water level normally do not create this condition.)

For such anticipated conditions, it is desirable when using granular materials (Class I and II) to specify that they be angular and graded to minimize migration.

Rounded particles have a tendency to flow when a considerable amount of water exists and material with a high void content provides "room" for migrating particles. The Army Corps of Engineers developed the following particle size requirements for properly grading adjacent materials to minimize migration:

(1) $D_{15}^{E} < 5D_{85}^{A}$

(2) $D_{50}^{E} \geq 25D_{85}^{A}$

Where the D_{15}, D_{50} and D_{85} are the particle sizes from a particle size distribution plot at 15%, 50% and 85%, respectively, finer by weight and where D^E is the embedment soil and D^A is the adjacent in-situ soil.

Another approach to preventing migration is to use geotextile separation fabrics. The fabric is sized to allow water to flow but to hold embedment materials around the pipe. Figure 3 shows a typical installation.

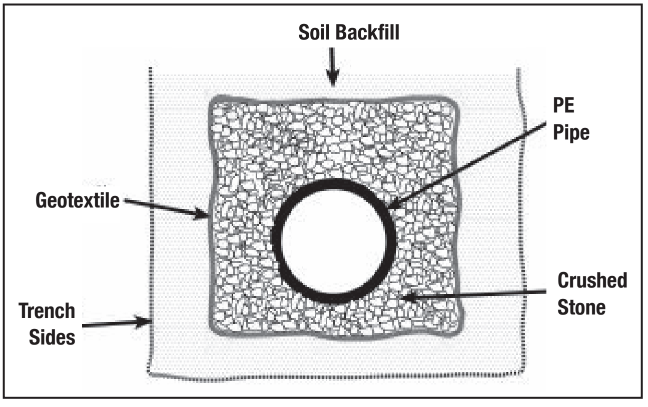

Figure 3 Installation of Geotextile Separation Fabrics

Cement Stabilized Sand

One special case of Class II material is Cement Stabilized Sand. Cement Stabilized Sand, once cured, is generally considered to give the same or better supporting strength as compacted Class I material. Cement Stabilized Sand consists of sand mixed with 3 to 5 percent cement. To achieve proper density, the material is placed with compaction rather than poured as with concrete. The material must be placed moist (at or near optimum moisture content) and then compacted in lifts as a Class II material. (The optimum moisture content is that moisture content at which a material can achieve its highest density for a given level of compaction.) If desired, deflection can be reduced if the cement sand embedment material is allowed to cure overnight before placement of backfill to grade. If the trench is backfilled immediately, cement sand will give the same support as a Class II material, but the lag factor will be reduced. Cement sand is usually placed in both the primary initial and secondary initial backfill zones (see figure 1).

Class III and Class IVA

Class lIl and Class IVA materials provide less supporting stiffness than Class I or II materials for a given density or compaction level, in part because of the increased clay content. In addition, they require greater compactive effort to attain specified densities and their moisture content must be closely controlled within the optimum limit. Placement and compaction of Class IVA materials are especially sensitive to moisture content. If the Class IVA material is too wet, compaction equipment may sink into the material; if the soil is too dry, compaction may appear normal, but subsequent saturation with ground water may cause a collapse of the structure and lead to a loss of support. Typically, Class IVA material is limited to applications with pressure pipe at shallow cover.

Class IVB and Class V

Class IVB and Class V materials offer hardly any support for a buried pipe and are often difficult to properly place and compact. These materials are normally not recommended for use as pipe embedment unless the pipe has a low SDR (or high ring stiffness), there are no traffic loads, and the depth of cover is only a few feet. In many cases the pipe will float in this type of soil if the material becomes saturated.

Compaction of Embedment Materials

Compaction criteria for embedment materials are a normal requirement in flexible pipe construction. Compaction reduces the void space between individual grains and increases the embedment density, thereby greatly improving pipe load carrying ability while reducing deflection, settlement, and water infiltration problems. Compaction of the embedment often will increase the stiffness of the in-situ soil and provide a sort of pre-stressing for the embedment and in-situ soils. Because of these benefits compaction should be considered on all projects.

Density Requirements

The required degree of compaction for an installation will be set by the designer in consideration of height of cover, extent of live loading, water table elevation and soil properties. Generally, the “moderate” compaction requirements listed in Table 2-7 of chaper 6 are quite satisfactory. When compacting to this “moderate” level, it is suggested that the minimum target values for field measured densities be set as 90 percent Standard Proctor Density. This field density requirement will ensure that the actual densities will always be within the “moderate” range presented in Table 2-7.

The Standard Proctor density of embedment materials is normally measured using ASTM D-698, "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3)) while the Modified Proctor density is measured using ASTM D-1557, "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))." See Appendix 2 for a discussion of the difference between density and compaction and a discussion of the various test methods.

Compaction Techniques

Compaction of the embedment material should be performed by the most economical method available, consistent with providing uniform compaction and attaining the minimum specified density. Typical equipment used for compaction are hand held tamping bars (see Figure 4), gasoline driven impact tampers ("whackers"), vibratory plates, and air driven impact tampers ("pogo sticks"). With crushed stone, some degree of densification can be achieved by the technique of shovel slicing, which consists of cutting the soil with a shovel.

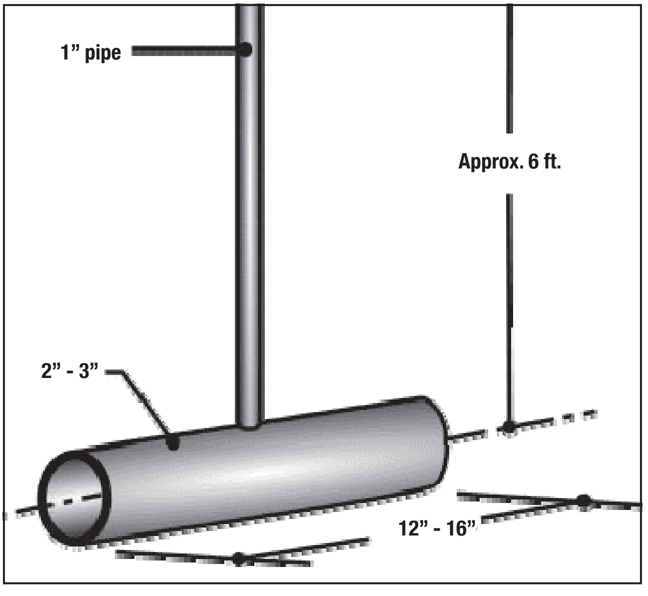

Figure 4 Tamping Tool

Compaction of the haunching material can best be accomplished by hand with tampers or suitable power compactors, taking particular care in the latter case not to disturb the pipe from its line and grade. In 36" and larger pipe, hand tampers are often used to reach under the haunches; they are then followed up with power compaction alongside the pipe.

When compacting the embedment near the pipe with impact-type tampers, caution should be taken to not allow direct contact of the equipment with the pipe. Avoid use of impact tampers directly above the pipe until sufficient backfill (usually 12”) has been placed to ensure no local deformation of the pipe. Compaction of the embedment material alongside the pipe should not cause pipe to lift off of grade, but if upward movement occurs, reduce the compaction level below the springline or move the compactor away from the pipe toward the side of the trench.

Compaction of primary initial backfill should be conducted at, or near, the material’s optimum moisture content. The backfill should be placed in layers, or lifts, that are brought up evenly on both sides of the pipe, otherwise the pipe could be moved off alignment. Each lift should be thoroughly compacted prior to placement of the next layer. The maximum lift height that will allow development of uniform density will vary depending on the material, its moisture content, and compactive effort. In general, maximum lifts of approximately 12 inches for Class I, 8 inches for Class II, and 6 inches for all others are adequate.

Compaction of Class I and II Materials

Compaction by vibration is most effective with granular (Class I and II) materials. Compaction of stone does not deform the stone but it does move it into a more compact or dense arrangement. In cases where the engineer specifies a minimum soil density of 90 percent of Standard Proctor or higher, as for installations under deep cover, mechanical compaction of Class I materials will be required. Impact tampers will also increase the density of Class I and II materials, primarily due to vibration. Impact tamping also acts to drive the embedment into the in-situ soil, which stiffens the trench wall interface. For this reason, impact compaction of Class I material should be considered for any application where the pipe will be below the ground water table or where the stability of the in-situ soil is in question.

An alternate method of achieving compaction with Class I materials is shovel slicing. Materials having been shovel sliced thoroughly will generally yield a modulus of around 1000 psi. The effectiveness of this method depends on the frequency of slicing along the length of the pipe. This technique should be limited to dry or firm (or better) in-situ soils. Where Class I materials are dumped around the pipe without any compactive effort (or shovel slicing), E’s may be considerably lower than those given in the Chapter 6, Table 2-7. This is especially the case in wet or loose ground. A few passes with a vibratory compactor will increase the density and modulus of soil reaction.

Mechanical compaction of Class II materials can be aided by slight wetting. When so doing, care must be taken not to saturate the material or flood the trench, particularly when the native trench material does not drain freely. Flooding can result in flotation of the pipe.

Compaction by saturation, also called flooding or water tamping, is sometimes used to compact Class II materials. This method of compaction rarely yields Proctor densities greater than 75 percent, and therefore it will generally not give an E' of 750 psi or higher. Flooding is only suited for those applications where the pipe has sufficient internal supporting strength for the design load and does not depend on the soil for side support. (When considering this method for embedment that must provide side support, a geotechnical engineer should be consulted.) Compaction by saturation is limited to applications where both the embedment soil and in-situ soil are free draining. Compaction should be done in lifts not exceeding the radius of the pipe or 24 inches, whichever is smaller. Only enough water should be placed to saturate the material. It should be determined through proper monitoring that the desired level of compaction is being attained in each lift. Compaction by saturation should not be used in freezing weather. Water jetting, or the introduction of water under pressure to the embedment material, should not be used with plastic pipe.

Compaction of Class III and IV Materials

Compaction by impact is usually most effective with Class lIl and Class IVa materials. The use of mechanical impact tampers is most practical and effective. Depending on the embedment material, its moisture content, and lift height, several compaction passes may be required. A maximum lift height of 6 inches should be used when compacting by impact. Embedment density should be suitably monitored to ensure that specification requirements are met.

Density Checks

It is prudent to routinely check density of the embedment material. Typically, several checks are made during start-up of the project to ensure that the compaction procedure is achieving the desired density. Random checks are subsequently made to verify that the materials or procedures have not changed. Checks should be made at different elevations of the embedment material to assure that the desired compaction is being achieved throughout the embedment zone.

Trench Construction

Trenches should be excavated to line and grade as indicated by contract documents and in accordance with applicable safety standards. Excavation should proceed upgrade. Excessive runs of open trench should be avoided to minimize such problems as trench flooding, caving of trench walls and the freezing of trench bottom and backfill material, and to minimize hazards to workmen and traffic. This can be accomplished by closely coordinating excavation with pipe installation and backfilling.

Principal considerations in trench construction are trench width, stability of the native soil supporting and containing the pipe and its embedment soil, stability of trench walls, and water accumulation in the trench. When encountering unstable soils or wet conditions, they should be controlled by providing an alternate foundation, sloping or bracing the trench walls, de-watering the trench bottom, or some other such measure.

Trench Width

Since flexible pipe has to support, at most, only the weight of the "prism" or vertical column of soil directly over the pipe, the precaution of keeping the trench as narrow as possible is not the concern that it is for a rigid pipe, which can be subjected to the weight of the soil beside the prism as well as the prism itself. With PE pipe, widening the trench will generally not cause a loading greater than the prism load on the pipe. Trench width in firm, stable ground is determined by the practical consideration of allowing sufficient room for the proper preparation of the trench bottom and placement and compaction of the pipe embedment materials, and the economic consideration of the costs of excavation and of imported embedment materials. Trench width in firm, stable ground will generally be determined by the pipe size and the compacting equipment used. Table 2 below gives minimum trench width values.

The trench width may need to be increased over the values in Table 2 to allow for sufficient clearance between the trench sidewalls and the pipe for compaction equipment. Typically for large diameter pipe (18" and larger), this required clearance will vary from 12 to 18 inches. If two or more pipes are laid in the same trench, sufficient space must be provided between the pipes so that embedment material can be compacted.

TABLE 2
Minimum Trench Width in Stable Ground vs. Pipe Size

Nominal Pipe Size (in.)	MinimumTrench Width (in.)
< 3	12
3 - 24	Pipe O. D. + 12
> 24 - 63	Pipe O. D. + 24

Note to Table 2: Minimum trench widths do not apply to trenching techniques that use chain or wheel trenchers or plows to lay PE pipe. Chain and wheel trenching techniques feed PE pipe over the earth-cutting machine and lay the pipe immediately into the earth-cut. These techniques use round-bottom chain or wheel trenching machines that match pipe radius and do not require extra trench width to place embedment in the pipe haunches below the pipe springline. Plowing techniques feed smaller diameter PE pipe or tubing through a chute that is integrated into an earth plow. Plowing may not require backfilling.

Trench Length

Table 3 lists the recommended lengths of trench openings for each placement of continuous lengths of fused pipe, assembled above the trench. When the trench sidewalls are significantly sloped, somewhat shorter trench openings may be used. When space or ground conditions do not permit these suggested trench openings, the pipe lengths may be joined within the trench, using a joining machine or flanged couplings. When bell-and-spigot jointed pipe or flange-end pipe is used, the trench opening needs to be only long enough to accommodate placement and assembly of a single pipe length.

TABLE 3
Suggested Length of Minimum Trench Opening (Feet) for Installation of Joined Lengths of PE Pipe

Nominal Pipe Size (in.)	Depth of Trench (Feet)					
	3	5	7	9	11	13
½ to 3	15	20	25	30	35	40
4 to 8	25	30	35	40	45	50
10 to 14	35	40	45	50	55	60
16 to 22	45	50	55	60	65	70
24 to 42	-	60	65	70	75	80
48	-	-	80	90	100	110

Stability of the Trench

Although the native soil in which PE pipe is installed need not be as strong and stiff as the pipe embedment materials, it should provide adequate support and stable containment of the embedment material so that the density of the embedment material does not diminish. If the trenching conditions present construction problems such as trench sidewalls that readily slough off or a soft trench floor that will not support workers or compaction, it is termed unstable. The instability is usually a condition of the trench and not the soil. Most often the primary cause of the instability is high groundwater, not the soil. Even soft or loose soils can provide good support for the pipe if they are confined. The problem with unstable conditions generally occurs during the installation. When the trench is opened where groundwater is present, most soils, except firm, cohesive soils (firm clays) or cemented soils, tend to slough off the trench wall. This results in a trench that keeps widening, with loose material falling into the trench floor.

Soil formations that commonly lead to unstable trenching conditions include materials with fine grain soils (silts or clays) saturated with water and uncemented sands saturated with water. In some cases, where the soil has an extremely high water content, such as with peat or with clay (or silt) having a water content beyond the liquid limit, the soil behaves "hydraulically", that is, the water in the soil controls the soil's behavior. Here, the backfill must be designed to sustain all the pressure from the pipe without support from the in-situ soil. These conditions may occur in saturated fine grained soils where the unconfined compressive strength of the soil is less than 500 psf, or in saturated, sandy soils where the standard penetration value, N, is less than 6 blows per ft. In this case, an engineering evaluation should be made to determine the necessity for special procedures such as a “wide” trench or permanent trench sheeting of the trench width.

As mentioned above, most trench stability problems occur in trenches that are excavated below the groundwater level. (However, the designer and the contractor should keep in mind that all trenches pose the risk of collapse and therefore workers should not be in trenches that are not adequately braced or sloped.) Stability can be improved by lowering the water table through deep wells, well-points, or other such means. In some ground the permeability is such that the only option is to remove the water after it has seeped out of the trench walls. Here the contractor will use underdrains or sumps on the trench floor. De-watering should continue throughout the pipe laying operation until sufficient cover is placed over the pipe so that it will not float.

Stability of Trench Floor

Trench floor stability is influenced by the soils beneath the trench. The floor must be stable in order to support the bedding material. A stable bedding minimizes bending of the pipe along its horizontal axis and supports the embedment enveloping the pipe. Generally, if the trench floor can be walked on without showing foot prints it is considered stable.

In many cases the floor can be stabilized by simply dewatering. Where dewatering is not possible or where it is not effective, stabilization of the trench floor may be accomplished by various cost-effective methods which can be suited to overcome all but the most difficult soil conditions. Included among these are the use of alternate trench foundations such as wood pile or sheathing capped by a concrete mat, or wood sheathing with keyed-in plank foundation; stabilization of the soil by the use of special grout or chemicals; geofabric migration barriers; or ballasting (undercutting). A cushion of bedding material must be provided between any special foundation and the pipe. Permanently buried timber should be suitably treated.

Stabilization by ballasting (undercutting) is the removal of a sufficient quantity of undesirable material. This technique is frequently employed to stabilize randomly encountered short sections of unstable soil. The extent of required over-excavation and details of accompanying construction requirements will be determined by the engineer in consideration of the qualities of the unstable soil and the specific design requirements. The following are general guidelines:

The trench bottom should be over-excavated over the full trench width from 18 to 36 inches below the pipe grade (depending on the soil strength and pipe diameter) and then brought back to grade with a foundation of ballast material topped with Class I material. An appropriate bedding should then be placed on the foundation. The grading of the foundation material should be selected so that it acts as an impervious mat into which neither the bedding, other embedment material, nor the surrounding native soil will migrate.

These guidelines are suitable for most situations except for extremely weak soils (such as quicksands, organic silts, and peats) which may call for further overexcavation, or other special treatment.

Stability of Trench Walls

In order to control deflection, the embedment material must be placed from undisturbed trench sidewall to undisturbed trench sidewall. Where trench walls are unstable, it may be necessary to use trench shields, bracing, or permanent sheeting to achieve a stable sidewall while installing the pipe. Where material sloughs into the trench it should be removed. This technique often leads to widening the trench.

Walls of trenches below the elevation of the crown of the pipe should be maintained as vertical as possible. The shape of the trench above the pipe will be determined by the stability of the trench walls, excavation depth, surface loadings near the trench, proximity of existing underground structures, presence of groundwater or runoff water, safety and practical considerations. These will determine if the trench walls may be vertical, excavated with slope or benched sides, or shored. When trench walls are shored or otherwise stabilized, the construction scheme must allow for the proper placement and compaction of pipe embedment materials. Some suggested trench construction schemes follow. The final procedure must be in compliance with all applicable safety regulations.

Sloping of trench walls in granular and cohesionless soils should be provided whenever the walls are more than about four feet in depth or otherwise required by state, local or federal regulations. For safety, if the walls are not sloped, they should be stabilized by alternate means such as shoring or bracing. The slope should be no greater than the angle of repose of the materials being excavated and should be approved by the engineer.

Shoring or bracing will frequently be required in wet fine grained cohesive type soils and clays. Bracing or sheathing that is constructed of treated timber, steel or other acceptable material may be used to stabilize trench walls either permanently or temporarily. Wherever possible, sheathing and bracing should be installed so that its bottom extends no lower than about one-quarter of the pipe diameter below the pipe crown. When so installed, pulling the sheathing will minimally disturb the embedment material and the side support it provides. Sheathing that is installed to project below the pipe springline should be left in place unless, as with some thinner sheathing, it is designed to be pulled and removed without disturbing the embedment next to the pipe. In this case, the trench width should be increased by 12 to 24 inches depending on the pipe diameter to allow for minor disturbance to the embedment near the sheathing. Vibratory placement or extraction of sheeting is not advised. This method can cause severe disturbance to the bedding and liquefaction of the surrounding soils. Where steel sheet piling is used as sheathing and is to be removed or pulled, to minimize disturbance to the pipe embedment, it should be installed so that it is not closer than one pipe diameter or 18 inches, whichever is larger, from either side of the pipe. The void left by removal of the sheathing should be filled with embedment material.

Portable Trench Shield

Portable trench shields or boxes which provide a moveable safe working area for installing pipe can be used with flexible pipe. However, the installation technique of flexible pipe with the shield is not the same as it is for rigid pipe. In order to use the shield with PE pipe, all excavation of the trench below the pipe crown elevation should be done from inside of the shield. That is, the backhoe operator should dig inside of the shield and force the shield down as soil is removed. (The technique of digging out a large hole to pipe invert grade then sliding the shield into it will result in excess deflection of PE pipe and therefore, should not be used.) After placing the pipe in the trench, embedment material should be placed in lifts and the shield vertically raised after each lift is placed so that workers can shovel embedment material under the shield to fill the void created by the shield wall. Figure 5 illustrates the steps used with a Portable Trench Shield.

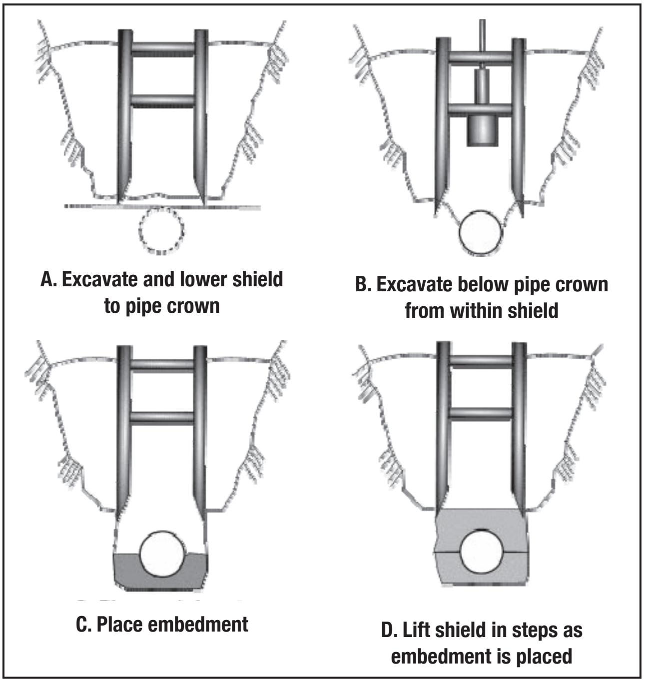

Figure 5 Installing PE Pipe with a Portable Trench Shield

If trench soil quality and applicable safety regulations permit, it is best to use shields that are placed with no portion of their sides extending lower than one-quarter of a pipe diameter below the pipe crown. This minimizes the amount of lifting required and precludes the possibility for disturbing embedment materials. If the sides of the trench box or shield do project below this point, then the box should be lifted vertically as described above, before moving along the trench.

The minimum inside clear width of the box, or shield, should allow for the minimum trench width requirements for the pipe to be satisfied plus an additional 12 to 24 inches depending on the pipe diameter.

Installation Procedure Guidelines

The installation procedure discussed in this section consists of trench floor preparation, providing a sufficiently stable working platform, and meeting the design grade requirements. Following pipe placement, backfill material which has been selected with regards to potential material migration, required density, depth of cover, weight of soil and surcharge loads is installed as follows:

1. Bedding material is placed and leveled.

2. Haunching is placed and, if required, compacted so as not to disturb the pipe from its line and grade.
3. The remainder of the primary initial backfill is placed and, if required, compacted in lifts.
4. Secondary backfill is used to protect the pipe during the final backfilling operation and also to provide support for the top portion of the pipe.
5. The final backfill may consist of any qualifying material that satisfies road construction or other requirements and, when required, must be compacted.

Trench Floor Preparation

The trench floor must have sufficient stability and load-bearing capacity to present a firm working platform during construction to maintain the pipe at its required alignment and grade and sustain the weight of the fill materials placed around and over the pipe. The trench bottom should be smooth and free from sloughed sidewall material, large stones, large dirt clods, frozen material, hard or soft spots due to rocks or low-bearing-strength soils, and any other condition that could lead to non-uniform or unstable support of the pipe. The trench bottom must be kept dry during installation of the pipe and the embedment materials. All foundation and bedding materials must be placed and compacted according to the design requirements. Such materials should be selected to provide the necessary migration control when required.

Over-excavation of the trench floor by more than 6 inches beyond grade requires that the over-excavation be filled with acceptable embedment material that is compacted to a density equal to that of the embedment material. If the over excavation exceeds 12 inches, it should be brought to proper grade with a suitably graded Class I or II material that is compacted to the same density as that of the native soil but not less than the density requirements for the embedment materials.

In stable soils the trench floor should be undercut by machine and then brought up to proper grade by use of a well-leveled bedding consisting of a 4 to 6-inch layer of embedment material. This material should be compacted by mechanical means to at least 90 percent Standard Proctor Density. Class I material may be shovel sliced where the depth of cover permits.

In unstable soils that may be too soft, of low load-bearing capacity or otherwise inadequate, the trench bottom must first be stabilized by soil modification, by providing an alternate foundation, or by the removal of the undesirable material and replacement with stable foundation material. A cushion of at least 4 inches of compacted bedding should be provided between any special foundation and the pipe. Adequacy of trench bottom stability is difficult to evaluate by visual observation and is therefore best determined by soil tests or at the site during installation. However, a warning of a potentially unstable soil condition is given by a trench bottom that cannot support the weight of workmen.

Uneven soil support conditions, where the grade line traverses both soft and hard spots, requires special consideration. Ballasting is the most frequently employed technique to deal with randomly encountered short sections of soft soils.

When differential conditions of pipe support might occur, such as in transitions from manholes to trench or from hard to soft soils, a transition support region should be provided to ensure uniform pipe support and preclude the development of shear, or other concentrated loading on the pipe. The following procedure may be used:

The soil next to the more rigid support is over-excavated to a depth of not less than 12 inches over a distance of 2 pipe diameters along the pipe line; over the next 2 diameters away from the rigid support, the depth of over-excavation is gradually decreased until it meets the normal trench depth. See Figures 6 and 7. Pipe grade is then restored by the addition of granular material that is compacted. In the case of connections to manholes and buildings, the distance of over-excavation along the pipe length should be no less than required to reach undisturbed soil.

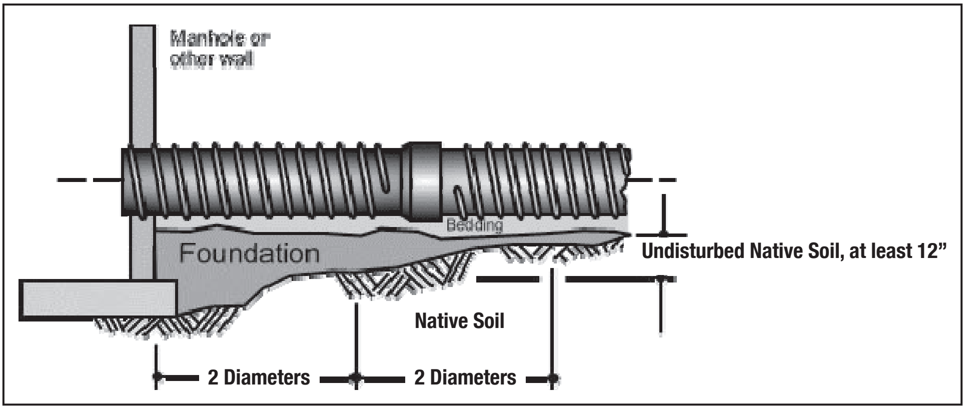

Figure 6 Pipe Support in Transition from Rigid Support to Normal Trench Support

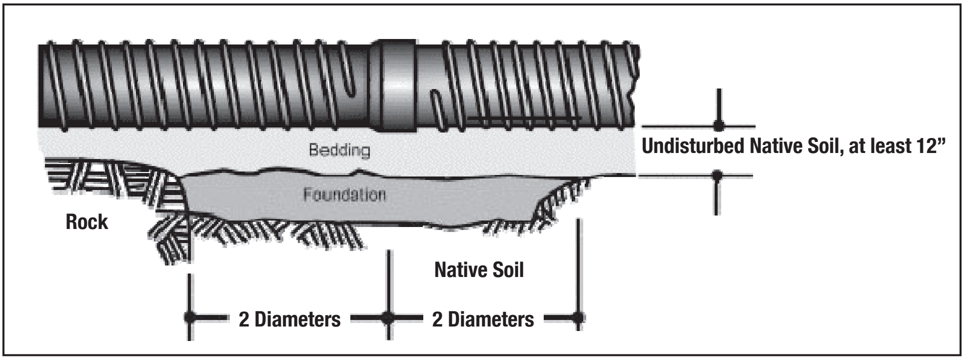

Figure 7 Proper Transition from Rock Trench Bottom to Normal Trench Support

Backfilling and Compaction

Backfilling should follow pipe placement and assembly as closely as possible. Such practice prevents the pipe from being shifted out of line by cave-ins, protects the pipe from external damage, eliminates pipe lifting due to flooding of open trench and in very cold weather lessens the possibility of backfill material becoming frozen. The quality of the backfill materials and their placement and compaction will largely determine the pipe's ultimate deformation and alignment. Backfill material should be selected with consideration of potential material migration to, or from, the trench wall and other layers of embedment material. Under most circumstances, compaction will be required for all material placed in the trench from 6 inches beneath the pipe to at least 6 inches above the pipe.

The required density of the bedding, haunching and the primary and secondary initial backfill material will depend on several considerations such as depth of cover, weight of soil, and surcharge loads. The minimum density for these materials should be equal to 85 percent Standard Proctor Density for Class I and II materials or 90 percent Standard Proctor Density for Class III or IVa materials. For Class II,III, and IVa materials, compaction will always be required to obtain these densities. Class I material placed by shovel slicing will generally have a minimum density of 85 percent Standard Proctor; however, its E′ may not be greater than 750 psi. Just dumping Class I material into the trench may produce densities near 85 percent. However, except in shallow cover without live loads, this method will normally not provide adequate support to the pipe as voids may exist under the pipe haunches or elsewhere in the material.

Backfill Placement

Bedding performs a most important function in that it levels out any irregularities in the trench bottom, assuring uniform support and load distribution along the barrel of each pipe section and supports the haunching material. A mat of at least 6 inches of compacted embedment material will provide satisfactory bedding.

Haunching material must be carefully placed and compacted so as not to disturb the pipe from its line and grade while ensuring that it is in firm and intimate contact with the entire bottom surface of the pipe. Usually a vibratory compactor has less tendency to disturb the pipe than an impact tamper.

Primary initial backfill should be placed and compacted in lifts evenly placed on each side of the pipe. The lifts should not be greater than 12 inches for Class 1, 8 inches for Class II, and 6 inches for Class III and IVa materials. The primary initial backfill should extend up to at least three-quarters of the pipe diameter to perform its function of pipe side support as shown in Figure 1. If the construction does not call for the use of a secondary initial backfill, then the primary layer should extend to not less than 6 inches above the pipe crown. In any location where the pipe may be covered by existing or future groundwater, the primary initial backfill should extend up to at least 6 inches over the pipe crown for pipe up to 27-inch diameter and to at least 12 inches over the pipe for larger pipe.

Secondary initial backfill serves to protect the pipe during the final backfilling operation and to provide support to the top portion of the pipe. Secondary initial backfill should extend to 6 inches above pipe for pipe up to 24 inches and to 12 inches for larger pipe. These depths can be modified slightly depending on the depth of burial, groundwater level, and type of native soil. Compaction of this layer should be to the same extent as that specified for the primary initial backfill. If the final backfill material contains large rock (boulder or cobble size) or clumps, then 18 inches of cushion material should be provided in the secondary initial backfill. Secondary initial backfill may consist of a different material than the primary initial backfill; however, in most cases, it should be a material that will produce an E′ of at least 750 psi.

The final backfill may consist of any material that satisfies road construction or other requirements. The material must be free of large stones or other dense hard objects which could damage the pipe when dropped into the trench or create concentrated pipe loading. The final backfill may be placed in the trench by machines.

There should be at least one foot of cover over the pipe before compaction of the final backfill by the use of self-powered compactors. Construction vehicles should not be driven over the pipe until a three foot cover of properly compacted material is placed over the pipe.

When backfilling on slopes, the final backfill should be well compacted if there is any risk of the newly backfilled trench becoming a “french drain.” Greater compaction may be achieved by tamping the final backfill in 4 inch layers all the way from the top of the initial backfill to the ground or surface line of the trench. To prevent water from undercutting the underside of the pipe, concrete collars keyed into the trench sides and foundation may be poured around the pipe or a PE waterstop can be fabricated onto the pipe.

Sunlight Exposure

Placing pipe that has been in direct sunlight in a cooler trench will result in thermal contraction of the pipe's length. This contraction can generate force which could result in pull-out at mechanical couplings or other buried structures. Allow pipe to cool before making connections to an anchored joint, flange, or a fitting that requires protection against excessive pull-out forces. Covering the pipe with embedment will facilitate cooling.

Cold (Field) Bending

Coiled lengths and long strings of PE fused pipe may be cold bent in the field. The allowable bend ratio is determined by the pipe diameter and the dimension ratio. See Figure 8 and Table 4. Because fittings and flange connections are rigid compared to the pipe, the minimum bend radius is 100 times the pipe's outside diameter (OD), when a fitting or flange connection is present in the bend. The bend radius should be limited to 100 x OD for a distance of about 5 times the pipe diameter on either side of the fitting location.

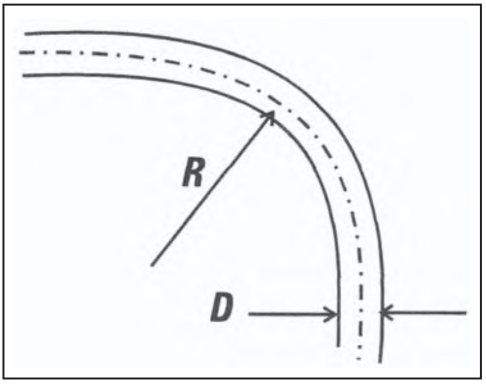

Figure 8 Bend Radius, R

TABLE 4
Minimum Bend Radius for PE Pipe Installed in Open Cut Trench

Dimension Ration, DR	Minimum Cold Bend Radius
7, 7.3, 9	20 x Pipe OD
11, 13.5	25 x Pipe OD
17, 21	27 x Pipe OD
26	34 x Pipe OD
32.5	42 x Pipe OD
41	52 x Pipe OD
Fitting or flange present in bend	100 x Pipe OD

Installation of Pipe in Curves

Field bending involves excavating the trench to the desired bend radius, then sweeping or pulling the pipe string into the required bend and placing it in the trench. Temporary restraints may be required to bend the pipe, and to maintain the bend while placing the pipe in the trench and placing initial backfill. Temporary blocks or restraints must be removed before installing final backfill, and any voids must be filled with compacted initial backfill material. **Considerable force may be required to field bend the pipe, and the pipe may spring back forcibly if the restraints slip or are inadvertently released while bending. Observe appropriate safety precautions during field bending.**

Transition from PE Pressure Pipe to Gasket Jointed Pipe

The heat fusion joint used for PE pipe creates an essentially continuous length of pipe. When the pipe is pressurized two significant internal forces are present in the pipe. End thrust from bends or end caps is transmitted through the pipe as a longitudinal force. Hoop stress (hoop thrust) occurs due to the internal pressure. The longitudinal force tends to grow the pipe length while the hoop thrust expands the diameter (ever so slightly) and tends to contract the pipe's length in proportion to Poisson's Ratio. In an all PE pipe system the length effects from these two forces tend to cancel each other out. As a result, buried PE pipes are self-restrained and require no thrust blocking. A different situation occurs when PE pipe transitions to a type of pipe material that is joined by non-restrained gasket joints. The longitudinal force may be no longer present. The result is that hoop expansion is unbalanced and will cause contraction of the PE pipe. This contraction can result in pulling apart of gasket joints in line with the PE pipe.

Generally, it is necessary to anchor the ends of a PE pipeline that transitions into an unrestrained gasket jointed pipe system. If the gasket joints are restrained anchoring is unnecessary. See Appendix 3, "Pull-out of Mechanical Joints due to the Poisson Effect" for a complete discussion of the pull-out effect.

The transition of PE pipe to DI and PVC pipe is discussed in TN-36, "General Guidelines for Connecting PE Potable Water Pressure Pipes to DI and PVC Piping Systems.

Proper Burial of Fabricated PE Fittings

A common question is "Does the installation of heat fused PE solid wall pipe and fittings need thrust blocks?" The simple answer to this question is that heat fused PE pipe and fittings are a monolithic structure which does not require thrust blocks to restrain the longitudinal loads resulting from pipe pressurization.

Since fittings are part of the monolithic structure no thrust blocks are needed to keep the fittings from separating from the PE pipe. Bell and spigot piping systems must have thrust blocks or restrained joints to prevent separation of pipe from fittings when there is a change of direction.

Pipe movement due to elastic deformation, thermal expansion/contraction, etc. is not detrimental to PE pipe, but pipe movement or the attachment of valves or other appurtenances used with PE pipe systems can cause excessive loads. Proper backfill prevents excessive loads in most situations.

Common fittings, elbows and equal tees normally require the same backfill as specified for the pipe. When service connections are made from PE water mains, no special compaction is required. When service connections are made under an active roadway, 95% Standard Proctor density is normally required around the pipe and the service connection.

In water systems and fire protection piping systems, reducing tees are frequently used to connect from the main to valves and hydrants. Figure 9 shows the use of concrete support pads, thrust blocks on hydrants, self restrained PE MJ adapters and sand stabilized with cement around the reducing tee. While no true thrust blocks are on the PE pipe or fittings in this arrangement, the sand stabilized with cement provides proper support for the reducing tee. Compaction of the soil around these fittings is difficult and the use of sand stabilized with cement or flowable fill is usually easy.

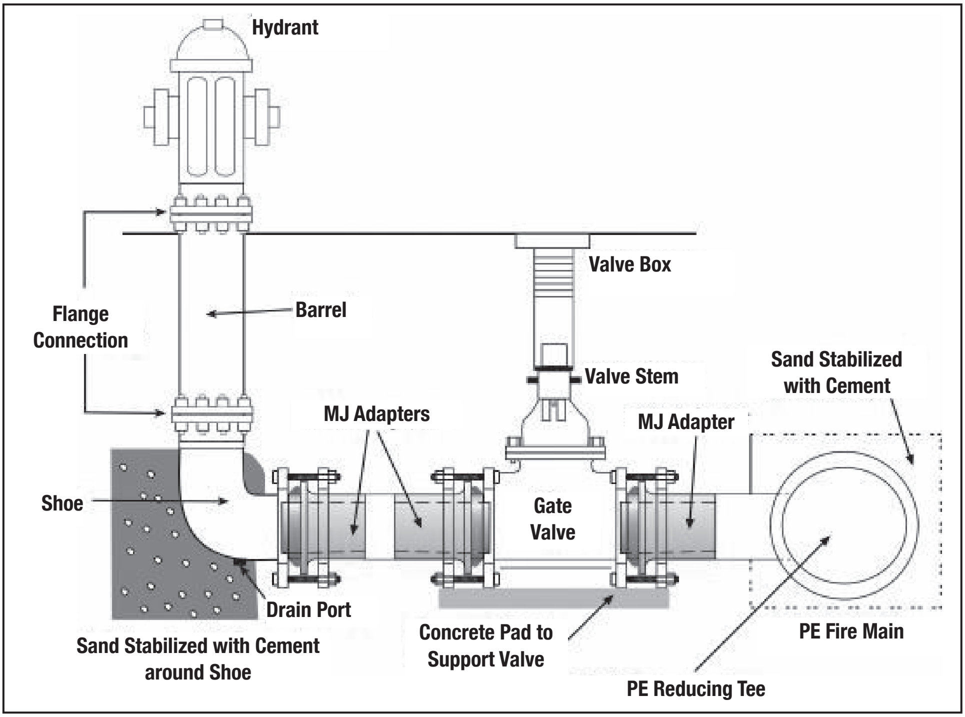

Figure 9 Typical Assembly and Support Arrangement for PE Pipe Connections to Valves and Hydrants

As with all piping systems, proper compaction of the soil around pipe and fittings is important. In water and/or fire protection systems, when in-situ embedment materials can be compacted to a Standard Proctor density of 85% for installation outside of roadways or 95% Standard Proctor density in roadways, these materials should be used. When in-situ materials do not provide proper support, then sand stabilized with cement or flowable fill should be used.

Figure 9 shows an PE self-restrained mechanical joint (MJ) adapter being used to connect to the valve. When large reducing tees or equal tees are used, MJ adapters, flanges or electrofusion couplings should be fused to the reducing tees before it is placed in the trench. The direct connection of long pipe sections or valves can create bending loads on the leg of the reducing tee. The use of PE MJ adapters, flanges or electrofusion couplings on the reducing leg of the tee makes installation of reducing tees easier and safer while preventing stresses on the tee.

Inspection

The engineer should provide inspection commensurate with the application. Good inspection would include some or all of the following:

- Verification that all embedment materials meet the specification and verification of pipe grade and alignment,
- Verification that the correct pipe is installed (see numerical code printed on pipe),
- Observation of pipe installation, placement of embedment and backfill materials, and trench excavation methods,
- Verification that proper pipe storage and handling procedures are followed, that pipe placement in the trench, attachment of mechanical joints, fittings and appurtenances, and transitions to other pipes were done in accordance with recommended methods, that scratches or gouges do not exceed the permitted depth, and that the minimum bend radius was not exceeded,
- In the case of large diameter gravity pipes (gasket joined) inspection for deflection by either pulling a mandrel through the pipe or taking physical measurements of the pipe vertical diameter.
- In the case of pressure pipes record results of leak testing.

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Appendix 1

Embedment Classification per ASTM D-2321

Pipe embedment materials have been grouped by ASTM D-2321-05, "Underground Installation of Flexible Thermoplastic Sewer Pipe", into five general embedment classes based on their particle size (grain size) with the materials most suitable for use being assigned the lowest class numbers. Table A1 gives a summary of these groupings.

TABLE A1
Embedment Classes for Plastic Pipes

Class	Soil Description	Soil Group Symbol
IA	Manufactured aggregate, angular open-graded and clean includes crushed stone, crushed cinders or shells, contains little or no fines.	None
IB	Processed aggregate, angular dense-graded and clean. Includes IA material mixed with sand and gravel to minimize migration.	None
II	Coarse-grained soils, clean. Includes gravels, gravel-sand mixtures, and well and poorly graded sands. Contains little or no fines (less than 5% passing a #200 sieve.)	GW, GP SW, SP
II	Coarse-grained soils, borderline clean to "with fines". Contains 5% to 12% fines (passing #200).	GM-GC SP-SM
III	Coarse-grained soils containing 12% to 50% fines. Includes clayey gravel, silty sands, and clayey sands.	GM, GC SM, SC
IVA	Fine-grained soils (inorganic). Includes inorganic silts, rock flour, silty-fine sands, clays of low to medium plasticity, and silty or sandy clays.	ML, CL
IVB	Fine-grained soils (inorganic). Includes diatomaceous silts, elastic silts, fat clays.	MH, CH
V	Organic soils. Includes organic silts or clays and peat.	OL, OH PT

Appendix 2

Basic Soil Concepts For Flexible Pipe Installation

Soil Classification

The embedment soil surrounding a flexible pipe prevents pipe from deflecting through its shear strength and stiffness. Shear strength enables the soil to resist distortion much like a solid body. Shear strength, or shear resistance as it is often called, arises from the structure of the soil's fabric. Soil is an assemblage of (1) mineral particles such as silica or aluminum silicates, (2) water, and (3) air. Mineral particles can range in size from the large, such as boulders, to the microscopic, such as the colloidal particles making up clay. The size of the individual soil particles or grains has a significant effect on the soil's behavior. Embedment soil is classified as either "fine" grained or "coarse" grained.

Fine Grain Soil (Clay and Silt)

Very small (colloidal) size soil particles are capable of absorbing large quantities of water, as much as 10 times their own weight. These particles attract each other to produce a mass which sticks together. This property is called cohesion or plasticity. Soils containing such particles are referred to as "cohesive" and include clayey soils. Cohesion gives clayey soils resistance to shear. The strength of clayey soils is dependent on the amount of water within the soil. As the content of water increases, the shear resistance decreases. Therefore, when using clays as pipe embedment beneath the ground water level, one must examine its sensitivity to water. Fat clays (CH), which are highly expansive, usually make poor embedment materials. (CH is the USCF soil classification symbol for fat clay.) Lean clays (CL), or other clays having relative low sensitivity to water, sometimes can be used for embedment.

While silts possess little to no cohesion, they are composed of very fine grains, which makes them behave somewhat like clay in that they can contain a high percentage of water. It is also common for silt and clay to occur together. Therefore, the general classification schemes for pipe embedment usually treat silts and clays similarly. (USCF symbols for inorganic silts are ML and MH, and for organic silts OL and OH.)

Coarse Grain Soils

Assemblages of larger-sized particles such as sands (S) and gravels (G) do not exhibit plasticity. Water has less effect on these materials. These soils are called "cohesionless" or "granular. " Normally, cohesionless soils have high shear resistances. When a mass of cohesionless soil is sheared, individual grains either roll, slide, fracture, or distort along the surface of sliding. Likewise, many cohesive soils contain grains of sand, so they can exhibit significant shear resistance. These materials make excellent embedment in wet or dry conditions.

Density and Compaction

When discussing the installation of embedment material, two terms are use extensively. They are compaction and density. These terms are defined, herein, to assist the reader.

Density refers to the weight of a particular volume of soil As discussed above, soil consists of three materials or phases: a mineral phase, water, and air. As the soil is compacted, the mineral phase may undergo some change, but typically the air and water are expelled from the soil and the overall volume is reduced. The weight of the mineral phase stays the same. Thus, a given weight of mineral phase occupies a smaller volume after compaction. Typically, when densities are given, they are based on the dry unit weight of the soil (which is the weight of the mineral phase only) occupying a given volume, say a cubic foot.

Compaction, on the other hand, refers to the amount of energy imparted into the soil to reduce its volume. Typically, more energy, often called compactive effort, is required to increase the density of a fine grain soil than a coarse grain soil. One reason for this is that the fine grain soil has cohesion which must be overcome in order for the mineral phase particles to be pushed closer together. Another reason is that it is harder to force the water out of a fine grain material because of its low permeability.

Methods of Measuring Density

There are two general categories of density measures. One method involves imparting a standard amount of energy into the soil, say a fixed number of blows with a specified weight. The Standard and Modified Proctor density tests are such methods. The other measure involves comparing the in-place density with the most dense and least dense arrangement that can be achieve with that soil. An example of this method is the Relative Density test.

The Proctor Density is the most common method used with pipe embedment and will be discussed in somewhat more detail. Typically, a soil sample is taken from the embedment material and tested in the laboratory, where a precisely defined amount of compaction energy is applied to it, which compacts the sample to its Proctor density. (This amount of energy is defined by the particular Proctor test, whether it is the Standard Proctor defined in ASTM D-698, "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3)) or the Modified Proctor defined in ASTM D-1557, "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))." The sample is then dried and its density measured. This density is the standard for this material and is considered to be 100 percent of the Proctor density. The technician then makes measurement of the density (dry unit weight per cubic ft.) of the compacted embedment in the field using, say, the nuclear density gauge. That density can then be compared with the density obtained in the laboratory. The comparison is usually expressed in percent. Typically, the field density must be at least 90 percent of the laboratory density. In this case, we would say the minimum density is 90 percent of the Proctor.

For pipe installation, the important factor is soil stiffness. If two soils are compacted to the same Proctor density, that does not mean that the two soils provide equal supporting stiffness for the pipe. A crushed stone at 90 percent Proctor will be much stiffer than a clay compacted to 90 percent Proctor. This fact is illustrated by the different E' values assigned to these materials at these densities. In the case of the crushed stone its E' equals 3000 psi, whereas the clay has an E' of only a 1000 psi.

Methods used to measure soil stiffness such as the California Bearing Ratio test are not convenient for field testing of pipe. Therefore, it is common to measure and monitor density.

Comparison of Installation of Rigid and Flexible Pipe

The underground installation of PE piping is similar to the installation of other flexible piping materials. The performance of the pipe will depend on the quality of the installation. Most PE piping is considered flexible, which means that the pipe installed for non-pressure applications will depend to some extent on the support of the embedment soil. Often the installation of flexible pipe is contrasted with the installation of rigid pipe, but general requirements for both types of pipe are similar. A narrow trench keeps loads on both types of pipe at a minimum. Both pipes require firm, stable bedding and uniform support under the haunches. The major difference between the two types of pipes is that the flexible non-pressure pipe requires side support, whereas the rigid pipe does not. Side support comes from the placement of firm, stable material beside the pipe. Often this is the same material used beside the rigid pipe with the exception that the material must be compacted. Sufficient space alongside the pipe must be provided for compacting the embedment material. The trench backfill placed above the pipe can be treated in the same manner for both flexible and rigid pipe. The denser the material above the pipe, the smaller the load applied to the pipe.

PE pipe interacts advantageously with the embedment soil. The viscoelastic properties of PE and most soils are similar. As the pipe deflects, much of the earth is transmitted by arching action to the soil around the pipe. Thus the need for stable soil beside the pipe. Rigid pipe is typically manufactured from materials that are not compliant with soil deformation. As the soil settles, load accumulates on the rigid pipe. If this load exceeds the pipe materials' yield strength, the pipe will fail by a sudden rupture or crack. PE is a ductile material that can yield. Under excessive loads, PE pipe will deform without cracking. The deformation is often sufficient to relieve the accumulated stresses, so performance is not interrupted.

Deflection is usually the main criterion for judging the performance of a gravity flow flexible pipe. Deflection is usually not much of a consideration for PE pipe installed for pressure applications unless they are in deep fill applications and have high DR's. Pipes that deflect have two advantages over rigid pipe: (1) the deflection permits the release of accumulated stresses which promotes arching and causes a more uniform distribution of earth pressure around the pipe and (2) the deflection affords a convenient method of inspecting the quality of the installation - generally the less deflection the better the installation.

Appendix 3

Pull-out of Mechanical Joints due to the Poisson Effect

When a tensile stress is applied to a material, the material elongates in the direction of the applied stress, and draws in at right angles to the direction of the applied stress. This relationship, called the Poisson effect, is a natural response to applied stress that occurs with all materials, but is particularly apparent with ductile materials. For example, when a metal bar is pulled in a tensile test, it stretches out and necks down on the sides. Likewise, a rubber band elongates and necks down on the sides when it is pulled. When pipes such as polyethylene, PVC and metal pipes are pressurized, the diameter will expand slightly, and due to the Poisson effect, the pipe will shorten in length.

A pipe section with fully restrained joints such as a long string of butt-fused PE pipe will transmit Poisson effect pipe shortening from length to length through the restrained joints along the pipe string. Restrained joints include fusions, bolted flange connections, MJ adapter connections or other restrained mechanical connections. If an unrestrained bell and spigot or mechanical sleeve joint is in-line with the restrained section, the cumulative Poisson effect shortening may cause in-line unrestrained joints or connections to be pulled apart. Therefore, unrestrained joints or mechanical connections that are in-line with fully restrained PE pipe must be either restrained or otherwise protected against pullout disjoining.

Connection Restraint Techniques

Adapters for Flanges and Mechanical Joints
Adapters are available for connecting PE pipe to flanges and to Mechanical Joints. Flange Adapters and MJ Adapters are fully pressure rated and fully restrained. Flange Adapters and MJ Adapters are butt fused to the PE pipe, then connected to the mating flange or mechanical joint.

Plain-End PE Pipe Connections
When a plain-end PE pipe is inserted into a PVC or ductile iron bell or into a mechanical joint bell or component, a stiffener inside the PE pipe end and an external mechanical joint restraint are required. The internal stiffener must extend into the PE pipe end so that the stiffener supports the PE pipe under the seal and under the joint restraint clamp. The external restraint provides pullout resistance.

An ID stiffener and external mechanical restraint are required when plain end PE pressure pipe is connected to:

- Bell and spigot (push-on) joint in PVC pipe and ductile iron fittings, valves, hydrants and pipe;

- Bolted sleeve couplings;
- Mechanical joint pipe, fittings, valves and hydrants (when a MJ adapter is not used).

For PE butt fusion and where Flange Adapter and MJ Adapter fittings are used, ID stiffeners and external joint restraints are NOT required.

Pullout Prevention Techniques

The transition region where a long PE pipe string is connected in-line to unrestrained piping can extend several joints into the non-PE pipe system because a restrained connection at the transition joint can transmit Poisson shortening to the next in line unrestrained joint in the non-PE pipe. Typical pullout prevention techniques include restraining several non-PE pipe joints down line from the transition connection, or restraining the transition connection and installing an in-line anchor in the PE pipe close to the transition connection. Figures A1 and A2 illustrate typical pullout prevention techniques.

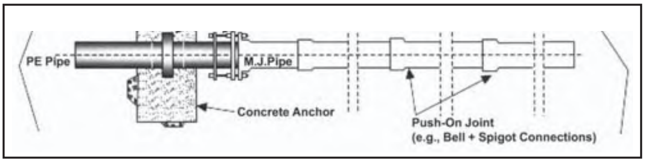

Figure A1 Pullout Prevention Technique

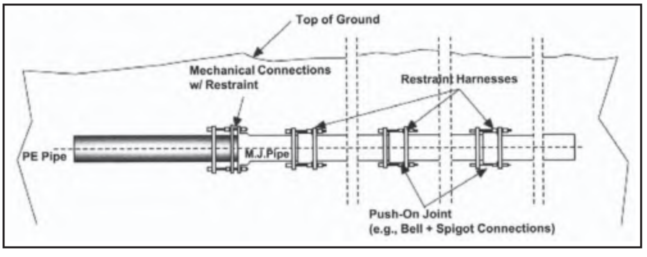

Figure A2 Pullout Prevention Technique

Pullout Force

Poisson effect pipe shortening will occur whenever the pipe is pressurized. Because internal pipe pressures are higher during pressure testing and surge events, Poisson effect pipe shortening can be greater at these times compared to normal steady pressure operation.

Caution – Before pressure testing, all mechanical joint restraints must be completely installed and secured per manufacturer's instructions, and concrete at in-line anchors and thrust blocking (if used) must be sufficiently cured and properly backfilled.

The Engineer should determine the Poisson Effect pullout force conditions that are appropriate for this application; then determine the appropriate techniques to protect unrestrained in-line mechanical connections against disjoining from Poisson effect pullout forces.

For a given PE pipe diameter and DR, approximate Poisson effect pullout force may be determined by multiplying the end area of the PE pipe by the product of the internal pressure hoop stress and the appropriate Poisson ratio.

$$F = S\,\mu\,\pi\,{D_M}^2\left[\frac{1}{DR} - \frac{1}{DR^2}\right]$$

WHERE

F = pullout force, lbs

S = internal pressure hoop stress, lb/in^2

$$S = \frac{P\,(DR - 1)}{2}$$

P = internal pressure, lb/in^2

DR = dimension ratio

μ = Poisson ratio (for PE, 0.45 for long-term stress; 0.35 for short-term stress)

π = Pi (approximately 3.142)

DM = pipe mean diameter, in

Table A2 presents approximate Poisson effect pullout forces for selected sizes of PE pipe while operating at rated system internal pressure, during leak testing at 150% of rated system pressure and during a severe water hammer event while operating at steady pressure that causes a pressure surge to 200% of rated system pressure.

TABLE A2
Approximate Poisson Effect Pullout Force

DIPS Pipe Size (DR 11)	Approximate Pullout Force, lbs (a)		
	Operating at Full Rated Pressure (b)	During Pressure Tests at 150% of Rated Pressure (c)	Operating at Full Rated Pressure Plus Maximum Allowable Occasional Surge Pressure (d)
4”	1,892	2,208	3,364
6”	4,102	4,786	7,293
8”	6,953	8,112	12,361
10”	10,801	12,602	19,202
12”	15,195	17,727	27,013
16”	23,928	27,916	42,539

(a) Values for water at 73°F.

(b) Rated pressure for DR 11, Class 160 = 160 psi. Pullback force determined using long-term Poisson ratio of 0.45.

(c) Pullback force determined using short-term Poisson ratio of 0.35.

(d) Total pressure in pipe during surge event = 160 psi steady pressure + 160 psi surge pressure = 320 psi. Values determined by combining pullback force for steady pressure (long-term Poisson ratio of 0.45) plus pullout force for surge event (short-term Poisson ratio of 0.35).

Other longitudinal forces from thermal expansion and contraction, fluid thrust, or installation are not incorporated into table values.

Chapter 8

Above-Ground Applications for PE Pipe

Introduction

In above ground applications PE piping may be suspended or cradled in support structures or, it may simply be placed directly on the ground surface. These types of installations may be warranted by any one of several factors. One is the economic considerations of a temporary piping system. Another is the ease of inspection and maintenance. Still another is simply that prevailing local conditions and even the nature of the application itself may require that the pipe be installed above ground.

PE pipe provides unique joint integrity, toughness, flexibility, and low weight. These factors combine to make its use practical for many "above-ground" applications. This resilient material has been used for temporary water lines, various types of bypass lines, dredge lines, mine tailings, and fines-disposal piping. PE pipe is used for slurry transport in many industries such as those that work with kaolins and phosphates. The ease of installation and exceptional toughness of PE pipe often make it practical for oil and gas collection. The economics and continued successful performance of this unique piping material is evident despite the extreme climatic conditions that may sometimes exist in some of these diverse applications.

This chapter presents design criteria and prevailing engineering methods that are used for above-ground installation of PE pipe. The effects of temperature extremes, chemical exposure, ultraviolet radiation, and mechanical impact are discussed in detail. Engineering design methodology for both "on-grade" and suspended or cradled PE pipe installations are presented and illustrated with typical sample calculations. All equations in the design methodology were obtained from published design references. These references are listed so the designer can verify the applicability of the methodology to his particular project. Additional installation considerations are also discussed.

Design Criteria

Conditions and effects which can influence the behavior and thus, the design of above ground PE piping systems include:

· Temperature

· Chemical exposure

· Ultraviolet radiation

· Potential mechanical impact or loading

- Internal Pressure

Figure 1 Above-Ground Installation of PE Pipe in a Wyoming Mining Operation

Temperature

The diversity of applications for which PE pipes are used in above-ground applications reflects the usable temperature range for this material. Above-grade installations are usually exposed to demanding fluctuations in temperature extremes as contrasted to a buried installation where system temperatures can be relatively stable. Irradiation by sunlight, seasonal changes, and day-to-night transitions can impose a significant effect on any piping material installed above the ground.

As a general rule, PE pipe for pressure applications can be safely used at temperatures as low as -40°F (-40°C) and as high as 140°F (60°C). For non-pressure service, the allowable temperature range widens up to 180°F (82°C). There are a few PE piping materials that have qualified for a pressure rating at 180°F. The interested reader is advised to consult with the PPI for more information on these materials. However, PE is a thermoplastic material and, as such, these extremes impact the engineering properties of the piping. Additional information in this regard is available within the engineering properties chapter of this handbook.

Pressure Capability

Because above ground installations of PE piping can be subject to exposures to wider temperature and pressure fluctuations and, sometimes also to effects of different environments, careful attention should be paid in the selection of PE piping which has an appropriate pressure rating for the anticipated temperature and environmental exposure. A detailed discussion of these issues is included in Chapters 6.

Low Temperature Extremes

Generally speaking, the limitation for extremely low environmental service temperature is the potential for embrittlement of the material. Note, however, that most PE piping materials tested at extremely low temperatures have shown no indication of embrittlement.

The effect of low temperature on PE pipe is unique. As discussed in Chapter 3 and as shown in tables in the Appendix of Chapter 3, the apparent modulus of elasticity increases as temperatures are lowered. In effect, the pipe becomes stiffer but retains its ductile qualities. The actual low temperature embrittlement of most PE is below -180°F (-118°C). In actual practice, PE pipe has been used in temperatures as low as -75°F (-60° C).[4,5] Obviously, service conditions at these extremes may warrant insulation to prevent heat loss and freezing of the material being conveyed.

It should be noted that in extreme service applications operating at high pressure and increasingly lower temperature that the ability of some PE piping materials to absorb and dissipate energy such as that associated with sudden impact may be compromised. In these situations, it is possible that, with the addition of a sustaining or driving force, a through-wall crack can form which is capable of traveling for significant distances along the longitudinal axis of the pipe. This phenomenon is generally referred to as rapid crack propagation or RCP, and can occur in any pressure piping or pressure vessel design regardless of the material of manufacture.

This type of phenomenon is generally not experienced in PE in liquid transport applications as the energy dissipation associated with the sudden release of fluid from the pipe mediates the driving force required to sustain the crack. Gas or compressed air handling applications do not provide for the dissipation of energy and, as such, a driving or sustaining force is a potential possibility. For these reasons, the operation of PE pipe above ground in extremely cold environments (<32°F) should be carefully researched in light of the potential application and prevailing service conditions. The reader is referred to the pipe manufacturer for additional information regarding RCP and specific design measurers for above ground, cold weather installations.

Expansion and Contraction

The coefficient of linear expansion for unrestrained PE pipe is approximately ten times that of metal or concrete. The end result is that large changes in the length of unrestrained PE piping may occur due to temperature fluctuations. While the potential for expansion (or contraction) is large when compared with that of metal, concrete, or vitrified clay pipe, note that the apparent modulus of elasticity for PE is substantially lower than that of these alternative piping materials. This implies that the degree of potential movement associated with a specific temperature change may be higher for the PE, but the stress associated with restraint of this movement is significantly less. The end result is that the means of restraint required to control this movement potential is often less elaborate or expensive. The stresses imposed by contraction or expansion of a PE piping system are usually on an order of 5% to 10% of those encountered with rigid piping materials.

Chemical Exposure

Standard pressure ratings for PE pipe are for water at 73°F (23°C). Also, as is well established, in common installations either below or above ground, PE pipe will not rust, rot, corrode or be subject to galvanic corrosion. However, if the pipe is intended for the conveyance of a fluid other than water or, if it is intended to be installed in a chemically aggressive environment, consideration should be given to the appropriateness of the assigned standard pressure rating. Continuous exposure to certain substances can result in a reduction in the long-term strength of the PE material due to chemical attack or adsorption.

In some cases, such as with strong oxidizing or other agents that chemically attack PE, a gradual and irreversible reduction in strength may seriously compromise performance properties. In these cases the useful service life depends on the chemical aggressiveness of the agent, its concentration, total time of exposure and temperature. There are many cases where even though there is gradual chemical attack, PE pipe still offers sufficiently long life and is the most economical alternative.

In cases where PE piping is exposed to liquid hydrocarbons, a small adsorption of these materials into the pipe wall can occur which may result in a decrease in long-term strength. The effect is limited by the maximum amount of hydrocarbon that can be adsorbed which depends on the nature of the hydrocarbon and the temperature of the service. This effect on long-term strength is generally limited because hydrocarbon adsorption does not attack PE's chemical structure. Further, it should be noted that adsorption may slowly reverse when exposure to the hydrocarbon is decreased or removed. For lighter weight hydrocarbons such as condensates of gaseous hydrocarbons, adsorption reversal may occur within weeks or months after removal from exposure. However, the reverse adsorption of heavier liquid hydrocarbons may be so slow that the effect may be considered permanent. Exposure to most gaseous hydrocarbons is not known to reduce the long term strength of PE.

Finally, heat fusion joining between pipes after adsorption of liquid hydrocarbons can be affected. The presence of adsorbed liquid hydrocarbons in the pipe wall can result in low-strength heat fusion joining because the adsorbed hydrocarbons will liquefy and then vaporize when heated and reduce or prevent melt fusion. Hydrocarbon contamination is usually identified by a bubbly or pockmarked melt appearance upon heater plate removal. Because the strength and reliability of hydrocarbon contaminated joints is suspect, mechanical joining methods are used in these situations. The strength and reliability of heat fusion joints made before hydrocarbon adsorption is not affected

Ultraviolet Exposure

When PE pipe is utilized outdoors in above-ground applications, it will be subjected to extended periods of direct sunlight. The ultraviolet component in sunlight can produce a deleterious effect on the PE unless the material is sufficiently protected. Weathering studies have shown that pipe produced with a minimum 2.0% concentration of finely divided and evenly dispersed carbon black is protected from the harmful effects of UV radiation for indefinite periods of time.[18] PE pipe that is protected in this manner is the principal material selected for above-ground installations. Black pipe (containing 2.0% minimum carbon black) is normally recommended for above-ground use. Consult the manufacturer's recommendations for any non-black pipe that is either used or stored above ground.

Mechanical Impact or Loading

Any piping material that is installed in an exposed location is subject to the rigors of the surrounding environment. It can be damaged by the movement of vehicles or other equipment, and such damage generally results in gouging, deflecting or flattening of the pipe surfaces. If an above-ground installation must be located in a region of high traffic or excessive mechanical abuse (along a roadway, etc.), the pipe requires extra protection. It may be protected by building a berm or by encasing the pipe where damage is most likely. Other devices may be used, as appropriate to the situation. Design criteria for the installation of buried flexible thermoplastic pipe should be used for those areas where the above-ground PE system must pass under a roadway or other access, and where an underground installation of a portion of the system is necessary.[7,8] In general, in a pressurized installation in which any section of PE pipe has been gouged in excess of 10% of the minimum wall thickness, the gouged portion should be removed and replaced. This has long been an established procedure in the use of smaller diameter (up to 16-inch) PE pipe in natural gas applications. However, it is noted that this rule only applies to smaller size pipe.

Therefore, for any gouges or damage to larger pipe sizes with thicker walls, the user is advised to consult the manufacturer for assistance. When the PE pipe has been excessively or repeatedly deflected or flattened, it may exhibit stress-whitening, crazing, cracking, or other visible damage, and any such regions should be removed and replaced with new pipe material.

Design Methodology

As previously discussed, above-ground piping systems can be subjected to variations in temperature. These temperature fluctuations can impact the pressure capability of the exposed piping to some degree. The possible effects resulting from expansion and contraction characteristics of PE pipe must also be addressed in light of the anticipated variations in temperature. Further, the installation characteristics of the proposed above-ground system must be analyzed in some detail. Each of these concerns will be briefly discussed in the sections which follow. This discussion will be supplemented and facilitated with a few example calculations.

Pressure Capability

As mentioned earlier, the design of PE piping for internal pressure service is covered in significant detail in Chapter 6 of this Handbook. In addition, the Appendix to Chapter 3 contains a table of re-rating factors that can be applied to arrive at the appropriate pressure rating for the application under consideration.

Likewise, where the apparent modulus of elasticity of the pipe material is a consideration, the reader is referred to the modulus tables and associated temperature re-rating factors also found in Appendix, Chapter 3.

The following four example calculations are being presented to illustrate the effect of temperature on various design considerations for hypothetical above- ground PE pipe installations.

EXAMPLE 1

What is the pressure capability of an SDR 11 series of PE 4710 PE pipe used to transport water at 73°F (23°C)?
From Chapter 5,

$$P = 2\,(HDS)(F_T)\,/\,(SDR - 1)$$

WHERE

HDS = **Hydrostatic Design Stress for PE Material at 73ºF (23ºC). For PE4710 = 1000 psig**

F_T = **Temperature Re-rating Design Factor; at 73ºF, F_T = 1.0 per Appendix, Chapter 3.**

P = **2(1000)(1.0) / (11-1) = 200psig at 73ºF**

What is this pipe's pressure capability at 100°F (38°C)?
From Appendix, Chapter 3, F_T at 100°F = 0.78

$$P = 2(1000)\ (0.78)/(11\ -1) = 156 \text{ psig at } 100°F$$

Example 1 assumes that exposure of the pipe to sunlight, combined with the thermal properties of the material flowing within the pipe, has resulted in a normal average operating temperature for the system at 100°F (38°C). Exposure of the pipe to direct sunlight can result in high, up to about 150°F outside surface temperatures, particularly if the pipe is black.[9] In the majority of cases, the material flowing within the pipe is substantially cooler than the exterior of the exposed above-ground pipe. The cooler nature of the material flowing through the pipe tends to moderate the outside surface temperature of the exposed pipe. This results in a pipe wall temperature that is intermediate between that of the outside surface of the pipe and that of the flow stream. Obviously, the longer the period of irradiation of the pipe by sunlight, the greater the potential will be to raise the temperature of the flow stream.

Several texts related to temperature design criteria and flow are included in the literature references of this chapter.[10,11]

In addition, the reader is referred to Chapters 3 and 6 for more detailed information on the topic of the pressure ratings of the different PE materials designation codes and applicable temperature re-rating factors.

Expansion and Contraction

As noted in the Design Criteria section of this chapter, temperature changes can produce a substantial change in the physical dimensions of PE pipe. This is evidenced by a coefficient of expansion or contraction that is notably higher than that of many other piping materials. The design methodology for above-ground installation must take this potential for expansion or contraction into consideration.

The expansion or contraction for an unrestrained PE pipe can be calculated by using the following Equation.

Pipe Length vs. Temperature Change

(3) $$\Delta L = \alpha\ (T_2 - T_1)\ L$$

WHERE

ΔL **= Theoretical length change (in.)**

ΔL**>0 is expansion**

ΔL**<0 is contraction**

α **= Coefficient of linear expansion, see Appendix, Chapter 3**

T_1 **= Initial temperature (°F)**

T_2 **= Final temperature (°F)**

L **= Length of pipe (in.) at initial temperature, T_1**

EXAMPLE 2

A 100 foot section of 10-inch (10.75-inch OD) SDR 11 (PE 4710 pipe) is left unrestrained overnight. If the initial temperature is 70°F (21°C), determine the change in length of the pipe section at dawn the next morning if the pipe stabilizes at a nighttime temperature of 30°F (-1°C).

Using Equation 3,

$$\Delta L = (8.0 \times 10^{-5})(30° - 70°)(100 \text{ ft})(12 \text{ in/ft}) = -3.84 \text{ Inches}$$

The negative sign indicates a contraction, so the final length is 99 ft., 8.16 in.

As shown in Example 2, the contraction or expansion due to temperature change can be quite significant. However, this calculated change in length assumes both an unrestrained movement of the pipe and an instantaneous drop in temperature. Actually, no temperature drop is instantaneous, and obviously, the ground on which the pipe is resting creates a retarding effect on the theoretical movement due to friction. Practical field experience for PE pipe has shown that the actual contraction or expansion that occurs as a result of temperature change is approximately one-half that of the theoretical amount.

Field experience has also shown that changes in physical length are often further mitigated by the thermal properties or heat-sink nature of the flow stream within the pipe. However, conservative engineering design warrants that consideration be given to the effects of temperature variation when the flow stream is static or even when there is no flow stream.

In cases where PE pipe will be exposed to temperature changes, it is common practice to control the pipe movement by judiciously placing restraining devices. Typical devices include tie-down straps, concrete anchors, thrust blocks, etc. The anchor selection must consider the stresses developed in the pipe wall and the resultant loads that are generated as a result of the anticipated temperature changes. While Equations 4 and 5 provide examples of how to calculate generated loads and stress, the Equations are not all inclusive.

(4) Longitudinal Stress vs. Temperature Change

$$\sigma_T = \alpha (T_2 - T_1) E$$

WHERE

σ_T **= Theoretical longitudinal stress (psi)(Negative for contraction; positive for expansion)**

α **= Coefficient of expansion or contraction (see Eq. 3)**

T_1 **= Initial temperature (°F)**

T_2 **= Final temperature (°F)**

E **= Apparent short-term modulus of elasticity (see Appendix, Chapter 3) at average temperature (T_m)**

T_m **= (T_2 + T_1)/2**

(5) Longitudinal Force vs. Temperature Change

$$F_T = \sigma_T\,(A)$$

WHERE

F_T **= Theoretical longitudinal force (lbs)**

σ_T **= Theoretical longitudinal stress (psi) from Eq. 4**

A **= Pipe wall cross-sectional area (in^2)**

EXAMPLE 3

Assuming the same conditions as Example 2, what would be the potential maximum theoretical force developed on the unrestrained end of the 100 foot section if the other end is restrained effectively? Assume that the cross-sectional area of the pipe wall is approximately 30 in^2, the temperature change is instantaneous, and the frictional resistance against the soil is zero.

$$\sigma_T = \alpha\,(T_2 - T_1)\,E$$

Note: This E (apparent modulus) value is the average of the materials value at each of the two temperatures used in this example calculation.

= (8.0×10^{-5})(30°-70°) (130,000 x [1.65 + 1.00] /2)

= -551 psi

$$F_T = (\sigma_T)(A)$$

= - 551 psi x 30 in^2

=-16,530 lbs

As previously mentioned, for these conditions where the temperature change is gradual, the actual stress level is approximately half that of the theoretical value. This would account for an actual force at the free end of about -8,265 Ibs. To illustrate the differences between the expansion and contraction characteristics of PE pipe versus those of steel, consider the following example:

EXAMPLE 4

Assume the same conditions as Example 2 for 10-inch Schedule 40 steel pipe. The pipe wall has a cross-sectional area of 11.90 in^2, the value of α for steel is 6.5 x 10^{-6} in/in/°F, and the value of E for this material is 30,000,000. [14]

$$\sigma_T = \alpha_{steel} (T_2 - T_1) E$$

$$= (6.5 \times 10^{-6}) (30° - 70°) (3 \times 10^7)$$

$$= -7{,}800 \text{ psi}$$

$$F_T = (\sigma_T)(A)$$

$$= -7{,}800 \text{ psi} \times 11.90 \text{ in}^2$$

$$= -92{,}820 \text{ lbs}$$

Thus, as shown by Examples 3 and 4, even though the coefficient of thermal expansion is high in comparison to other materials, the comparatively low modulus of elasticity results in correspondingly reduced thermal stresses and generated loads.

These design considerations provide a general introduction to the understanding of temperature effects on PE pipe in above-ground applications. They do not include other factors such as the weight of the installed pipe, frictional resistance of pipe lying on-grade, or grade irregularities. All of these factors affect the overall expansion or contraction characteristics, and individual pipe manufacturers should be consulted for further detail.

Installation Characteristics

There are two basic types of above-ground installations. One of these involves "stringing-out" the pipe over the naturally-occurring grade or terrain. The second involves suspending the pipe from various support structures available along the pipeline right-of-way. Figure 2 illustrates some typical installations for both types. Each type of installation involves different design methodologies, so the installation types are discussed separately.

On-Grade Installations

As indicated previously, pipe subjected to temperature variation will expand and contract in response to temperature variations. The designer has two options available to counteract this phenomenon. Basically the pipe may be installed in an unrestrained manner, thus allowing the pipe to move freely in response to temperature change. Or the pipe may be anchored by some means that will control any change of physical dimensions; anchoring can take advantage of PE's unique stress relaxation properties to control movement and deflection mechanically.[12]

Free Movement

An unrestrained pipe installation requires that the pipe be placed on a bed or right-of-way that is free of material that may abrade or otherwise damage the exterior pipe surface. The object is to let the pipe "wander" freely without restriction or potential for point damage. This installation method usually entails "snaking" the PE pipe along the right-of-way. The excess pipe then allows some slack that will be taken up when the temperature drops and the pipe contracts.

Figure 2 Typical Above-Ground Installations with PE Pipe

Figure 2a On-grade Installation of PE Pipe in an Industrial Application. Note "snaking" along right of way.

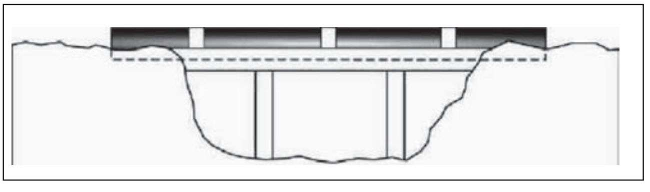

Figure 2b Continuous Support of PE Pipe at Ravine Crossing

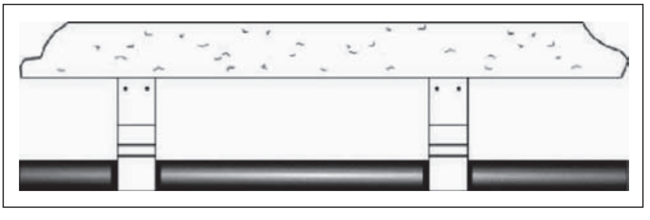

Figure 2c Intermittent Support of PE Pipe Suspended from Rigid Structure

In all likelihood, a free-moving PE pipe must eventually terminate at or connect to a rigid structure of some sort. It is highly recommended that transitions from free-moving PE pipe to a rigid pipe appurtenance be fully stabilized so as to prevent stress concentration within the transition connection.

Figure 3 illustrates some common methods used to restrain the pipe at a distance of one to three pipe diameters away from the rigid termination. This circumvents the stress-concentrating effect of lateral pipe movement at termination points by relieving the stresses associated with thermal expansion or contraction within the pipe wall itself.

Figure 3 Typical Anchoring Methods at Rigid Terminations of Free-Moving PE Pipe Sections

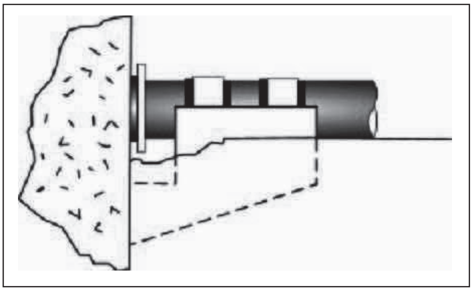

Figure 3a Connection to Concrete Vault Using Grade Beam

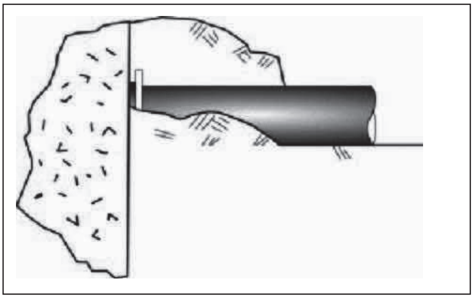

Figure 3b Connection to Rigid Structure Using Consolidated Earthen Berm

Restrained Pipelines

The design for an above-ground installation that includes restraint must consider the means by which the movement will be controlled and the anchoring or restraining force needed to compensate for, or control, the anticipated expansion and contraction stresses. Common restraint methods include earthen berms, pylons, augered anchors, and concrete cradles or thrust blocks.

The earthen berm technique may be either continuous or intermittent. The pipeline may be completely covered with a shallow layer of native earth over its entire length, or it may be stabilized at specific intervals with the earthen berms between the anchor locations. Typical earthen berm configurations are presented in Figure 4.

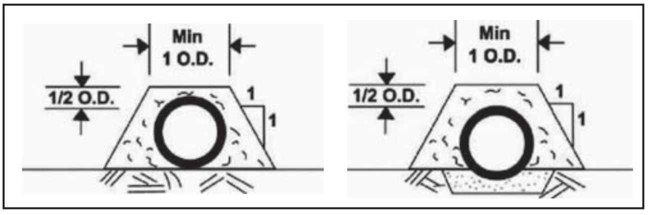

Figure 4 Earthern Berm Configurations

The continuous earthen berm serves not only to stabilize the pipe and restrain its movement but also to moderate temperature fluctuations. With less temperature fluctuation the tendency for pipe movement is reduced.

An intermittent earthen berm installation entails stabilization of the pipe at fixed intervals along the length of the pipeline. At each point of stabilization the above-ground pipe is encased with earthen fill for a distance of one to three pipe diameters. The economy of this method of pipeline restraint is fairly obvious.

Other means of intermittent stabilization are available which provide equally effective restraint of the pipeline with a greater degree of ease of operation and maintenance. These methods include pylons, augered anchors [13], or concrete cradles. These restraint techniques are depicted schematically in Figures 5 through 7.

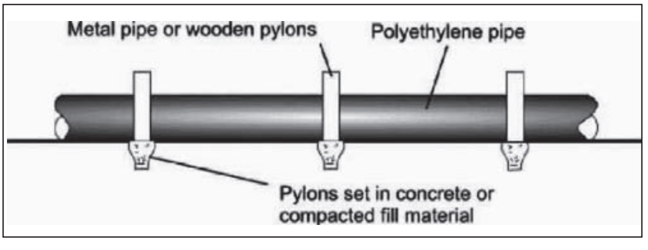

Figure 5 Pylon Type Stabilization

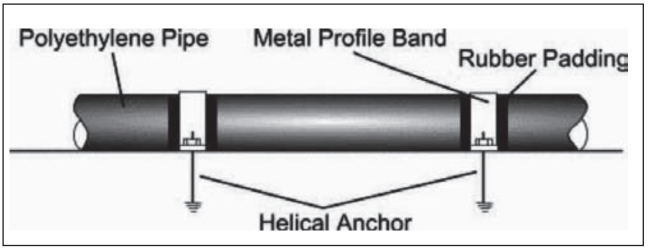

Figure 6 Augered Anchor Stabilization

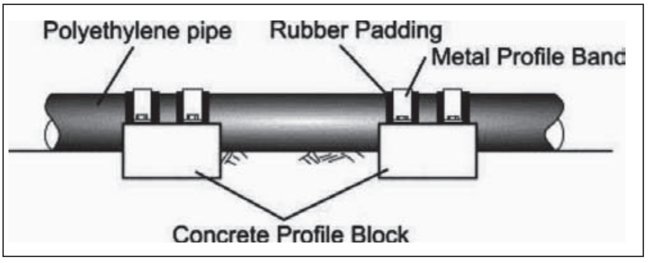

Figure 7 Concrete Cradle or Thrust Block Stabilization

A pipeline that is anchored intermittently will deflect laterally in response to temperature variations, and this lateral displacement creates stress within the pipe wall. The relationships between these variables are determined as follows:

Lateral Deflection (Approximate from Catenary Eq.)

(6) $$\Delta y = L \sqrt{0.5\,\alpha\,(\Delta T)}$$

WHERE

Δy = Lateral deflection (in.)

L = Distance between anchor points (in.)

α = Coefficient of expansion/contraction; see Appendix, Chapter 3

ΔT = Temperature change (T_2 - T_1) in °F

(7) Bending Strain Development

$$\varepsilon = \frac{D \sqrt{96\,\alpha\,(\Delta T)}}{L}$$

WHERE

ε = Strain in pipe wall (%)

D = Outside diameter of pipe (in)

α = Coefficient of expansion/contraction; see Appendix, Chapter 3

ΔT = (T_2 - T_1) in °F

L = Length between anchor points (in)

As a general rule, the frequency of stabilization points is an economic decision. For example, if lateral deflection must be severely limited, the frequency of stabilization points increases significantly. On the other hand, if substantial lateral deflection is permissible, fewer anchor points will be required, and the associated costs are decreased.

Allowable lateral deflection of PE is not without a limit. The upper limit is determined by the maximum permissible strain in the pipe wall itself. This limit is a conservative 5% for the majority of above-ground applications. It is determined by use of Equation 7 based on the assumption that the pipe is anchored between two posts at a distance L from each other. Equations 6 and 7 are used to determine the theoretical lateral deflection or strain in overland pipelines. Actual deflections and strain characteristics may be significantly less due to the friction imposed by the prevailing terrain, the weight of the pipe and flow stream, and given that most temperature variations are not normally instantaneous. These factors allow for stress relaxation during the process of temperature fluctuation.

EXAMPLE 5

Assume that a 10-inch (OD = 10.75) SDR 11 (PE 4710) pipe is strung out to grade and anchored at 100-foot intervals. What is the maximum theoretical lateral deflection possible, given a 50°F (27.8°C) temperature increase? What strain is developed in the pipe wall by this temperature change? What if the pipe is anchored at 50-foot intervals?

Calculations for 100-foot intervals:

$$\Delta y = L\sqrt{0.5\alpha\,(\Delta T)}$$

$$= 100 \times 12\,[0.5\,(8 \times 10^{-5})\,(50)]^{1/2}$$

= 53.7 inches lateral displacement

$$\varepsilon = \frac{D\sqrt{96\alpha(\Delta T)}}{L}$$

$$= \frac{10.75\sqrt{(96)\,(8 \times 10^{-5})(50)}}{100(12)}$$

= 0.56% strain

Calculations for 50-foot intervals:

$$\Delta y = L\sqrt{0.5\alpha(\Delta T)}$$

$= 50 \times 12\ [0.5(8 \times 10^{-5})(50)]^{1/2}$

= 26.8 inches lateral displacement

$$\varepsilon = D\sqrt{\frac{96\alpha(\Delta T)}{L}}$$

$$= 10.75\sqrt{\frac{96\,(0.0001)\,(50)}{50\,(12)}}$$

= 1.11% strain

From the calculations in Example 5, it is apparent that lateral deflections which appear significant may account for relatively small strains in the pipe wall. The relationship between lateral deflection and strain rate is highly dependent on the selected spacing interval.

Supported or Suspended Pipelines

When PE pipeline installations are supported or suspended, the temperature and corresponding deflection characteristics are similar to those discussed above for unsupported pipelines with intermittent anchors. There are two additional parameters to be considered as well: beam deflection and support or anchor configuration.

Support or Suspension Spacing

Allowable spans for horizontal lines are principally influenced by the need to comply with these objectives:

- Keep the pipe bending stresses within suitable limits
- Limit deflections (sagging), if necessary for
  - Appearance
  - Avoiding pockets (to allow complete drainage)
  - Avoid interferences with other pipes or, items

In most cases, the limiting pipe spans which allow the above objectives to be met can readily be obtained from the equations which are presented below. These equations are based on the simple beam relationship.

(8) Support Spacing Requirements

$$L = \left(\frac{3\,(OD^4 - ID^4)\,\sigma_m\pi}{8qOD}\right)^{1/2}$$

WHERE

L = **Center-to-center span (in)**

OD = **Outside diameter (in)**

ID = **Inside diameter (in)**

σ_m = **Maximum allowable bending stress (psi); see Note below**

= **100 psi for pressurized pipelines**

= **400 psi for non-pressurized pipelines**

q = **Load per unit length (lb/in.)**

Note: A common and conservative design objective (in the case on non-pressure pipelines) is to limit the bending stress to one half of the PE pipe material's HDS for the maximum anticipated operating temperature. For pressure pipelines, the objective is to limit the bending stress to 1/8th of the HDS. For example, for a PE4710 material – one having an HDS of 1000psi for water for 73°F – the corresponding bending limits for 73°F would be 500 (for non-pressure) and 125psi (for pressure). And, for a different maximum operating temperature these limits would be modified in accordance with the temperature adjustment factors given in the Appendix to Chapter 3. Also, if environment is a factor this should also be recognized.

(9) Load per Unit Length

$$q = \frac{W}{12} + \frac{\pi\sigma(ID)^2}{6912}$$

WHERE

q = **Load per unit length (lb/in)**

W = **Weight of pipe (lbs/ft)**

σ = **Density of Internal fluid (lb/ft³)**

π = **3.1416**

This calculation gives a conservative estimate of the support span in cases where the pipe is not completely restrained by the supports. (The pipe is free to move within the supports.) A more complex analysis of the bending stresses in the pipe may be performed by treating the pipe as a uniformly loaded beam with fixed ends. The actual deflection that occurs between spans may be determined on the basis of this type of analysis, as shown in Equation 10.

(10) Simple Beam Deflection Analysis[14,15] Based on Limiting Deflection

$$d = \frac{fqL^4}{E_L I}$$

WHERE

d = **Deflection or sag (in)**

f = **Deflection Coefficient, (Refer to Table 2)**

L = **Span length (in)**

q = **Load per unit length (lb/in)**

E_L **= Apparent long-term modulus of elasticity at average long-term temperature from Appendix, Chapter 3**
I **= Moment of inertia (in^4)**
= (π/64)(OD^4 - ID^4)

Simple beam analysis reflects the deflection associated with the proposed support spacing configuration and the apparent modulus of elasticity at a given service temperature. It does not take into consideration the increased or decreased deflection that may be attributed to expansion or contraction due to thermal variations. These phenomena are additive - Equation 11 illustrates the cumulative effect.

(11) Cumulative Deflection Effects

Total deflection = beam deflection + thermal expansion deflection

$$= d + \Delta y$$

$$d = \frac{fqL^4}{E_L I} + L\sqrt{0.5\alpha(\Delta T)}$$

Simple beam analysis assumes one support point at each end of a single span. Most supported pipelines include more than one single span. Normally, they consist of a series of uniformly spaced spans with relatively equal lengths. The designer may analyze each individual segment of a multiple-span suspended pipeline on the basis of simple beam analysis. However, this approach may prove overly conservative in the majority of multiple-span supported pipelines. Equation 12 presents a more realistic approach to deflection determination on the basis of continuous beam analysis.

(12) Continuous Beam Analysis

$$d = \frac{fqL^4}{E_L I}$$

WHERE

d **= Deflection or sag (in)**
f **= Deflection coefficient (Refer to Table 2)**
q **= Load per unit length (lbs/in)**
L **= Span length (in)**
E_L **= Apparent long-term modulus of elasticity at average long-term temperature from Appendix, Chapter 3**
I **= Moment of inertia (in^4)**
= (π/64)(OD^4 - ID^4)

The deflection coefficient, f, is a function of the number of spans included and whether the pipe is clamped securely, fixed, or simply guided (not fixed) within the supports. Practical values for the deflection coefficient, f, are provided in Table 2.

TABLE 2
Deflection Coefficients, f, for Various span Configurations [17]

1 Span	2 Spans	3 Spans	4 Spans
N-N	N-N-N	N-N-N-N	N-N-N-N-N
		1 2 1	1 2 2 1
f=0.013	f=0.0069	f1=0.0069	f1=0.0065
		f2=0.0026	f2=0.0031
F–N	F-N-N	F-N-N–N	F-N-N-N-N
	1 2	1 2 2	1 2 2 2
f=0.0054	f=0.0026	f1=0.0026	f1=0.0026
	f2=0.0054	f2=0.0054	f2=0.0054
F-F	F-N-F	F-N-N-F	F-N-N-N-F
		1 2 1	1 2 2 1
f=0.0026	f=0.0026	f1=0.0026	f1=0.0026
		f2=0.0031	f2=0.0031
	F-F-F	F-F-F-F	F-F-F-F-F
	f=0.0026	f=0.0026	f=0.0026
F = Fixed Securely N = Not Fixed			

As was the case for simple beam analysis, continuous beam analysis addresses the deflection resulting from a given span geometry at a specified service temperature. The equation does not take into consideration the additional deflection associated with expansion or contraction due to temperature variations. Equation 13 combines the effect of deflection due to span geometry (using continuous beam analysis) with deflection resulting from expansion due to a temperature increase. A total span deflection of ½ to 1 inch is generally considered as a maximum.

(13) Total Span Deflection Based on Continous Beam Analysis and Thermal Response

$$\text{Total Deflection (in)} = \frac{fqL^4}{E_L I} + L\sqrt{0.5\alpha(\Delta T)}$$

WHERE

f **= Deflection Coefficient (Refer to Table 2)**

q **= Load per unit length from Eq. 9 (lbs/in)**

L **= Span length from Eq. 8 (in)**

E_L **= Apparent long-term modulus of elasticity at average long-term temperature from Appendix, Chapter 3**

I **= Moment of inertia (in.^{4})**

= $(\pi/64)(OD^4 - ID^4)$

Anchor and Support Design

Proper design of anchors and supports is as important with PE piping as it is with other piping materials. A variety of factors must be considered.

Some installations of PE pipe have the pipe lying directly on the earth's surface. In this type of installation, the surface under the pipe must be free from boulders, crevices, or other irregularities that could create a point-loading situation on the pipe.

On-grade placement over bed rock or "hard pan" should be avoided unless a uniform bed of material is prepared that will cushion the pipe. If the PE pipe rests directly on a hard surface, this creates a point loading situation and can increase abrasion of the outer pipe surface as it "wanders" in response to temperature variations.

Intermittent pipe supports should be spaced properly, using the design parameters discussed in the preceding pages. Where excessive temperatures or unusual loading is encountered, continuous support should be considered.

Supports that simply cradle the pipe, rather than grip or clamp the pipe, should be from one-half to one-pipe diameter in length and should support at least 120 degrees of the pipe diameter. All supports should be free from sharp edges.

The supports should have adequate strength to restrain the pipe from lateral or longitudinal deflection, given the anticipated service conditions. If the design allows free movement during expansion, the sliding supports should provide a guide without restraint in the direction of movement. If on the other hand, the support is designed to grip the pipe firmly, the support must either be mounted flexibly or have adequate strength to withstand the anticipated stresses.

Heavy fittings or flanges should be fully supported and restrained for a distance of one full pipe diameter, minimum, on both sides. This supported fitting represents a rigid structure within the flexible pipe system and should be fully isolated from bending stresses associated with beam sag or thermal deflection.

Figure 8 includes some typical pipe hanger and support arrangements that are appropriate for use with PE pipe, and Figure 9 shows some anchoring details and cradle arrangements.

Pressure-Testing

It is common practice to pressure-test a pipe system prior to placing it in service. For the above-ground systems described in this chapter, this test should be conducted hydrostatically. Hydrostatic testing procedures are described in a number of publications, including PPI Technical Report 31.[8] The Plastics Pipe Institute does not recommend pneumatic pressure testing of an above-ground installation.[16] An ASTM test method for leakage testing of PE pipe installations is under development and may be applicable. The reader is also advised to refer to Chapter 2 of this Handbook where the subject of pressure testing of installed PE pipe systems is covered in greater detail.

Figure 8 Typical Pipe Hangers and Supports

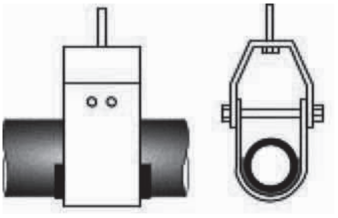

Figure 8.1 Pipe Stirrup Support

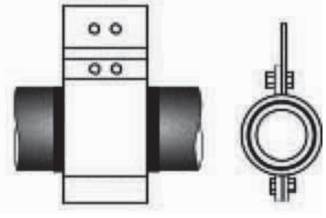

Figure 8.2 Clam Shell Support

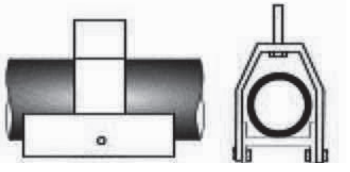

Figure 8.3 Suspended I-Beam or Channel-Continuous Support

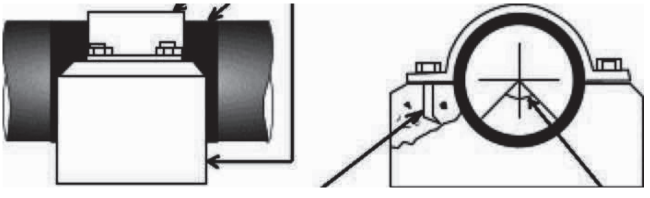

Figure 9 Typical Anchoring and Cradling Details

Conclusion

PE pipe has been used to advantage for many years in above-ground applications. The unique light weight, joint integrity, and overall toughness of PE has resulted in the above-ground installation of PE pipe in various mining, oil, gas production and municipal distribution applications. Many of these systems have provided years of cost-effective service without showing any signs of deterioration.

The key to obtaining a quality above-ground PE piping system lies in careful design and installation. This chapter is intended to serve as a guide by which the designer and/or installer may take advantage of the unique properties of PE pipe for these types of applications. In this way, excellent service is assured, even under the demanding conditions found with above-ground installations.

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Eq 10. Ibid.
Eq 11. Ibid.
Eq 12. Ibid.

Chapter 9

PE Pipe Joining Procedures

Introduction

An integral part of any pipe system is the method used to join the system components. Proper engineering design of a system will take into consideration the type and effectiveness of the techniques used to join the piping components and appurtenances, as well as the durability of the resulting joints. The integrity and versatility of the joining techniques used for PE pipe allow the designer to take advantage of the performance benefits of PE in a wide variety of applications.

General Provisions

PE pipe or fittings are joined to each other by heat fusion or with mechanical fittings. PE pipe may be joined to other pipe materials by means of compression fittings, flanges, or other qualified types of manufactured transition fittings. There are many types and styles of fittings available from which the user may choose. Each offers its particular advantages and limitations for each joining situation the user may encounter. Contact with the various manufacturers is advisable for guidance in proper applications and styles available for joining as described in this document. The joining methods discussed in this chapter cover both large and small diameter pipe. Large diameter PE pipe is considered to be sizes 3" IPS (3.500" OD, Iron Pipe Size) and larger. All individuals involved in the joining PE pipe systems, whether it be using the typical heat fusion methods or employing mechanical connections, should be fully trained and qualified in accordance with applicable codes and standards and/or as recommended by the pipe or fitting manufacturer. Those assigned to making joints in PE pipe for gas applications must meet the additional requirement of compliance with U.S. Department of Transportation Pipeline Safety Regulations(10). The equipment used in the process of making heat fused joints must be designed to operate for the selected pipe and fusion procedures. Additionally, the equipment should be well maintained and capable of operating to specification.

Thermal Heat Fusion Methods

There are three types of conventional heat fusion joints currently used in the industry; Butt, Saddle, and Socket Fusion. Additionally, electrofusion (EF) joining is available with special EF couplings and saddle fittings.

The principle of heat fusion is to heat two surfaces to a designated temperature, then fuse them together by application of a sufficient force. This force causes the melted materials to flow and mix, thereby resulting in fusion. When fused according to the pipe and/or fitting manufacturers' procedures, the joint area becomes as strong as, or stronger than, the pipe itself in both tensile and pressure properties and properly fused joints are absolutely leak proof. As soon as the joint cools to near ambient temperature, it is ready for handling. The following sections of this chapter provide a general procedural guideline for each of these heat fusion methods.

Butt Fusion

The most widely used method for joining individual lengths of PE pipe and pipe to PE fittings is by heat fusion of the pipe butt ends as illustrated in Figure 1. This technique produces a permanent, economical and flow-efficient connection. Quality butt fusion joints are produced by using trained operators and quality butt fusion machines in good condition.

The butt fusion machine should be capable of:

- Aligning the pipe ends
- Clamping the pipes
- Facing the pipe ends parallel and square to the centerline
- Heating the pipe ends
- Applying the proper fusion force

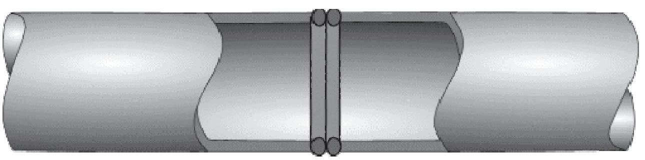

Figure 1 A Standard Butt Fusion Joint

The six steps involved in making a butt fused joint are:

1. Clean, clamp and align the pipe ends to be joined
2. Face the pipe ends to establish clean, parallel surfaces, perpendicular to the center line
3. Align the pipe ends
4. Melt the pipe interfaces
5. Join the two pipe ends together by applying the proper fusion force
6. Hold under pressure until the joint is cool

Butt Fusion of PE Pipe Products with Different Wall Thicknesses

PE pipes of the same outside diameter but having different specified wall thicknesses, that is, different DR designations, may be butt fused to each other under special conditions. Since this represents a special situation, it is subject to limitations. Therefore, the user is advised to consult with the pipe manufacturer to determine if the special procedures can be applied to the pipe components involved in the particular installation in question. If so, a written copy of the applicable assembly recommendations should be obtained.

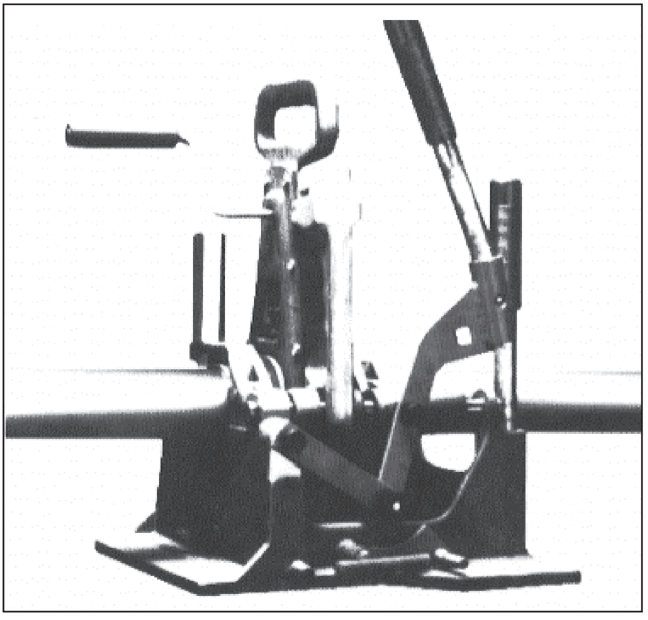

Figure 2 Typical Butt Fusion Machine for Smaller Diameter Pipe
(Butt Fusion machines are available to fuse pipe up to 65 inches in diameter)

Most pipe manufacturers have detailed parameters and procedures to follow. The majority of them helped develop and have approved the PPI Technical Report TR-33 for the generic butt fusion joining procedure for PE pipe [15] and ASTM F 2620.

Optional Bead Removal

In some pipe systems, engineers may elect to remove the inner or outer bead of the joint. External, or both beads are removed with run-around planing tools, which are forced into the bead, then drawn around the pipe. Power planers may also be used, but care must be taken not to cut into the pipe's outside surface.

It is uncommon to remove internal beads, as they have little or no effect on flow, and removal is time-consuming. Internal beads may be removed from pipes after each fusion with a cutter fitted to a long pole. Since the fusion must be completely cooled before bead removal, assembly time is increased slightly.

Saddle/Conventional Fusion

The conventional technique to join a saddle to the side of a pipe, illustrated in Figure 3, consists of simultaneously heating both the external surface of the pipe and the matching surface of the "saddle" type fitting with concave and convex shaped heating tools until both surfaces reach proper fusion temperature. This may be accomplished by using a saddle fusion machine that has been designed for this purpose.

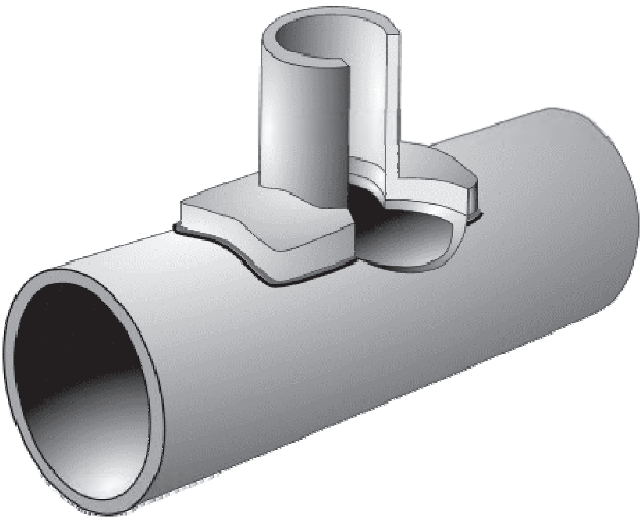

Figure 3 Standard Saddle Fusion Joint

Saddle fusion using a properly designed machine, provides the operator better alignment and force control, which is very important to fusion joint quality. The Plastics Pipe Institute recommends that saddle fusion joints be made only with a mechanical assist tool unless hand fusion is expressly allowed by the pipe and/or fitting manufacturer.[16]

There are eight basic sequential steps that are normally used to create a saddle fusion joint:

1. Clean the pipe surface area where the saddle fitting is to be located
2. Install the appropriate size heater saddle adapters

3. Install the saddle fusion machine on the pipe
4. Prepare the surfaces of the pipe and fitting in accordance with the recommended procedures
5. Align the parts
6. Heat both the pipe and the saddle fitting
7. Press and hold the parts together
8. Cool the joint and remove the fusion machine

Most pipe manufacturers have detailed parameters and procedures to follow. The majority of them helped develop and have approved the PPI Technical Report TR-41 for the generic saddle fusion joining procedure for PE pipe [16] and ASTM 2620.

Socket Fusion

This technique consists of simultaneously heating both the external surface of the pipe end and the internal surface of the socket fitting until the material reaches the recommended fusion temperature, inspecting the melt pattern, inserting the pipe end into the socket, and holding it in place until the joint cools. Figure 4 illustrates a typical socket fusion joint. Mechanical equipment is available to hold both the pipe and the fitting and should be used for sizes larger than 2" CTS to help attain the increased force required and to assist in alignment. Most pipe manufacturers have detailed written procedures to follow. The majority refer to ASTM F 2620.

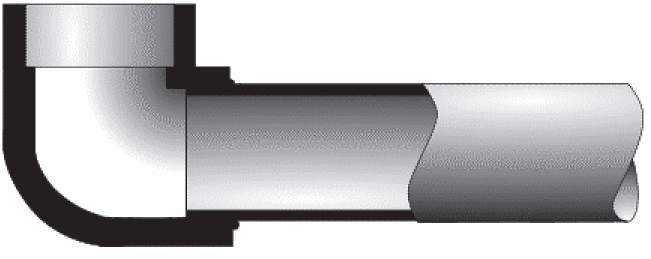

Figure 4 Standard Socket Fusion Joint

Follow these general steps when performing socket fusion:

1. Thoroughly clean the end of the pipe and the matching inside surface of the fitting
2. Square and prepare the pipe end
3. Heat the parts

4. Join the parts
5. Allow to cool

Equipment Selection

Select the proper size tool faces and heat the tools to the fusion temperature recommended for the material to be joined. For many years, socket fusion tools were manufactured without benefit of any industry standardization. As a result, variances of heater and socket depths and diameters, as well as depth gauges, do exist. More recently, ASTM F1056[7] was written, establishing standard dimensions for these tools. Therefore, mixing various manufacturers' heating tools or depth gauges is not recommended unless the tools are marked "F1056," indicating compliance with the ASTM specification and, thereby, consistency of tooling sizes.

Square and Prepare Pipe

Cut the end of the pipe square. Chamfer the pipe end for sizes 1¼"-inch diameter and larger. (Chamfering of smaller pipe sizes is acceptable and sometimes specified in the instructions.) Remove scraps, burrs, shavings, oil, or dirt from the surfaces to be joined. Clamp the cold ring on the pipe at the proper position, using the integral depth gauge pins or a separate (thimble type) depth gauge. The cold ring will assist in re- rounding the pipe and provide a stopping point for proper insertion of the pipe into the heating tool and coupling during the fusion process.

Heating

Check the heater temperature. Periodically verify the proper surface temperature using a pyrometer or other surface temperature measuring device. If temperature indicating markers are used, do not use them on a surface that will come in contact with the pipe or fitting. Bring the hot clean tool faces into contact with the outside surface of the end of the pipe and with the inside surface of the socket fitting, in accordance with pipe and fitting manufacturers' instructions.

Joining

Simultaneously remove the pipe and fitting from the tool using a quick "snap" action. Inspect the melt pattern for uniformity and immediately insert the pipe squarely and fully into the socket of the fitting until the fitting contacts the cold ring. Do not twist the pipe or fitting during or after the insertion, as is the practice with some joining methods for other pipe materials.

Cooling

Hold or block the pipe in place so that the pipe cannot come out of the joint while the mating surfaces are cooling. These cooling times are listed in the pipe or fitting manufacturer's instructions.

Electrofusion (EF)

This technique of heat fusion joining is somewhat different from the conventional fusion joining thus far described. The main difference between conventional heat fusion and electrofusion is the method by which the heat is applied. In conventional heat fusion joining, a heating tool is used to heat the pipe and fitting surfaces. The electrofusion joint is heated internally, either by a conductor at the interface of the joint or, as in one design, by a conductive polymer. Heat is created as an electric current is applied to the conductive material in the fitting. Figure 5 illustrates a typical electrofusion joint. PE pipe to pipe connections made using the electrofusion process require the use of electrofusion couplings.

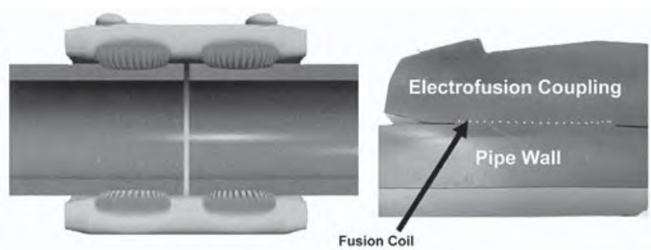

Figure 5 Typical Electrofusion Joint

General steps to be followed when performing electrofusion joining are:

1. Prepare the pipe (scrape, clean)
2. Mark the pipe
3. Align and restrain pipe and fitting per manufacturer's recommendations
4. Apply the electric current
5. Cool and remove the clamps
6. Document the fusion process

Prepare the Pipe (Clean and Scrape)

Assure the pipe ends are cut square when joining using electrofusion couplings. The fusion area must be clean from dirt or contaminants. This may require the use of water or 90% isopropyl alcohol (NO ADDITIVES OR NOT DENATURED). Next, the pipe surface in the fusion must be scraped, that is material must be removed to expose clean virgin material. This may be achieved by various special purpose tools available from the fitting manufacturer.

Mark the Pipe

Mark the pipe for stab depth of couplings or the proper fusion location of saddles. (Caution should be taken to assure that a non-petroleum marker is used.)

Align and Restrain Pipe or Fitting Per the Manufacturer's Recommendations

Align and restrain fitting to pipe per manufacturer's recommendations. Place the pipe(s) and fitting in the clamping fixture to prevent movement of the pipe(s) or fitting. Give special attention to proper positioning of the fitting on the prepared pipe surfaces. Large pipe diameters may need re-rounding prior to the electrofusion process.

Apply Electric Current

Connect the electrofusion control box to the fitting and to the power source (see Figure 6). Apply electric current to the fitting as specified in the manufacturer's instructions. Read the barcode which is supplied with the electrofusion fitting. If the control does not do so automatically, turn off the current when the proper time has elapsed to heat the joint properly.

Figure 6 Typical Electrofusion Control Box and Leads with Clamps and Fittings

Cool Joint and Remove Clamps

Allow the joint to cool for the recommended time. If using clamps, premature removal from the clamps and any strain on a joint that has not fully cooled can be detrimental to joint performance.

Consult the fitting manufacturer for detailed parameters and procedures.

Documenting fusion

The Electrofusion control box that applies current to the fitting also controls and monitors the critical parameters of fusion, (time, temperature, & pressure). The control box is a micro- processor capable of storing the specific fusion data for each joint. This information can be downloaded to a computer for documentation and inspection of the days work.

Heat Fusion Joining of Unlike PE Pipe and Fittings

Research has indicated that PE pipe and fittings made from unlike resins can be heat-fused together to make satisfactory joints. Some gas companies have been heat-fusion joining unlike PEs for many years with success. Guidelines for heat fusion of unlike materials are outlined in TN 13, issued by the Plastics Pipe Institute. Refer to Plastics Pipe Institute Technical Reports TR-33 and TR-41, ASTM F 2620 and the pipe and fitting manufacturers for specific procedures.

As mentioned earlier, fusion joints, whether they involve the conventional butt, socket or saddle heat fusion assembly procedures or the electrofusion procedure, should only be made by personnel fully trained and qualified in those procedures. The equipment used shall be designed to operate for the selected pipe and fusion procedures. The equipment should be well maintained and capable of operating to specification. In addition, it is important that only the specified or recommended joining procedures be followed at all times during assembly operations.

Mechanical Connections

As in the heat fusion methods, many types of mechanical connection styles and methods are available. This section is a general description of these types of fittings.

The Plastics Pipe Institute recommends that the user be well informed about the performance attributes of the particular mechanical connector being utilized. Fitting selection is important to the performance of a piping system. Product performance and application information should be available from the fitting manufacturer to assist in the selection process as well as instructions for use and performance limits, if any. Additional information for these types of products is also contained in a variety of specifications such as ASTM F1924, F1973, and AWWA C219.

PE pipe, conduit and fittings are available in outside diameter controlled Iron Pipe Sizes (IPS), Ductile Iron Pipe Sizes (DIPS), Copper Tubing Sizes (CTS) and Metric Sizes. There are also some inside diameter controlled pipe sizes (SIDR-PR). Before selecting mechanical fittings, establish which of the available piping system sizes and types are being installed to ensure proper fit and function. The pipe manufacturer can provide dimensional information, and the fitting manufacturer can advise on the correct fitting selection for the application.

Mechanical Compression Couplings for Small Diameter Pipes

This style of fitting comes in many forms and materials. The components, as depicted in Figure 7, are generally a body; a threaded compression nut; an elastomer seal ring or O-ring; a stiffener; and, with some, a grip ring. The seal and grip rings, when compressed, grip the outside of the pipe, effecting a pressure-tight seal and, in most designs, providing pullout resistance which exceeds the yield strength of the PE pipe. It is important that the inside of the pipe wall be supported by the stiffener under the seal ring and under the gripping ring (if incorporated in the design), to avoid deflection of the pipe. A lack of this support could result in a loss of the seal or the gripping of the pipe for pullout resistance. This fitting style is normally used in service lines for gas or water pipe 2" IPS and smaller. It is also important to consider that three categories of this type of joining device are available. One type provides a seal only, a second provides a seal and some restraint from pullout, and a third provides a seal plus full pipe restraint against pullout.

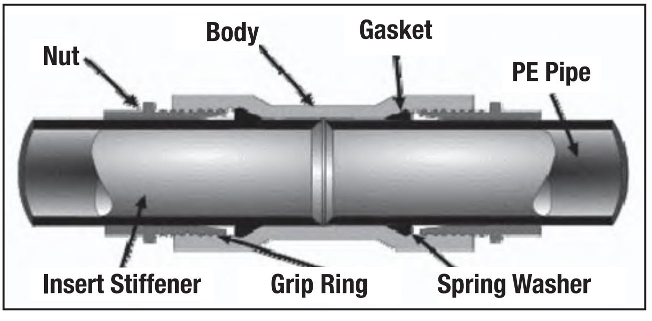

Figure 7 Typical Compression Nut Type Mechanical Coupling for Joining PE Pipe to PE Pipe

Stab Type Mechanical Fittings

Here again many styles are available. The design concept, as illustrated in Figure 8, is similar in most styles. Internally there are specially designed components including an elastomer seal, such as an "O" ring, and a gripping device to effect pressure sealing and pullout resistance capabilities. Self-contained stiffeners are included in this design. With this style fitting the operator prepares the pipe ends, marks the stab depth on the pipe, and "stabs" the pipe in to the depth prescribed for the fitting being used. These fittings are available in sizes from ½"CTS through 2" IPS and are all of ASTM D2513(2) Category I design, indicating seal and full restraint against pullout.

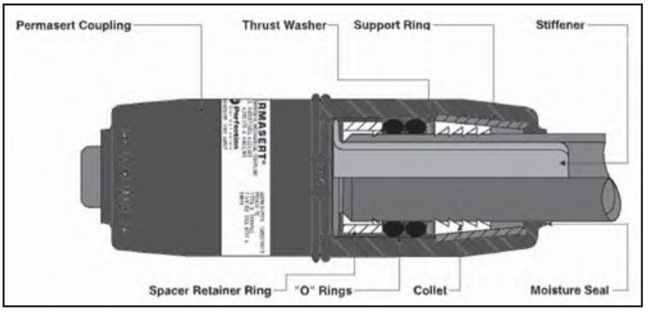

Figure 8 Stab Type Fitting

Mechanical Bolt Type Couplings

There are many styles and varieties of "Bolt Type" couplings available to join PE to PE or other types of pipe such as PVC, steel and cast iron in sizes from 1¼" IPS and larger. Components for this style of fitting are shown in Figure 9. As with the mechanical compression fittings, these couplings work on the general principle of compressing an elastomeric gasket around each pipe end to be joined, to form a seal. The gasket, when compressed against the outside of the pipe by tightening the bolts, produces a pressure seal. These couplings may or may not incorporate a grip ring, as illustrated, that provides pullout resistance sufficient to exceed the yield strength of the PE pipe. When PE pipe is pressurized, it expands a little and shortens slightly due to Poisson's effect. In a run of PE pipe, the cumulative shortening may be enough to cause separation of unrestrained mechanical joints that are in-line with the PE pipe. This can be a particular concern where transitioning from PE pipe to Ductile Iron pipe. Joint separation can be prevented by installing external joint restraints (gripping devices or flex restraints; see Figure 16) at mechanical connections, or by installing in-line anchors or a combination of both. Additional restraint mechanisms are available to supplement the pull resistance of these types of fittings if needed. The fitting manufacturer can help guide the user with that information. Use of a stiffener is needed in this fitting style to support the pipe under the area of the seal ring and any gripping devices incorporated for pullout resistance.

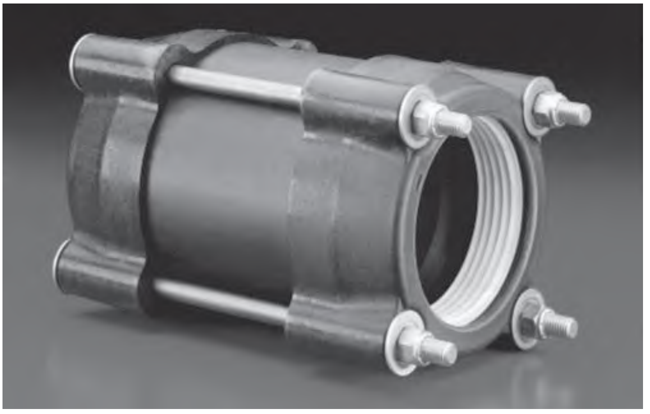

Figure 9 Mechanical Bolt Type Coupling for Joining Steel Pipe to PE or for Joining Two PE Pipes

Stiffener Installation Guidelines

When connecting PE pipe to the bell end of a ductile iron or PVC pipe, it is recommended that a stiffener be added to the ID of the pipe to insure a good connection between the seal in the bell and the pipe. Check the pipe for toe in. If it is severe, cut the pipe back to remove it. If possible, have some means to press the stiffener into place. Lubricant will minimize the insertion effort required. A detergent or silicone grease is recommended.

There are two types of stiffeners available on the market. One type is a fixed diameter stiffener that matches the ID of the pipe being repaired (see Figure 10). Caution should be used when using fixed diameter stiffeners to be sure they are sized properly to obtain the proper press fit in the PE pipe. These are mainly used with smaller diameter service lines.

Figure 10 Fixed Diameter Stiffener for PE Pipe

Figure 11a Split Ring Stiffener for PE Pipe

The other type of stiffener is a split ring stiffener (see Figure 11a). These are normally made of stainless steel and provide a thin yet strong pipe wall reinforcement without disturbing the flow characteristic of the pipe. The easy installation instructions are shown in Figure 11b.

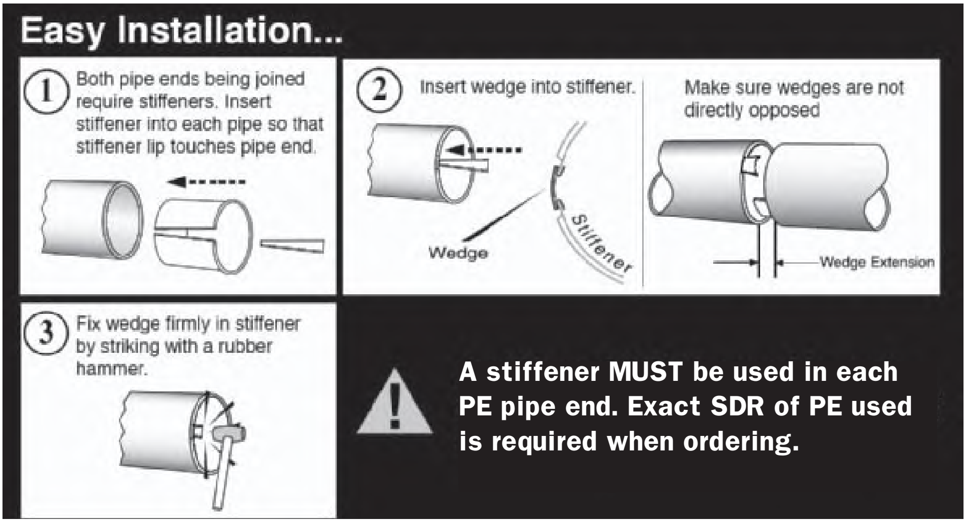

Figure 11b Easy Installation Instructions

Figure 12 Install Split Ring Stiffener in PE Pipe

Flanged Connections

PE Flange Adapters and Stub Ends

When joining to metal or to certain other piping materials, or if a pipe section capable of disassembly is required, PE flange adapters, as depicted in Figures 13-15, are available. The "Flange Adapter" and its shorter version, the "Stub End," are designed so that one end is sized the same as the PE pipe for butt fusion to it. The other end has been especially made with a flange-type end that, provides structural support, which eliminates the need for a stiffener and, with the addition of a metal back-up ring, permits bolting to a similar flanged end connection — normally a 150-pound ANSI flange.[1]

The general procedures for joining would be:

1. Slip the metal ring onto the PE pipe section, far enough away from the end to avoid interference with operation of the butt fusion equipment.
2. If a stub end is used, first butt-fuse a short length of PE pipe to the pipe end of the stub end. If a "flange adapter" is used, the PE pipe-sized end is usually long enough that this step is unnecessary.
3. Butt fuse the flange adapter to the PE pipe segment.
4. The fusion bead may need to be removed to clear the back-up ring as it is moved against the flange.
5. Position the flanged face of the adapter at the position required so that the back-up ring previously placed on the PE pipe segment can be attached to the metal flange.
6. Install and tighten the flange bolts in a criss-cross pattern sequence (see TN 38), normally used with flange type connections, drawing the metal and PE flange faces evenly and flat. Do not use the process of tightening the flanges to draw the two sections of pipe together.

At lower pressure, typically 80 psi or less, a gasket is usually not required. At greater pressure, the serrated surface of the flange adapter helps hold the gasket in place. The flange face serration's should be individual closed concentric serration's as opposed to a continuous spiral groove which could act as a leak path. Standard Back-Up Rings are AWWA C207 Class D for 160 psi and lower pressure ratings, or Class 150 for higher pressure. Back-up ring materials are steel, primer coated steel, epoxy coated steel, or stainless steel. Ductile iron and fiberglass back-up ring materials are also available. In below ground service, coatings and cathodic protection may be appropriate to protect metal back-up rings from corrosion. One edge of the back-up ring bore must be rounded or chamfered. This edge fits against the back of the sealing surface flange.

An all-PE flange without a back-up ring is not recommended because PE flanges require uniform pressure over the entire sealing surface. Without a back-up ring, a PE flange will leak between the bolts.

Flange adapters differ from stub-ends by their overall length. A flange adapter is longer allowing it to be clamped in a fusion machine like a pipe end. The back-up ring is fitted to the flange adapter before fusion, so external fusion bead removal is not required.

A stub end is short and requires a special stub-end holder for butt fusion. Once butt fused to the pipe, the external bead must be removed so the back-up ring can be fitted behind the sealing surface flange. In the field, flange adapters are usually preferred over stub-ends.

Figure 13 Flange Adapter Assembly

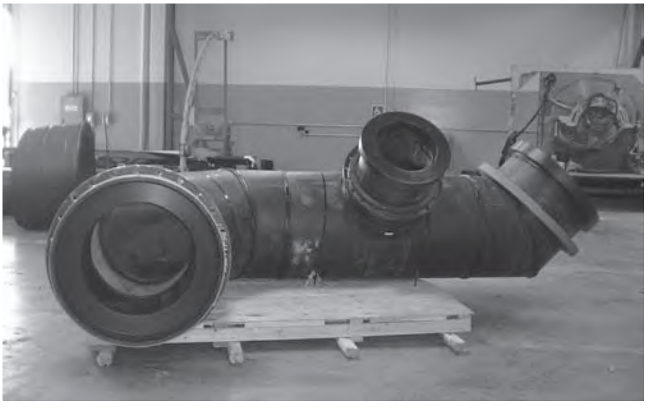

Figure 14 Fused Manifold Assembly with Flange Adapters and Back Up Rings

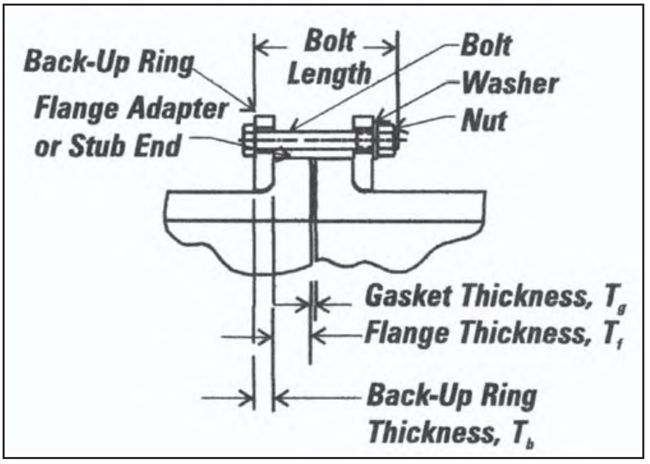

Figure 15 Flange Adapter Bolted Assembly Cross Section

Flange Gasket

A flange gasket may not be required between PE flanges. At lower pressures (typically 80 psi or less) the serrated flange sealing surface may be adequate. Gaskets may be needed for higher pressures and for connections between PE and non-PE flanges. If used, gasket materials should be chemically and thermally compatible with the internal fluid and the external environment, and should be of appropriate hardness, thickness and style. Elevated temperature applications may require higher temperature capability. Gasket thickness should be about 1/8"-3/16" (3-5mm) and about 60-75 Shore A hardness. Too soft or too thick gaskets may blow out under pressure. Overly hard gaskets may not seal. Common gasket styles are full-face or drop-in. Full-face style gaskets are usually applied to larger sizes, because flange bolts hold a flexible gasket in place while fitting the components together. Drop-in style gaskets are usually applied to smaller pipe sizes.

Flange Bolting

Mating flanges are usually joined together with hex bolts and hex nuts, or threaded studs and hex nuts. Bolting materials should have tensile strength equivalent to at least SAE Grade 3 for pressure pipe service, and to at least SAE Grade 2 for non-pressure service. Corrosion resistant materials should be considered for underground, underwater, or other corrosive environments. Flange bolts are sized 1/8" smaller than the blot hole diameter. Flat washers should be used between the nut and the back-up ring.

Flange bolts must span the entire width of the flange joint, and provide sufficient thread length to fully engage the nut.

Flange Assembly

Mating flanges must be aligned together before tightening. Tightening misaligned flanges can cause flange assembly failure. Surface or above grade flanges must be properly supported to avoid bending stresses. Below grade flange connections to heavy appurtenances such as valves or hydrants, or to metal pipes, require a support foundation of compacted, stable granular soil (crushed stone), or compacted cement stabilized granular backfill, or reinforced concrete. Flange connections adjacent to pipes passing through structural walls must be structurally supported to avoid shear loads.

Prior to fit-up, lubricate flange bolt threads, washers, and nuts with a non-fluid lubricant. Gasket and flange sealing surfaces must be clean and free of significant cuts or gouges. Fit the flange components together loosely. Hand-tighten bolts and re-check alignment. Adjust alignment if necessary. Flange bolts should be tightened to the same torque value by turning the nut. Tighten each bolt according to the patterns and torques recommended by the flange manufacturer. PE and the gasket (if used) will undergo some compression set. Therefore, retightening is recommended
about an hour or so after torquing to the final torque value the first time. In criss-cross pattern sequence, retighten each bolt to the final torque value. For high pressure or environmentally sensitive or critical pipelines, a third tightening, about 4 hours after the second, is recommended.

Special Cases

When flanging to brittle materials such as cast iron, accurate alignment, and careful tightening are necessary. Tightening torque increments should not exceed 10 ft.-lbs. PE flange adapters and stub ends are not full-face, so tightening places a bending stress across the flange face. Over-tightening, misalignment, or uneven tightening can break brittle material flanges.

When joining a PE flange adapter or stub end to a flanged butterfly valve, the inside diameter of the pipe flange should be checked for valve disk rotation clearance. The open valve disk may extend into the body of the flange adapter/stub end. Valve operation may be restricted if the pipe flange interferes with the disk. If disk rotation clearance is a problem, a tubular spacer may be installed between the mating flanges, or the pipe flange bore may be chamfered slightly. At the sealing surface, chamfering must not increase the flange inside diameter by more than 10%, and not extend into the flange more than 20% of the flange thickness. If spacer plates are used, the flange bolt length must be increased by the length of the spacer.

Mechanical Flange Adapters

Mechanical Flange Adapters are also available and are shown in Figure 16. This fitting combines the mechanical bolt type coupling shown in Figure 9 on one end with the flange connection shown in Figure 10 on the other. This fitting can provide a connection from flange fittings and valves to plain end pipes. The coupling end of this fitting must use a stiffener when used to join PE pipe. Mechanical flange adapters may or may not include a self-restraint to provide restraint against pipe pullout as part of the design. Alternative means of restraint should be used when joining PE pipe if the mechanical flange adapter does not provide restraint. Contact the manufacturer of these fittings for assistance in selecting the appropriate style for the application.

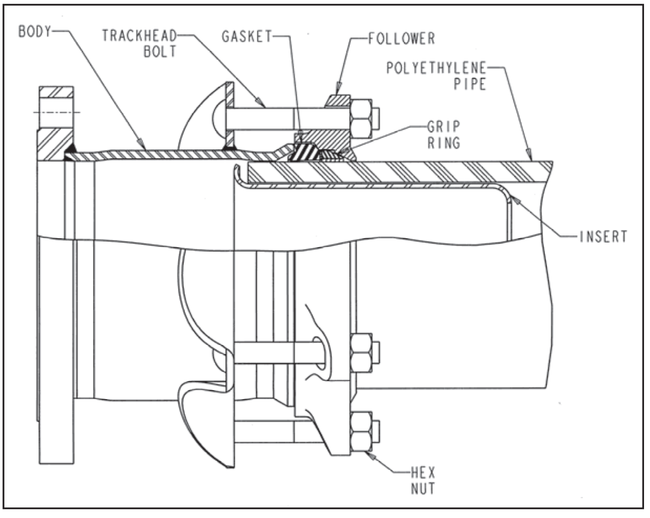

Figure 16 Bolt Type Mechanical Flange Adapter

Solid DI Sleeve Connections to PE pipe

Solid Sleeves are ductile iron fittings designed to connect DI/PVC pipe to other piping materials including PE pipe. They come in a variety of configurations depending on the application. Most solid sleeves have a flange or MJ hub to attach to the PE pipe. On the ductile iron pipe side, a Megalug flange is attached to the pipe and a gasket is installed over the pipe and into the sleeve before bolting the Megalug to the Sleeve flange. A standard PE MJ Adapter kit is used on the PE pipe side to complete the assembly. Be sure to use the manufacturer's recommended bolting procedures for this assembly. (See Figure 17.)

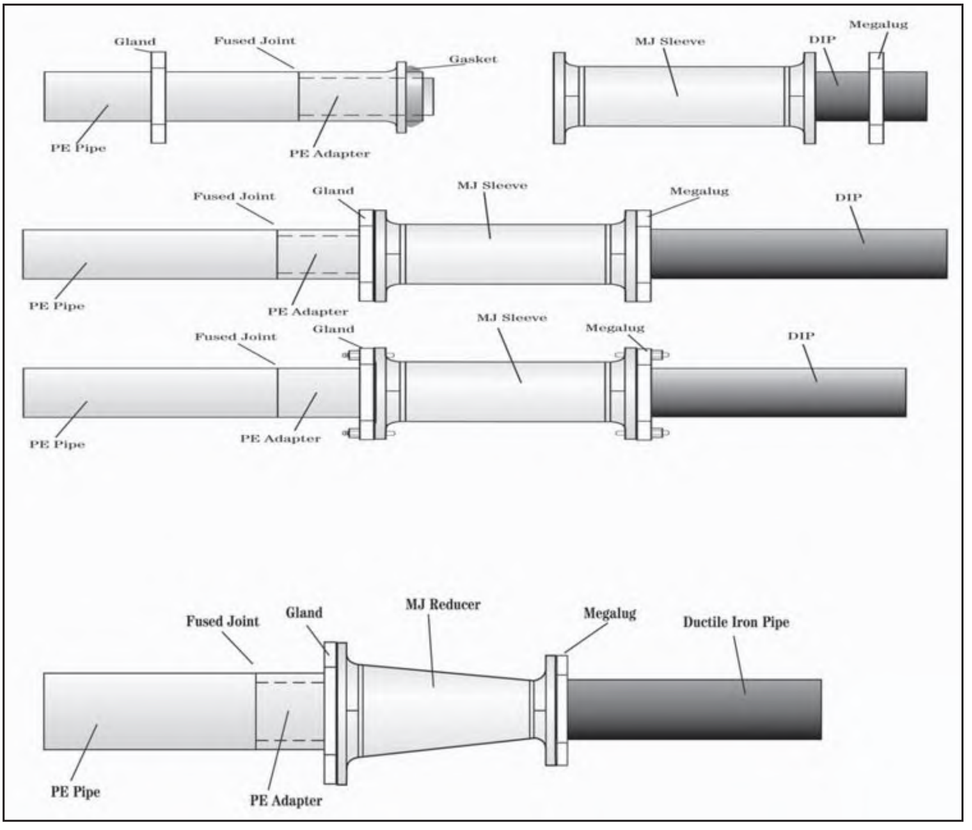

Figure 17 Solid DI Sleeve Connections to PE pipe

Another solid sleeve design is called a "One Bolt" Solid Sleeve and can be used to connect PE pipe to PVC or DI pipe. This is similar to a standard PE mechanical connector but has a special locking ring that grips the PE pipe to prevent pullout. It is recommended to use a stiffener inside the PE pipe, especially if the DR is more than 11. This connection can be installed very quickly in the field and may also be used for repair. Consult with the sleeve manufacturer for application and restraint advice.

Figure 18 One Bolt Solid Sleeve Connection

PE Pipe Connection to DI or PVC Bell End

Another method of restraining the above mentioned connection would be the use of a restraint harness and the attachment of flex restraint sections to the PE pipe. These flex restraint pieces are electro-fused to the PE pipe to achieve the proper stab depth in the PVC or DI bell and the restraint harness plate is attached behind them. The opposite end of the restraint harness is attached behind the DI/PVC hub. Install the PE pipe in the PVC/DI bell until it bottoms out on the flex restraints and tighten the tie rods to prevent the assembly from pulling apart. As discussed above: to maintain proper contact with the seal in the DI/PVC fitting, it is recommended that a stiffener be installed in the PE pipe end.

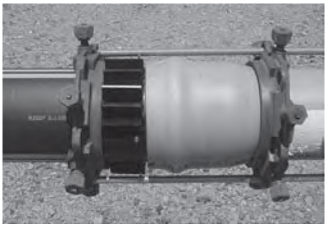

Figure 19 PE Pipe Connection to DI/PVC Bell End Using Flex Restraints on the PE Pipe

PE Bell Adapters to DI or PVC Pipe End

There are PE Bell Adapters available, up to 24" IPS, that are machined to the standard MJ Adapter internal configurations and have an external stainless steel backup ring installed to ensure positive seal contact. This connection incorporates a back-up flange behind the PE Adapter and a Mega-Lug flange on the PVC or DI pipe. Standard MJ seals and bolts are used to connect the assembly.

Figure 20 PE Bell Adapter to DI or PVC Pipe End

DI Valve with PE Ends

In most potable water systems, a valve is installed between the main and the hydrant. This can be fused in line using this special valve assembly with PE pipe installed on each side and available up to 12” pipe size. It has an PE ends installed on each side of the valve.

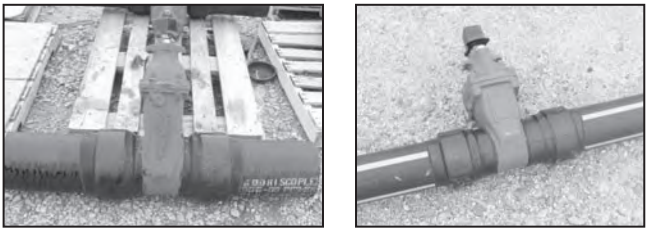

Figure 21 Ductile Iron Gate Valve with PE Ends

Dismantling Joint

Dismantling joints simplify installations and replacement of flanged fittings in retrofitting applications. Dismantling Joints provide the solution for adding, repairing or replacing flanged fittings within a flanged pipe system. In all applications, a restrained dismantling joint is required unless otherwise specified. (See Section titled Restraint Methods.)

Adjustable, slip joint design accommodates either wide gaps or close quarter installations and eliminates the need for precise measurements between flange connections. Available in sizes 2” and larger, for ductile iron or flanged PE piping systems. Standard flanges AWWA C207 Class D Flange. Other flanges are available upon request.

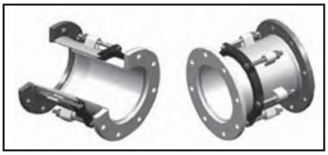

Figure 22 Dismantling Joint

Mechanical Joint (MJ) Adapters

PE pipe can be connected to traditional hydrants, valves and metal pipes using an MJ Adapter. A gland ring is placed behind the adapter before fusing, which can be connected to a standard ANSI/AWWA mechanical joint. When the gland ring is used, restraining devices are not required on the PE pipe.

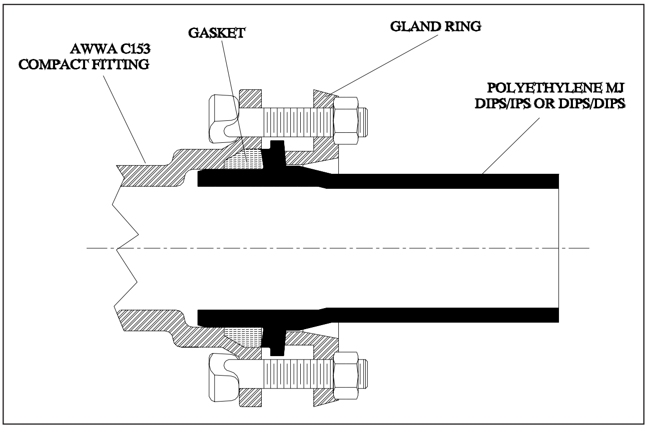

Figure 23 Typical Application of PE MJ Adapter

Transition Fittings

Other methods are available that allow joining of PE to metal. Transition fittings are available which are pre-assembled at the manufacturer's facility. These transition fittings are normally pull-out resistant, seal tight with pressure and have tensile values greater than that of the PE pipe part of a system. However, the user should insist on information from the manufacturer to confirm design capabilities or limitations. Transition fittings are available in all common pipe sizes and PE materials from CTS and larger with a short segment of PE pipe for joining to the PE pipe section. The metal end is available with a bevel for butt welding, with male or female pipe threads, or is grooved for a Victaulic[14] style, or flanged for connecting to an ANSI 150-pound flange.[1]

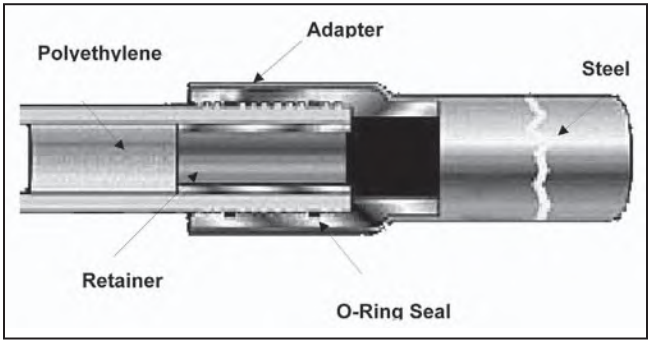

Figure 24 Standard Fitting for PE Pipe to Steel Pipe Transition

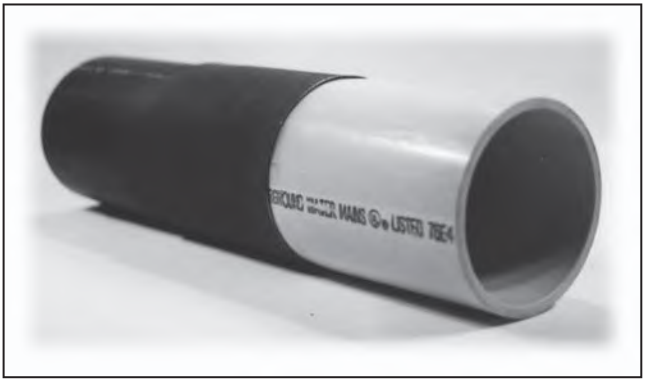

Figure 25 Transition Fitting - PE Pipe to PVC

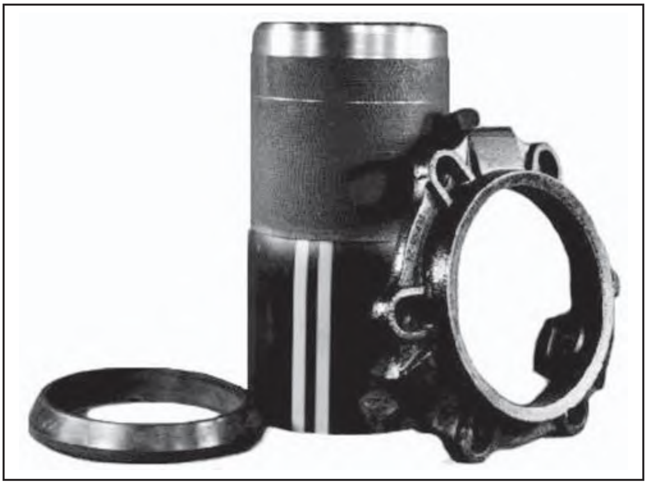

Figure 26 Transition Fitting - PE Pipe to DI with MJ Adapter

Figure 27 Hydrant Swivel Transition Fitting - PE Pipe to DI

Mechanical Joint Saddle Fittings

Mechanical joint saddle fittings have at least one mechanical joint which may connect the outlet to the service or branch pipe, or may connect the fitting base to the main, or both connections may be mechanical joints. Mechanical joint saddle fittings are made from PE, metals, and other materials.

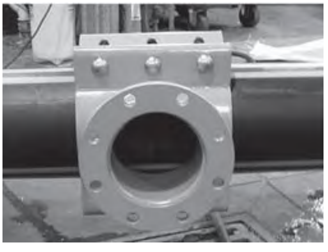

Figure 28 Mechanical Saddle

For mechanical joint outlets, the service or branch pipe is either supported with a tubular stiffener in the pipe ID, or the pipe end is fitted over a spigot (insert) end of the fitting. The outlet joint is completed using mechanical compression around the service or branch pipe OD. Depending upon design, gaskets may or may not be used. Observe the fitting manufacturer's instructions in making the outlet connection.

Plastic outlet pipes must be protected against shear or bending loads by installing protective sleeves or bridging sleeves, or special care must be taken to ensure that embedment materials are properly placed and compacted around the outlet.

The connection between the saddle base and the main may be by hot plate saddle fusion, or by electrofusion, or by mechanical connection. Hot plate saddle fusion and electrofusion have been previously discussed.

Mechanical saddle base connections are clamped or strapped to the side or top of the main pipe. Typically, gaskets or o-rings are used to seal between the saddle base and the main pipe OD surface to prevent leakage when the main wall is tapped. Once secured to the main per the fitting manufacturer's instructions, the main may be pierced to allow flow into the service or branch pipe.

Some mechanical joint saddle fittings can have an internal cutter to pierce the main pipe wall (Fig. 28). "Tapping tees or tapping saddles" (Fig. 29) are generally suitable for installation on a "live" or pressurized main (hot tapping). Branch saddles or service saddles that do not have internal cutters may also be hot tapped using special tapping equipment. Contact equipment manufacturer for information.

Figure 29 PE Tapping Tee with Cutter

Restraint Methods

A pipe section with fully restrained joints such as a long string of butt fused PE pipe will transmit Poisson effect pipe shortening from length to length through the restrained joints along the pipe string. Restrained joints include butt fusions, electro-fusions, socket fusions, bolted flange connections, MJ Adapter connections or other restrained mechanical connections. If an unrestrained bell and spigot or mechanical sleeve joint is in-line with the restrained section, the cumulative Poisson effect shortening and possible thermal expansion/contraction effect may cause in-line unrestrained joints or connections to be pulled apart. Therefore, unrestrained joints or mechanical connections that are in-line with fully restrained PE pipe must be either restrained or otherwise protected against pullout disjoining.

Wall Anchor

A typical pullout prevention technique is to restrain the transition connection by butt fusing a Wall Anchor in the PE pipeline close to the connection and pouring a concrete anchor around it as shown in Figure 30. Refer to the pipe manufacturer's recommendations on anchor size and pull out loads.

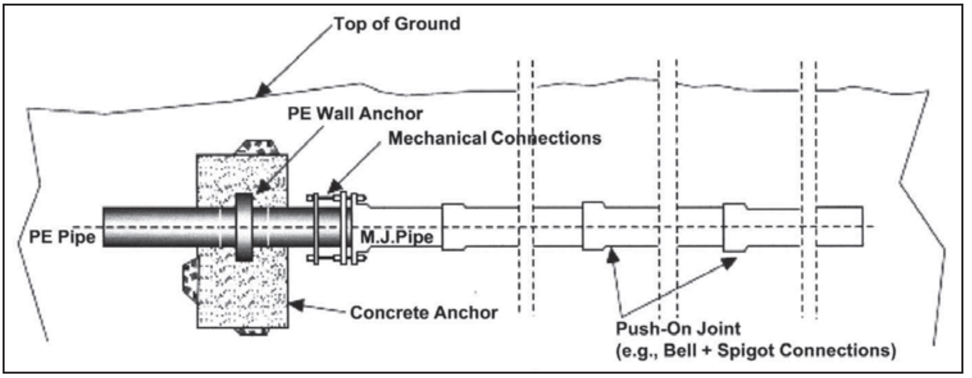

Figure 30 Wall Anchor Diagram

Another method of anchoring this connection is to electro-fuse several Flex Restraints to the PE pipe instead of butt fusing a wall anchor to the line as shown in Figure 31.

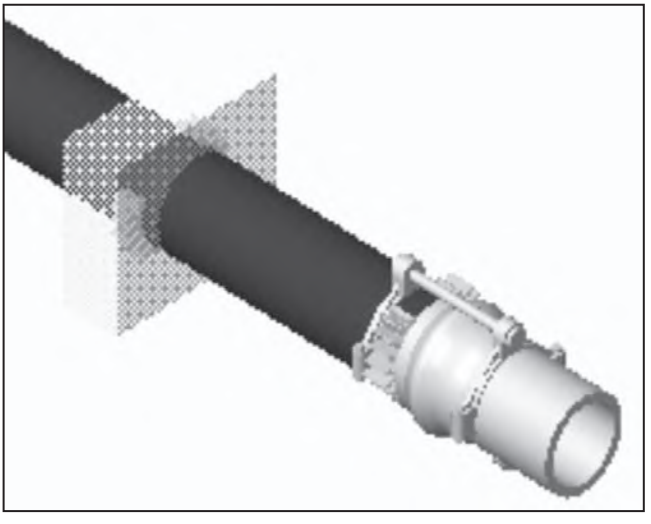

Figure 31 Flex Restraint Anchor

Mechanical Restraint Anchor

A typical pullout prevention technique is to restrain the transition connection and several non-PE bell and spigot joints down line from the transition connection as shown in Figure 32.

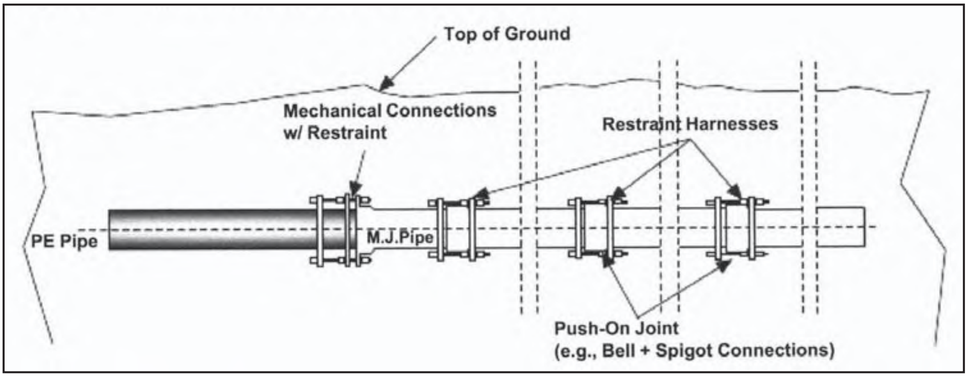

Figure 32 Mechanical Restraint of Existing Pipeline when Attaching to PE Pipe

Buried Poly Anchor

This product is designed to be buried in the soil and resist any linear movement that might occur with PE pipe without pouring a concrete anchor around it. In order to mobilize its buried anchoring restraint action, the Poly-Anchor simply requires at least 85% standard Proctor Density soil compaction in-situ to the top of the plate. Consult with the fitting manufacturer to ensure that the anchor size is adequate for the bearing capacity of the soil.

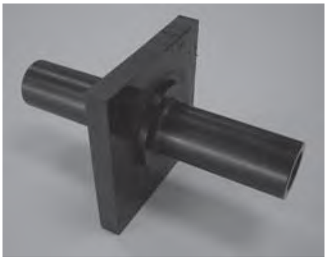

Figure 33 Buried Poly Anchor

Above Ground Pipeline Anchor

The above ground anchor fitting is commonly used to manage PE pipe from thermal expansion and contraction. The fitting is fused into the pipe-line, and a metal band (C-Clamp) is secured over the anchor fitting in the middle, and securely bolted to an I-beam, support bracket, or embedded into a concrete block up-to the spring-line with C-clamp over the pipe crown and bolted to the block . The metal band attaches the pipeline to the anchoring point; the OD rings prevent the pipeline from moving in expansion or contraction in either direction. The width of the center groove can be made as wide as required so as to get sufficient grip on the PE pipe for the thermal excursions expected.

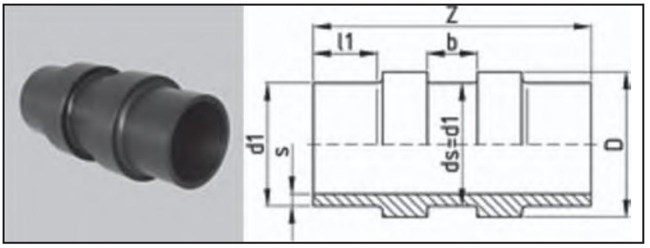

Figure 34 Above Ground Pipeline Anchor

PE to PVC Slip-Joint Anchor Fitting

A gasketed PVC pipe bell to plain end PE pipe should be restrained against PE thermal contraction and pressure thrust, to avoid possible long-term joint separation. The PVC-Bell slip-Joint Anchor Fitting (PVC-SJA Fitting) with internal stiffener to support gasket load, provides the restrained connection from PE pipe to bell-end PVC pipe. (For plain-end PVC, refer to Section titled PE Bell Adapters to DI or PVC Pipe End). When the restraint rings with tie-rod option is specified, the rods and rings are supplied separately from the SJA fitting.

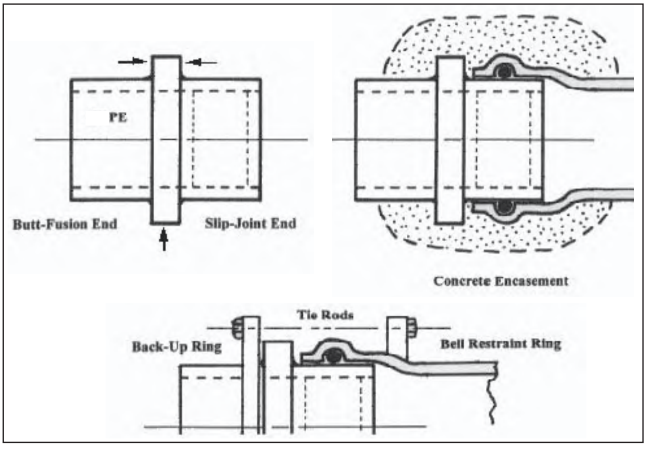

Figure 35 PE to PVC Slip-Joint Anchor Configurations

Summary

The applications for PE piping products continue to expand at an accelerating rate. Gas distribution lines, potable water systems, submerged marine installations, gravity and force main sewer systems, and various types of above-ground exposed piping systems are but a few of the installations for which PE pipe and fittings have been utilized.

As piping products applications expand, so does the use of new and existing joining methods expand.

A key element to this continued success is the diversity of methods available to join PE pipe and fittings. The integrity of the butt and socket fusion joining technique has been proven by the test of time in a variety of applications. The manufacturers of PE pipe and fittings have made every effort to make the systems as comprehensive as possible by producing a variety of fittings and components to insure compatibility with alternate piping materials and system appurtenances.

The purpose of this chapter has been to provide the reader with an overview of the various methods by which PE piping materials may be joined. As a result the reader has developed a further appreciation for the flexibility, integrity, and overall utility afforded in the design, installation, and performance of PE piping systems and components.

It should be noted that this chapter does not purport to address the safety considerations associated with the use of these procedures. Information on safe operating procedures can be obtained from the manufacturers of the various types of joining equipment or PE products.

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Chapter 10

Marine Installations

Introduction

Since the early 1960's, just a few years after its first introduction, polyethylene (PE) piping has been increasingly used for various marine applications such as effluent outfalls, river and lake crossings, and fresh and salt-water intakes. Immunity to galvanic corrosion is a major reason for selecting PE. The combination of air and water, but particularly seawater, can be very corrosive to ordinary metallic piping materials. But other beneficial features, as follows, combine to make PE piping particularly well-suited for marine applications:

Light weight – For a given pipe diameter and equivalent performance requirements, the weight of PE pipe is around one tenth of the weight of concrete pipe and less than one half that of cast iron. Handling of PE requires a minimum of heavy equipment.

It floats – Because PE's density is about 96% of that for fresh water, and about 94% of that for sea water, PE pipe floats even when full of water. Long lengths can be assembled on shore where the empty pipe may be weighted to an extent that allows air-filled pipe to be floated to its intended location, and in most cases, is also sufficiently weighted to keep it anchored at its final submerged location after the air has been replaced with water.

Integral, "bottle-tight" joints – By means of the butt fusion method, continuous lengths of PE pipe can be readily assembled without the need of mechanical fittings. The resultant heat fusion joints are as strong as the pipe, and they eliminate the risk of joint leakage.

Flexibility –The flexibility of PE pipe allows it to be gradually sunk and to adapt to the natural topography of underwater surfaces. This results in a more simplified sinking procedure, and it also means that the flexible pipeline can normally be placed directly on the natural bottom without any trenching or other form of preparation of continuous level support.

Ductility (strainability) – Because of its relatively high strain capacity, PE piping can safely adjust to variable external forces generated by wave and current action. High strain capacity also allows the PE piping to safely shift or bend to accommodate itself to altered bedding that can result by the underscouring that may sometimes occur with strong wave and current actions.

Conventional, non-flexible materials such as concrete or iron pipe can only afford relatively small deformations before risking leakage at, or structural failure of, the joints. As the exact magnitude of the maximum forces that can act on rigid pipes is difficult to predict, installations using piping that only allows relatively small deformation at the joints, or limited bending strain in the pipe, requires a large "safety factor," such as a relatively heavy loading to stabilize the pipe against movement, or the trenching of the pipe into sea bed sediments so as to stabilize it against movement that can result from heavy sea action. Such construction techniques tend to be more difficult, time-consuming and relatively expensive. In contrast, the flexibility and ductility of PE allows it to adapt to unconsolidated river and sea bottoms, and also to safely shift or bend under the forces resulting from occasionally strong currents or other actions. For most marine installations, PE piping needs only to be sufficiently weighted to keep it at the intended location and to prevent it from floating. This results in easier and less costly installations and in a submerged piping system that is capable of delivering very reliable and durable service. By choosing PE pipes, many projects have been accomplished which would not have been economically realistic with traditional piping materials. The lower overall cost of PE piping installations allows for the option of installing several small outfalls rather than one large one. Multiple outfalls can achieve greater environmental protection by the discharging of smaller quantities of effluent at separated points of discharge, and their use often results in lower onshore pretreatment costs.

A marine pipeline installation may involve considerable risk to the pipeline integrity both during installation and while in service. Guidance provided herein on the design and installation of PE piping is limited to those issues that are specific or are related to this material. It is not the intent of this chapter to cover the many other design, construction and safety issues that need to be considered in a marine installation.

The primary focus of this chapter is the design and installation of underwater lines by the "float-and-sink" method that is made possible through the use of the light-in-weight and flexible PE pipe. Under certain conditions – such as when it is not possible to delay navigation long enough to launch and sink a pipeline – it may be necessary, or it may be more practical, to use a variation of the "float-and-sink" method that is herein described. In one variation, one or more separate long-segments of the pipeline with a flange at each end are assembled and floated. These segments are then sunk, properly positioned and bolted together by divers. Another alternative method is the "bottom-pull" method, which is briefly described at the end of Step 8. However, regardless of which method is used, the general design and installation principles that apply to the "float-and-sink" method also apply to alternate methods.

Other marine applications for which PE piping has proven to be very suitable include temporary water surface pipelines, lines installed over marshy soils and lines used in dredging operations. These are described briefly. Design and installation for these marine applications are conducted in accordance with essentially the same criteria and principles as described for the "float-and-sink" method.

The Float-and-Sink Method – Basic Design and Installation Steps

In nearly all underwater applications, the design and installation of PE piping is comprised of the following basic steps:

1. Selection of an appropriate pipe diameter
2. Selection of an appropriate pipe SDR (i.e., an appropriate wall thickness) in consideration of the anticipated installation and operating conditions
3. Selection of the design, weight and frequency of spacing of the ballast weights that will be used to sink and then hold the pipe in its intended location
4. Selection of an appropriate site for staging, joining and launching the pipe

5. Preparing the land-to-water transition zone and, when required, the underwater bedding
6. Assembly of the individual lengths of pipe into a continuous string of pipe
7. Mounting of the ballast weights (This step may be done in conjunction with the next step.)
8. Launching the joined pipe into the water
9. Submersion of the pipeline into the specified location
10. Completion of the land-to-water transition

General guidance for the conduct of each of these steps follows. Since the specific conduct of each step can be affected by the choice of design and installation options discussed in other steps, the reader should review the entire chapter before deciding on the most applicable design and installation program.

Step 1 Selection of an Appropriate Pipe Diameter

Selection of an appropriate pipe diameter involves the estimation of the minimum flow diameter that is needed to achieve the design discharge rate. Guidance for doing this is provided in Chapter 6 of this Handbook.

A confirmation is then performed after the required pipe dimension ratio (DR) is determined in accordance with Step 2 which follows. Since the actual internal diameter of a pipe that is made to a standard outside diameter is dependent on the choice of pipe DR (see Table in the Appendix A.1 and A.2 in Chapter 6), the nominal pipe diameter/DR combination that is finally selected needs to have an actual inside diameter that is at least as large as the above determined minimum required flow diameter.

Step 2 Determination of the Required DR or SDR

The DR of the PE pipe, in combination with the pipe material's assigned maximum hydrostatic design stress, should allow the pipe to operate safely at the maximum anticipated sustained net internal pressure at the maximum anticipated operating temperature. Information, including temperature and environmental de-rating factors, for determining the appropriate pipe DR is presented in Chapter 6 and in Appendix, Chapter 3 of this Handbook. As an added "safety factor" it is common practice to pressure rate the pipe for the maximum anticipated operating temperature of either the internal or external environment, whichever is higher.

A check should be made to ensure that the selected pipe pressure rating is also sufficient to safely withstand any momentary pressure surges above normal operating pressure. Pressure surges tend to occur during pump start-ups or shut-downs, and also during sudden pump stops caused by emergencies, such as loss of power. Guidance for selecting a PE pipe with sufficient surge pressure strength is also presented in Chapter 6 of this Handbook.

A sudden pump stop can sometimes also result in flow separation, giving rise to a momentary reduction in pressure along some portion of the pipeline. Since underwater pipelines can be subject to relatively large external hydrostatic pressure, flow separation can sometimes lead to a significant net negative internal pressure. A check needs to be made to ensure that the pipe DR that has been selected based on maximum internal pressure considerations is also adequate to safely resist buckling, or pipe collapse, under the largest net negative internal pressure that could ever develop from whatever cause. Guidance for this design check is also provided in Chapter 6 of this Handbook. The ballast weights that are attached to PE pipe for purposes of its submersion also fulfill an important role as ring stiffeners that tend to enhance a pipe's inherent resistance to buckling. Common design practice is to accept this benefit as an added "safety factor," but not to directly consider it in the design procedure for selection of a pipe of appropriate ring stiffness.

Step 3 Determination of the Required Weighting, and of the Design and the Spacing of Ballast Weights

The determination of these parameters is made in accordance with the following sub-steps.

Step 3a Maximum Weighting that Allows Weighted Pipe to be Floated into Place

The buoyant or vertical lift force exerted by a submerged PE pipe is equal to the sum of the weight of the pipe and its contents minus the weight of the water that the pipe displaces. This relationship can be expressed mathematically as follows:

(1) $$F_B = [W_P + W_C] - W_{DW}$$

WHERE

F_B **= buoyant force, lbs/foot of pipe**

W_P **= weight of pipe, lbs/foot of pipe**

W_C **= weight of pipe contents, lbs/foot of pipe**

W_{DW} **= weight of water displaced by pipe, lbs/foot of pipe**

Since the density of PE (~59.6 lbs/cubic foot) is only slightly lower than that of fresh water (~62.3 lbs/cubic foot) the pipe contributes somewhat towards net buoyancy. However, the major lift force comes from the air-filled inner volume of the pipe. Since, for a pipe of given outside diameter, the size of the inner volume is determined by the pipe's wall thickness – the greater the thickness, the smaller the inner volume – and since a pipe's actual wall thickness can be expressed in terms of the pipe's diameter ratio (DR), Equation 1 can be rearranged as shown in Equation 2. The resultant net buoyancy force can be determined from the pipe's actual outside diameter, its DR (or SDR), the extent to which the pipe is filled with air, the density of the water into which the pipe is submerged, and the densities of the pipe and of the liquid inside the pipe:

(2)

$$F_B = \left[0.00545 D_o^2 \rho_w\right]\left[4.24\frac{(DR-1.06)}{(DR)^2}\frac{\rho_p}{\rho_w} + \left(1-\frac{2.12}{DR}\right)^2 (1-R)\frac{\rho_c}{\rho_w} - 1\right]$$

WHERE

F_B **= buoyant force, lbs/foot of pipe**

D_o **= external diameter of pipe, in**

D_R **= pipe dimension ratio, dimensionless**

R **= fraction of inner pipe volume occupied by air**

ρ_w **= density of the water outside the PE pipe, lbs/cu. ft**

ρ_p **= density of the pipe material, lbs/ cu. ft.**

ρ_c **= density of pipe contents, lbs/ cu. ft.**

The derivation of Equation 2 is presented in Appendix A-1. The reader is advised that Equation 2 does not consider lift forces that can result from water currents; refer to Appendix A-2 for further assistance with this topic.

A more succinct way of expressing the principle embodied in Equation 2 is as follows:

(3) $F_B = W_{DW}$ ["K"]

WHERE

W_{DW} **= 0.00545** $D^2_0\rho_w$

Stated in words, the resultant buoyant force (F_B) is equal to the potential theoretical buoyant force (W_{DW}) times a buoyancy reduction factor ("K") that takes into account inner pipe volume, degree of air filling and the densities of the pipe and the liquid inside the pipe.

The manner by which the buoyancy reduction factor "K" is affected by a pipe's DR and the extent to which its inner pipe volume is filled with air, R, is indicated by the calculation results reported in Table 1. The values in this table have been computed based on the following densities: 62.3 lbs/ cu. ft for water both inside and outside the pipe, and 59.6 lbs/cu. ft for the PE pipe material. Using these K-values for approximation of the net buoyant force of a submerged pipeline in which a portion of the line is occupied by air greatly simplifies the calculations involved.

TABLE 1
Typical values of "K" in equation 3.0

"K" is the fraction of maximum potential buoyancy. The exact value of "K" is determined by the particular combination of pipe diameter ratio (SDR), pipe material and liquid densities and the extent (R) to which a PE pipe is filled with air*

Pipe SDR	Value of "K" as a function of R, the fraction of inner pipe volume that is occupied by air					
	R = 0.10	R = 0.15	R = 0.20	R = 0.25	R = 0.30	R =1.0 (100% Air)
9	-0.078	-0.107	-0.136	-0.166	-0.195	-0.604
11	-0.081	-0.113	-0.146	-0.178	-0.211	-0.667
13.5	-0.084	-0.119	-0.155	-0.190	-0.226	-0.723
17	-0.087	-0.125	-0.163	-0.202	-0.240	-0.776
21	-0.089	-0.130	-0.170	-0.210	-0.251	-0.817
26	-0.091	-0.133	-0.176	-0.218	-0.260	-0.850
32.5	-0.093	-0.137	-0.180	-0.224	-0.268	-0.879

* The "K" values in this table have been computed using Equation 2 and based on the following assumptions: a density of 62.3 lbs/cu ft for water outside and inside the pipe and 59.6 lbs/cu ft for the PE pipe material. The minus sign before each resultant value of "K" indicates a net upward, or buoyant force.

Step 3b Determining the Maximum Weighting That Still Allows PE Pipe To Float

When a PE pipe that is completely filled with air is weighted so that the submerged weighting is equal to W_{DW} (the weight of the water that is displaced by the outer volume of the pipe) times the appropriate value of "K" (e.g., the value given in the last column of Table 1), that pipe achieves neutral buoyancy – it neither sinks nor floats. Therefore, "K" represents the fraction of pipe displacement that, when counteracted by the placement of external weighting on the pipe, results in neutral buoyancy. With the objective in mind of facilitating a marine installation by the floating of a PE pipe so that it may readily be stored above water and then towed and maneuvered to its intended location, the weighting that is attached to the pipe needs to be limited to an amount that still allows an air-filled pipe to freely float on top of the water. To this end, the practice is to limit the weighting of an air-filled PE pipe to about 85% of the pipe displacement times the "K" value that corresponds to that pipe's DR and the densities of the pipe material and the water, for example, the "K" values reported in the last column of Table 1. This practice results in the limiting of the weighting of an air-filled pipe that is to be installed by the "float-and-sink" method to a maximum that can vary, depending on the pipe's DR, from about 57 to 75% of the pipe's displacement.

Step 3c Determining the Required Minimum Weighting for the Anchoring of a Submerged Pipe in its Intended Location

Fortunately, as indicated by analysis and confirmed by experience[1,2], in most cases a weighting of 25 to 50% of the pipe displacement is quite sufficient to maintain a properly anchored submerged PE pipe after it has been filled with water. The lower weighting has been found satisfactory in cases, like in lake crossings, where current and wave action are relatively mild, while the larger weighting is used in sea installations where sea actions are stronger. However, even for pipes that are exposed to normal sea conditions close to the shore, it has been found that a weighting of about 70% of the pipe displacement is quite satisfactory[1]. As indicated by the values shown in Table 1, this extent of weighting still allows most PE pipes to float when air-filled.

In an article summarizing the state of the art in utilizing plastics pipe for submarine outfalls, Janson[3] reports that, based on past practical experience and theoretical studies, a 40-inch diameter PE ocean outfall line was installed in Sweden where, for depths greater than 40 feet, the pipe was weighted to 25% of its displacement; and in the surf zone, where the waves break and the water depth is about 10 feet, the loading was increased to 60% of the displacement. Closer to the shore, where wave action is at its strongest, it is common to protect the pipe by trenching it. In respect to trenched pipe, Janson also reports that, when a trench is refilled with fine-grained soil, the buried pipe can sometimes float from the trench, apparently a reaction resulting from the fluidization of the fill by strong wave action. This reference further reports that the possibility of floating from fine-grained backfill can be avoided by weighting the pipe to at least 40% of its displacement.

Calculation techniques have been developed for the determination of the required weighting of plastic pipes depending on anticipated current and wave action. A brief overview of the technical considerations upon which these calculations are based is included in Appendix A-2. References for further information are also provided.

In cases where it is indicated that the pipeline, or certain sections of the line, should be weighted to a greater extent than that which allows the pipe to float while filled with air, the attachment of the required ballast weights can be conducted in two stages: preliminary weighting is conducted so as to still allow the pipe to be floated into position, and then the additional required weights are added where required after the completion of the submerging of the pipe. Another option is to temporarily increase the pipe's buoyancy by the use of empty tanks or drums, or large blocks of rigid plastic foamed material that are then released as the pipe is being submerged. A further option, which is illustrated in Figure 1, is to attach the required ballast weights onto the pipe from a barge from which the pipe is slid to the bottom by means of a sled that has been designed to ensure that the bending of the pipe is less than that which might risk buckling (See the discussion on pipe submersion).

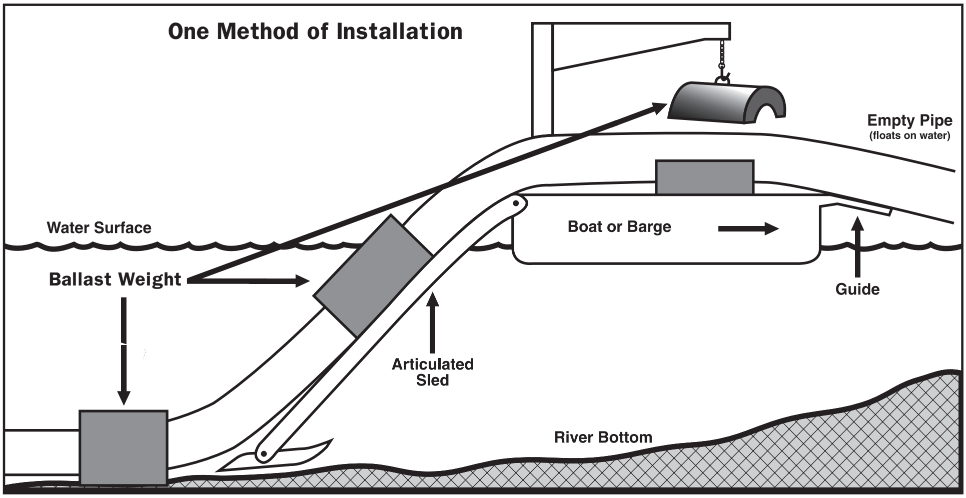

Figure 1 Submerging a heavily weighted pipe from a barge

Step 3d Ensuring that the Required Weighting Shall Not Be Compromised by Air Entrapment

As suggested by the "K" values in Table 1 that apply to pipes that are partially filled with air, even a modest amount of air entrapment can result in a lift force that can significantly reduce the quality of pipe anchorage. For example, if a pipeline is weighted to 25% of the water it displaces and in a section of that pipeline enough air accumulates to occupy just 10% of the pipe's inner volume, the lift produced by that amount of air will reduce the effective weighting in that portion of the pipeline to about only 15% of the pipe displacement. Such reduction is sure to compromise the stability of that pipe section against wave and current actions. Accordingly, one important objective in the design of the piping system to prevent the entrance and accumulation of air in all portions of the submerged section. In outfall systems, one effective means for achieving this objective is to utilize a surge or "drop" chamber into the system design, as illustrated in Figure 2. Another precautionary measure is to ensure that there are no localized high points along the submerged pipeline that could accumulate air or gases, particularly during periods of low or no flow rate.

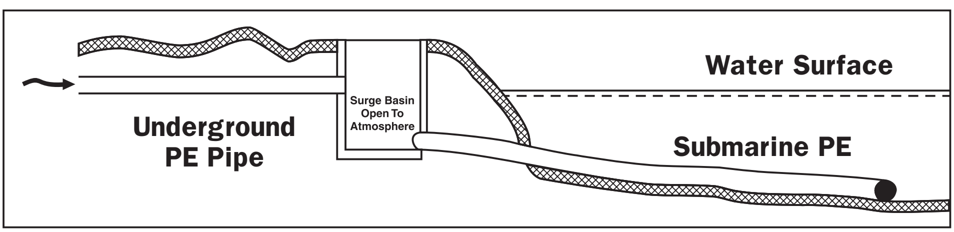

Figure 2 A surge chamber may be used to prevent air from entering a pipeline

In cases where the possibility of some accumulation of air or gas – which may be given off by chemical reactions – cannot be avoided, or where the line may at some time be emptied, it is necessary to add enough ballast weighting to offset the additional negative buoyancy so as to always hold the pipe in its intended location.

Step 3e Determining the Spacing and the Submerged Weight of the Ballasts To Be Attached to the Pipe

The objectives for limiting the spacing between ballast weights are essentially the same as those for establishing the support spacing requirements for above-ground suspended pipelines. In both cases the pipes are subject to a distributed loading – in the case of submerged pipelines, by the combined effect of current, lift and wave actions. The objective of the design is to limit resultant pipe deflection so that the resultant maximum fiber bending stresses and strains are within safe limits. An additional reason for limiting deflection in submerged pipelines is to reduce the chances of forming pockets in which air or gas can accumulate. The lift created by air-filled pockets can, if large enough, compromise the quality of the anchoring of the submerged pipe. Information on conducting the required calculations and on the appropriate limiting values for bending stress and strain is included in the chapter on design. Because of the concern of trapping air, support spacing for submerged pipes is normally delimited by allowable pipe deflection – considerably greater deflection would generally be permitted under the criteria of maximum bending stress or strain.

Listed in Table 2 are commonly used ballast spacings. To satisfy the objective for minimizing air entrapment, the spans in this table are somewhat shorter than for pipes that are suspended above ground. An added benefit of shorter spans is that they better distribute anchoring loads on the sea bottom, which often offers only moderate load bearing capacity. Additionally, these shorter spans minimize the chance of pipe shifting, help smooth out the submersion process and they lead to ballasts that are more manageable both in size and in weight.

TABLE 2
Commonly Used Values for the Spacing of Ballasts

Nominal Pipe Diameter, in	Approximate Spacing (L), ft
Up to 12	5 to 10
Over 12, up to 24	7.5 to 15
Over 24, up to 63	10 to 20

Source: AWWA M55, PE Pipe – Design and Installation, Chp 8: Installation, Denver, Colorado, USA

The required submerged weight of the ballasts can be determined from the following:

(4) $$B_W = W_S \times L$$

WHERE

B_W **= weight of ballast in water, lbs**

W_s **= required submerged weighting by ballasts, lbs per foot**

L **= center to center spacing between ballasts, feet**

The resultant dry weight of the ballast depends on the density of the ballast material as compared to that of the water into which the ballast is to be submerged:

(5) $$B_A = B_W \frac{\rho_B}{(\rho_B - \rho_W)}$$

WHERE

B_A **= weight of ballast in air, lbs**

ρ_B **= density of ballast, lbs/cu. ft (~144 lbs/cu ft for plain concrete, ~ 150 for reinforced)**

ρ_W **= density of water, lbs/ cu ft (~62.3 lbs/cu ft for fresh water, ~64.0 lbs/cu ft for sea water)**

Since the weight of a ballast cannot be closely predicted or readily adjusted, it is more practical to tune in the final weighting to the required value by adjusting the distance between ballasts of known weight. To this end the following formula, derived by combining Equations 4 and 5, may be used:

(6) $$L = \frac{B_A}{W_S} \frac{(\rho_B - \rho_W)}{\rho_B}$$

Step 3f Design and Construction of Ballast Weights

To prevent cracking of ballasts when handling, tightening and moving PE pipe, they are typically made of suitably reinforced concrete. Ballasts can be made to different shapes, although a symmetrical design such as round, square, or hexagonal is preferred to avoid twisting during submersion. Flat-bottomed ballasts are preferred if the submerged piping is likely to be subjected to significant currents, tides or wave forces because they help prevent torsional movement of the pipe.

Also, when such conditions are likely to occur, the ballasts should place the pipeline at a distance of at least one-quarter of the pipe diameter above the sea or river bed. The lifting force caused by rapid water movement that is at a right angle to a pipe that rests on, or is close to a sea or river-bed is significantly greater than that which acts on a pipe that is placed at a greater distance from the bed. This means that ballasts designed to give an open space between the pipe and the bed will give rise to smaller lifting forces.

For example, in accordance with the calculation procedure developed by Janson (See Appendix A-2), the lifting force that develops on a 12-in PE pipe that is resting directly on a sea bed and that is at an angle of 60° to the direction of a strong current that is flowing at a rate of about 10 feet per second is approximately 100 lbs per foot. When this pipe is raised above the sea bed so that the space between the bottom of the pipe and the sea bed is one-quarter of the pipe's outside diameter, the lifting force is reduced to about 25 lbs per foot.

The ballasts should comprise a top and bottom section that, when mated together over a minimum gap between the two halves, the resultant inside diameter is slightly larger than the outside diameter of the pipe. This slightly larger inside diameter is to allow the placement of a cushioning interlining to protect the softer PE pipe from being damaged by the hard ballast material. Another function of the interlining is to provide frictional resistance that will help prevent the ballasts from sliding along the pipe during the submersion process. Accordingly, slippery interlining material such as polyethylene film or sheeting should not be used. Some suggested interlining materials include several wraps of approximately 1/8-in thick rubber sheet or approximately ¼-in thick neoprene sponge sheet.

The purpose of the minimum gap between the two halves of the ballasts is to allow the two halves to be tightened over the pipe so as to effect a slight decrease in pipe diameter and thereby enhance the hold of the ballast on the pipe.

Additionally, experience has shown that in certain marine applications where tidal or current activity may be significant, it is feasible for the pipe to "roll" or "twist". This influence combined with the mass of the individual ballasts may lead to a substantial torsional influence on the pipe. For these types of installations, an asymmetric ballast design in which the bottom portion of the ballast is heavier than the upper portion of the ballast is recommended. Typical design considerations for this type of ballast are shown in Appendix A-3.

Suitable lifting lugs should be included in the top and bottom sections of the ballasts. The lugs and the tightening hardware should be corrosion resistant. Stainless steel strapping or corrosion-resistant bolting is most commonly used. Bolting is preferable for pipes larger than 8-in in diameter because it allows for post-tightening prior to submersion to offset any loosening of the gripping force that may result from stress-relaxation of the pipe material.

Examples of various successfully used ballast designs are shown in Appendix A-3.

Figure 3 Two-piece Concrete Anchors in Storage at Marine Job-Site

Step 4 Selection of an Appropriate Site for Staging, Joining and Launching the Pipe

The site for staging, joining and launching the pipe should preferably be on land adjacent to the body of water in which the pipeline is to be installed and near the point at which the pipe is to enter the water. Also, the site should be accessible to land delivery vehicles. If these requirements are not easily met, the pipe may be staged, joined and weighted at another more accessible location and then floated to the installation site. Long lengths of larger diameter PE pipe have been towed over substantial distances. However, considerable precautions should be exercised for insuring the stability of the towed materials in light of marine traffic, prevailing currents or impending weather considerations.

To facilitate proper alignment of the pipe-ends in the fusion machine and to leave enough room for the attachment of the ballast weights, the site near the water should be relatively flat. It is best to allow a minimum of two pipe lengths between the fusion joining machine and the water's edge. The site should also allow the pipe to be stockpiled conveniently close to the joining machine.

The ground or other surface over which the pipe is to be moved to the water should be relatively smooth and free of rocks, debris or other material that may damage the pipe or interfere with its proper launching. When launching a pipe with ballast weights already attached, provision should be made for a ramp or a rail skidway arrangement to allow the ballasts to move easily into the water without hanging up on the ground. As elaborated under the launching step, the end of a pipe that is moved into the water needs to be sealed to prevent water from entering and, thereby, compromising its capacity to float freely.

Step 5 Preparing the Land-to-Water Transition Zone and, When Required, the Underwater Bedding

At some point in time before the start of the submersion procedure, usually before the pipe is launched, a trench needs to be prepared in which to place the pipe between the point where it leaves the shore and the first underwater location beyond which the pipe is completely submerged without the need for external protection. The trench needs to be deep and long enough to protect the pipe from wave action, tidal scour, drifting ice and boat traffic. Special care should be employed in the design and construction of the land-to-water transition in ocean outfalls where occasional rough seas can result in very strong waves and in the scouring of the material below and around the pipe.

Unless weighted to a relatively high extent, say to at least 40% of the pipe displacement, a pipe lying in a land-to-water transition trench that has been filled with fine silt or sand could float up when that zone is subjected to strong wave action. One method of controlling this tendency would be to utilize increased weighting via enhanced ballast design. Alternatively, the submerged pipe could be placed on a bed of prepared backfill and subsequently surrounded by graded material in accordance with ASTM D2774, Standard Practice for Underground Installation of Thermoplastic Pressure Pipe. This ASTM standard provides that plastic pipe installed underground will be bedded and backfilled using material with a particle size in the range of ½" to 1 ½" depending on the outside pipe diameter. However, it may be necessary to place a layer of even larger particle sized fill (1 ½" to 4") over the graded material to avoid movement of the stone backfill in some tidal zones or areas of strong current activity. Protection and stabilization of the pipe installation may be further enhanced by the placement of a 1 to 2 foot cover of blast rock over the completed installation.

With regard to the preparation of the underwater support generally, no dredging of filling needs to be carried out because the ballasts act to keep the pipe above the bottom material. The principal requirement is that the pipe should not rest or come in contact with large stones. To this end, larger stones that project above the bottom and that could come in contact with the pipe should be removed, as well as those that lie within about 3 pipe diameters on either side of the pipe.

Step 6 Assembly of Individual Lengths of PE Pipe Into Long Continuous Lengths

The butt fusion of individual lengths into a long string of pipe should be conducted by trained personnel and by means of appropriate equipment. The heat fusion parameters – e.g., temperature, interfacial pressure, heating and cooling times – should be as recommended by the pipe manufacturer for the particular pipe material and the joining conditions, including outdoor temperature and wind. (See Chapter 9 on PE Joining Procedures.)

Upon the completion of the heat fusing of an added individual length to the pipeline, the resultant longer pipe string is further moved into the water. As discussed elsewhere, the pipe should always be moved to the water using suitable mechanical equipment that will cause no damage to the pipe or to the pipe ends.

Ballast weights can be mounted before the pipe string reaches the water. If circumstances make it more practical, the ballasts can also be attached on the floating pipe from a floating barge by a scheme such as illustrated in Figure 4.

Step 7 Mounting the Ballasts on the Pipe

Since the process of heat fusing a new pipe section on a string of pipe usually takes less time than the attaching of ballasts, the later procedure can be quickened by increasing the number of work stations. It is also helpful to stockpile the ballasts adjacent to each work station. Adequate lift equipment needs to be on hand to move the ballasts from the stockpile to the pipe location and to lift the pipe to allow the ballasts to be positioned under it. This equipment can also be used to lift and pull the pipe into the water. A suitable ramp or skidway should be provided to move weighted pipe into the water with a minimum of drag. (See discussion on launching the pipeline.)

For mounting ballasts on the floating pipe it is necessary to have low-profile equipment such as a barge or raft that is of sufficient size to accommodate the required lifting equipment and to carry sufficient ballasts to allow for efficient operation. In this method the barge is brought alongside the floating pipe, the pipe is lifted to install one or more ballasts, and after their installation the pipe is returned to the water and a new section is moved onto the barge or the barge is advanced along the floating string of pipe. In either case, the working surface or platform of
the barge should be as close as possible to the water to reduce the need for a high lifting of the weighted pipe.

The steps involved in the mounting of ballasts include the following:

1. The placing of the protective/friction inducing material around the pipe. This can be done by first placing a pad over the lower half of the ballast and then placing a similar pad over the top of the pipe before the upper half of the ballast is lowered into position.

2. Lifting the pipe and positioning the lower half of the ballast under the pipe

3. Lowering the pipe so that it sits in the lower half of the ballast

4. Positioning and then lowering the upper half of the ballast so it sits on top of the pipe
5. Applying the strapping or tightening the bolts so that the ballasts are held fast to the pipe. (Note: before submersion, retightening of the bolts may be necessary to overcome any loss of gripping that may result from the stress-relaxation effect).

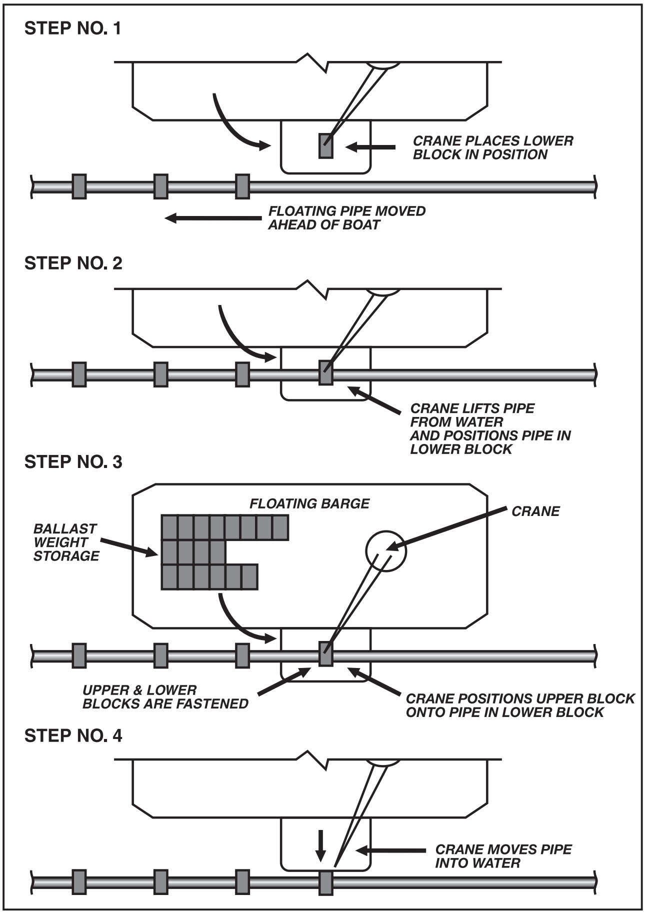

Figure 4 Installation of ballast weights from a raft or barge

Step 8 Launching the Pipeline into the Water

As previously cautioned, pipe that is launched into the water needs to have its ends closed, or its outlets located sufficiently high above the water, to prevent any water from entering the pipe. When the pipe is launched in the form of shorter strings of pipe that will later be joined to each other to produce the required overall length of submerged pipe, each separate section needs to have both ends sealed to prevent water from entering. In this respect, effluent outfall lines require special consideration.

Effluent outfalls usually terminate in one or more diffuser sections. Diffusers can be of different designs such as a "Y" or "T" outlet, a pipe length in which holes have been drilled on top of the pipe within 10 and 2 o'clock, or a pipe length onto which vertical risers consisting of short sections of smaller diameter PE pipe have been fused. Diffusers are often designed for connection to the pipe by means of flange assemblies. The connection can be made prior to launching, or by divers after the pipeline has been submerged. When a diffuser is attached prior to launching, it is necessary to float the diffuser higher up over the water by means of some additional buoyancy. This is necessary to prevent water from entering the pipe through the diffuser openings. This additional buoyancy is released as the pipe is sunk into position.

Extreme care should be taken in the submersion of a marine line with an engineered diffuser attached to the pipeline which is being sunk in place. The sinking process can create considerable stresses on the fittings that may be inherent to the design of the diffuser itself such as flanges, tees and/or other mechanical connections. A preferred method when placing a highly engineered diffuser into an HDPE marine pipeline is to first sink the flanged effluent pipe and then submerge the diffuser separately in easily controlled segments which may be connected to the main effluent pipe underwater using qualified diving contractors.

A pipe end that does not terminate in a diffuser section is best closed against entering water by attaching a blind flange assembly. The flange assembly consists of a PE stub end that is butt fused to the pipe end on which has been bolted a slip-on metal flange. A number of required tapped holes are drilled on the blind flange so as to allow for the installation of valves and other fittings required to control the sinking operation. (See the section on submersion of the pipeline.)

Figure 5 Unballasted PE Pipeline Being Floated Out to Marine Construction Barge Where Ballast Weights are Installed

Pipe with attached ballast weights should be moved into the water by means of a ramp or skidway arrangement that allows the ballasts to move easily into the water without hanging up on the ground. The ramp or skidway must extend sufficiently into the water so that when the pipe leaves this device the ballast weight is fully supported by the floating pipe. Pipe without ballast weights may be moved over the ground provided it is free of rocks, debris or any other material that may damage the pipe. When this is not practical, wooden dunnage or wooden rollers may be placed between the pipe and the ground surface.

The pipe should be moved using suitable equipment. The pipe may be moved by lifting and then pulling it using one piece of equipment while using another piece of equipment to simultaneously push the pipe from its inboard end. PE pipe should only be lifted using wide-band nylon slings, spreader slings with rope or band slings, or any other means that avoids the development of concentrated point loading. Under no conditions should the flange assemblies be used to pull the pipe.

Prior to the launching of the pipe into the water, a strategy should be worked out to control the floating pipeline as it moves into the water and to store it away from navigational traffic until such time as the entire length is ready for submerging. For this purpose, suitable marine equipment – such as boats that have adequate tugging power and maneuverability – may need to be on hand. Other means for controlling the pipe can be a system of heavy block anchors that are positioned on either side of the proposed site into which the pipe will be submerged. In the case of river crossings, a system of guide cables that are anchored on the opposite shore can serve to control the position of the pipeline, particularly when the pipeline is subject to strong river flow.

In the case of river crossings when navigational traffic prohibits the float-and sink procedure, a “bottom-pull” procedure, illustrated in Figure 6, has been successfully used. When using this procedure, only sufficient ballast is added to the pipe to ensure that the pipe follows the river bottom as it is winched from one shore to the other. After the completion of the “bottom-pull,” additional ballast can be added or the pipeline can be adequately backfilled to produce the required anchoring and to offset any lift that may be created by currents or river flow.

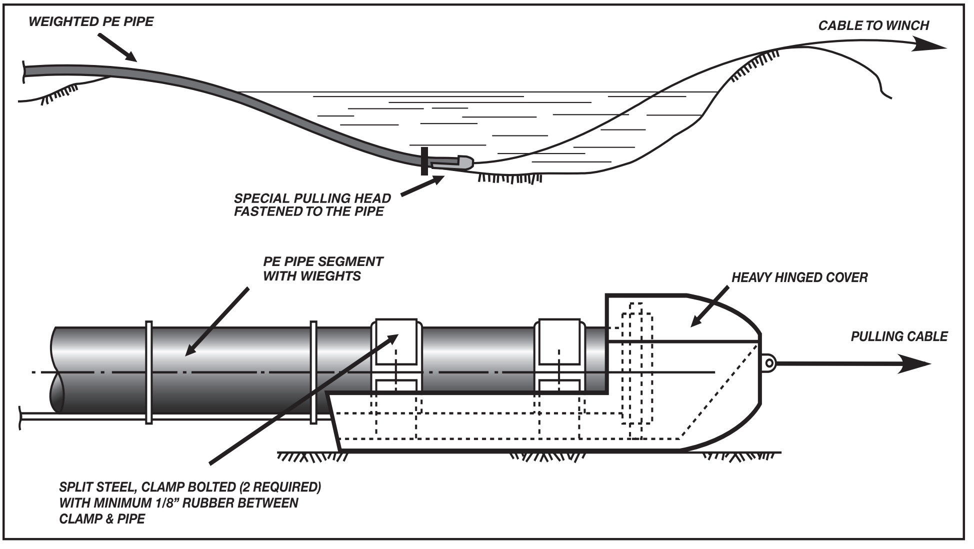

Figure 6 “Bottom-Pull” Installation of PE Pipe

Step 9 Submersion of the Pipeline Using the Float-and-Sink Method

To prepare the pipe for submersion, it is first accurately positioned over its intended location. The sinking operation basically consists of the controlled addition of water from the on-shore end of the pipe and the release of the entrapped air from the opposite end. The sinking is conducted so that it starts at the shore where the pipe enters the body of water and then gradually progresses into deeper waters. To achieve this, an air pocket is induced by lifting the floating pipe close to the shore. As the water is allowed to enter the pipe from the shore side, the added weight causes this initial air pocket to move outward and the intermediate section of pipe between the air pocket and the shore end to sink. As additional water is added, this pocket moves to deeper waters causing the sinking to progress to its terminal point in the body of water. This controlled rate of submersion minimizes pipe bending and it allows the pipeline to adjust and conform to the bottom profile so that it is evenly supported along its entire length (See Figure 7).

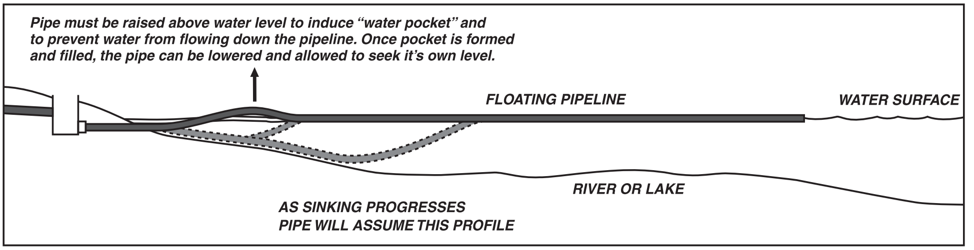

Figure 7 An induced water pocket initiates the submersion of the pipe and, as the pocket enlarges, it allows the submerging to gradually progress forward

A potential risk during the submersion operation is that, when the pipe sinking occurs too quickly, the bending of the pipe between the water-filled and air-filled portions may be sharp enough to risk the development of a kink, a form of localized pipe buckling. As a pipe is bent, its circumferential cross-section at the point of bending becomes increasingly ovalized. This ovalization reduces the pipe's bending moment of inertia, thus decreasing the bending force. Upon sufficient ovalization, a hinge or kink can form at the point of maximum bending an event that also leads to a sudden reduction of the bending force. Since the formation of a kink impedes the submersion process and can also compromise the pipe's flow capacity and structural integrity – in particular, the pipe's resistance to collapse under external pressure – it is essential that during submersion the bending of the pipeline be limited to an extent that will not risk the formation of a localized kink. The pipe bending radius at which buckling is in risk is given by the following expression:

(7)

$$R_b = D_o \frac{(DR - 1)}{1.12}$$

WHERE

R_b = **bending radius at which buckling can be initiated, in**

D_o = **outside pipe diameter, in**

DR = **pipe diameter ratio = average outside diameter divided by minimum wall thickness, dimensionless**

Janson's relationship for determination of minimum buckling radius (Eq. 7) was derived on the basis of a maximum pipe deflection (ovalization) due to bending of the pipe of 7% and a maximum strain limit in the pipe wall of 5%. In actuality, the short term strain limit for modern polyethylene pipe materials is somewhat higher, on the order of 7-10%. Further, we know that these pipe materials are capable of long-term service at higher degrees of ovalization in buried pipe installations. (Please refer to Chapter 6 of this Handbook.) As a result, the values presented in Table 3 are considered conservative guidelines for the short-term bending radius of polyethylene pipe during submersion of most marine pipelines. The designer may want to utilize a higher minimum bending radius to compensate for additional factors such as extremely strong currents, tidal activity, prevailing marine traffic, frequency of ballast placement, or other installation variables associated with a specific installation.

TABLE 3
Pipe Diameter Multipliers for the Determining of Minimum Bending Radii

Pipe DR	Multiplier*
11	8.9
13.5	11.2
17	14.3
21	17.8
26	22.3
32.5	28.1

* The minimum buckling radius of a pipe, in inches, is equal to the pipe's outside diameter, in inches, times the listed multiplier

It is essential that the water be introduced into the pipe at a controlled rate. This is done to ensure that the submersion process occurs at a rate that does not result in excessive localized pipe bending that could buckle the pipe. It also allows the pipe to settle properly on the bottom – thus avoiding any bridging between high spots which may make the pipe more vulnerable to movement when subjected to strong currents. Experience has shown that submerging the pipe at a rate in the range of about 800 to 1500 feet per hour has been found to be adequate for most cases. While the pipe is in the bent condition, long stoppage of the submersion procedure must be avoided. Consult with the pipe manufacturer and design engineer for specific submersion techniques for individual installations.

The risk of buckling can be minimized by applying a suitable pulling force during the submerging, such as illustrated by Figure 8.

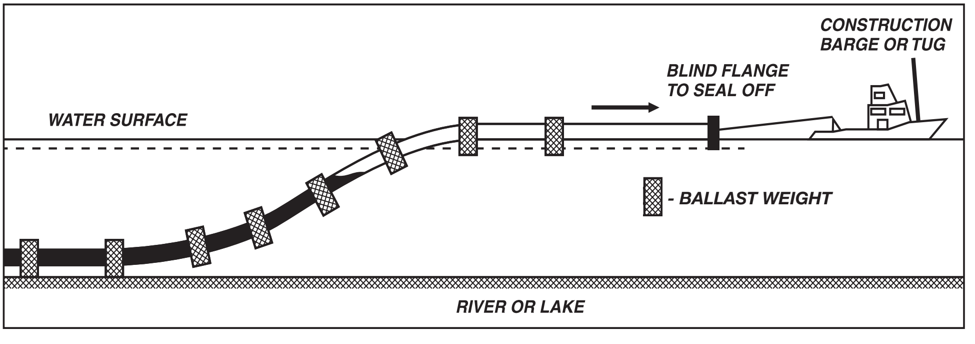

Figure 8 Pulling the pipe during submersion is a means for avoiding excessive bending that could risk buckling of the pipe

As water is being added at the shore-end of the pipe, air must be allowed to escape from the opposite end. In the case of outfall pipelines that terminate in one or more diffuser sections, the air is released through the diffuser outlets. When a pre-attached diffuser is used, it is necessary to support it with some additional buoyancy as a precaution against the water entering the pipe and causing that section of the pipeline to sink prematurely. Extreme care should be taken in the ballasting and submersion of elaborate diffuser systems that are sunk in concert with the main effluent pipe as the submersion process can create significant stresses on the tees, elbows or other fittings used in the design of the diffuser system. The preferred method is to submerge the flange or valved main effluent pipe and the diffuser separately and join the two sections underwater using qualified diving contractors.

When the end of a pipe that is being submerged terminates with a flange connection, air release can best be accomplished by installing a valved outlet in the blind flange outlet. To ensure that water will not enter through this outlet, a length of hose may be connected to the outlet, and the free end is held above water on a boat or by means of a float. After the completion of the submersion, a diver can remove the hose.

Should a problem be encountered during the submersion, the availability of a valved outlet on the outboard end of the pipeline allows the sinking procedure to be reversed. Compressed air can be pumped into the submerged line to push the water out and thus allow the line to be raised. Because compressed air packs a lot of potential energy – which, when suddenly released through a failure of a piping component, could present a serious safety hazard – the rule of thumb is to limit air pressure to not more than one-half the pipe's pressure rating for water.

Under certain methods, such as the bottom-pull method that is described above, the necessary ballast to offset floatation during the installation of a water filled PE pipe can be of a temporary nature – for example, steel reinforcing bars that are strapped on the outside of the pipe. This temporary ballast can be removed after the installation of permanent anchoring. Permanent anchoring can consist of an appropriate quantity of stable backfill that is placed on pipe that has been installed in a trench, or it can consist of tie-down straps that are installed by augering or other procedures that result in the permanent anchoring of the pipeline. However, when considering an alternate means for anchoring a pipeline, it should be kept in mind that, as discussed earlier, a pipeline lying on the sea or river floor is subject to greater lift action by currents or waves than a pipeline that lies even a short distance above the bottom.

Step 10 Completing the Construction of the Land-to-Water Transition

After the pipeline has been submerged, the portion of the pipeline that has been lowered into a land-to-water transition trench should be backfilled with specified material and to the required depth of cover.

Post-Installation Survey

Upon completion of the installation of a submerged pipeline, it is advisable to have the complete line surveyed by a competent diver to ensure that:

- The pipeline is located within the prescribed right-of-way
- The ballasts holding the pipeline are all properly sitting on the bottom contour and that the line is not forced to bridge any changes in elevation
- The pipe is not resting on any rocks, debris or material that could cause damage
- Any auxiliary lines, such as hoses, ropes, buoyancy blocks or any other equipment used during the installation has been removed
- Where required, the pipe has been backfilled and the backfilling was done properly
- All other installation requirements established by the designer for the subject application have been complied with.

Other Kinds of Marine Installations

Because of its flexibility, light-weight and toughness PE piping has also emerged as a choice material for other types of marine applications. The basic design and installation principles described above for the “float-and-sink” method are, with some modifications, also valid for other types of marine applications. A brief description of some other kinds of marine applications is presented in the paragraphs that follow.

Winter Installations

Where ice conditions permit, PE pipe may be submerged from the surface of a frozen lake or river. After a long pipe length is assembled by means of heat fusion it can be easily pulled alongside the right-of-way. The heat fusion process needs to be performed in an adequately heated tent, or other shelter, to ensure fusion joint quality. Once the heat fusion has been completed, the ballast weights can be mounted. An ice trench is then cut with a saw, the ice blocks are moved out of the way and the pipeline is pushed into the trench. The submersion is carried out in accordance with the procedure previously described.

Installations in Marshy Soils

Installation of pipe in marshy or swampy soils represents one of the most demanding applications for any design engineer. Generally, marshy soils do not provide the firm and stable foundation that is required by rigid, more strain sensitive traditional piping materials.

Due to its flexibility and butt fusion joining technology, PE piping can readily adapt itself to shifting and uneven support without sacrifice of joint integrity. As soil conditions vary, the PE pipe can accommodate these irregularities by movement within the fluid-like soil envelope. Of course, care must be taken to consider any line, grade or external hydrostatic design requirements of the pipeline based on the operating conditions of the system. However, with these design aspects in mind, it is possible to utilize the engineering features of PE pipe to design a cost-effective and stable piping system that can provide years of satisfactory service in this highly variable environment.

In certain situations, the high water table that is characteristic of these soils can result in significant buoyant forces that may raise the pipe from the trench in which it has been installed. When this possibility presents itself, a ballast system may be designed using the same guidelines presented in this chapter which can prevent or minimize pipe flotation.

Water Aeration Systems

Smaller diameter submerged PE pipe, with small holes drilled into the top of the pipe has been used for the de-icing of marinas. Compressed air that bubbles out of these pipes raises warmer water that melts ice that forms on the water surface. When the system is operating, the submerged pipe is full of air, and the ballast weight design should be adequate to prevent the line from floating. Ballast also needs to be spaced frequently enough to minimize the upward deflection that results from the buoyancy force.

Dredging

PE piping is a natural choice for use in marine dredging operations. Its flexibility, combined with its light weight, buoyant nature and overall durability, provides for a piping material which has been successfully used for years in the demanding rigors of dredging operations. Generally, these types of applications require that the HDPE pipe be fused into manageable lengths that can be easily maneuvered within the dredge site. These individual lengths are then mechanically joined together using flanges or quick-connect type fittings to create a pipeline structure of suitable length for the project. As the dredge operation proceeds, pipe segments may be added or removed to allow for optimum transport of the dredge material.

Dredging operations can vary significantly in type of slurry, scale or operation and overall design. As such, a detailed analysis of dredge design using HDPE pipe is beyond the scope of this writing. However, the reader should note that as the particulate size and nature varies from project to project, it is possible to ballast the pipe so that it still floats and can be managed from the surface using tow boats or booms. This is accomplished by analysis of the composition of the dredge material and the design and attachment of suitable floats to the HDPE discharge or transport pipe.

Temporary Floating Lines

PE piping has also been used for temporary crossings of rivers and lakes. Its natural buoyancy allows a PE pipeline to float on or near the water surface. The principal design and installation requirement for floating line applications is to work out a system to maintain the pipe in its intended location when it is subject to currents, winds and wave action. To this end, cable restraints are generally used. The cables need to hold the pipe by means of stable collars that do not slip along the axis of the pipe and that cause no damage to the pipe material.

Conclusion

Modern HDPE piping materials are a natural choice for marine installations. The overall durability and toughness of these products, combined with the innovative and cost-effective installation methods that they facilitate, are compelling reasons for their use in effluent discharge systems, water intake structures and potable water or sanitary sewer force main marine crossings, as well as more temporary marine systems such as dredging operations.

The dependable butt fusion system of joining PE pipe, supplemented by the availability of a wide array of mechanical fittings, means that the design engineer has an abundance of tools available by which to design a leak-free piping system that lends itself to the most demanding marine installations. This same system of joining allows for the cost-effective installation of long lengths of pipe via the float and sink method, directional drilling or pull-in-place techniques. Utilizing the unique features of the PE piping system allows the designer to investigate installation methods that minimize the necessity of costly pipe construction barges or other specialized equipment. These same installation techniques may minimize the economic impact associated with marine traffic disruption.

This chapter provides an overall design perspective for some of the more typical applications of HDPE pipe in marine environments. Its intent is to provide the designer with a basic understanding of the utility that PE pipe brings to the designer of these challenging installations. More elaborate design investigation and methodology may be required depending on the specifics of the project under consideration. However, through a basic understanding of the benefits of PE pipe in marine installations and a fundamental understanding of the installation flexibility that they provide, it can be seen that PE pipe systems are a proven choice for modern, durable marine piping structures.

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Appendix A-1

Derivation of the Equation for the Determining of the Buoyant Force Acting on a Submerged PE Pipe (Equation 2 in the Text)

The first bracketed term in Equation 2, namely $[0.00545D^2_0\rho_W]$, is one commonly used form of the formula for obtaining a numerical value for the term W_{DW} in Equation 1, the weight of water that is displaced by the submerged PE pipe. This displaced weight is equivalent to the lift force acting on a submerged pipe that has an infinitely thin wall and that is completely filled with air. The sum of the three terms within the second set of brackets expresses the reduction of this potential lift force in consequence of the weight of the pipe (the first term) and that of its contents (the second term). As is evident from inspection of Equation 2, the extent to which the inner volume of a pipe is occupied by air (represented by the fraction R) exerts the more significant effect on resultant pipe buoyancy. Since a decrease in pipe DR (i.e., an increase in pipe wall thickness) results in a decrease in potential air volume space, a lower DR tends to reduce the potential buoyancy that can result from air filling.

1. The net buoyant (upward acting force) acting on a submerged PE pipe is:

(1) $$F_B = [W_p + W_c] - W_{DW}$$

WHERE

F_B **= buoyant force, lbs/foot of pipe**

W_P **= weight of pipe, lbs/foot of pipe**

W_C **= weight of pipe contents, lbs/foot of pipe**

W_{DW} **= weight of the water displaced by the pipe, lbs/foot of pipe**

2. W_p, the weight of pipe is:

$$W_p = V_p P_p$$

WHERE

V_p **= volume occupied by pipe material per foot of pipe**

P_p **= density of pipe material, lbs/ cu. ft**

Since

$$V_p = \frac{\pi}{144} D_m t_a$$

WHERE

D_m **= mean pipe diameter of the pipe, in**

t_a **= average wall thickness, in**

And since

$$DR = \frac{D_o}{t_m}$$

WHERE

D_o **= outside pipe diameter, in**

t_m **= minimum wall thickness, in**

Then, by assuming that the average wall thickness (t_a**) is 6% larger than the minimum (**t_m**), it can be shown that:**

(2)

$$W_p = \frac{1.06\pi}{144}\left(\frac{D_o}{DR}\right)^2 (DR - 1.06)\rho_p$$

3. W_c, the weight of the pipe contents is equal to the volume occupied by the liquid inside the pipe times the density of the liquid:

$$W_c = V_L \rho_L$$

WHERE

V_L **= the volume occupied by the liquid, cu ft/linear ft**

P_L **= the density of the liquid inside the pipe, lbs/cu ft**

If the fraction of the inside volume of the pipe (V_I**) is expressed as** R **and as the formula for the inside volume is as follows:**

$$V_I = \frac{\pi D_I^2}{4} \frac{1}{144}$$

WHERE

D_I **= inside diameter of the pipe, in**

And also, since $D_I = D_o - 2t_a$ **(where** t_a *is* $1.06\ t_m$, **as previously assumed) it can then be shown that:**

(3)

$$Wc = \frac{\pi}{144}\frac{\rho_L}{4}\left[D_o\left(1-\frac{2.12}{DR}\right)\right]^2(1-R)$$

4. W_{DW}, the weight of the water displaced by the pipe is determined by means of the following formula:

(4)

$$W_{DW} = \frac{\pi D_o^2}{4}\frac{1}{144}\rho_W$$

WHERE

ρ_W **= the density of the displaced water, lbs/cu ft**

5. By substituting Equations 2, 3 and 4 into Equation 1, and by simplifying the resultant relationship, the following formula (Equation 2 in the text) is obtained:

$$F_B = \left[0.0054 D_o^2 \rho_W\right]\left[4.24\frac{(DR-1.06)}{(DR)^2}\frac{\rho_p}{\rho_w} + \left(1-\frac{2.12}{DR}\right)^2(1-R)\frac{\rho_c}{\rho_w} - 1\right]$$

Appendix A-2

Water Forces Acting on Submerged PE Piping

The following is a brief introduction to the technology for the estimating of the magnitude of the lateral forces that can act on a submerged pipe in consequence of water currents and wave action. As this technology is relatively complex and it is still emerging, the objective of this introduction is to provide basic information and references that can provide initial guidance for the proper design of PE piping for submerged applications. It is the responsibility of the designer to determine the design requirements and appropriate design protocol for the specific anticipated conditions and design requirements of a particular project. In addition to the information and references herein provided, the reader should consult the technical staff of PPI member companies for further information, including references to engineering companies that have experience in the use of PE piping for submerged applications.

Submerged pipes can be subject to lateral forces generated by currents or by wave action. A principal design objective is to ensure that the resultant lateral forces do not subject the pipe to excessive deflection, nor to fiber stresses or strains that could challenge the pipe material's capabilities. Thus, the capacity to estimate with some reasonable accuracy the potential maximum lateral stresses to which a submerged pipe may be subjected is an important element for achieving a successful design.

Currents impinging on a submerged pipe can cause two principal forces: a drag force in the direction of the current; and a vertical force at right angles to the drag force. The magnitude of these forces depends on the angle between the direction of the current flow and the pipe. They are at their maximum when the current flow is at a right angle to the pipe. As this angle (Θ) is reduced, the resultant force is reduced by $\sin^2 \Theta$.

For the purpose of estimating the drag and lift forces that a current can exert on a submerged pipe, Janson developed the graphical solution that is herein reproduced as Figure A-2-1. This graph is applicable to the condition where the current velocity, expressed in feet per second, times the pipe diameter, expressed in feet, is equals to or is greater than 0.5 m^2/sec (2.7 ft^2/sec).

Janson's nomagraph is based on the assumption that certain design variables are known. These design variables are as follows:

D = **external diameter of pipe, in meters (feet)**

l = **distance from the bottom, in meters (feet)**

u_m = **mean velocity of water, in m/sec (ft/sec)**

h = **depth of water, in meters (feet)**

k = **hydraulic roughness of the water bed, meters (feet)**

Θ = **angle between the direction of the current and that of the pipe, degrees**

λ = **ratio of l/h, dimensionless**

= **0 for pipe placed on seafloor or bed of body of water**

Janson determined that for values of $D \times U_m > 0.50$ m^2/sec, a nomograph could be constructed which allowed for a relatively quick approximation of the drag and/or lift forces for which an underwater HDPE piping installation must be designed.

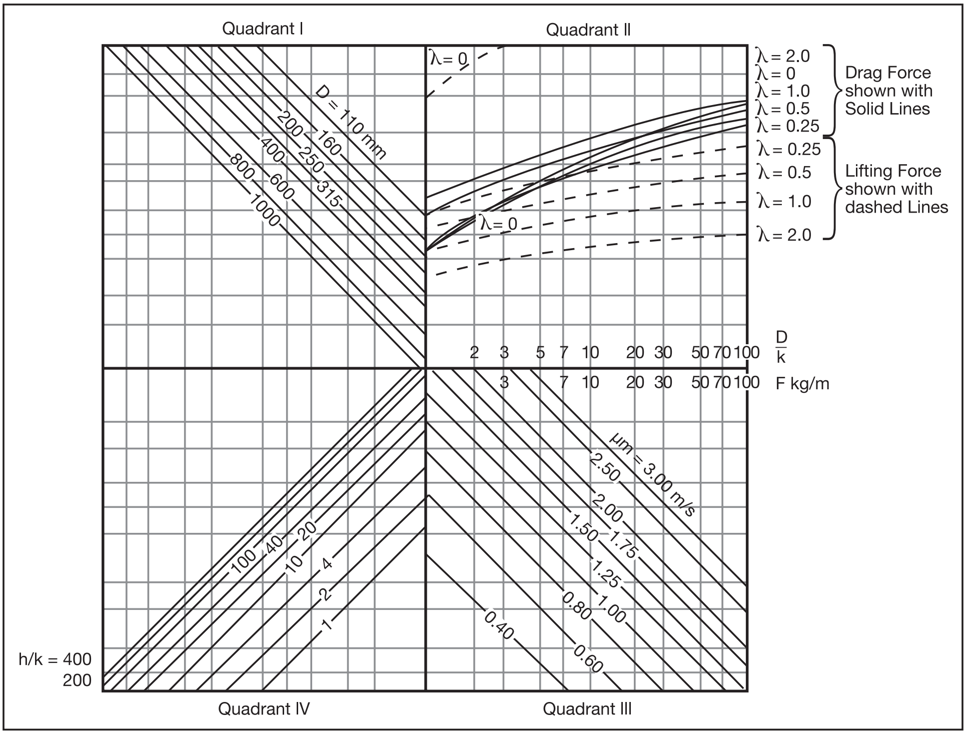

Figure A-2-1 Graph for the estimation of drag and lifting forces on underwater pipes when the flow rate of the current times the pipe diameter is 0.5 m^2/sec, or greater [4]

Consider the following example:

A 315 mm HDPE pipe is to be placed directly on the floor of a body of water that is flowing at approximately 3 m/sec and at 90 degrees to longitudinal axis of the pipe. The depth of the water is 10 meters and the pipe will be placed directly on a bed of gravel for which we will assume a hydraulic roughness of 10 cm.

Step 1 First, check to see if the nomograph is applicable

$$D \times u_m = 0.315 \text{ m} \times 3 \text{ m/sec} = 0.96 \text{ m}^2\text{/sec}$$

So, the nomograph can be utilized.

Step 2 Determine the two key dimensionless design ratios, D/k and h/k

GIVEN THAT

D **= 315 mm = 0.315 meter**

and

k **= 10 mm = 0.10 meter**

Then

D/k = **0.315 m / 0.10 m = 3.2**

h/k = **10 m / 0.10 m = 100**

Step 3 Determine the Drag Force

Utilizing the nomograph in Figure A-2-1, start at the horizontal axis between quadrant II and III. On the D/k axis locate the point 3.2 from the calculation in step 2. Draw a line vertically up to the solid curve (drag force) for $\lambda = 0$ (the pipe will rest on the bed of the body of water). Now draw a horizontal line from quadrant II into quadrant I to the line for diameter, in this case 315 mm. At the point of intersection with this line, draw another line downward to the line for h/k = 100 shown in quadrant IV. At that point of intersection, then draw another line horizontally back across to quadrant III to the line for flow velocity, in this example 3m/sec. From this point draw a line upward to the original axis and read drag velocity directly from nomograph. The result is 20 kg/m.

Step 4 Determine the Lift Force

Generally speaking, the lift force for a pipe laying on the floor of a body of water is eight times that of the drag force. In this case, the lift force generated is approximately 160 kg/m.

Alternatively, the lift force could have also been approximated from the nomograph by starting on the same axis between quadrant II and III and proceeding up to the dashed line for $\lambda = 0$ in quadrant II. The dashed line represent the curves for lift force relationships. From the intercept with the dashed curve for $\lambda = 0$, the procedure of is the same as that described for determination of the drag force from the nomograph.

Consider another example:

Now, using the scenario outlined in the preceding example, assume that the pipe is oriented in the water such that the angel of impact, θ, is 60 degrees.

Solution:

The revised angle of impact suggest that the drag force may be reduced by a factor, $\sin^2\theta$.

$$\text{Sin}^2\theta = \sin^2 60^\circ = 0.75.$$

Using this, we get a net drag force as follows:

$$\text{Drag Force}_{(90)} \text{ x Sin}^2\theta = 20 \text{ kg/m x } 0.75 = 15 \text{ kg/m}$$

English Units

Janson's nomograph was originally published in metric units. However, the curves presented in quadrants II and IV are dimensionless. By converting quadrants I and III and the horizontal axis to English units then the nomograph may be used for pipe sized and installed accordingly. For ease of reference, Janson's nomograph is recreated using English units in figure A-2-2 below.

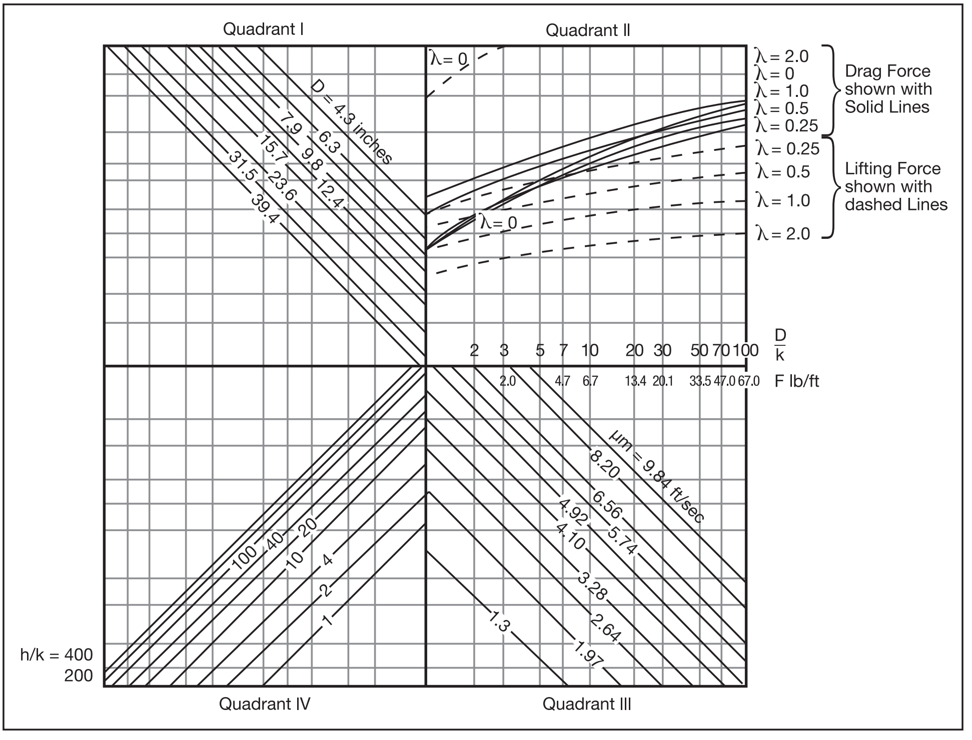

Figure A-2-2 Graph for the estimation of drag and lifting forces on underwater pipes when the flow rate of the current times the pipe diameter is 2.7 ft²/sec, or greater

Consider the previous example restated in English units

A 12" IPS HDPE (325 mm) pipe is to be placed directly on the floor of a body of water that is flowing at approximately 9.8 ft/sec (3 m/sec) and at 90 degrees to longitudinal axis of the pipe. The depth of the water is 33 feet (10 meters) and the pipe will be placed directly on a bed of gravel for which we will assume a hydraulic roughness of 4 inches (10 cm).

Step 1 First, check to see if the nomograph is applicable

$$D \times u_m = 1 \text{ ft} \times 9.8 \text{ ft/sec} = 9.8 \text{ ft}^2/\text{sec} = 0.91 \text{ m}^2/\text{sec} > 0.50 \text{ m}^2/\text{sec}$$

So, the nomograph can be utilized.

Step 2 Determine the two key dimensionless design ratios, D/k and h/k

GIVEN THAT

D **= 12.75 inches = 1.06 foot**

and

k **= 4 inches = 0.33 foot**

Then

D/k **= 1.06/0.33 = 3.2**

h/k **= 33/ 0.33 m = 100**

Step 3 Determine the Drag Force

Utilizing the English version of the nomograph in Figure A-2-2, start at the horizontal axis between quadrant II and III. On the D/k axis locate the point 3.1 from the calculation in step 2. Draw a line vertically up to the solid curve (drag force) for $\lambda = 0$ (the pipe will rest on the bed of the body of water). Now draw a horizontal line from quadrant II into quadrant I to the line for diameter, in this case 12 inch. At the point of intersection with this line, draw another line downward to the line for h/k = 100 shown in quadrant IV. At that point of intersection, then draw another line horizontally back across to quadrant III to the line for flow velocity, in this example 9.8 ft/sec. From this point draw a line upward to the original axis and read drag velocity directly from nomograph. The result is 13.5 lbf/ft. The reader should keep in mind that this is only an approximation and is not intended to displace a more detailed engineering analysis of a specific marine installation design.

Step 4 Determine the Lift Force

As with the previous example, the lift force for a pipe laying on the floor of a body of water is eight times that of the drag force. In this case, the lift force generated is approximately 108 lbf/ft.

The lift force may be approximated from Figure A-2-2 by starting on the same axis between quadrant II and III and proceeding up to the dashed line for $\lambda = 0$ in quadrant II. The dashed line represent the curves for lift force relationships. From the intercept with the dashed curve for $\lambda = 0$, the procedure of is the same as that described for determination of the drag force from the nomograph.

APPENDIX A-3

Some Designs of Concrete Ballasts

Concrete ballast designs may take on a variety of different sizes, shapes and configurations depending on job-site needs, installation approach and/or availability of production materials. Table A-3-1 below provides some typical designs for concrete ballasts and details some suggested dimensional considerations based on pipe size, density of unreinforced concrete at 144 lb/ft^3 and per cent air entrapment in a typical underwater installation. The reader is advised to consider these dimensions and weights for reference purposes only after a careful analysis of the proposed underwater installation in accordance with the guidelines presented in this chapter.

TABLE A-3-1
Suggested Concrete Weight Dimensions (All dimensions in inches)

Nominal Pipe Size	Mean Outside Diameter (inches)	Spacing of Weights To Offset % Air (feet)			Approx. Weight of Concrete Block (pounds)		Approximate Block Dimensions (inches)						Bolt Dimensions (inches)	
		10%	15%	20%	In Air	In Water	"D"	"X"	"Y"	"T"	"S" (min)	"W"	Dia.	Length
3 IPS	3.50	10	6 ¾	5	12	7	4	9	3 ¾	2 ½	1 ½	2 ½	¾	12
4 IPS	4.50	10	6 ¾	5	20	10	5	11	4 ¾	2 ½	1 ½	3	¾	12
5 IPS	5.56	10	6 ¾	5	30	18	6	12	5 ¼	3 ½	1 ½	3	¾	12
6 IPS	6.63	10	6 ¾	5	35	20	7 1/8	13	5 ¾	3 ½	1 ½	3	¾	12
7 IPS	7.13	10	6 ¾	5	45	26	7 5/8	13 ½	6	4 ¼	1 ½	3	¾	12
8 IPS	8.63	10	6 ¾	5	55	30	9 ¼	15 ¼	6 7/8	4 ¼	1 ½	3	¾	12
10 IPS	10.75	10	6 ¾	5	95	55	11 ¾	19 ¼	8 5/8	4 ½	2	4	¾	12
12 IPS	12.75	10	6 ¾	5	125	75	13 ¼	21 ¼	9 5/8	5	2	4	¾	13
13 IPS	13.38	10	6 ¾	5	175	100	13 7/8	24	11	5 ¼	2	5	¾	13
14 IPS	14.00	15	10	7 ½	225	130	14 ½	24 ½	11 ¼	6 ½	2	5	1	13
16 IPS	16.00	15	10	7 ½	250	145	16 ½	26 ½	12 ¼	6 ½	2	5	1	13
18 IPS	18.00	15	10	7 ½	360	210	18 ½	28 ½	13 ¼	8 ¼	2	5	1	13
20 IPS	20.00	15	10	7 ½	400	235	20 ½	30 ½	14 ¼	8 ¼	2	6	1	13
22 IPS	22.00	15	10	7 ½	535	310	22 ½	34 ½	16 ¼	8 ½	2	6	1	13
24 IPS	24.00	15	13 ½	7 ½	610	360	24 ½	36 ½	17 ¼	8 ¾	2	6	1	13
28 IPS	28.00	20	13 ½	10	900	520	28 ½	40 ¼	19 ¼	11 ¼	2	6	1	13
32 M	31.59	20	13 ½	10	1140	660	32	44	21	12 ¼	2	6	1	13
36 IPS	36.00	20	13 ½	10	1430	830	36 ½	48 ½	23 ¼	13 ½	2	6	1	13
40 M	39.47	20	13 ½	10	1770	1020	40 1/8	52	25	15 ¼	2	6	1	13
42 IPS	42.00	20	13 ½	10	1925	1125	42 ½	54 ½	26 ¼	15	2	6	1	13
48 IPS	47.38	20	13 ½	10	2500	1460	48 ¼	60 ¼	29 1/8	17	2	6	1 1/8	13
55 M	55.30	20	13 ½	10	3390	1980	55 ¾	68	33	18 ¾	2	6 1/8	1 1/8	15
63 M	63.21	20	13 ½	10	4450	2600	63 ¾	78	38	18 ½	2	7 1/8	1 1/8	15

Notes to Table A-3-1

1. Suggested underpad material: 1/8” black or red rubber sheet, 1/4” neoprene sponge padding width to be “T”+ 2” minimum to prevent concrete from contacting pipe surface.
2. Concrete interior surface should be smooth (3000 psi – 28 days).
3. Steele pipe sleeves may be used around the anchor bolts (1” for 3/4” bolt, etc.). Hot dip galvanize bolts, nuts, washers and sleeves.
4. A minimum gap, “S”, between mating blocks **must** be maintained to allow for tightening on the pipe.
5. To maintain their structural strength some weights are more than the required minimum.
6. Additional weight may be required for tide or current conditions.
7. Weights calculated for fresh water.
8. All concrete blocks should be suitably reinforced with reinforcing rod to prevent cracking during handling, tightening, and movement of weighted pipe.
9. See Table II for alternative weight design and suggested reinforcement for use with 28” to 48” HDPE pipe.

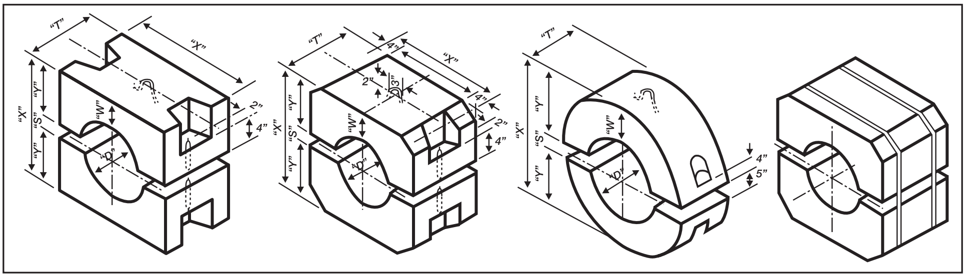

Figure A-3-1 Schematics of Concrete Ballast Designs

TABLE A-3-2

Suggested Dimensions and Reinforcing for Bottom-heavy Concrete Weights (For Extra Stability)
All dimensions in inches

Nominal Pipe Size	Mean Outside Diameter (inches)	Spacing of Weights To Offset % Air (feet)			Approx. Weight of Concrete Block (pounds)		Approximate Block Dimensions (inches)						Bolt Dimensions (inches)	
		10%	15%	20%	In Air	In Water	“D”	“X”	“Y”	“Z”	“R”	“T”	Dia.	Length
28 IPS	28.00	20	13 ½	10	900	520	28 ½	44	19 ½	26 ½	48	7 ½	1	54
32 M	31.59	20	13 ½	10	1140	660	32 1/8	48	21	28	51	8 ½	1	57
36 IPS	36.00	20	13 ½	10	1430	830	36	52	23	30 ½	55 ½	9 3/8	1	61 ½
40 M	39.47	20	13 ½	10	1770	1020	40 1/8	56	25	33	60	10 ¼	1	66
42 IPS	42.00	20	13 ½	10	1925	1125	42 ½	59	26 ½	34 ½	63	10	1 1/8	69
48 M	47.38	20	13 ½	10	2500	1460	48 ¼	64	29	39	70	11 ½	1 1/8	76
55 M	55.30	20	13 ½	10	3390	1980	55 ¾	72	33	43	78	12 ¾	1 1/8	84
63 M	63.21	20	13 ½	10	4450	2600	63 ¾	80	37	47	86	14 ½	1 1/8	92

Notes to Table A-3-2

1. Minimum cover of rebar to be 2 ½”.
2. Rebar to be rail steel or equivalent.
3. Anchor bolt material to be ASTM A307.
4. It may be desirable to increase the amount of reinforcing used in the 55” and 63” pipe weights.
5. See recommended bore detail on the following page.

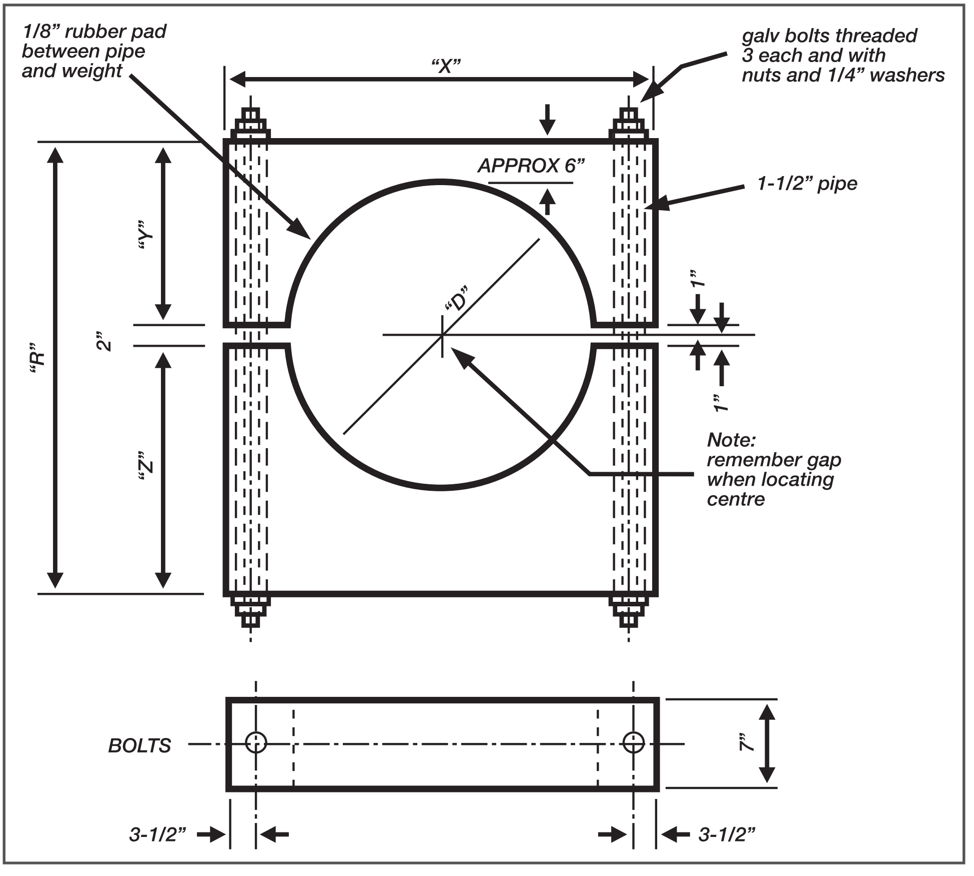

Figure A-3-2 Typical Detail of Concrete Ballast Showing 1-inch Gap Between Ballast Sections

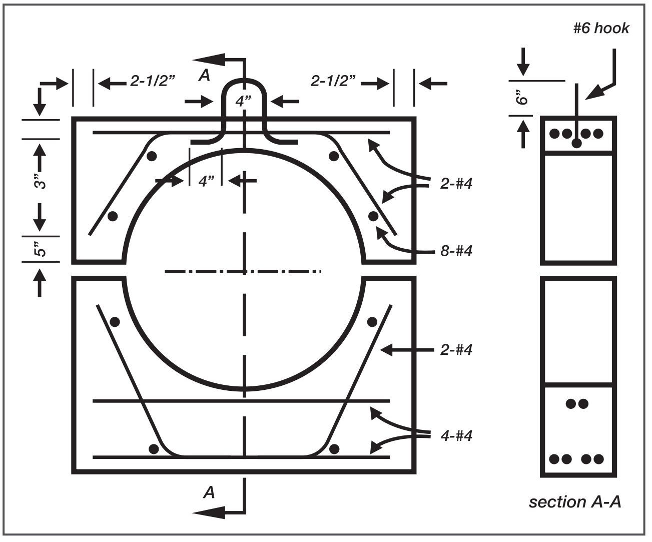

Figure A-3-3 Typical Rebar Detail in Concrete Ballast Design

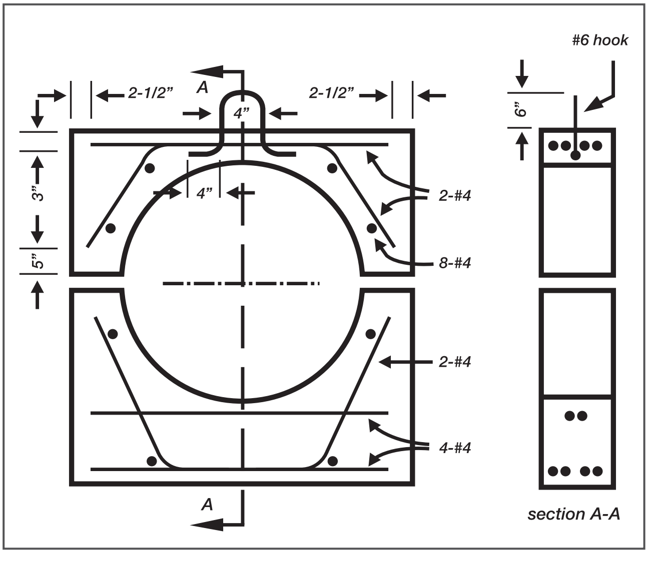

Figure A-3-4 Bore Detail for Concrete Ballast Design

Chapter 11

Pipeline Rehabilitation by Sliplining with PE Pipe

Introduction

An integral part of the infrastructure is the vast network of pipelines, conduits, and culverts in North America. These are among the assets we take for granted, since most are buried and we never see them. We do not see them deteriorate either, but we know that they do. Television inspection of the interiors of these systems often reveals misaligned pipe segments, leaking joints, or other failing pipe integrity.

The effects of continued deterioration of a pipeline could be quite drastic and costly. A dilapidated gravity sewer system permits substantial infiltration of groundwater, which increases the volume of flow and reduces the available hydraulic capacity of the existing line. So the old pipeline often increases treatment and transportation costs for the intended flow stream(24). Continued infiltration may also erode the soil envelope surrounding the pipe structure and cause eventual subsidence of the soil.

The case for positive-pressure pipelines is somewhat different, but the results are equally unacceptable. In this situation, continued leakage through the existing pipeline allows exfiltration of the contents of the flow stream that eventually leads to extensive property damage or water resource pollution. Also, in many cases, the contents of the flow stream are valuable enough that their loss through exfiltration becomes another economic factor. PE pipe provides an excellent solution to the problem of leaky joints, whether it is due to infiltration or to exfiltration. This is because the standard method of joining PE pipe uses a heat fusion process that results in a monolithic pipe system, that is, the joints are as strong as, and as leak free, as the pipe itself.

When the harmful results of pipeline deterioration become apparent, we must either find the most economical method that will restore the original function or abandon the failed system. Excavation and replacement of the deteriorating structure can prove prohibitively expensive and will also disrupt the service for which the original line is intended[18]. An alternate method for restoration is "sliplining" or "insertion renewal" with polyethylene pipe. More than 30 years of field experience shows that this is a proven cost-effective means that provides a new pipe structure with minimum disruption of service, surface traffic, or property damage that would be caused by extensive excavation.

The sliplining method involves accessing the deteriorated line at strategic points within the system and subsequently inserting polyethylene pipe lengths, joined into a continuous tube, throughout the existing pipe structure. This technique has been used to rehabilitate gravity sewers[11, 24], sanitary force mains, water mains, outfall lines, gas mains[2, 13], highway and drainage culverts[18], and other piping structures with extremely satisfactory results. It is equally appropriate for rehabilitating a drain culvert 40-feet long under a road or straight sewer line with manhole access as far as ½ mile apart. The technique has been used to restore pipe as small as 1-inch, and there are no apparent maximum pipe diameters.

Mechanical connections are used to connect PE pipe systems to each other and to connect PE pipe systems to other pipe materials and systems. The reader can refer to the Handbook chapter that is titled 'Polyethylene Joining Procedures' for additional information on Mechanical Connections and Mechanical Joint (MJ) Adapters.

Design Considerations

The engineering design procedure required for a sliplining project consists of five straightforward steps:

1. Select a pipe liner diameter.
2. Determine a liner wall thickness.
3. Determine the flow capacity.
4. Design necessary accesses such as terminal manholes, headwall service and transition connections.
5. Develop the contract documents.

Select a Pipe Liner Diameter

To attain a maximum flow capacity, select the largest feasible diameter for the pipe liner. This is limited by the size and condition of the original pipe through which it will be inserted. Sufficient clearance will be required during the sliplining process to insure trouble-free insertion, considering the grade and direction, the severity of any offset joints, and the structural integrity of the existing pipe system.

The selection of a polyethylene liner that has an outside diameter 10% less than the inside diameter of the pipe to be rehabilitated will generally serve two purposes. First, this size differential usually provides adequate clearance to accommodate the insertion process. Second, 75% to 100% or more of the original flow capacity may be maintained. A differential of less than 10% may provide adequate clearance in larger diameter piping structures. It is quite common to select a 5% to 10% differential for piping systems with greater than 24-inch diameters, assuming that the conditions of the existing pipe structure will permit insertion of the liner.

Determine a Liner Wall Thickness

Non-Pressure Pipe

In the majority of gravity pipeline liner projects, the principal load that will act on the polyethylene pipe is the hydrostatic load that is created when the water table rises above the crown (top) of the liner.

The generic Love's equation (Eq. 1) shows that the ability of a free-standing pipe to withstand external hydrostatic loading is essentially a function of the pipe wall moment of inertia and the apparent modulus of elasticity of the pipe material. The critical buckling pressure, P_C, for a specific pipe construction can be determined by using equation Eq. 1.

(1) Love's Equation

$$P_c = \frac{24EI}{\left(1-\nu^2\right)\times D_m^{\ 3}} \times f_0$$

WHERE

P_C = Critical buckling pressure, psi

E = Apparent modulus of elasticity (Refer to Appendix, Chapter 3, for the appropriate value for the Material Designation Code of the PE pipe being used and the applicable service conditions.)

I = Pipe wall moment of inertia, in^4/in

= $t^3/12$ for solid wall PE, where t = minimum wall thickness of the pipe, in

ν = Poisson's Ratio, 0.45 for all PE pipe materials

D_m = Mean diameter, inches (outside diameter minus one wall thickness)

f_0 = Ovality compensation factor, dimensionless (see Figure 1)

D = Pipe average outside diameter, in

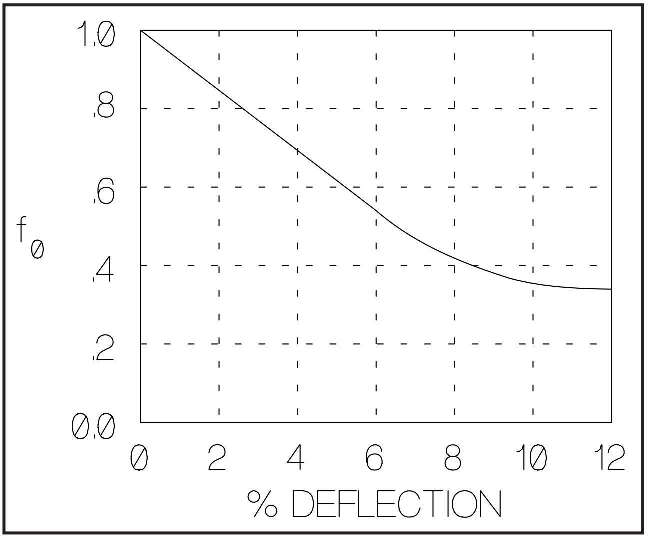

Figure 1 % Deflection vs. Ovality Correction Factor, f_0

where $\% \text{Deflection} = \frac{D - D_{min}}{D} \times 100$

D_{min} = Pipe minimum diameter, in

To compute the buckling pressure of a dimension ratio (DR) series polyethylene pipe (i.e., a grouping of solid wall pipes of different diameters but with the same ratio of specified outside diameter to minimum wall thickness), the following variation of Love's equation[22], Eq. 2, is used.

(2) Love's Equation for DR Solid Wall Pipe

$$P_c = E \times \left(\frac{2}{1-\nu^2}\right) \times \left(\frac{1}{DR-1}\right)^3 \times f_o$$

WHERE

DR = Dimension ratio, dimensionless (OD/t)

OD = Actual outside diameter, inches

t = Minimum wall thickness, inches

The process of calculating the buckling resistance of a free-standing pipe is iterative in that, once the critical buckling resistance of a trial choice has been determined, it can be compared to the anticipated hydrostatic load. If the pipe's calculated buckling resistance is significantly larger than the anticipated hydrostatic loading, the procedure can be used to evaluate a lesser wall thickness (with the advantages of lighter weight materials and lower costs). The prudent practice is to select a design buckling resistance that provides an adequate safety factor (SF) over the maximum anticipated hydrostatic load.

(3) Safety Factor, SF

$$SF = \frac{P_c}{\text{Anticipated Hydrostatic Load}}$$

For an example of the calculations that can be made with Equations 2 and 3, consider a 22-inch DR 26 solid-wall polyethylene liner placed within a 24-inch clay tile pipe and subjected to a maximum excess hydrostatic load of 3 feet of water table.

1. Calculate the equivalent hydrostatic load in psi.
   Water load = 3 ft x 62.4 lb/ft^3 x 1 ft^2/144 in^2 = 1.3 psi

2. Calculate the critical buckling pressure, P_c, using Eq. 2 assuming the following variable values: E = 28,200 psi, $\nu = 0.45$ and $f_o = 0.79$

3. Calculate the Safety Factor, SF, from Eq. 3 for this load assumption.
   SF = 3.6/1.3 = 2.8

A safety factor of 2.0 or greater is often used for frequent or long-term exposure to such loads. If a larger safety factor is preferred, repeat the procedure for a heavier wall configuration or consider the enhancement of the pipe's buckling strength by the effects of external restraint.

Love's equation assumes that the liner being subjected to the indicated hydrostatic load is free-standing and is not restrained by any external forces. Actually, the existing pipe structure serves to cradle the flexible liner, enhancing its collapse resistance. Maximum external reinforcement can be provided, where required, by placing a stable load-bearing material such as cement, fly ash, polyurethane foam, or low-density grout in the annular space between the liner and the existing pipe. Studies show that filling the annular cavity will enhance the collapse resistance of a polyethylene pipe by at least a four-fold factor and often considerably more, depending on the load-bearing capabilities of the particular fill material. Contact the pipe suppliers for additional information.

For solid wall PE pipe, the significant variable that determines adequate wall stiffness is the pipe DR. It is a simple matter to specify the DR once the amount of the loading on the pipe is determined. A typical manufacturer's recommendation for safe long-term (50-year) external pressure loading might follow the guidelines in Table 1, which were derived according to the procedure shown in ASTM F585, Practice for Insertion of Flexible Polyethylene Pipe into Existing Sewers.

TABLE 1
Allowable Height [1] of Water Above DR Dimensioned Pipe at the Maximum Operating Temperature of 73°F (23°C) [2] and Under a Continuous Duration of Loading of 50-years [3]. Not Grouted vs. Grouted Pipe

Pipe Dimension Ratio (DR)	Height of water (feet) above pipe made from materials designated as PE 4XXX [4]		Height of water (feet) above pipe made from materials designated as PE 3XXX [4]	
	Not Grouted	Grouted	Not Grouted	Grouted
32.5	2.0	10.0	1.9	9.5
26	4.0	20.0	3.9	19.5
21	7.9	39.5	7.6	38.0
17	15.4	77.0	14.8	74.0
13.5	32.2	161.0	31.1	155.0
11	62.9	314.5	60.8	304.0

Notes:
(1) The values of allowable height were computed by means of equation (2) and under the following assumptions:
- The apparent modulus E is 28,000 psi for PE3XXX and 29,000 psi for PE4XXX materials at 73°F and for a 50-year load duration; refer to Appendix, Chapter 3 of this Handbook.
- The value of Poisson's ratio (μ) is 0.45
- The value of fo, the pipe ovality correction factor, is 0.75, which corresponds to a pipe deflection of 3%
- A safety factor of 2.0 was used. See preceding discussion on selecting an appropriate safety factor
- For grouted applications, the height of water above pipe was computed by multiplying by 5 the height obtained for the corresponding non-grouted applications.

(2) Table B.1.2 of the Appendix of Chapter 3 lists temperature adjusting factors which may be used to convert the above results to other maximum operating temperatures
(3) Values for apparent modulus for other periods of continuous loading are listed in Table B.1.1 in the Appendix to Chapter 3
(4) The first numeral after PE is the standard classification for the PE's density. The X's designate any recognized value for the other coded properties. See the section on Structural Properties of Chapter 3 for a detailed description of the PE piping material designation code.

The figures in this table represent a Safety Factor, SF, of 2.0 and a diametrical ovality of 3%. Grouted strength of the pipe was derived by applying a multiplier of 5 to the non-grouted value[32]. If the existing sewer will not provide structural integrity to earth and live loads, a more conservative Safety Factor should be used.

For profile wall pipe the variable that determines adequate wall stiffness is a function of the pipe wall moment of inertia and pipe inside mean diameter. The following equation can be used to estimate maximum allowable long-term (50-year) height of water above the pipe with no grout:

(4)
$$H = \frac{0.9 \times RSC}{D_m}$$

WHERE
H = Height of water, feet

RSC = Measured Ring Stiffness Constant

D_m = Mean diameter, inches

This equation contains a Safety Factor (SF) of 2.0 based on pipe with a maximum 3% deflection.

For grout with a minimum compressive strength of 500 psi at 24 hours (1,800 psi at 28 days), the allowable long-term (50-year) height of water above the pipe may be determined from the following equation:

(5)

$$H = 5 \times \frac{(0.9 \times RSC)}{D_m}$$

This equation contains a Safety Factor (SF) of 2.0.

Pressure Pipe

A liner, which will be exposed to a constant internal pressure or to a combination of internal and external stresses must be analyzed in a more detailed manner. The guidelines for a detailed loading analysis such as this are available from a variety of resources that discuss in detail the design principles concerned with underground installation of flexible piping materials.[3,15,16,19,26,29] The reader is also advised to refer to Chapters 3 and 6 of this Handbook for additional information on design principles and the properties applicable to the particular Material Designation Code of the PE pipe being used.

In those installations where the liner will be subjected to direct earth loading, the pipe/soil system must be capable of withstanding all anticipated loads. These include earth loading, hydrostatic loading, and superimposed loads. The structural stability of a polyethylene liner under these conditions is determined largely by the quality of the external support. For these situations, refer to any of the above referenced information sources that concern direct burial of thermoplastic pipe. A polyethylene liner that has been selected to resist hydrostatic loading will generally accommodate typical external loading conditions if it is installed properly.

Other Loading Considerations

Filling of the entire annular space is rarely required. If it is properly positioned and sealed off at the termination points, a polyethylene liner will eliminate the sluice path that could contribute to the continued deterioration of most existing pipe structures. With a liner, a gradual accumulation of silt or sediment occurs within the annular space, and this acts to eliminate the potential sluice path.

On occasion, deterioration of the original pipe may continue to occur even after the liner has been installed.[18] This situation may be the result of excessive ground-water movement combined with a soil quality that precludes sedimentation within the annular space. Soil pH and resistivity can also help deteriorate the host culvert or pipe. As a result, uneven or concentrated point loading upon the pipe liner or even subsidence of the soil above the pipe system may occur. This can be avoided by filling the annular space with a cement-sand mixture, a low-density grout material[10], or fly ash.

Determine the Flow Capacity

The third step in the sliplining process is to assess the impact of sliplining on the hydraulic capacity of the existing pipe system. This is accomplished by using commonly-accepted flow equations to compare the flow capacity of the original line against that of the smaller, newly-installed polyethylene liner. Two equations widely used for this calculation are the Manning Equation (Eq. 6) and the Hazen-Williams Approximation for other than gravity flow systems (Eq. 7).[2,5] The reader is referred to Chapter 6 of this Handbook, where the subject of fluid flow is covered extensively.

(6) Manning Equation for Gravity Flow

$$Q = \frac{1.486 \times A \times R^{0.667} \times S^{0.5}}{n}$$

WHERE

Q = Flow, ft^3/sec

A = Flow area, ft^2 (3.14 x ID^2/4)

R = Hydraulic radius, feet (ID/4 for full flow)

S = Slope, ft/ft

n = Manning flow factor for piping material, 0.009 for smooth wall PE

ID = Inside diameter, feet

For circular pipe flowing full, the formula may be simplified to

$$Q = \frac{0.463 \times ID^{2.667} \times S^{0.5}}{n}$$

(7) Hazen-Williams Approximation for Other Than Gravity Flow

$$H = \frac{1044 \times G^{1.85}}{C_H^{\,1.85} \times ID^{4.865}}$$

WHERE

H = Friction loss in ft of H_2O/100 ft

G = Volumetric flow rate, gpm

= 2.449 x V x ID^2

V = Flow velocity, ft/sec

ID = Inside diameter, inches

C_H = Hazen Williams flow coefficient, dimensionless

= 150 for smooth wall polyethylene

The insertion of a smaller pipe within the existing system may appear to reduce the original flow capacity. However, in the majority of sliplining applications, this is not the case. The polyethylene liner is extremely smooth in comparison to most piping materials. The improved flow characteristic for clear water is evidenced by a comparatively low Manning Flow Coefficient, n of 0.009, and a Hazen-Williams coefficient, C_H, of 150.

While a reduction in pipe diameter does occur as a consequence of sliplining, it is largely compensated by the significant reduction in the Manning Flow Coefficient. As a result, flow capacity is maintained at or near the original flow condition.[18] Manning Flow Coefficients and Hazen-Williams Flow Coefficients for a variety of piping materials are listed in Table 2a and 2b. These factors may be used to approximate the relative flow capacities of various piping materials.

TABLE 2A
Typical Manning Flow Coefficients for Water Flowing through Common Piping Materials

Polyethylene (solid wall)	0.009
PVC	0.009
Cement-lined Ductile Iron	0.012
New Cast Iron, Welded Steel	0.014
Wood, Concrete	0.016
Clay, New Riveted Steel	0.017
Old Cast Iron, Brick	0.020
CSP	0.023
Severely Corroded Cast Iron	0.035

TABLE 2B
Typical Hazen-Williams Flow Coefficients for Water Flowing through Common Piping Materials[31]

Polyethylene (solid wall)	150
PVC	150
Cement-lined Ductile Iron	140
New Cast Iron, Welded Steel	130
Wood, Concrete	120
Clay, New Riveted Steel	110
Old Cast Iron, Brick	100
Severely Corroded Cast Iron	80

Quite often the hydraulic capacity of a gravity flow pipe can actually be improved by an insertion renewal. For example, consider the following illustrations of calculations using the Manning Equation (Eq. 6).

Calculation for Flow Rate, Q, through a 24-inch ID Concrete Pipe at 1% slope (1 ft/100 ft)

$$Q = \frac{1.486 \times 3.14 \times 1^2 \times 0.5^{0.667} \times 0.01^{0.5}}{0.016} = \mathbf{18.3\ ft^3/sec\ \ (8{,}248\ gpm)}$$

Calculation of Flow Rate, Q, through a 22-inch OD Polyethylene Pipe with a 20.65-Inch ID at 1% slope (1 ft/100 ft)

$$Q = \frac{1.486 \times 3.14 \times 0.8604^2 \times 0.429^{0.667} \times 0.01^{0.5}}{0.009} = \mathbf{21.8\ ft^3/sec\ (9{,}800\ gpm)}$$

Comparison of the two calculated flow rates shows that sliplining this 24-inch concrete pipe with the smaller polyethylene pipe actually improves the capacity by 1,000 gallons per minute. This will often be the situation. Occasionally, the theoretical flow capacity of the liner may appear to be equivalent to or slightly less than that of the original system. In many such cases, the presence of the liner eliminates the infiltration associated with the deterioration of the original pipe and the corresponding burden this places on the existing flow capacity. So an apparently small reduction in theoretical flow capacity may, in reality, prove to be quite acceptable since it eliminates the infiltration and the effect this produces on available hydraulic capacity.

Design the Accesses

The polyethylene liner will need to be connected to existing system components or appurtenances. Proper planning for a rehabilitation project must include the specific engineering designs by which these connections will be made.

Gravity flow pipeline rehabilitation often requires that the individual liner lengths be terminated at manholes or concrete headwalls that already exist within the system that is being sliplined. The annular space at these locations must provide a water-tight seal against continued infiltration in the void area that exists between the liner and the original pipe where they connect to these structures.

Typically, the required seal can be made by compacting a ring or collar of Okum saturated with non-shrink grout into the void area to a distance equal to one-half to one full liner diameter. The annular space is then "dressed" with a non-shrink elastomeric grout. The face of the elastomeric grout may then be covered with a quick-set chemical-resistant concrete. The same concrete material may then be used to reconstruct an invert in the manhole. This type of seal is shown in Figure 2.

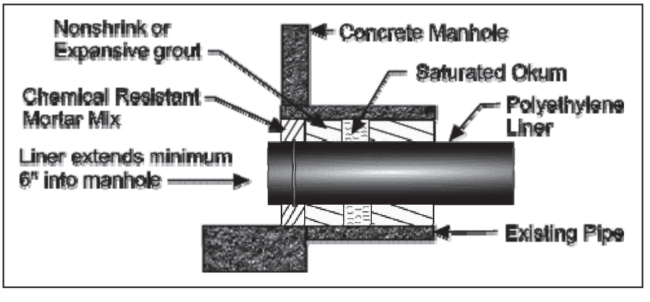

Figure 2 Typical Manhole Seal for Gravity Flow Applications

For those installations where a new manhole or headwall will be set, the amount of elastomeric grout may be minimized by fusing a water-stop or stub end onto the liner length before it is finally positioned. This fitting may then be embedded within the poured headwall or grouted into the new manhole. Some typical connecting arrangements for newly constructed appurtenances are shown in Figure 3. The connection described (water stop/wall anchor grouted in place) can also work on existing structures.

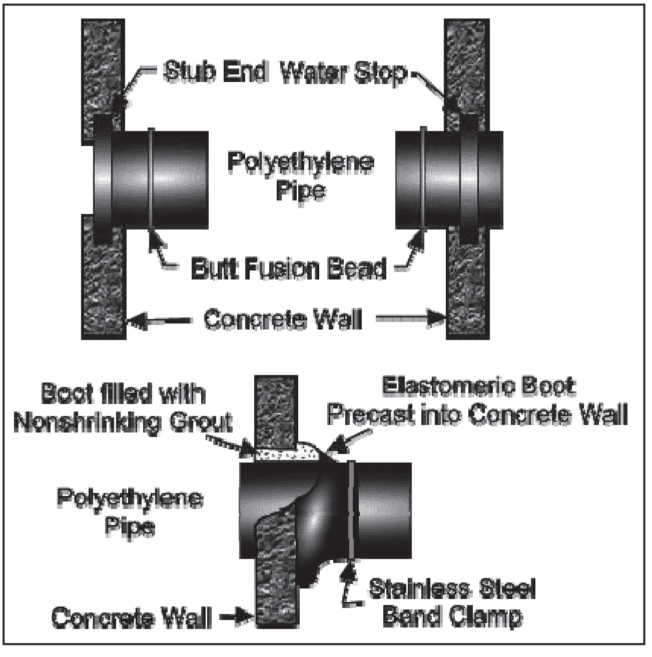

Figure 3 Newly Constructed Headwall or Manhole Placements

Deteriorated lateral service connections are a leading cause of infiltration in gravity flow pipelines.[19] An integral part of the insertion process is rebuilding these connections. This aspect of sliplining assures maximum reduction of infiltration, provides for long-term structural stability of the service, and minimizes the potential for continued deterioration of the existing pipe system.

Individual home services or other laterals may be connected to the liner by using any of several different connection methods. For example, upon relaxation of the liner, sanitary sewer connections may be made to the polyethylene liner by using a strap-on service saddle or a side-wall fusion fitting. Either of these options provides a secure water-tight connection to the liner and allows for effective renewal of the riser with no reduction in the inside diameter of the service. Both of these types of connection are shown in Figure 4.

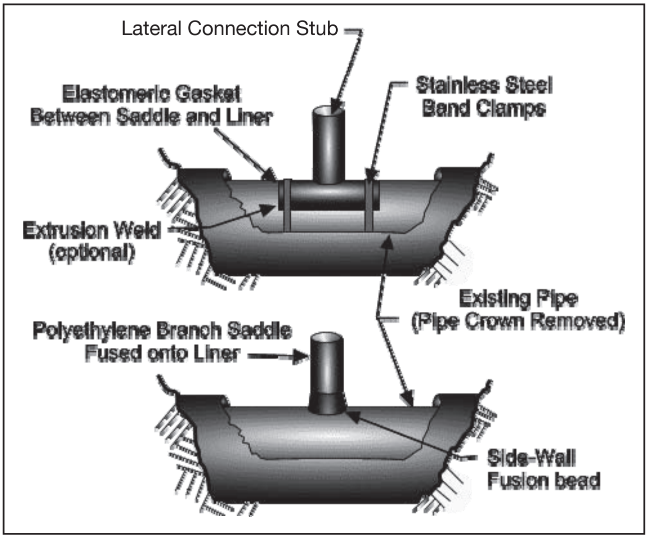

Figure 4 Lateral Service Connections for Sliplining Gravity Pipelines

Rehabilitation of pressure pipelines often requires that connections be made to lateral pressure-rated piping runs. Connections to these lines should be designed to insure full pressure capability of the rehabilitated system. Several alternatives are available to meet this requirement. These include in-trench fusion of molded or fabricated tees, sidewall fusion of branch saddles, insertion of spool pieces via electrofusion and insertion of low-profile mechanical connectors. One of these options is illustrated schematically in Figure 5. Performance requirements and installation parameters of the rehabilitation project most often dictate the selection of one specific connection design.

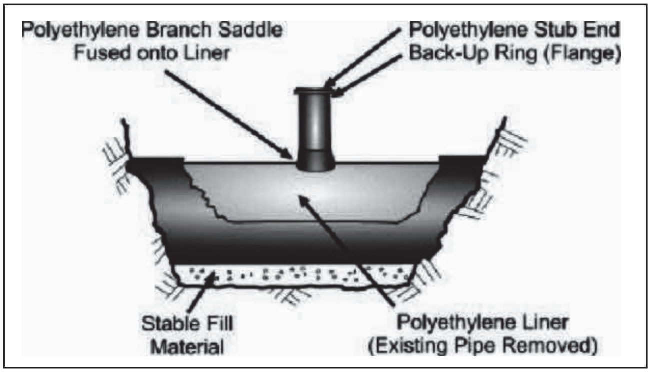

Figure 5 Typical Lateral Service Connection for Sliplining Pressure Pipelines

Develop the Contract Documents

When the rehabilitation design has been completed, attention will be focused on writing the specifications and contract documents that will ensure a successful installation. Reference documents for this purpose include: ASTM D3350(4), ASTM F585(5), ASTM F714(6), and ASTM F894.(7) To assist further in the development of these documents, a model sliplining specification is available from the Plastics Pipe Institute, "Guidance and Recommendations on the Use of Polyethylene (PE) Pipe for the Sliplining of Sewers."

The Sliplining Procedure

The standard sliplining procedure is normally a seven-step process. While the actual number of steps may vary to some degree in the field, the procedure remains the same for all practical purposes.(23,24) The procedures for rehabilitation of gravity and positive pressure pipelines are essentially the same. Some subtle differences become apparent in the manner by which some of the basic steps are implemented. The seven basic steps are as follows:

1. Inspect the existing pipe.
2. Clean and clear the line.
3. Join lengths of polyethylene pipe.
4. Access the original line.
5. Installation of the liner.
6. Make service and lateral connections.
7. Make terminal connections and stabilize the annular space.

1. Inspect the Existing Pipe

The first step for a sliplining project is the inspection of the existing pipe. This will determine the condition of the line and the feasibility of insertion renewal. During this step, identify the number and the locations of offset pipe segments and other potential obstructions.

Use a remote controlled closed circuit television camera to inspect the pipe interior. As the unit is pulled or floated through the original pipe, the pictures can be viewed and recorded with on-site television recording equipment.

2. Clean and Clear the Line

The existing pipeline needs to be relatively clean to facilitate placement of the polyethylene liner. This second step will ensure ease of installation. It may be accomplished by using cleaning buckets, kites or plugs, or by pulling a test section of polyethylene liner through the existing pipe structure.

Obviously, to attempt a liner insertion through a pipeline obstructed with excess sand, slime, tree roots or deteriorated piping components would be uneconomical or even impossible. Step 2 is often undertaken in conjunction with the inspection process of Step 1.

3. Weld Lengths of Polyethylene Pipe

Polyethylene pipe may be joined by butt fusion technology, gasketed bell and spigot joining methods, or by extrusion welding. The specific method to be used will be determined by the type of polyethylene pipe being inserted into the existing pipe structure. Solid wall polyethylene pipe is usually joined using butt fusion techniques. Polyethylene profile walled pipe, on the other hand, can be joined by integral gasketed bell and spigot joining methods or by the extrusion welding technique. Consult the manufacturer for the recommended procedure.

Butt Fusion — Solid Wall Pipe

Individual lengths of solid wall polyethylene pipe are joined by using the butt fusion process technique. The integrity of this joining procedure is such that, when it is performed properly, the strength of the resulting joint equals or exceeds the structural stability of the pipe itself. This facilitates the placement of a leak-free liner throughout the section of the existing system under rehabilitation.

The external fusion bead, formed during the butt fusion process, can be removed following the completion of joint quality assurance procedures by using a special tool prior to the insertion into the existing system. The removal of the bead may be necessary in cases of minimal clearance between the liner and the existing pipeline, but otherwise not required.

Pulling Lengths

Individual pulling lengths are usually determined by naturally occurring changes in grade or direction of the existing pipe system. Severe changes in direction that exceed the minimum recommended bending radius of the polyethylene liner may be used as access points. Likewise, severe offset joints, as revealed during the television survey, are commonly used as access points. By judicious planning, potential obstructions to the lining procedure may be used to an advantage.

There is a frequent question regarding the maximum pulling length for a given system. Ideally, each pull should be as long as economically possible without exceeding the tensile strength of the polyethylene material. It is rare that a pull of this magnitude is ever attempted. As a matter of practicality, pulling lengths are more often restricted by physical considerations at the job site or by equipment limitations.[23]

To ensure a satisfactory installation, the designer may want to analyze what is considered the maximum pulling length for a given situation. Maximum pulling length is a function of the tensile strength and weight of the polyethylene liner, the temperature at which the liner will be manipulated, the physical dimensions of the liner, and the frictional drag along the length of the polyethylene pipe liner.

Equations 8 and 9 are generally accepted for determination of the maximum feasible pulling length. One of the important factors in these calculations is the tensile strength of the particular polyethylene pipe product, which must be obtained from the manufacturer's literature.

(8) Maximum Pulling Force, MPF

$$MPF = f_y \times f_t \times T \times \pi \times OD^2 \left(\frac{1}{DR} - \frac{1}{DR^2} \right)$$

WHERE

MPF = Maximum pulling force, lb-force

f_y = Tensile yield design (safety) factor, 0.40

f_t = Time under tension design (safety) factor, 0.95*

T = Tensile yield strength, psi (Refer to Appendix, Chapter 3, for the appropriate value for the Material Designation Code of the PE pipe being used and the applicable service conditions.)

OD = Outside diameter, inches

DR = Dimension Ration, dimensionless

* The value of 0.95 is adequate for pulls up to 12 hours.

(9) Maximum Pulling Length, MPL

$$MPL = \frac{MPF}{W \times CF}$$

WHERE

MPL = Maximum straight pulling length on relatively flat surface, ft

MPF = Maximum pulling force, lb-force (Eq. 8)

W = Weight of pipe, lbs/ft

CF = Coefficient of friction, dimensionless

= 0.1, flow present through the host pipe

= 0.3, typical for wet host pipe

= 0.7, smooth sandy soil

Profile Wall Pipe

Profile wall PE pipe is available in the market place in different or unique wall constructions. Some of these products feature bell and spigot gasket type joint assembly; others are joined using one or more of the various heat fusion techniques such as, extrusion welding, butt fusion, and or electrofusion. The products having the bell and spigot gasketed joint arrangement must be pushed or "jacked" rather than pulled, into the line being rehabilitated. Because of this and the many other differences, it is not instructive or beneficial to try and cover all of these special products in this Handbook. Therefore, the reader who may have interest in learning more about the design and application of these products for pipeline rehabilitation service, is advised to consult directly with the product supplier.

4. Access the Original Line

Excavation of the access pits is the next step in the insertion renewal procedure. Access pits will vary considerably in size and configuration, depending on a number of project-related factors such as:

- Depth of the existing pipe
- Diameters of the liner and the existing pipe
- Stiffness of liner pipe
- Prevailing soil conditions
- Equipment availability
- Traffic and service requirements
- Job site geography

For example, a fairly large access pit may be required when attempting to slipline a large diameter system that is buried deep in relatively unstable soil. In contrast, the access pit for a smaller diameter pipeline that is buried reasonably shallow (5 to 8 feet) may be only slightly wider than the liner itself. In actual practice, the simpler situation is more prevalent. An experienced contractor will recognize the limiting factors at a particular job site and utilize them to the best economic advantage, thus assuring a cost-effective installation.

A typical access pit for sliplining with pre-fused or welded lengths of solid wall polyethylene pipe is illustrated in Figure 6. Figure 7 is a schematic of an access method that may be used with profile pipe.

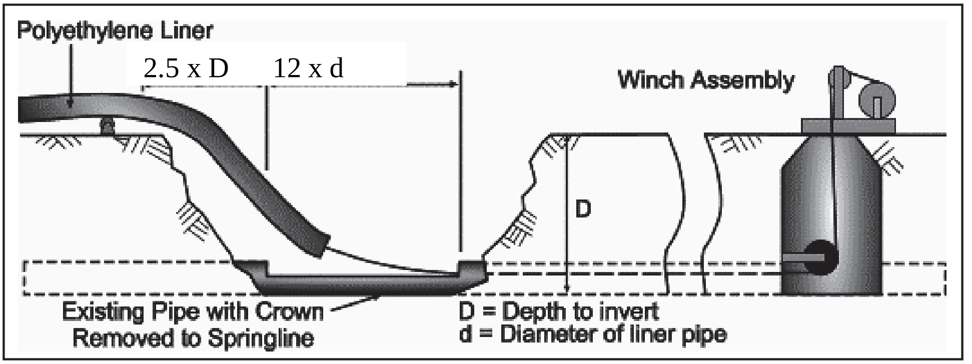

Figure 6 Typical Sliplining Access Pit for Prefused Lengths of Polyethylene Liner

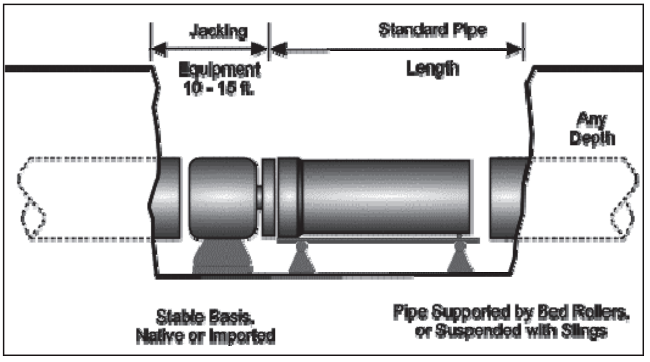

Figure 7 Typical Sliplining Access Pit for Bell and Spigot Polyethylene Liner

5. Installation of the Liner

Insertion of the polyethylene liner may be accomplished by one of several techniques. Prefused or welded lengths of solid wall polyethylene pipe may be "pulled" or "pushed" into place. Gasket-Jointed profile pipe, on the other hand, must be installed by the push method to maintain a water-tight seal.

The "Pulling" Technique

Prefused or welded lengths of polyethylene liner may be pulled into place by using a cable and winch arrangement. The cable from the winch is fed through the section of pipe that is to be sliplined. Then the cable is fastened securely to the liner segment, thus permitting the liner to be pulled through the existing pipe and into place.

Figure 6 is a schematic of an installation in which the liner is being pulled through the existing pipe from the left side toward a manhole at the right. This procedure requires some means, such as a pulling head, to attach the cable to the leading edge of the liner. The pulling head may be as simple or as sophisticated as the particular project demands or as economics may allow.

The pulling head may be fabricated of steel and fastened to the liner with bolts. They are spaced evenly around the circumference of the profile so that a uniform pulling force is distributed around the pipe wall. This type of fabricated pulling head will usually have a conical shape, aiding the liner as it glides over minor irregularities or through slightly offset joints in the old pipe system. The mechanical pulling head does not normally extend beyond the Outside Diameter (O.D.) of the polyethylene liner and is usually perforated to accommodate flow as quickly as possible once the liner is inserted inside the old system. Three practical styles of typical mechanical pulling heads are shown in Figure 8.

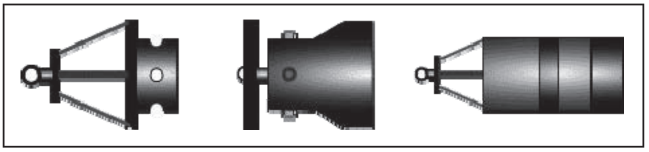

Figure 8 Fabricated Mechanical Pulling Heads

A less sophisticated but cost-effective approach is to fabricate a pulling head out of a few extra feet of liner that has been fused onto a single pipe pull. Cut evenly spaced wedges into the leading edge of the extra liner footage, making it look like the end of a banana being peeled. Collapse the ends toward the center and fasten them together with bolts or all-thread rods. Then attach the cable to secondary bolts that extend across the collapsed cross section. This simple technique is illustrated in Figure 9.

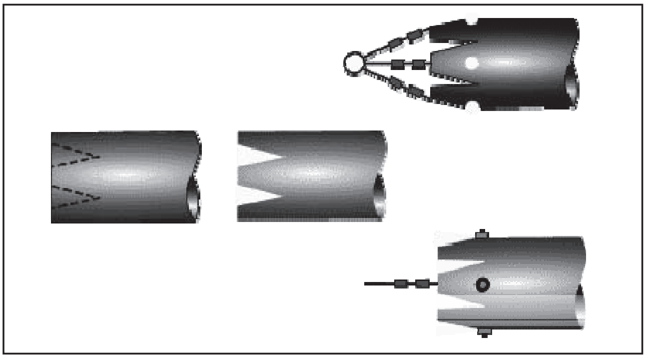

Figure 9 Field-Fabricated Pulling Heads

As the polyethylene liner is pulled into the pipeline, a slight elongation of the liner may occur. A 24-hour relaxation period will allow the liner to return to its original dimensions. After the relaxation period, the field fabricated pulling head may be cut off. It is recommended the liner be pulled past the termination point by 3-5%. This allows the liner to be accessible at the connection point after the relaxation period.

The pull technique permits a smooth and relatively quick placement of the liner within an old pipe system. However, this method may not be entirely satisfactory when attempting to install a large-diameter heavy-walled polyethylene pipe. This is especially true when the load requires an unusually large downstream winch. A similar problem may exist as longer and larger pulls are attempted so that a heavier pulling cable is required. When the pull technique is not practical, consider the advantages that may be offered by the push technique.

The "Push" Technique

The push technique for solid wall or welded polyethylene pipe is illustrated schematically in Figure 10. This procedure uses a choker strap, placed around the liner at a workable distance from the access point. A track-hoe, backhoe, or other piece of mechanical equipment pulls the choker to push the liner through the existing pipe. With each stroke of the backhoe, the choker grips the pipe and pushes the leading edge of the liner further into the deteriorated pipe. At the end of each stroke, the choker must be moved back on the liner, usually by hand. The whole process may be assisted by having a front-end loader or bulldozer simultaneously push on the trailing end of the liner segment.

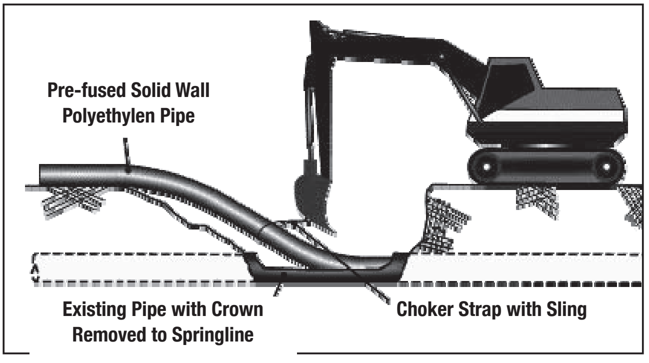

Figure 10 Pushing Technique for Solid Wall Polyethylene Pipe

Gasketed PE pipe requires the use of the push technique in order to keep the joints from separating, as well as to position the liner. The push technique for gasketed pipe is shown schematically in Figure 10. This process inserts the liner without the necessity for having a high capacity winch and cable system.

The Combination Technique

The pushing and pulling techniques can sometimes be combined to provide the most efficient installation method. Typically, this arrangement can be used when attempting the placement of unusually heavy walled or long lengths of polyethylene liner.

Flow Control

For most insertion renewal projects it is not necessary to eliminate the entire flow stream within the existing pipe structure. Actually, some amount of flow can assist positioning of the liner by providing a lubricant along the liner length as it moves through the deteriorated pipe structure. However, an excessive flow can inhibit the insertion process. Likewise, the disruption of a flow stream in excess of 50% of pipe capacity should be avoided.

The insertion procedure should be timed to take advantage of cyclic periods of low flow that occur during the operation of most gravity piping systems. During the insertion of the liner, often a period of 30 minutes or less, the annular space will probably carry sufficient flow to maintain a safe level in the operating sections of the system being rehabilitated. Flow can then be diverted into the liner upon final positioning of the liner. During periods of extensive flow blockage, the upstream piping system can be monitored to avoid unexpected flooding of drainage areas.

Consider establishing a flow control procedure for those gravity applications in which the depth of flow exceeds 50%. The flow may be controlled by judicious operation of pump stations, plugging or blocking the flow, or bypass pumping of the flow stream.

Pressurized piping systems will require judicious operation of pump stations during the liner installation.

6. Make Service and Lateral Connections

After the recommended 24-hour relaxation period following the insertion of the polyethylene liner, each individual service connection and lateral can be added to the new system. One common method of making these connections involves the use of a wrap-around service saddle. The saddle is placed over a hole that has been cut through the liner and the entire saddle and gasket assembly is then fastened into place with stainless steel bands. Additional joint integrity can be obtained by extrusion welding of the lap joint created between the saddle base and the liner. The service lateral can then be connected into the saddle, using a readily available flexible coupling(11). Once the lateral has been connected, following standard direct burial procedures can stabilize the entire area.

For pressure applications, lateral connections can be made using sidewall fusion of branch saddles onto the liner. As an alternate, a molded or fabricated tee may be fused or flanged into the liner at the point where the lateral connection is required (see Figures 3 and 4). Mechanical fittings are also a viable option; refer to Chapter 9, PE Joining Procedures, in this Handbook.

7. Make Terminal Connections and Stabilize the Annular Space Where Required

Making the terminal connections of the liner is the final step in the insertion renewal procedure. Pressurized pipe systems will require connection of the liner to the various system appurtenances. These terminal connections can be made readily through the use of pressure-rated polyethylene fittings and flanges with fusion technology. Several common types of pressurized terminal connections are illustrated in Figure 11. All of these require stabilization of the transition region to prevent point loading of the liner. Mechanical Joint (MJ) Adapters can be used. Refer to Chapter 9, PE Joining Procedures, in this Handbook.

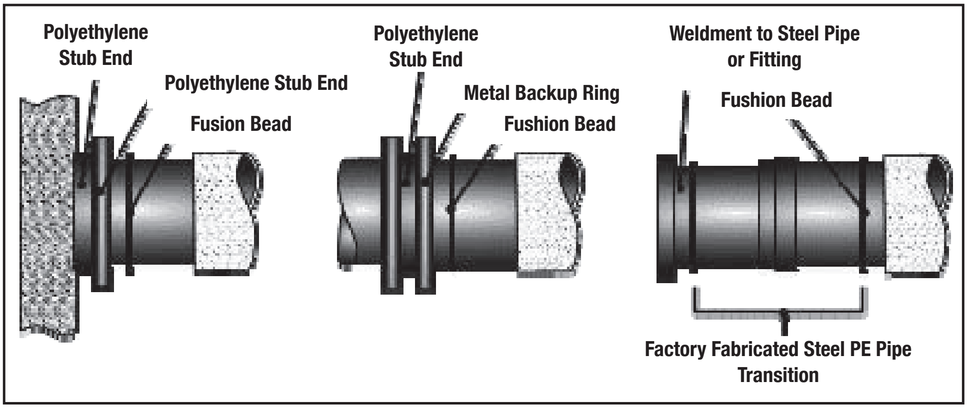

Figure 11 Terminal and Transition Connections for Pressurized Insertion Renewal Projects

Gravity lines do not typically require pressure-capable connections to the other system appurtenances. In these situations, the annular space will be sealed to prevent migration of ground water along the annulus and, ultimately, infiltration through the manhole or headwall connection. The typical method for making this type of connection is shown in Figure 11. Sealing materials should be placed by gravity flow methods so that the liner's buckling resistance is not exceeded during installation. Consideration should be given to the specific load bearing characteristics of the fill material in light of the anticipated loading of the liner.

Other Rehabilitation Methods

Rehabilitation by sliplining is only one (but probably the most popular) of a number of methods using polyethylene pipe currently available for pipeline rehabilitation. As mentioned in the introduction to this chapter, sliplining has been in use for more than thirty years.

Several other methods of rehabilitation that use polyethylene piping will be described briefly here. Please note that, due to rapidly advancing technology, this listing may become incomplete very quickly. Also note that any reference to proprietary products or processes is made only as required to explain a particular methodology.

Swagelining

A continuous length of polyethylene pipe passes through a machine where it is heated. It then passes through a heated die, which reduces the outside diameter (OD). Insertion into the original pipeline then follows through an insertion pit. The liner pipe relaxes (pressurization may be used to speed the process) until the OD of the liner matches the inside diameter (ID) of the original pipeline. Grouting is not required.

Rolldown

This system is very similar to swagelining except OD reduction is by mechanical means and expansion is through pressurization.

Titeliner

A system that is very similar to the swagelining and rolldown systems.

Fold and Form

Continuous lengths of polyethylene pipe are heated, mechanically folded into a "U" shape, and then coiled for shipment. Insertion is made through existing manholes. Expansion is by means of a patented heat/pressure procedure, which utilizes steam. The pipe is made, according to the manufacturer, to conform to the ID of the original pipeline; therefore, grouting is not required.

Pipe Bursting

A technique used for replacing pipes made from brittle materials, e.g. clay, concrete, cast iron, etc. A bursting head (or bursting device) is moved through the pipe, simultaneously shattering it, pushing the shards aside, and drawing in a polyethylene replacement pipe. This trenchless technique makes it possible to install pipe as much as 100% larger than the existing pipe.

Pipe Splitting

A technique, similar to pipe bursting, used for pipes made from ductile materials, e.g. steel, ductile iron, plastic, etc. A "splitter" is moved through the existing pipe, simultaneously splitting it with cutter wheels, expanding it, and drawing in a polyethylene replacement pipe. This trenchless technique is generally limited to replacement with same size or one pipe size (ie., 6" to 8") larger replacement pipe.

Summary

This chapter has provided an introductory discussion on the rehabilitation of a deteriorated pipe structure by insertion renewal with continuous lengths of polyethylene pipe. It also includes a brief description of other rehabilitation methods that utilize polyethylene piping. The sliplining or insertion renewal procedure is a cost-effective means by which a new pipeline is obtained with a minimum interference with surface traffic. An inherent benefit of the technology is the installation of a new, structurally sound, leak-free piping system with improved flow characteristics. The resulting pipe structure allows for a flow capacity at or near that of the deteriorating pipe system while eliminating the potential for infiltration or exfiltration. And the best feature of all is the vastly improved longevity of the PE pipe, especially compared to the decay normally associated with piping materials of the past.

The continuing deterioration of this country's infrastructure necessitates innovative solutions to persistent and costly problems. Insertion renewal, or sliplining, is a cost-effective means by which one aspect of the infrastructure dilemma may be corrected without the expense and long-term service disruption associated with pipeline replacement.

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Chapter 12

Horizontal Directional Drilling

Introduction

The Horizontal Directional Drilling (HDD) Industry has experienced so much growth in the past two decades that HDD has become commonplace as a method of installation. One source reported that the number of units in use increased by more than a hundred-fold in the decade following 1984. This growth has been driven by the benefits offered to utility owners (such as the elimination of traffic disruption and minimal surface damage) and by the ingenuity of contractors in developing this technology. To date, HDD pipe engineering has focused on installation techniques, and rightfully so. In many cases, the pipe experiences its maximum lifetime loads during the pullback operation.

The purpose of this chapter is to acquaint the reader with some of the important considerations in selecting the proper PE pipe. Proper selection of pipe involves consideration not only of installation design factors such as pullback force limits and collapse resistance, but also of the long-term performance of the pipe once installed in the bore-hole. The information herein is not all-inclusive; there may be parameters not discussed that will have significant bearing on the proper engineering of an application and the pipe selection. For specific projects, the reader is advised to consult with a qualified engineer to evaluate the project and prepare a specification including recommendations for design and installation and for pipe selection. The reader may find additional design and installation information in ASTM F1962, “Standard Guide for Use of Maxi-Horizontal Directional Drilling for Placement of PE Pipe or Conduit Under Obstacles, Including River Crossings,” and in the ASCE Manual of Practice 108, “Pipeline Design for Installation by Directional Drilling.”

Background

Some of the earliest uses of large diameter PE pipe in directional drilling were for river crossings. These are major engineering projects requiring thoughtful design, installation, and construction, while offering the owner the security of deep river bed cover with minimum environmental damage or exposure, and no disruption of river traffic. PE pipe is suited for these installations because of its scratch tolerance and the fused joining system which gives a zero-leak-rate joint with design tensile capacity equal to that of the pipe.

To date, directional drillers have installed PE pipe for gas, water, and sewer mains; communication conduits; electrical conduits; and a variety of chemical lines. These projects involved not only river crossings but also highway crossings and right-of-ways through developed areas so as not to disturb streets, driveways, and business entrances.

PE Pipe for Horizontal Directional Drilling

This chapter gives information on the pipe selection and design process. It is not intended to be a primer on directional drilling. The reader seeking such information can refer to the references of this chapter. Suggested documents are the "Mini-Horizontal Directional Drilling Manual" (1) and the "Horizontal Directional Drilling Good Practices Guidelines" (2) published by the North American Society for Trenchless Technology (NASTT).

Horizontal Directional Drilling Process

Knowledge of the directional drilling process by the reader is assumed, but some review may be of value in establishing common terminology. Briefly, the HDD process begins with boring a small, horizontal hole (pilot hole) under the crossing obstacle (e.g. a highway) with a continuous string of steel drill rod. When the bore head and rod emerge on the opposite side of the crossing, a special cutter, called a back reamer, is attached and pulled back through the pilot hole. The reamer bores out the pilot hole so that the pipe can be pulled through. The pipe is usually pulled through from the side of the crossing opposite the drill rig.

Pilot Hole

Pilot hole reaming is the key to a successful directional drilling project. It is as important to an HDD pipeline as backfill placement is to an open-cut pipeline. Properly trained crews can make the difference between a successful and an unsuccessful drilling program for a utility. Several institutions provide operator-training programs, one of which is University of Texas at Arlington Center for Underground Infrastructure Research and Education (CUIRE). Drilling the pilot hole establishes the path of the drill rod ("drill-path") and subsequently the location of the PE pipe. Typically, the bore-head is tracked electronically so as to guide the hole to a pre-designed configuration. One of the key considerations in the design of the drill-path is creating as large a radius of curvature as possible within the limits of the right-of-way, thus minimizing curvature. Curvature induces bending stresses and increases the pullback load due to the capstan effect. The capstan effect is the increase in frictional drag when pulling the pipe around a curve due to a component of the pulling force acting normal to the curvature. Higher tensile stresses reduce the pipe's collapse resistance. The drill-path normally has curvature along its vertical profile. Curvature requirements are dependent on site geometry (crossing length, required depth to provide safe cover, staging site location, etc.) But, the degree of curvature is limited by the bending radius of the drill rod and the pipe. More often, the permitted bending radius of the drill rod controls the curvature and thus significant bending stresses do not occur in the pipe. The designer should minimize the number of curves and maximize their radii of curvature in the right-of-way by carefully choosing the entry and exit points. The driller should also attempt to minimize extraneous curvature due to undulations (dog-legs) from frequent over-correcting alignment or from differences in the soil strata or cobbles.

Pilot Hole Reaming

The REAMING operation consists of using an appropriate tool to open the pilot hole to a slightly larger diameter than the carrier pipeline. The percentage oversize depends on many variables including soil types, soil stability, depth, drilling mud, borehole hydrostatic pressure, etc. Normal over-sizing may be from 1.2 to 1.5 times the diameter of the carrier pipe. While the over-sizing is necessary for insertion, it means that the inserted pipe will have to sustain vertical earth pressures without significant side support from the surrounding soil.

Prior to pullback, a final reaming pass is normally made using the same sized reamer as will be used when the pipe is pulled back (swab pass). The swab pass cleans the borehole, removes remaining fine gravels or clay clumps and can compact the borehole walls.

Drilling Mud

Usually a "drilling mud" such as fluid bentonite clay is injected into the bore during cutting and reaming to stabilize the hole and remove soil cuttings. Drilling mud can be made from clay or polymers. The primary clay for drilling mud is sodium montmorillonite (bentonite). Properly ground and refined bentonite is added to fresh water to produce a "mud." The mud reduces drilling torque, and gives stability and support to the bored hole. The fluid must have sufficient gel strength to keep cuttings suspended for transport, to form a filter cake on the borehole wall that contains the water within the drilling fluid, and to provide lubrication between the pipe and the borehole on pullback. Drilling fluids are designed to match the soil and cutter. They are monitored throughout the process to make sure the bore stays open, pumps are not overworked, and fluid circulation throughout the borehole is maintained. Loss of circulation could cause a locking up and possibly overstressing of the pipe during pullback.

Drilling muds are thixotropic and thus thicken when left undisturbed after pullback. However, unless cementitious agents are added, the thickened mud is no stiffer than very soft clay. Drilling mud provides little to no soil side-support for the pipe.

Pullback

The pullback operation involves pulling the entire pipeline length in one segment (usually) back through the drilling mud along the reamed-hole pathway. Proper pipe handling, cradling, bending minimization, surface inspection, and fusion welding procedures need to be followed. Axial tension force readings, constant insertion velocity, mud flow circulation/exit rates, and footage length installed should be recorded. The pullback speed ranges usually between 1 to 2 feet per minute.

Mini-Horizontal Directional Drilling

The Industry distinguishes between mini-HDD and conventional HDD, which is sometimes referred to as maxi-HDD. Mini-HDD rigs can typically handle pipes up to 10″ or 12″ diameter and are used primarily for utility construction in urban areas, whereas HDD rigs are typically capable of handling pipes as large as 48″diamter. These machines have significantly larger pullback forces ranging up to several hundred thousand pounds.

General Guidelines

The designer will achieve the most efficient design for an application by consulting with an experienced contractor and a qualified engineer. Here are some general considerations that may help particularly in regard to site location for PE pipes:

1. Select the crossing route to keep it to the shortest reasonable distance.
2. Find routes and sites where the pipeline can be constructed in one continuous length; or at least in long multiple segments fused together during insertion.
3. Although compound curves have been done, try to use as straight a drill path as possible.
4. Avoid entry and exit elevation differences in excess of 50 feet; both points should be as close as possible to the same elevation.

5. Locate all buried structures and utilities within 10 feet of the drill-path for mini-HDD applications and within 25 feet of the drill-path for maxi-HDD applications. Crossing lines are typically exposed for exact location.

6. Observe and avoid above-ground structures, such as power lines, which might limit the height available for construction equipment.

7. The HDD process takes very little working space versus other methods. However, actual site space varies somewhat depending upon the crossing distance, pipe diameter, and soil type.

8. Long crossings with large diameter pipe need bigger, more powerful equipment and drill rig.

9. As pipe diameter increases, large volumes of drilling fluids must be pumped, requiring more/larger pumps and mud-cleaning and storage equipment.

10. Space requirements for maxi-HDD rigs can range from a 100 feet wide by 150 feet long entry plot for a 1000 ft crossing up to 200 feet wide by 300 feet long area for a crossing of 3000 or more feet.

11. On the pipe side of the crossing, sufficient temporary space should be rented to allow fusing and joining the PE carrier pipe in a continuous string beginning about 75 feet beyond the exit point with a width of 35 to 50 feet, depending on the pipe diameter. Space requirements for coiled pipe are considerably less. Larger pipe sizes require larger and heavier construction equipment which needs more maneuvering room (though use of PE minimizes this). The initial pipe side "exit" location should be about 50' W x 100' L for most crossings, up to 100' W x 150' L for equipment needed in large diameter crossings.

12. Obtain "as-built" drawings based on the final course followed by the reamer and the installed pipeline. The gravity forces may have caused the reamer to go slightly deeper than the pilot hole, and the buoyant pipe may be resting on the crown of the reamed hole. The as-built drawings are essential to know the exact pipeline location and to avoid future third party damage.

Safety

Safety is a primary consideration for every directionally drilled project. While this chapter does not cover safety, there are several manuals that discuss safety including the manufacturer's Operator's Manual for the drilling rig and the Equipment Manufacturer's Institute (EMI) Safety Manual: *Directional Drilling Tracking Equipment*.[3]

Geotechnical Investigation

Before any serious thought is given to the pipe design or installation, the designer will normally conduct a comprehensive geotechnical study to identify soil formations at the potential bore sites. The purpose of the investigation is not only to determine if directional drilling is feasible, but to establish the most efficient way to accomplish it. With this information the best crossing route can be determined, drilling tools and procedures selected, and the pipe designed. The extent of the geotechnical investigation often depends on the pipe diameter, bore length and the nature of the crossing. Refer to ASTM F1962, Guide for Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossings [(4)] and ASCE MOP 108, Pipeline Design for Installation by Horizontal Directional Drilling [(5)] for additional information.

During the survey, the geotechnical consultant will identify a number of relevant items including the following:

a. Soil identification to locate rock, rock inclusions, gravelly soils, loose deposits, discontinuities and hardpan.

b. Soil strength and stability characteristics

c. Groundwater

(Supplemental geotechnical data may be obtained from existing records, e.g. recent nearby bridge constructions, other pipeline/cable crossings in the area.)

For long crossings, borings are typically taken at 700 ft intervals. For short crossings (1000 ft or less), as few as three borings may suffice. The borings should be near the drill-path to give accurate soil data, but sufficiently far from the borehole to avoid pressurized mud from following natural ground fissures and rupturing to the ground surface through the soil-test bore hole. A rule-of -thumb is to take borings at least 30 ft to either side of bore path. Although these are good general rules, the number, depth and location of boreholes is best determined by the geotechnical engineer.

Geotechnical Data For River Crossings

River crossings require additional information such as a study to identify river bed, river bed depth, stability (lateral as well as scour), and river width. Typically, pipes are installed to a depth of at least 20 ft below the expected future river bottom, considering scour. Soil borings for geotechnical investigation are generally conducted to 40 ft below river bottom.

Summary

The best conducted projects are handled by a team approach with the design engineer, bidding contractors and geotechnical engineer participating prior to the preparation of contract documents. The geotechnical investigation is usually the first step in the boring project. Once the geotechnical investigation is completed, a determination can be made whether HDD can be used. At that time, design of both the PE pipe and the installation can begin. The preceding paragraphs represent general guidance and considerations for planning and designing an HDD PE pipeline project. These overall topics can be very detailed in nature. Individual HDD contractors and consultant engineering firms should be contacted and utilized in the planning and design stage. Common sense along with a rational in-depth analysis of all pertinent considerations should prevail. Care should be given in evaluating and selecting an HDD contractor based upon successful projects, qualifications, experience and diligence. A team effort, strategic partnership and risk-sharing may be indicated.

Product Design: PE Pipe DR Selection

After completion of the geotechnical investigation and determination that HDD is feasible, the designer turns attention to selecting the proper pipe. The proper pipe must satisfy all hydraulic requirements of the line including flow capacity, working pressure rating, and surge or vacuum capacity. These considerations have to be met regardless of the method of installation. Design of the pipe for hydraulic considerations can be found in Chapter 6. For HDD applications, in addition to the hydraulic requirements, the pipe must be able to withstand (1) pullback loads which include tensile pull forces, external hydrostatic pressure, and tensile bending stresses, and (2) external service loads (post-installation soil, groundwater, and surcharge loads occurring over the life of the pipeline). Often the load the pipe sees during installation such as the combined pulling force and external pressure will be the largest load experienced by the pipe during its life. The remainder of this document will discuss the DR (Dimension Ratio) selection based on pullback and external service loads. (PE pipe is classified by DR. The DR is the “dimension ratio” and equals the pipe’s outer diameter divided by the minimum wall thickness.) A more detailed explanation of the DR concept is provided in Chapter 5.

While this chapter gives guidelines to assist the designer, the designer assumes all responsibility for determining the appropriateness and applicability of the equations and parameters given in this chapter for any specific application. Directional drilling is an evolving technology, and industry-wide design protocols are still developing. Proper design requires considerable professional judgment beyond the scope of this chapter. The designer is advised to consult ASTM F 1962, Guide for Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit

Under Obstacles, Including River Crossings [4] when preparing an HDD design. This methodology is applied to designing municipal water pipe crossings as shown in Petroff [6].

Normally, the designer starts the DR selection process by determining the DR requirement for the internal pressure. The designer will then determine if this DR is sufficient to withstand earth, live, and groundwater service loads. If so, then the installation (pullback) forces are considered. Ultimately, the designer chooses a DR that will satisfy all three requirements: the pressure, the service loads, and the pullback load.

Although there can be some pipe wall stresses generated by the combination of internal pressurization and wall bending or localized bearing, generally internal pressure and external service load stresses are treated as independent. This is permissible primarily since PE is a ductile material and failure is usually driven by the average stress rather than local maximums. There is a high safety factor applied to the internal pressure, and internal pressurization significantly reduces stresses due to external loads by re-rounding. (One exception to this is internal vacuum, which must be combined with the external pressure.)

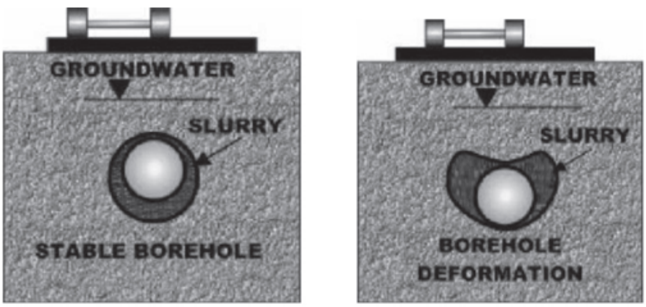

Figure 1 Borehole Deformation

Design Considerations for Net External Loads

This and the following sections will discuss external buried loads that occur on directionally drilled pipes. One important factor in determining what load reaches the pipe is the condition of the borehole, i.e. whether it stays round and open or collapses. This will depend in great part on the type of ground, the boring techniques, and the presence of slurry (drilling mud and cutting mixture). If the borehole does not deform (stays round) after drilling, earth loads are arched around the borehole and little soil pressure is transmitted to the pipe. The pressure acting on the pipe is the hydrostatic pressure due to the slurry or any groundwater present. The slurry itself may act to keep the borehole open. If the borehole collapses or deforms substantially, earth pressure will be applied to the pipe. The resulting pressure could exceed the slurry pressure unless considerable tunnel arching occurs above the borehole. Where no tunnel arching occurs, the applied external pressure is equal to the combined earth, groundwater, and live-load pressure. For river crossings, in unconsolidated river bed soils, little arching is anticipated . The applied pressure likely equals the geostatic stress (sometimes called the prism load). In consolidated soils, arching above the borehole may occur, and the applied pressure will likely be less than the geostatic stress, even after total collapse of the borehole crown onto the pipe. If the soil deposit is a stiff clay, cemented, or partially lithified, the borehole may stay open with little or no deformation. In this case, the applied pressure is likely to be just the slurry head or groundwater head.

In addition to the overt external pressures such as slurry head and groundwater, internal vacuum in the pipe results in an increase in external pressure due to the removal of atmospheric pressure from inside the pipe. On the other hand, a positive internal pressure in the pipe may mediate the external pressure. The following equations can be used to establish the net external pressure or, as it is sometimes called, the differential pressure between the inside and outside of the pipe.

Depending on the borehole condition, the net external pressure is defined by either Eq. 1 (deformed/collapsed borehole) or Eq. 2 (open borehole):

(1) $$P_N = P_E + P_{GW} + P_{SUR} - P_I$$

(2) $$P_N = P_{MUD} - P_I$$

WHERE

P_N **= Net external pressure, psi**

P_E **= External pressure due to earth pressure, psi**

P_{GW} **= Groundwater pressure (including the height of river water), psi**

P_{SUR} **= Surcharge and live loads, psi**

P_I **= Internal pressure, psi (negative in the event of vacuum)**

P_{MUD} **= Hydrostatic pressure of drilling slurry or groundwater pressure, if slurry can carry shear stress, psi**

(Earth, ground water, and surcharge pressures used in Eq. 1 are discussed in a following section of this chapter.)

(3) $$P_{MUD} = \frac{g_{MUD} H_B}{144}$$

WHERE

g_{MUD} **= Unit weight of slurry (drilling mud and cuttings), pcf**

H_B **= Elevation difference between lowest point in borehole and entry or exit pit, ft**

(144 is included for units conversion.)

When calculating the net external pressure, the designer will give careful consideration to enumerating all applied loads and their duration. In fact, most pipelines go through operational cycles that include (1) unpressurized or being drained, (2) operating at working pressure, (3) flooding, (4) shutdowns, and (5) vacuum and peak pressure events. As each of these cases could result in a different net external pressure, the designer will consider all phases of the line's life to establish the design cases.

In addition to determining the load, careful consideration must be given to the duration of each load. PE pipe is viscoelastic, that is, its effective properties depend on duration of loading. For instance, an HDD conduit resists constant groundwater and soil pressure with its long-term apparent modulus stiffness. On the other hand, an HDD force-main may be subjected to a sudden vacuum resulting from water hammer. When a vacuum occurs, the net external pressure equals the sum of the external pressure plus the vacuum. Since surge is instantaneous, it is resisted by the pipe's short-term apparent modulus,, which can be four times higher than the long-term apparent modulus.

For pressure lines, consideration should be given to the time the line sits unpressurized after construction. This may be several months. Most directionally drilled lines that contain fluid will have a static head, which will remain in the line once filled. This head may be subtracted from the external pressure due to earth/groundwater load. The designer should keep in mind that the external load also may vary with time, for example, flooding.

Earth and Groundwater Pressure

Earth loads can reach the pipe when the borehole deforms and contacts the pipe. The amount of soil load transmitted to the pipe will depend on the extent of deformation and the relative stiffness between the pipe and the soil. Earth loading may not be uniform. Due to this complexity, there is not a simple equation for relating earth load to height of cover. Groundwater loading will occur whether the hole deforms or not; the only question is whether or not the slurry head is higher and thus may in fact control design. Thus, what loads reach the pipe will depend on the stability of the borehole.

The designer may wish to consult a geotechnical engineer for assistance in determining earth and groundwater loads, as the loads reaching the pipe depend on the nature of the soil.

Stable Borehole - Groundwater Pressure Only

A borehole is called stable if it remains round and deforms little after drilling. For instance, drilling in competent rock (rock that can be drilled without fracturing and collapsing) will typically result in a stable borehole. Stable boreholes may occur in some soils where the slurry exerts sufficient pressure to maintain a round and open hole. Since the deformations around the hole are small, soil pressures transmitted to the pipe are negligible. The external load applied to the pipe consists only of the hydrostatic pressure due to the slurry or the groundwater, if present. Equation 4 gives the hydrostatic pressure due to groundwater or drilling slurry. Standing surface water should be added to the groundwater.

(4)

$$P_{GW} = \frac{g_W H_W}{144}$$

WHERE

P_{GW} = **Hydrostatic fluid pressure due to ground and surface water, psi**

g_w = **Unit weight of water, pcf**

H_W = **Height to free water surface above pipe, ft (144 is included for correct units conversion.)**

Borehole Deforms/Collapse With Arching Mobilized

When the crown of the hole deforms sufficiently to place soil above the hole in the plastic state, arching is mobilized. In this state, hole deformation is limited. If no soil touches the pipe, there is no earth load on the pipe. However, when deformation is sufficient to transmit load to the pipe, it becomes the designer's chore to determine how much earth load is applied to the pipe. At the time of this writing, there have been no published reports giving calculation methods for finding earth load on directionally drilled pipes. Based on the successful performance of directionally drilled PE pipes, it is reasonable to assume that some amount of arching occurs in many applications. The designer of HDD pipes may gain some knowledge from the approaches developed for determining earth pressure on auger bored pipes and on jacked pipes. It is suggested that the designer become familiar with all of the assumptions used with these methods. For additional information on post installation design of directionally drilled pipelines see Petroff (9).

O'Rourke et. al. (7) published an equation for determining the earth pressure on auger bored pipes assuming a borehole approximately 10% larger than the pipe. In this model, arching occurs above the pipe similar to that in a tunnel where zones of loosened soil fall onto the pipe. The volume of the cavity is eventually filled with soil that is slightly less dense than the insitu soil, but still capable of transmitting soil load. This method of load calculation gives a minimal loading. The method published here is more conservative. It is based on trench type arching as opposed to tunnel arching and is used by Stein (8) to calculate loads on jacked pipe. In Stein's model, the maximum earth load (effective stress) is found using the modified form of Terzaghi's equation given by Eq. 6., Petroff (9). External groundwater pressure must be added to the effective earth pressure. Stein and O'Rourke's methods should only be considered where the depth of cover is sufficient to develop arching (typically exceeding five (5) pipe diameters), dynamic loads such as traffic loads are insignificant, the soil has sufficient internal friction to transmit arching, and conditions are confirmed by a geotechnical engineer.

Using the equations given in Stein, the external pressure is given below:

(5)

$$P_E = \frac{k\, g_{SE} H_C}{144}$$

(6)

$$k = \frac{1 - \exp\left(-2 \dfrac{KH_C}{B} \tan\left(\dfrac{\delta}{2}\right)\right)}{2 \dfrac{KH_C}{B} \tan\left(\dfrac{\delta}{2}\right)}$$

WHERE

P_E = **external earth pressure, psi**

g_{SE} = **effective soil weight, pcf**

H_C = **depth of cover, ft**

k = **arching factor**

B = **"silo" width, ft**

δ = **angle of wall friction, degrees (For HDD, δ = f)**

f = **angle of internal friction, degrees**

K = **earth pressure coefficient given by:**

$$K = \tan^2\left(45 - \frac{f}{2}\right)$$

The "silo" width should be estimated based on the application. It varies between the pipe diameter and the borehole diameter. A conservative approach is to assume the silo width equals the borehole diameter. (The effective soil weight is the dry unit weight of the soil for soil above the groundwater level, it is the saturated unit weight less the weight of water for soil below the groundwater level.)

Borehole Collapse with Prism Load

In the event that arching in the soil above the pipe breaks down, considerable earth loading may occur on the pipe. In the event that arching does not occur, the upper limit on the load is the weight of the soil prism ($P_E = g_{SE}H_C$) above the pipe. The prism load is most likely to develop in shallow applications subjected to live loads, boreholes in unconsolidated sediments such as in some river crossings, and holes subjected to dynamic loads. The "prism" load is given by Eq. 7.

(7)
$$P_E = \frac{g_{SE} H_C}{144}$$

WHERE

P_E **= earth pressure on pipe, psi**

g_{SE} **= effective weight of soil, pcf**

H_C **= soil height above pipe crown, ft**

(Note: 144 is included for units conversion.)

Combination of Earth and Groundwater Pressure

Where groundwater is present in the soil formation, its pressure must be accounted for in the external load term. For instance, in a river crossing one can assume with reasonable confidence that the directionally drilled pipe is subjected to the earth pressure from the sediments above it combined with the water pressure.

Case 1 Water level at or below ground surface

(8)
$$P_E + P_{GW} = \frac{g_B H_W + g_D (H_C - H_W) + g_W H_W}{144}$$

Case 2 Water level at or above ground surface (i.e. pipe in river bottom)

(9)
$$P_E + P_{GW} = \frac{g_B H_C + g_W H_W}{144}$$

WHERE

H_W **= Height of Ground water above pipe springline, ft**

H_C **= height of cover, ft**

g_B **= buoyant weight of soil, pcf**

g_W **= weight of water, pcf**

g_D **= dry unit weight of soil, pcf**

Live Loads

Wheel loads from trucks or other vehicles are significant for pipe at shallow depths whether they are installed by open cut trenching or directional drilling. The wheel load applied to the pipe depends on the vehicle weight, the tire pressure and size, vehicle speed, surface smoothness, pavement and distance from the pipe to the point of loading. In order to develop proper soil structure interaction, pipe subject to vehicular loading should be installed at least 18" or one pipe diameter (whichever is larger) under the road surface. Generally, HDD pipes are always installed at a deeper depth so as to prevent inadvertent returns from occurring during the boring.

The soil pressure due to live load such as an H20 wheel load can be found in Tables 3-3 and 3-4 in Chapter 6 or can be calculated using one of the methods in Chapter 6. To find the total pressure applied to the pipe, add the soil pressure due to live load, P_L, to the earth pressure, P_E. See Example 1 in Appendix A.

Performance Limits

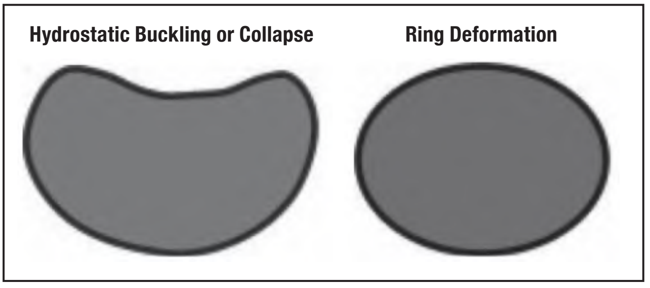

Figure 2 Performance Limits of HDD Pipe Subjected to Service Loads

Performance Limits of HDD Installed Pipe

The design process normally consists of calculating the loads applied to the pipe, selecting a trial pipe DR, then calculating the safety factor for the trial DR. If the safety factor is adequate, the design is sufficient. If not, the designer selects a lower DR and repeats the process. The safety factor is established for each performance limit of the pipe by taking the ratio of the pipe's ultimate strength or resistance to the applied load.

External pressure from earth load, groundwater, vacuum and live load applied to the HDD pipe produces (1) a compressive ring thrust in the pipe wall and (2) ring bending deflection. The performance limit of unsupported PE pipe subjected to compressive thrust is ring buckling (collapse). The performance limit of a PE pipe subjected to ring bending (a result of non-uniform external load, i.e. earth load) is ring deflection. See Figure 2.

Viscoelastic Behavior

Both performance limits are proportional to the apparent modulus of elasticity of the PE material. For viscoelastic materials like PE, the modulus of elasticity is a time-dependent property, that is, its value changes with time under load. A newly applied load increment will cause a decrease in apparent stiffness over time. Unloading will result in rebounding or an apparent gain in stiffness. The result is a higher resistance to short term loading than to long-term loading. Careful consideration must be given to the duration and frequency of each load, so that the performance limit associated with that load can be calculated using PE material properties representative of that time period. The same effects occur with the pipe's tensile strength. For instance, during pullback, the pipe's tensile yield strength decreases with pulling time, so the safe (allowable) pulling stress is a function of time under load, and temperature.

Typical safe pull tensile stress values for MDPE and HDPE are given in Table 1. Consult the manufacturer for specific applications. The values are given as a function of the duration of continuous loading. For pipe temperatures (not outside air temperatures) other than 73ºF, multiply the value in Table 1 by the temperature compensating multipliers found in Table B.1.2 of the Appendix to Chapter 3. The Safe Pull Load at 12 hours is given for a variety of pipe sizes and DR's in Tables 3 and 4 (3xxx material) and Tables 5 and 6 (4xxx material) in a following section, "Tensile Stress During Pullback".

TABLE 1
Safe Pull Tensile Stress @ 73º F

Duration (Hours)	Typical Safe Pull Stress (psi) @ 73ºF		
	PE2xxx (PE2406)	PE3xxx (PE3408)	PE4xxx (PE4710)
0.5	1100	1400	1500
1	1050	1350	1400
12	850	1100	1150
24	800	1050	1100

The safe pull stress is the stress at 3% strain. For strains less than 3% the pipe will essentially have complete strain recovery after pullback. The stress values in Table 1 were determined by multiplying 3% times the apparent tensile modulus from the Appendix to Chapter 3 adjusted by a 0.60 factor to account for the high stress level during pullback.

Ring Deflection (Ovalization)

Non-uniform pressure acting on the pipe's circumference such as earth load causes bending deflection of the pipe ring. Normally, the deflected shape is an oval. Ovalization may exist in non-rerounded coiled pipe and to a lesser degree in straight lengths that have been stacked, but the primary sources of bending deflection of directionally drilled pipes is earth load. Slight ovalization may also occur during pullback if the pipe is pulled around a curved path in the borehole. Ovalization reduces the pipe's hydrostatic collapse resistance and creates tensile bending stresses in the pipe wall. It is normal and expected for buried PE pipes to undergo ovalization. Proper design and installation will limit ovalization (or as it is often called "ring deflection") to prescribed values so that it has no adverse effect on the pipe.

Ring Deflection Due to Earth Load

As discussed previously, insitu soil characteristics and borehole stability determine to great extent the earth load applied to directionally drilled pipes. Methods for calculating estimated earth loads, when they occur, are given in the previous section on "Earth and Groundwater Pressure."

Since earth load is non-uniform around a pipe's circumference, the pipe will undergo ring deflection, i.e. a decrease in vertical diameter and an increase in horizontal diameter. The designer can check to see if the selected pipe is stiff enough to limit deflection and provide an adequate safety factor against buckling. (Buckling is discussed in a later section of this chapter.)

The soil surrounding the pipe may contribute to resisting the pipe's deflection. Formulas used for entrenched pipe, such as Spangler's Iowa Formula, are likely not applicable as the HDD installation is different from installing pipe in a trench where the embedment can be controlled. In an HDD installation, the annular space surrounding the pipe contains a mixture of drilling mud and cuttings. The mixture's consistency or stiffness determines how much resistance it contributes. Consistency (or stiffness) depends on several factors including soil density, grain size and the presence of groundwater. Researchers have excavated pipe installed by HDD and observed some tendency of the annular space soil to return to the condition of the undisturbed native soil. See Knight [11] and Ariaratnam [12]. It is important to note that the researched installations were located above groundwater, where excess water in the mud-cuttings slurry can drain. While there may be consolidation and strengthening of the annular space soil particularly above the groundwater level, it may be weeks or even months before significant resistance to pipe deflection develops. Until further research establishes the soil's contribution to resisting deflection, one option is to ignore any soil resistance and to use Equation 10 which is derived from ring deflection equations published by Watkins and Anderson [13]. (Coincidentally, Equation 10 gives the same deflection as the Iowa Formula with an E′ of zero.) Spangler's Iowa formula is discussed in Chapter 6. The design deflection limits for directionally drilled pipe are given in Table 2. Design deflection limits are for use in selecting a design DR. Field deflection measurements of directionally drilled pressure pipe are normally not made. Design deflection must be limited to control buckling resistance.

(10) $$\frac{\Delta y}{D} = \frac{\frac{0.0125 P_E}{E}}{12\,(DR - 1)^3}$$

WHERE

Δy **= vertical ring deflection, in**

D **= pipe diameter, in**

P_E **= Earth pressure, psi**

DR **= Pipe Dimension Ratio**

E **= apparent modulus of elasticity, psi (Refer to Appendix, Chapter 3, Engineering Properties, for the appropriate value for the Material Designation Code of the PE pipe being used and the applicable service conditions)**

* To obtain ring deflection in percent, multiply $\Delta y/D$ by 100.

TABLE 2
Design Deflection Limits of Buried Polyehtylene Pipe, Long Term, %*

DR or SDR	21	17	15.5	13.5	11	9	7.3
Deflection Limit (% $\Delta y/D$) Non-Pressure Applications	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Deflection Limit (%$\Delta y/D$) Pressure Applications	7.5	6.0	6.0	6.0	5.0	4.0	3.0

* Design deflection limits per ASTM F1962, Guide for Use of Maxi-Horizontal Directional Drilling for Placement of PE Pipe or Conduit Under Obstacles, Including River Crossings.

Unconstrained Buckling

Uniform external pressure applied to the pipe either from earth and live load, groundwater, or the drilling slurry creates a ring compressive hoop stress in the pipe's wall. If the external pressure is increased to a point where the hoop stress reaches a critical value, there is a sudden and large inward deformation of the pipe wall, called buckling. Constraining the pipe by embedding it in soil or cementitious grout will increase the pipe's buckling strength and allow it to withstand higher external pressure than if unconstrained. However, as noted in a previous section it is not likely that pipes installed below the groundwater level will acquire significant support from the surrounding mud-cuttings mixture and for pipe above groundwater support may take considerable time to develop. Therefore, until further research is available it is conservative to assume no constraint from the soil. The following equation, known as Levy's equation, may be used to determine the allowable external pressure (or negative internal pressure) for unconstrained pipe.

(11) $$P_{UC} = \frac{2E}{(1-\mu^2)} \left(\frac{1}{DR-1}\right)^3 \frac{f_O}{N}$$

WHERE

P_{uc} **= Allowable unconstrained buckling pressure**

E **= Apparent modulus of elasticity, psi (Refer to Appendix, Chapter 3, Engineering Properties, for the appropriate value for the Material Designation Code of the PE pipe being used and the applicable service conditions.)**

μ **= Poisson's Ratio = 0.45 for all PE pipe materials**

DR **= Dimension Ratio (D_o/t), where D_o =Outside Pipe Diameter and t = Minimum Wall Thickness**

f_o **= Ovality compensation factor (see figure 3)**

N **= Safety factor, generally 2.0 or higher**

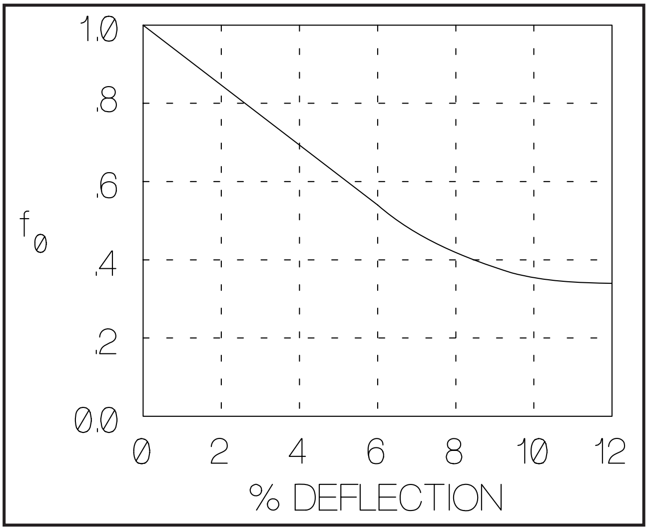

Figure 3 Ovality Compensation Factor=f_o

For a detailed discussion of buckling see the section in Chapter 6 titled "Unconstrained Pipe Wall Buckling (Hydrostatic Buckling). Note that the apparent modulus of elasticity is a function of the duration of the anticipated load. When selecting a modulus to use in Equation 11 consideration should be given to internal pressurization of the line. When the pressure in the pipe exceeds the external pressure due to earth and live load, groundwater and/or slurry, the stress in the pipe wall reverses from compressive to tensile stress and collapse will not occur. For determining the pipe's resistance to buckling during pullback, an additional reduction for tensile stresses is required, which is discussed in a later section of this chapter.

Wall Compressive Stress

The compressive stress in the wall of a directionally drilled PE pipe rarely controls design and it is normally not checked. However, it is included here because in some special cases such as directional drilling at very deep depths such as in landfills it may control design.

The earth pressure applied to a buried pipe creates a compressive thrust stress in the pipe wall. When the pipe is pressurized, the stress is reduced due to the internal pressure creating tensile thrust stresses. The net stress can be positive or negative depending on the depth of cover. Buried pressure lines may be subject to net compressive stress when shut down or when experiencing vacuum. These are usually short-term conditions and are not typically considered significant for design, since the short-term design stress of polyolefins is considerably higher than the long-term design stress. Pipes with large depths of cover and operating at low pressures may have net compressive stresses in the pipe wall. The following equation can be used to determine the net compressive stress:

(12)

$$S_c = \frac{P_S D_O}{288t} - \frac{PD}{2t}$$

WHERE

S_C = **Compressive wall stress, psi**

P_S = **Earth load pressures, psf**

D_O = **Pipe outside diameter, in**

t = **Wall thickness, in**

P = **(Positive) internal pressure, psi**

D = **Mean diameter, D_O-t, in**

The compressive wall stress should be kept less than the allowable compressive stress of the material. For PE4710 PE pipe grade resins, 1150 psi is a safe allowable stress. For other materials see the Appendix of Chapter 3.

EXAMPLE CALCULATIONS An example calculation for selecting the DR for an HDD pipe is given in Appendix A.

Installation Design Considerations

After determining the DR required for long-term service, the designer must determine if this DR is sufficient for installation. Since installation forces are so significant, a lower DR (stronger pipe) may be required.

During pullback the pipe is subjected to axial tensile forces caused by the frictional drag between the pipe and the borehole or slurry, the frictional drag on the ground surface, the capstan effect around drill-path bends, and hydrokinetic drag. In addition, the pipe may be subjected to external hoop pressures due to net external fluid head and bending stresses. The pipe's collapse resistance to external pressure given in Equation 2 is reduced by the axial pulling force. Furthermore, the drill path curvature may be limited by the pipe's bending radius. (Torsional forces occur but are usually negligible when back-reamer swivels are properly designed.) Considerable judgment is required to predict the pullback force because of the complex interaction between pipe and soil. Sources for information include experienced drillers and engineers, programs such as DRILLPATH[14] and publications such as ASTM F1962 and ASCE MOP 108, "Pipeline Design for Installation by Horizontal Directional Drilling". Typically, pullback force calculations are approximations that depend on considerable experience and judgment.

The pullback formulas given herein and in DRILLPATH and ASTM F1962 are based on essentially an "ideal" borehole. The ideal borehole behaves like a rigid tunnel with gradual curvature, smooth alignment (no dog-legs), no borehole collapses, nearly complete cuttings removal, and good slurry circulation. The ideal borehole may be approached with proper drilling techniques that achieve a clean bore fully reamed to its final size before pullback. The closer the bore is to ideal; the more likely the calculated pullback force will match the actual.

Because of the large number of variables involved and the sensitivity of pullback forces to installation techniques, the formulas presented in this document are for guidelines only and are given only to familiarize the designer with the interaction that occurs during pullback. Pullback values obtained should be considered only as qualitative values and used only for preliminary estimates. The designer is advised to consult with an experienced driller or with an engineer familiar with calculating these forces. The following discussion assumes that the entry and exit pits of the bore are on the same, or close to the same, elevation. For an overview, see Svetlik[15].

Pullback Force

Large HDD rigs can exert between 100,000 lbs. to 500,000 lbs. pull force. The majority of this power is applied to the cutting face of the reamer device/tool, which precedes the pipeline segment into the borehole. It is difficult to predict what portion of the total pullback force is actually transmitted to the pipeline being inserted.

The pulling force which overcomes the combined frictional drag, capstan effect, and hydrokinetic drag, is applied to the pull-head and first joint of PE pipe. The axial tensile stress grows in intensity over the length of the pull. The duration of the pullload is longest at the pull-nose. The tail end of the pipe segment has zero applied tensile stress for zero time. The incremental time duration of stress intensity along the length of the pipeline from nose to tail causes a varying degree of recoverable elastic strain and viscoelastic stretch per foot of length along the pipe.

The DR must be selected so that the tensile stress in the pipe wall due to the pullback force, does not exceed the permitted tensile stress for the pipe material. Increasing the pipe wall thickness will allow for a greater total pull-force. Even though the thicker wall increases the weight per foot of the pipe, the pullback force within the bore itself is not significantly affected by the increased weight. Hence, thicker wall pipe generally reduces stress. The designer should carefully check all proposed DR's.

Frictional Drag Resistance

Pipe resistance to pullback in the borehole depends primarily on the frictional force created between the pipe and the borehole or the pipe and the ground surface in the entry area, the frictional drag between pipe and drilling slurry, the capstan effect at bends, and the weight of the pipe. Equation 13 gives the frictional resistance or required pulling force for pipe pulled in straight, level bores or across level ground. Equation 13, gives the frictional resistance or required pulling force for pipe pulled in straight, level bores or across level ground. (See Kirby et al. [16]).

(13) $$F_P = mW_B L$$

WHERE

F_P **= pulling force, lbs**

m **= coefficient of friction between pipe and slurry (typically 0.25) or between pipe and ground (typically 0.40)**

w_B **= net downward (or upward) force on pipe, lb/ft**

L **= length, ft**

When a slurry is present, W_B equals the buoyant force on the pipe minus the weight of the pipe and its contents, if any. Filling the pipe with fluid significantly reduces the buoyancy force and thus the pulling force. PE pipe has a density near that of water. If the pipe is installed "dry" (empty) using a closed nose-pull head, the pipe will want to "float" on the crown of the borehole leading to the sidewall loading and frictional drag through the buoyancy-per-foot force and the wetted soil to pipe coefficient of friction. Most major pullbacks are done "wet". That is, the pipeline is filled with water as it starts to descend into the bore (past the breakover point). Water is added through a hose or small pipe inserted into the pullback pipe. (See the calculation examples.)

Note: The buoyant force pushing the empty pipe to the borehole crown will cause the PE pipe to "rub" the borehole crown. During pullback, the moving drill mud lubricates the contact zone. If the drilling stops, the pipe stops, or the mud flow stops, the pipe - slightly ring deflected by the buoyant force - can push up and squeeze out the lubricating mud. The resultant "start-up" friction is measurably increased. The pulling load to loosen the PE pipe from being "stuck" in the now decanted (moist) mud can be very high. This situation is best avoided by using thicker (lower DR) pipes, doing "wet" pulls, and stopping the pull only when removing drill rods.

Capstan Force

For curves in the borehole, the force can be factored into horizontal and vertical components. Huey et al.[17] shows an additional frictional force that occurs in steel pipe due to the pressure required by the borehole to keep the steel pipe curved. For bores with a radius of curvature similar to that used for steel pipe, these forces are insignificant for PE pipe. For very tight bends, it may be prudent to consider them. In addition to this force, the capstan effect increases frictional resistance when pulling along a curved path. As the pipe is pulled around a curve or bend creating an angle q, there is a compounding of the forces due to the direction of the pulling vectors. The pulling force, F_C, due to the capstan effect is given in Eq. 14. Equations 13 and 14 are applied recursively to the pipe for each section along the pullback distance as shown in Figure 4. This method is credited to Larry Slavin, Outside Plant Consulting Services, Inc. Rockaway, N.J.

(14) $$F_c = e^{mq}(mW_B L)$$

WHERE

e **= Natural logarithm base (e=2.71828)**

m **= coefficient of friction**

q **= angle of bend in pipe, radians**

w_B **= weight of pipe or buoyant force on pipe, lbs/ft**

L **= Length of pull, ft**

$$F_1 = \exp(m_g a)(m_g W_p (L_1 + L_2 + L_3 + L_4))$$

$$F_2 = \exp(m_b a)(F_1 + m_b W_b L_2 + W_b H - m_g W_p L_2 \exp(m_g a))$$

$$F_3 = F_2 + m_b W_b L_3 - \exp(m_b a)(m_g W_p L_3 \exp(m_g a))$$

$$F_4 = \exp(m_b b)(F_3 + m_b W_b L_4 - W_b H - \exp(m_b a)(m_g W_p L_4 \exp(m_g a)))$$

WHERE
H **= Depth of bore (ft)**
Fi **= Pull Force on pipe at Point i (lb)**
Li **= Horizontal distance of Pull from point to point (ft)**
m **= Coeff. of friction (ground (g) and borehole (b))**
W_p **= Weight of pipe (lb/ft)**
W_b **= Buoyant force on pipe minus weight of pipe and contents (lb/ft)**
a, b **= Entry and Exit angles (radians)**

Figure 4 Estimated Pullback Force Calculation

Hydrokinetic Force

During pulling, pipe movement is resisted by the drag force of the drilling fluid. This hydrokinetic force is difficult to estimate and depends on the drilling slurry, slurry flow rate pipe pullback rate, and borehole and pipe sizes. Typically, the hydrokinetic pressure is estimated to be in the 30 to 60 kPa (4 to 8 psi) range.

(15) $$F_{HK} = p\frac{\pi}{8}(D_H{}^2 - OD^2)$$

WHERE
F_{HK} **= hydrokinetic force, lbs**
p **= hydrokinetic pressure, psi**
D_H **= borehole diameter, in**
OD **= pipe outside diameter, in**

ASCE MOP 108 suggests a different method for calculating the hydrokinetic drag force. It suggests multiplying the external surface area of the pipe by a fluid drag coefficient of 0.025 lb/in^2 after Puckett [18]. The total pull back force, F_T, then is the combined pullback force, F_P, plus the hydrokinetic force, F_{HK}. For the example shown in Figure 4, F_P equals F_4.

Tensile Stress During Pullback

The maximum outer fiber tensile stress should not exceed the safe pull stress. The maximum outer fiber tensile stress is obtained by taking the sum of the tensile stress in the pipe due to the pullback force, the hydrokinetic pulling force, and the tensile bending stress due to pipe curvature. During pullback it is advisable to monitor the pulling force and to use a "weak link" (such as a pipe of higher DR) mechanical break- away connector or other failsafe method to prevent over-stressing the pipe.

The tensile stress occurring in the pipe wall during pullback is given by Eq. 16.

(16)

$$s_t = \frac{F_T}{\pi t\,(D_{OD} - t)} + \frac{E_T D_{OD}}{2R}$$

WHERE

s_T **= Axial tensile stress, psi**

F_T **= Total pulling force, lbs**

t **= Minimum wall thickness, in**

D_{OD} **= Outer diameter of pipe, in**

E_T **= Time-dependent apparent modulus, psi (Refer to Appendix, Chapter 3, Engineering Properties, for the appropriate value for the Material Designation Code of the PE pipe being used and the applicable service conditions**

R **= Minimum radius of curvature in bore path, in**

The axial tensile stress due to the pulling force should not exceed the pipe's safe pull load. As discussed in a previous section, the tensile strength of PE pipe is load-rate sensitive. Time under load is an important consideration in selecting the appropriate tensile strength to use in calculating the safe pull load. During pullback, the pulling force is not continually applied to the pipe, as the driller must stop pulling after extracting each drill rod in order to remove the rod from the drill string. The net result is that the pipe moves the length of the drill rod and then stops until the extracted rod is removed. Pullback is an incremental (discrete) process rather than a continuous process. The pipe is not subjected to a constant tensile force and thus may relax some between pulls. A one-hour apparent modulus value might be safe for design, however, a 12-hour value will normally minimize "stretching" of the pipeline. Tables 3 through 6 give safe pull loads for PE pipes based on a 12-hour value. The safe pull force also referred to as the allowable tensile load in the Tables 3 through 6 is based on the minimum pipe wall thickness and may be found using Equation 17. (The safe pull load may also be found using the average wall thickness. Check with the manufacture for the average wall values.) Allowable safe pullback values for gas pipe are given in ASTM F-1807, "Practice for Determining Allowable Tensile Load for Polyehtylene (PE) Gas Pipe during Pull-In Installation".

(17)
$$F_S = (T_{ALLOW})\pi D_{OD}^2 \left(\frac{1}{DR} - \frac{1}{DR^2}\right)$$

WHERE

F_S **= Safe Pull Force (lbs)**

T_{ALLOW} **= Safe Pull Stress (psi)**

D_{OD} **= Outside Diameter (in)**

DR **= Dimension Ratio**

After pullback, pipe may take several hours (typically equal to the duration of the pull) to recover from the axial strain. When pulled from the reamed borehole, the pull-nose should be pulled out about 3% longer than the total length of the pull. The elastic strain will recover immediately and the viscoelastic stretch will "remember" its original length and recover overnight. One does not want to come back in the morning to discover the pull-nose sucked back below the borehole exit level due to stretch recovery and thermal-contraction to an equilibrium temperature. In the worst case, the driller may want to pull out about 4% extra length (40 feet per 1000 feet) to insure the pull-nose remains extended beyond the borehole exit.

TABLE 3
PE 3xxx 12 hour Pull IPS Size

		Safe Pull Force, lbs			
Size	**Nom. OD**	**9**	**11**	**13.5**	**17**
1.25	1.660	940	787	653	527
1.5	1.900	1232	1030	855	690
2	2.375	1924	1610	1336	1079
3	3.500	4179	3497	2902	2343
4	4.500	6908	5780	4797	3872
6	6.625	14973	12529	10398	8393
8	8.625	25377	21235	17623	14225
10	10.750	39423	32988	27377	22098
12	12.750	55456	46404	38511	31086
14	14.000	66863	55949	46432	37480
16	16.000	87331	73076	60646	48954
18	18.000	110528	92487	76756	61957
20	20.000	136454	114182	94760	76490
22	22.000	165110	138160	114660	92553
24	24.000	196494	164422	136454	110146
26	26.000	230608	192967	160144	129268
28	28.000	267450	223796	185729	149920
30	30.000	307022	256909	213210	172102
32	32.000	N.A.	292305	242585	195814
34	34.000	N.A.	329985	273856	221056
36	36.000	N.A.	369949	307022	247827
42	42.000	N.A.	N.A.	417891	337321
48	48.000	N.A.	N.A.	N.A.	440582
54	54.000	N.A.	N.A.	N.A.	N.A.

*Tables are based on the Minimum Wall Thickness of Pipe

TABLE 4
PE 3xxx 12 hour Pull DIPS Size

		Safe Pull Force, lbs			
Size	**Nom. OD**	**9**	**11**	**13.5**	**17**
4	4.800	7860	6577	5458	4406
6	6.900	16241	13590	11279	9104
8	9.050	27940	23379	19403	15662
10	11.100	42031	35171	29188	23561
12	13.200	59440	49738	41277	33319
14	15.300	79856	66822	55456	44764
16	17.400	103282	86424	71724	57895
18	19.500	129717	108544	90081	72713
20	21.600	159160	133182	110528	89218
24	25.800	227074	190010	157690	127287
30	32.000	349323	292305	242585	195814
36	38.300	N.A.	418730	347506	280506
42	44.500	N.A.	N.A.	469121	378673
48	50.800	N.A.	N.A.	N.A.	493483

*Tables are based on the Minimum Wall Thickness of Pipe

TABLE 5
PE 4xxx 12 hour Pull IPS Size

		Safe Pull Force, lbs			
Size	**Nom. OD**	**9**	**11**	**13.5**	**17**
1.25	1.660	983	822	682	551
1.5	1.900	1287	1077	894	722
2	2.375	2012	1683	1397	1128
3	3.500	4369	3656	3034	2449
4	4.500	7222	6043	5015	4048
6	6.625	15653	13098	10870	8774
8	8.625	26531	22200	18424	14872
10	10.750	41214	34487	28621	23103
12	12.750	57977	48513	40262	32499
14	14.000	69902	58492	48543	39184
16	16.000	91300	76398	63403	51179
18	18.000	115552	96691	80244	64773
20	20.000	142657	119372	99067	79967
22	22.000	172615	144440	119871	96760
24	24.000	205426	171896	142657	115152
26	26.000	241090	201739	167424	135144
28	28.000	279607	233969	194172	156735
30	30.000	320978	268587	222901	179925
32	32.000	N.A.	305592	253612	204715
34	34.000	N.A.	344985	286304	231104
36	36.000	N.A.	386765	320978	259092
42	42.000	N.A.	N.A.	436886	352654
48	48.000	N.A.	N.A.	N.A.	460609
54	54.000	N.A.	N.A.	N.A.	N.A.

*Tables are based on the Minimum Wall Thickness of Pipe

TABLE 6
PE 4xxx 12 hour Pull DIPS Size

		Safe Pull Force, lbs			
Size	**Nom. OD**	**9**	**11**	**13.5**	**17**
4	4.800	8217	6876	5706	4606
6	6.900	16980	14208	11791	9518
8	9.050	29210	24442	20285	16374
10	11.100	43942	36770	30515	24632
12	13.200	62141	51998	43154	34834
14	15.300	83486	69859	57977	46799
16	17.400	107977	90353	74984	60527
18	19.500	135613	113478	94176	76018
20	21.600	166395	139235	115552	93273
24	25.800	237395	198647	164858	133073
30	32.000	365201	305592	253612	204715
36	38.300	N.A.	437764	363302	293256
42	44.500	N.A.	N.A.	490445	395886
48	50.800	N.A.	N.A.	N.A.	515914

*Tables are based on the Minimum Wall Thickness of Pipe

External Pressure During Installation

During pullback it is reasonable to assume that the borehole remains stable and open and that the borehole is full of drilling slurry. The net external pressure due to fluid in the borehole, then, is the slurry head, P_{MUD}. This head can be offset by pulling the pipe with an open nose or filling the pipe with water for the pullback. However, this may not always be possible, for instance when installing electrical conduit. In addition to the fluid head in the borehole, there are also dynamic sources of external pressure:

1. If the pulling end of the pipe is capped, a plunger action occurs during pulling which creates a mild surge pressure. The pressure is difficult to calculate. The pipe will resist such an instantaneous pressure with its relatively high short-term modulus. If care is taken to pull the pipe smoothly at a constant speed, this calculation can be ignored. If the pipe nose is left open, this surge is eliminated.

2. External pressure will also be produced by the frictional resistance of the drilling mud flow. Some pressure is needed to pump drilling mud from the reamer tool into the borehole, then into the pipe annulus, and along the pipe length while conveying reamed soil debris to the mud recovery pit. An estimate of this short term hydrokinetic pressure may be calculated using annular flow pressure loss formulas borrowed from the oil well drilling industry. This external pressure is dependent upon specific drilling mud properties, flow rates, annular opening, and hole configuration. This is a short-term installation condition. Thus, PE pipe's short-term external differential pressure capabilities are compared to the actual

short-term total external pressure during this installation condition. Under normal conditions, the annular-flow back pressure component is less than 4-8 psi.

In consideration of the dynamic or hydrokinetic pressure, P_{HK}, the designer will add additional external pressure to the slurry head:

(18) $$P_N = P_{MUD} + P_{HK} - P_I$$

Where the terms have been defined previously.

Resistance to External Collapse Pressure During Pullback Installation

The allowable external buckling pressure equation, Eq.11, with the appropriate apparent modulus (see chapter 3- Appendix) value can be used to calculate the pipe's resistance to the external pressure, P_N, given by Eq.18 during pullback. The following reductions in strength should be taken:

The tensile pulling force reduces the buckling resistance. This can be accounted for by an additional reduction factor, F_R. The pulling load in the pipe creates a hoop strain as described by Poisson's ratio. The hoop strain reduces the buckling resistance. Multiply Eq.11 by the reduction factor, F_R to obtain the allowable external buckling pressure during pullback.

(19) $$F_R = \sqrt{(5.57 - (r + 1.09)^2)} - 1.09$$

(20) $$r = \frac{s_T}{2S}$$

WHERE

s_T **= calculated tensile stress during pullback (psi)**

S **= safe pull stress (psi)**

r **= tensile stress ratio**

Since the pullback time is typically several hours, a modulus value consistent with the pullback time can be selected from Appendix, Chapter 3.

Bending Stress

HDD river crossings incorporate radii-of-curvature, which allow the PE pipe to cold bend within its elastic limit. These bends are so long in radius as to be well within the flexural bending capability of SDR 11 PE pipe which can be cold bent to 25 times its nominal OD (example: for a 12" SDR 11 PE pipe, the radius of curvature could be from infinity down to the minimum of 25 feet, i.e., a 50-foot diameter circle). Because the drill stem and reaming rod are less flexible, normally PE can bend easily to whatever radius the borehole steel drilling and reaming shafts can bend because these radii are many times the pipe OD. However, in order to minimize the effect of ovaling some manufacturers limit the radius of curvature to a minimum of 40 to 50 times the pipe diameter. As in a previous section, the tensile stress due to bending is included in the calculations.

Thermal Stresses and Strains

HDD pipeline crossings generally become fully restrained in the axial direction as progressive sedimentation and soil consolidation occur within the borehole. The rate at which restraint occurs depends on the soil and drilling techniques and can take from a few hours to months. This assumption is valid for the vast majority of soil conditions, although it may not be completely true for each and every project. During pipe installation, the moving pipeline is not axially restrained by the oversize borehole. However, the native soil tends to sediment and embed the pipeline when installation velocity and mud flow are stopped, thus allowing the soil to grip the pipeline and prevent forward progress or removal. Under such unfortunate stoppage conditions, many pipelines may become stuck within minutes to only a few hours.

The degree to which the pipeline will be restrained after completed installation is in large part a function of the sub-surface soil conditions and behavior, and the soil pressure at the depth of installation. Although the longitudinal displacement due to thermal expansion or contraction is minimal, the possibility of its displacement should be recognized. The PE pipe should be cut to length only after it is in thermal equilibrium with the surrounding soil (usually overnight). In this way the “installed” versus “operating” temperature difference is dropped to nearly zero, and the pipe will have assumed its natural length at the existing soil/water temperature. Additionally, the thermal inertia of the pipe and soil will oppose any brief temperature changes from the flow stream. Seasonal temperature changes happen so slowly that actual thermally induced stresses are usually insignificant within PE for design purposes.

Torsion Stress

A typical value for torsional shear stress is 50% of the tensile strength. Divide the transmitted torque by the wall area to get the torsional shear stress intensity. During the pullback and reaming procedure, a swivel is typically used to separate the rotating cutting head assembly from the pipeline pull segment. Swivels are not 100% efficient and some minor percent of torsion will be transmitted to the pipeline. For thick wall PE pipes of SDR 17, 15.5, 11, 9 and 7, this torsion is not significant and usually does not merit a detailed engineering analysis.

EXAMPLE CALCULATIONS Example Calculations are given in Appendix A and B.

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Appendix A

Design Calculation Example for Service Loads (Post-Installation)

Example 1

A 6″ IPS DR 11 PE4710 pipe is being pulled under a railroad track. The minimum depth under the track is 10 ft. Determine the safety factor against buckling.

GIVEN PARAMETERS

OD **= 6.625 in**
Nominal Pipe OD

DR **= 11 Pipe**
Dimension Ratio

H **= 10 ft.**
Max. Borehole Depth

g_s **= 120 lbf/ft³**
Unit Weight of Soil

P_{Live} **= 1,100 lbf/ft²**
E-80 Live Load

PE Material Parameters

Wheel loading from train will be applied for several minutes without relaxation. Repetitive trains crossing may accumulate. A conservative choice for the apparent modulus is the 1000-hour modulus. See Appendix of Chapter 3 Table B.1.1.

E_{mid} = 46,000 psi

μ = Poisson's Ratio = 0.45 for all PE pipe materials

Soil and Live Load Pressure on Pipe (Assuming that the earth load equals the prism load is perhaps too conservative except for a calculation involving dynamic surface loading.)

$P = (g_s H + P_{Live})\ 1/144$

P **= 16.0 psi**

Ring Deflection resulting from soil and live load pressures assuming no side support is given by equation 10.

$$\frac{\Delta y}{D} = \frac{0.0125P}{\frac{E_{mid}}{12(DR-1)^3}}$$

% $\Delta y/D$ **= 5.1 Percent deflection from soil loads**

Determine critical unconstrained buckling pressure based on deflection from loading and safety factor using Eq. 11

f_o = 0.58 Ovality compensation factor for 5.1% ovality from Figure 3

$$P_{UC} = \frac{2E_{mid}}{(1-\mu^2)}\left(\frac{1}{DR-1}\right)^3 f_O$$

P_{UC} **= 68.4 psi**

Critical unconstrained buckling pressure (no safety factor)

$$SF_{cr} = \frac{P_{UC}}{P}$$

SF_{cr} **= 4.3 Safety factor against buckling**

Example 2

A 6" IPS DR 13.5 PE4710 pipe is being pulled under a small river for use as an electrical duct. At its lowest point, the pipe will be 18 feet below the river surface. Assume the slurry weight is equal to 75 Ib/cu.ft. The duct is empty during the pull. Calculate a) the maximum pulling force and b) the safety factor against buckling for the pipe. Assume that the pipe's ovality is 3% and that the pulling time will not exceed 10 hours.

Solution

Calculate the safe pull strength or allowable tensile load.

OD **= 6.625in. - Pipe outside diameter**

DR **= 13.5 - Pipe dimension ratio**

T_{allow} **= 1150 psi - Typical safe pull stress for PE4710 for 12-hour pull duration. See Table 1.**

$$F_s = \pi T_{allow} \ OD^2 \left(\frac{1}{DR} - \frac{1}{DR^2}\right)$$

F_s **= 1.088 x 10⁴ lbf**

Safe pull force for 6" IPS DR 13.5 PE pipe assuming 12-hour maximum pull duration.
Also see Table 5 for safe pull force.

Step 1

Determine the critical buckling pressure during Installation for the pipe (include tensile reduction factor assuming the frictional drag during pull results in 1000 psi longitudinal pipe stress)

E **= 63,000 psi - Apparent modulus of elasticity (for 12 hours at 73 degrees F)**

μ **= Poisson's Ratio = 0.45 for all PE materials**

f_O **= 0.76 - Ovality compensation factor (for 3% ovality)**

$$f_R = \sqrt{5.57 - (r + 1.09)^2} - 1.09$$

R **= 0.435 - Tensile ratio (based on assumed 1000 psi pull stress calculation)**

f_R **= 0.71**

$$Pcr = \frac{2E}{(1-\mu^2)} \left(\frac{1}{DR-1}\right)^3 \cdot f_O \cdot f_R$$

Tensile Reduction Factor

P_{CR} **= 43.71**

Critical unconstrained buckling pressure for DR 13.5 pipe without safety factor

Step 2

Determine expected loads on pipe (assume only static drilling fluid head acting on pipe, and borehole intact with no soil loading)

g_{slurry} **= 75 lbf/ft^3, drilling fluid weight**

H **= 18 ft, Maximum bore depth**

$$P_{slurry} = Hg_{slurry}\left(\frac{1}{144}\right)$$

P_{slurry} **= 9.36 psi**

Total static drilling fluid head pressure if drilled from surface

Step 3

Determine the resulting safety factor against critical buckling during installation

$$SF_{CR} = \frac{P_{CR}}{P_{slurry}}$$

SF_{CR} **= 4.67**

Safety factor against critical buckling during pull

Example 3

Determine the safety factor for long-term performance for the communication duct in Example 2. Assume there are 10 feet of riverbed deposits above the borehole having a saturated unit weight of 110 lb/ft^3. (18 feet deep, 3% initial ovality)

Solution

Step 1

Determine the pipe soil load (Warning: Requires input of ovality compensation in step 4.

E long **= 29,000 psi - Long-term apparent modulus**

g_w **= 62.4 lbf/ft.^{3} - Unit weight of water**

H **= 18 ft Max. - Borehole depth**

g_S **= 110 lbf/ft.^{3} - Saturated unit weight of sediments**

GW **= 18 ft - Groundwater height**

C **= 10ft. - Height of soil cover**

OD **= 6.625 in - Nominal pipe OD**

DR **= 13.5 - Pipe dimension ratio**

μ **= Poisson's Ratio = 0.45 for all PE materials**

$$P_{soil} = (g_S - g_W)\,C\,\left(\frac{1}{144}\right)$$

Psoil **= 3.30 psi**

Prism load on pipe from 10' of saturated cover (including buoyant force on submerged soil)

Step 2

Calculate the ring deflection resulting from soil loads assuming no side support.

$$\% \, (\Delta y/D) = \frac{0.0125 \times P_{soil}}{\left[\frac{E_{long}}{12 \, (DR \, -1)^3} \right]} \times 100$$

$\% \, (\Delta y/D)$ **= 3.33 Percent deflection from soil loads**

t **= OD/DR t =0.491 in**

Step 3

Determine the long-term hydrostatic loads on the pipe

$$P_W = \left(\frac{GW}{2.31 \, ft/psi}\right) + P_{soil}$$

P_W **= 11.09**

External pressure due to groundwater head

$$g_{slurry} = 75 \, lb/cu.ft.^3$$

Unit weight of drilling fluid

$$P_{slurry} = g_{slurry} \, H \, \left(\frac{1}{144}\right)$$

P_{slurry} **= 9.37 psi**

External pressure due to slurry head

$$P_W > P_{slurry}$$

Therefor use PW for buckling load

Step 4

Determine critical unconstrained buckling pressure based on deflection from loading

f_o **= 0. 64 Five percent Ovality Compensation based on 3.3% deflection with an additional factor for conservatism.**

$$P_{UC} = \frac{2E_{long}}{(1 - \mu^2)} \left(\frac{1}{DR \, -1}\right)^3 \, f_O$$

P_{UC} **= 23.83 psi**

Critical unconstrained buckling pressure (no safety factor)

SF_{CR} **= 2.14**

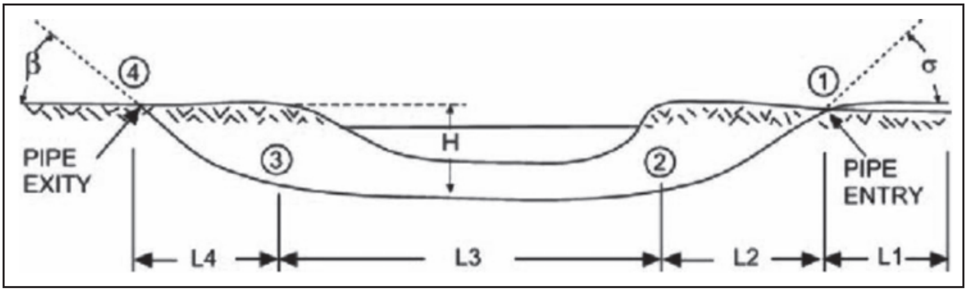
$$SF_{CR} = \frac{P_{UC}}{P_W} \qquad SF_{CR} = 2.14$$

Safety Factor against buckling pressure of highest load groundwater head (11.09 psi)

APPENDIX B

Design Calculations Example for Pullback Force

Example 1



Find the estimated force required to pull back pipe for the above theoretical river crossing using Slavin's Method. Determine the safety factor against collapse. Assume the PE pipe is 35 ft deep and approximately 870 ft long with a 10 deg. entry angle and a 15 deg. exit angle. Actual pullback force will vary depending on backreamer size, selection, and use; bore hole staying open; soil conditions; lubrication with bentonite; driller expertise; and other application circumstances.

PIPE PROPERTIES

Outside Diameter

OD = 24 in - Long-term Modulus - E_{long} = 29,000 psi, PE4710 Material

Standard Dimension Ratio

DR = 12 - 12 hr Modulus - E_{24hr} =63,000 psi

Minimum wall thickness

t = 2.182 in - Poisson's ratio (long term) - μ = 0.45 - Safe Pull Stress (12 hr) - s_{pb} = 1,150 psi

PATH PROFILE

H **= 35 ft Depth of bore**

g_{in} **= 10 deg Pipe entry angle**

g_{ex} **= 15 deg Pipe exit angle**

L_1 **= 100 ft Pipe drag on surface (This value starts at total length of pull, approximately 870 ft. then decreases with time. Assume 100 ft remaining at end of pull)**

L_{cross} **= 870 ft**

PATH LENGTH (DETERMINE L_2 AND L_4)

Average Radius of Curvature for Path at Pipe Entry g_{in} is given in radians

$$R_{avg\ in} = 2H/g_{in}^{\ 2}$$

$R_{avg\ in}$ **= 2.298 x 10^3 ft**

Average Radius of Curvature for Path at Pipe Exit

$$R_{avg\ ex} = 2H/g_{ex}^{\ 2}$$

$R_{avg\ ex}$ **= 1.021 x 10^3 ft**

Horizontal Distance Required to Achieve Depth or Rise to the Surface at Pipe Entry

$$L_2 = 2H/g_{in}$$

L_2 **= 401.07 ft**

Horizontal Distance Required to Achieve Depth or Rise to the Surface at Pipe Exit

WHERE

L_2 & L_4 **= horizontal transition distance at bore exit & entry respectively.**

DETERMINE AXIAL BENDING STRESS

R **= $R_{avg\ ex}$ - Min. Radius for Drill path**

R **= 1.021 x 10^3 ft**

OD **= 24 in**

Radius of curvature should exceed 40 times the pipe outside diameter to prevent ring collapse.

r **= 40 OD**

r **= 80 ft Okay**

$R > r$

Bending strain

e_a = OD/2R

e_a = 9.79 x 10^{-4} in/in

WHERE

e_a **= bending strain, in/in**

OD **= outside diameter of pipe, in**

R **= minimum radius of curvature, ft**

Bending stress

S_a **= $E_{12hr}e_a$**

Sa **= 61.68 psi**

WHERE

S_a **= bending stress, psi**

FIND PULLING FORCE

Weight of Empty Pipe

$P_w = 3.61 \times 10^{-2}$ lbf/in^3

$g_a = 0.95$

$g_b = 1.5$

$w_a = \pi OD^2 (DR-1/DR^2) r_w \, g_a$ 12 in/ft

$w_a = 61.54$ lbf/ft

Net Upward Buoyant Force on Empty Pipe Surrounded by Mud Slurry

$W_b = \pi(OD^2/4)\, r_w \, g_b$ 12 in/ft - w_a

$w_b = 232.41$ lbf/ft

WHERE

r_w = density of water, lb/in3

g_a = specific gravity of the pipe material

g_b = specific gravity of the mud slurry

w_a = weight of empty pipe, lbf/ft

$w_b = \pi(OD^2/4)$rwgb 12in/ft - wa

DETERMINE PULLBACK FORCE ACTING ON PIPE

See figure:

L_1 = 100 ft - $v_a = 0.4$

L_2 = 401.07ft - $v_b = 0.25$

L_3 = 200ft - $\sigma = g_{in}$ - σ = 10 deg = 0.175 radians

L_4 = 267.38 - $\beta = g_{ex}$ - β = 15 deg = 0.262 radians

$L_3 = L_{cross} - L_2 - L_4 - L_3$ = 201.549ft

$T_A = \exp(v_a \sigma)\,[v_a w_a (L_1 + L_2 + L_3 + L_4)]$

$T_A = 2.561 \times 10^4$ lbf

$T_B = \exp(v_b \sigma)\,(T_A + v_b [w_b]$ L2 $+ w_b H - v_a w_a L_2 \exp(v_b \sigma))$

$T_B = 4.853 \times 10^4$ lbf

T_C =TB + v_b [wb] $L_3 - \exp(v_b \sigma)\,(v_a w_a L_3.\exp(v_a \sigma))$

$T_C = 5.468 \times 10^4$ lbf

$T_D = \exp(v_b \sigma)\,[T_C + v_b [w_b] L_4 - w_b H - \exp(v_b \sigma)\,(v_a w_a L_4 \exp(v_b \sigma))]$

$T_D = 5.841 \times 10^4$ lbf

WHERE

T_A = pull force on pipe at point A, lbf

T_B = pull force on pipe at point B. lbf

T_C = pull force on pipe at point C, lbf

T_D = pull force on pipe at point D, lbf

L_1 = pipe on surface, ft

L_2 = horizontal distance to achieve desired depth, ft

L_3 = additional distance traversed at desired depth, ft

L_4 **= horizontal distance to rise to surface, ft**

v_a **= coefficient of friction applicable at the surface before the pipe enters bore hole**

v_b **= coefficient of friction applicable within the lubricated bore hole or after the (wet) pipe exits**

σ **= bore hole angle at pipe entry, radians**

β **= bore hole angle at pipe exit, radians**

(refer to figure at start of this appendix)

HYDROKINETIC PRESSURE

ΔP **= 10 psi**

Dh **= 1.5 OD**

Dh **= 36in**

$\Delta T = \Delta P (\pi/8)(Dh^2 - OD^2)$

$\Delta T = 2.82 \times 10^3 lbf$

WHERE:

ΔT **= pulling force increment, lbf**

ΔP **= hydrokinetic pressure, psi**

Dh **= back reamed hole diameter, in**

Compare Axial Tensile Stress with Allowable Tensile Stress During Pullback of 1,150 psi: (Assume the pull takes several hours and use 12 hours safe pull stress.)

Average Axial Stress Acting on Pipe Cross-section at Points A, B. C, D

s_1 **= 190.13 psi <1,150 psi OK**

s_2 **= 343.40 psi <1,150 psi OK**

s_3 **= 384.55 psi <1,150 psi OK**

s_4 **= 409.48 psi <1,150 psi OK**

$$s_1 = (Ti + \Delta T) \quad \left(\frac{1}{\pi OD^2}\right) \left(\frac{DR^2}{DR - 1}\right)$$

WHERE

$Ti = T_A, T_B, T_C, T_D$ **(lbf)**

si **= corresponding stress, psi**

Breakaway links should be set so that pullback force applied to pipe does not exceed 1,150 psi stress.

ID = OD - 2t

$Fb = s_{pb} (\pi/4)(OD^2 - ID^2)$

$Fb = 1.64 \times 10^5$ lbf

DETERMINE SAFETY FACTOR AGAINST RING COLLAPSE DURING PULLBACK

External Hydraulic Load

External static head pressure

$P_{ha} = (1.5)(62.4 \text{ lbf/ft}^3)(H)$

Pha = 22.75 psi

Combine static head with hydrokinetic pressure

$P_{effa} = P_{ha} + \Delta P$

$P_{effa} = 32.75$ psi

CRITICAL COLLAPSE PRESSURE

Resistance to external hydraulic load during pullback

$f_o = 0.76$ Ovality compensation factor (for 3% ovality)

$r = S_4/2S_{Pb}$

$r = 0.178$

Tensile ratio (based on 1,150 psi pull stress calculation)

Tensile reduction factor

$P_{CR} = 108$ psi

SAFETY FACTOR AGAINST COLLAPSE

SF = Pcr/Pha

F = 4.75

WHERE

P_{ha} = applied efflective pressure due to head of water of drilling

P_{cr} = calculated critical buckling pressure found by solving Equation 11 multiplied by Equation 19 for 24” DR11, psi

SF = Safety Factor

Chapter 13

HVAC Applications for PE Pipe

Introduction

The performance and use characteristics of polyethylene pipe make it an ideal choice for use in certain HVAC – Heating, Ventilation, and Air Conditioning – applications. Typically, HVAC is thought of as flexible vent pipes, steam pipes, etc. However, since the 1980's polyethylene pipe's flexibility, strength, and ease of use has had a major impact on HVAC applications such as geothermal heat pumps and radiant heating systems.

This chapter presents information and general design criteria for the use of polyethylene pipe in applications such as:

Ground Source Heat Pumps – basic use and standards, configuration, joining methods and installation considerations.

Solar Applications – use of PE pipe for solar water heating applications.

Vacuum Systems – use and design limitations.

Ground Source Heat Pump Systems

Due to polyethylene pipe's versatility, flexibility, durability, leakproof fusion joints, and ease of use, it has become a key component in the success of Ground Source Heat Pumps systems.

There are two basic types of heat pumps – air source and ground source. An air source system utilizes temperature variations in the air to gain operating efficiency. A ground source, or Geothermal Heat Pump (GHP) system uses an electric pump to circulate fluid from the heat pump cycle through a series of polyethylene pipes buried in the ground to take advantage of the relatively constant ground temperatures. These pipes are known as Ground Heat Exchangers. In simple terms, in the summer the heat pump's refrigerant cycle transfers heat from the building into the circulating fluid. The fluid is then circulated through the ground heat exchanger where the ground acts as a heat sink, cooling the fluid before it returns to the building. In the winter, the system works in reverse. The heat pump uses the earth to warm the circulating fluid, which is then transferred back to the inside heat exchanger. In addition to heating and cooling the air, a desuperheater can be added to this cycle that can provide most, if not all, hot water for use in the building as well.

The properties that control this process are based on the ability of the PE pipe to transfer heat either out of, or into, the system. The heat transfer by conduction mechanism that governs this system is the same as any heat exchanger. It is assumed that the ground is at a steady state condition. This type of heat transfer mechanism is governed by the basic equation:

$$q = (k\,A/x)\,(T_1 - T_2)$$

WHERE

q = **Heat loss, BTU/hr**

k = **Thermal conductivity, BTU/in/ft ^{2}/hr/°F**

A = **Heat transfer area, ft ^{2}**

x = **Wall thickness, inches**

T_1 = **Outside temperature, °F**

T_2 = **Inside pipe temperature, °F**

Note: The above equation only addresses the question of heat transfer through the PE pipe. Depending on the application (ground source heat exchange systems, snow melting, radiant heating, etc.) there are other factors that may have a significant influence on the accuracy of the heat transfer calculation including the thermal conductivity of the surrounding embedment material, the inside and outside film coefficients of the pipe and perhaps others. Therefore it is recommended that such calculations should be referred to engineers who are expert in this field.

Polyethylene itself is typically considered an insulator and holds heat rather well. However, in this application, the benefits of the polyethylene pipe far outweigh this performance characteristic. There are many other variables that need consideration when designing a GHP system. Most manufacturers have software available to aid in the determination of the size of the unit and the footage of pipe needed for the geothermal heat exchanger.

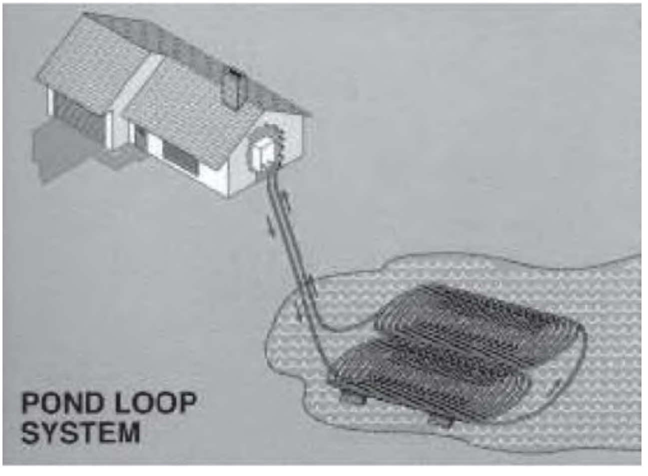
Geothermal heat pumps are very economical to operate and can save a substantial amount of money in operating costs over the life of the system. It has been reported(1) that a traditional furnace uses one unit of energy but returns less than one unit back as heat. A ground source heat pump uses one unit of energy but returns as much as three units back as heat. The polyethylene pipe acting as the heat transfer medium in the ground helps make this possible.

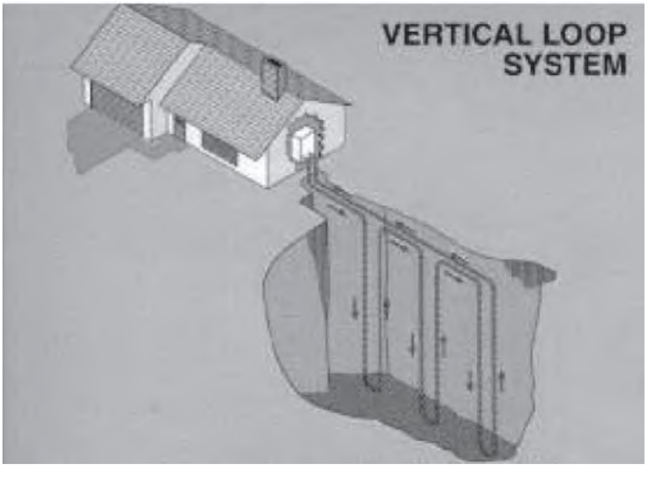
Types of Ground Heat Exchangers

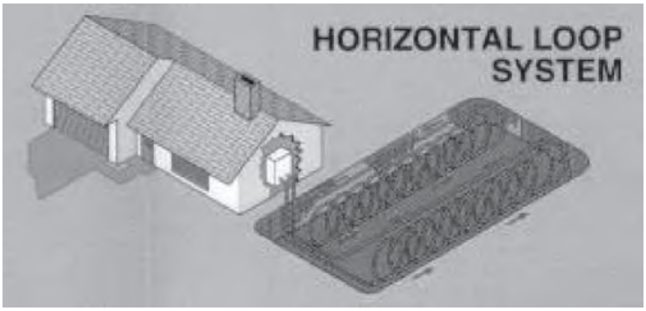
There are two basic types of heat exchangers: open and closed loop systems. Both can be configured several different ways depending on the size of the system, surrounding land, or availability of a large open water source.

Open systems require a suitable supply of water where open discharge is possible. This type of system uses the HDPE pipe to bring fresh water to the heat pump, and then discharges the water back into the water supply. Only fresh water is used, and there is no need for a special heat transfer or antifreeze solution. A key PE pipe design consideration for an open system is the fact that the system will have a suction and discharge loop. This means the pipe may need to be designed to handle negative vacuum pressures and positive pumping pressures.

The more common type of GHP installation is a closed loop system. A closed system is just that — a "closed loop" recirculating system where the HDPE pipe circulates an "antifreeze" solution continuously. This type of system can be installed several different ways such as: a pond loop system, a vertical loop system, or a horizontal (slinky) loop system. Each of these types of installation utilizes the basic performance benefits and versatility of HDPE pipe to get the most beneficial type installation for the surrounding conditions.







Pipe Specifications and Requirements

PE is the material of choice for the pipe in the heat exchanger for ground source heat pump system. The International Ground Source Heat Pump Association (IGSHPA) has developed some design and installation standards for the HDPE pipe that is required for a geothermal heat exchanger. For further details, refer to the latest edition of the IGSHPA publication "Closed Loop/Geothermal Heat Pump Design and Installation Standards.

The recommended specification takes into account the optimum performance based on the need to make sure the pipe and fittings can handle the pressures and stresses involved in the application, as well as the heat transfer requirements for the heat exchanger itself. Heavier wall pipe may be able to handle higher pressures and stresses, but the thicker wall lowers the heat transfer efficiency with the ground. All of these parameters must be balanced. When designing the PE pipe heat exchanger, maximum operating pressures and temperatures, as well as head and surge pressures must be taken into account.

For closed-loop geothermal heat exchangers, even though a high stress crack-resistant PE material is required, it is appropriate to make sure the antifreeze solution used in the heat exchanger does not adversely affect the stress crack performance of the pipe and fittings. The antifreeze solution manufacturer should be able to supply this information.

More information on the design of PE pipe systems for pressure, surges, flow capacities, etc. can be found in the Design of PE Piping Systems chapter of this Handbook.

Pipe Joining Methods

PE pipe can be joined by several different methods. One of the outstanding features of PE pipe is its ability to be heat-fused, producing a 100% leakproof joint that is as strong, or stronger, than the pipe itself.

IGSHPA recommends acceptable methods for joining as 1) a heat fusion process, or 2) stab-type mechanical fittings to provide a leak-free union between the pipe ends that is stronger than the pipe itself. This type of mechanical joint is also known as a Category 1 mechanical joint according to ASTM D 2513, Standard Specification for Thermoplastic Gas Pressure Pipe, Tubing and Fittings.

In addition, it is recommended that fusion transition fittings with threads must be used to adapt to copper pipe or fittings. Fusion transition fittings with threads or barbs must be used to adapt to high strength hose. Barbed fittings are not permitted to be connected directly to the PE pipe, with the exception of stab-type fittings as described above. All mechanical connections must be accessible.

Since mechanical connections must remain accessible, fusion joints are preferred wherever possible. Butt, socket or electro-fusion is used to join individual sections of pipe. “U-bend” fusion fittings are used for creating the return line in vertical bores. In fact, it is common for polyethylene pipe made for geothermal heat exchangers to be double wrapped on a coil and the “u-bend” fitting fused on at the factory. This makes insertion into a vertical bore very quick and easy. Sidewall fusion can be used to join parallel pipe loops to a header. All fittings must be pressure rated for the expected operating and surge pressures, and joined according to the manufacturer’s recommended procedures. This is a critical feature since this joint will be at the bottom of a well and grouted into place. Repair of a leaky joint in this location would be very difficult. However, this is a rare problem due to the nature of the fusion procedure and the dependability of the joints made using this process. Extensive information on joining PE pipe can be found in the PE Joining Procedures chapter of this handbook.

Pipe Installation

As discussed previously, there are several types of installation choices for ground source heat pumps. It is important to follow the GHP manufacturer’s requirements for the type of unit being used. This will define the amount of pipe needed for the particular installation and environment. However, there are some general guidelines for polyethylene pipe that will help assure a successful installation.

Generally, it is desired to keep the diameter of the HDPE pipe as small as possible, but not so small that pumping power to circulate the antifreeze solution becomes too great, thus losing the operating efficiency of the GHP. The smaller the diameter, the higher the surface to volume ratio will be, and the better chance for turbulent flow inside the pipe. Both of these conditions promote more efficient heat transfer. Most ground heat exchangers are constructed from ¾” to 2” diameter pipe. The headers will be 1 ¼” to 2”, and the individual loops will be ¾”, 1” or 1 ¼”. The amount of pipe utilized varies depending on environmental conditions and how much heating or cooling capacity is needed. As an example, a typical 3-ton ground heat exchanger may use 200 feet of headers and 400 feet for each parallel loop.

If trenching for a horizontal installation or header system, avoid sharp bends around corners. Pipe manufacturers have a minimum bend radius that will assure that the pipe is not overstressed. If a sharp corner is needed, utilize an elbow fitting. Remove any sharp rocks from backfill material. Long-term contact between the polyethylene pipe and a sharp object could lead to premature failure of the pipe. Even though PE pipe has very high stress-crack resistance, it is a good idea to minimize this kind of contact. The addition of sand in the bottom of the trench and preferably all around the pipe will help minimize incidental contact with sharp objects. It is also possible to plow the pipe directly into the ground using a vibratory plow. This works well up to 3-4 feet depth in areas with loose or unstable soils, and where there is not an excessive amount of rocks that could impinge on the pipe over time.

Vertical bores for ground heat exchangers are typically much simpler than drilling a water well. Generally casing is not needed if the borehole is sufficiently stable long enough to get the pipe loop installed. It is sometimes more economical to have several shallow bores rather than one deep bore. However, the bores need to be more than 50 ft. to be assured of reaching depths where ground temperatures are cooler and constant. Vertical bores must be backfilled appropriately to be sure the pipe loops have intimate contact with the soil or grout. If there are air gaps around the pipe, the heat transfer by conduction will be negatively affected.

For both types of installations leave a significant portion (3-5% of total length) of pipe extending from the bores or trenches to compensate for any relaxation from stretching, or contraction from temperature changes. Final connections to the header can be made after the system comes to steady state, usually within 24 hours. More detailed information on the installation and burial of PE pipe can be found in the Chapter entitled Underground Installation of PE Piping.

Pressure Testing Ground Heat Exchanger

After installation of pipe is completed, but prior to backfilling and/or grouting, it is necessary to flush, purge and pressure test the system. Flushing any dirt or foreign matter that entered the piping during construction is necessary in order to minimize excessive wear on pumps and seals. Purging of any air pockets will make sure that all loops are flowing as intended and heat transfer will be optimized. Flushing and purging can be done at the same time.

Before charging the system with antifreeze, it is necessary to pressure test the system with water (not air) to make sure all of the joints and connections were done correctly. Testing with air is not recommended due to safety considerations. Failure of any part of the system can be very dangerous due to the explosive nature of air under high pressure. It could result in serious injury to personnel in the area. Therefore, testing with air is discouraged. IGSHPA recommends that the heat exchanger be isolated and tested to 150% of the pipe design pressure, or 300% of the system operating pressure, whichever is less, when measured from the lowest point in the loop being tested. No leaks shall occur within a 30-minute test period. At this time flow rates and pressure drops can be compared to calculated design values. A minimum flow velocity of 2 ft/min. must be maintained for a minimum of 15 minutes to remove all air from the heat exchanger.

Since the PE pipe can expand slightly during this high level of pressurization, a certain amount of make-up water may be required. This is normal and does not indicate a leak in the system. If the pressure does not stabilize, then this may be an indication of a leak. Follow the pipe manufacturer's guidelines for pressure testing the system.

For additional information of Ground Source Heat Pump design and installation contact:
International Ground Source Heat Pump Association (IGSHPA) www.igshpa.okstate.edu.
American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) www.ashrae.org.

Solar Applications

The use of solar energy was virtually nonexistent 25 years ago, but has grown to become a significant industry in the United States. Most solar applications are geographically concentrated in the states with a high percentage of sunshine - California, Arizona, New Mexico, Colorado, and Florida.

Solar heating systems vary in size. The very simplest consist of nothing more than a black pipe lying in the sun connected to a swimming pool circulating pump. The more complex systems utilize collectors with 1, 2, or 3 layers of glazing plus piping and pumps. In addition, the latter systems may include heat transfer fluids, heat storage tanks, heat exchangers, and temperature and pressure controls. PE piping can play a major role in this application. Its combination of flexibility, high temperature properties, and resistance to freeze damage and corrosion are major advantages to this end-use. There are, however, precautions that should be taken to prevent misuse.

Check with the pipe manufacturer for recommendations on using PE pipe in solar applications.

Features and Benefits

The performance benefits of polyethylene pipe in solar heating are:

Ease of Installation – Minimizing the overall cost of solar heating is important to make them viable alternatives and to expand customer acceptance. Polyethylene pipe and tubing is available in many sizes and lengths. Its versatility and flexibility allows installations to be made with the most cost-effective design.

Freeze Tolerant – Frozen lines can be a major problem. Although collectors are protected, supply lines need to be protected from freezing or they should be made of materials that are resistant to damage if water freezes. Polyethylene pipe can normally handle a full-freeze situation without cracking or splitting.

High Temperature Resistance – For continuous use, polyethylene pipe must be suitable for high temperature environments. Polyethylene materials for use at elevated temperatures are listed in PPI's TR-4. Currently, the maximum rated temperature for PE pipe designed for pressure applications is 140°F (60°C). For use at higher temperatures contact the manufacturer for recommendations.

Collector Technologies

The most significant use of solar heating has been for swimming pool and space heating. Solar collectors are classified according to their water discharge temperatures: low temperature, medium temperature, and high temperature.
Low temperature systems generally operate at a temperature of 110ºF and have a maximum stagnation temperature of 180ºF. Medium temperature collectors typically have discharge temperatures of 180-200ºF, but can generate stagnation temperatures of 280ºF, or more, for several hours. High temperature collectors routinely operate at temperatures of at least 210ºF and can generate stagnation temperatures of more than 400ºF. Pipe or tubing made of PPI listed pressure rated PE materials can be used directly with low temperature collectors with no special precautions. In addition, PE piping is being used extensively inside unglazed collectors where temperatures rarely exceed 110ºF on a frequent basis.

To protect against ultraviolet exposure damage and to increase efficiency, plastic piping for use in collector panels should contain a minimum of 2% carbon black of proper particle size and with good dispersion. The carbon black has a two-fold benefit. One, the right kind of carbon black in the proper levels and adequately dispersed protects the PE from UV degradation. Two, the carbon black aids in the absorption and retention of solar radiation, making the pipe more efficient in the collection of solar energy. Check with the pipe manufacturer for recommendations on long-term UV exposure resistance.

Plastic piping should not be used in conjunction with high temperature collectors such as the evacuated tube or concentrating types because of their extreme temperatures. In between these two extremes are the systems with medium temperature collectors that constitute the bulk of the market. These glazed collectors are used for domestic hot water and space heating systems. Depending on the type of collector and system design, some special precautions should be taken. The major types of medium temperature systems are described in the following paragraphs along with appropriate precautions. Medium temperature systems are either passive or active types.

Passive systems use no pumps or mechanical equipment to transport the heated water. The breadbox (passive) design uses a tank placed under a glazing material. The tank is painted flat black or coated with a selective absorber to increase the solar energy absorption. The collector may be the primary storage tank or the storage tank may be in the house. In the later case, when a preset temperature is reached, water flows by gravity to the storage tank in the home and fresh water from the main is added to bring the system up to volume. In the thermosyphon passive design, a storage tank is mounted above a collector and cold water flows down into the collector. As the water is heated in the collector, it rises through thermosyphon action back up to the storage tank. Because of the large volume of water in the collector, passive solar systems are not subject to high stagnation temperatures. Thus, polyethylene piping can be used throughout, including a hook-up directly to the collector system.

Active solar systems utilize a pump to move heat transfer fluids through the collector. Some utilize potable water as the heat transfer fluid (open systems) while others use solutions such as ethylene glycol, propylene glycol, silicone oils, or hydrocarbon oils (closed systems). Hydrocarbon oil or silicone oils are generally not recommended with polyethylene pipe. In closed systems, heat is transferred from the heat transfer fluid to potable water by means of a heat exchanger in the hot water storage tank. There are many types of heat transfer fluids, and it is necessary to verify that the fluid being used is compatible and will not negatively affect the long-term performance of the pipe or other system components; refer to PPI TR-33 for further assistance.

Precautions

The extreme conditions encountered during stagnation can be a problem in active medium temperature collectors. As mentioned earlier, stagnation temperatures can exceed 280ºF in most active medium temperature collectors. Under no circumstances should any PE piping be used inside the collector, or in the system where it will be exposed to such temperatures.

Installation

In general, solar collector manufacturers do not provide piping for the system.

The installer most likely will purchase the piping from the local plumbing supply wholesaler or solar supply house. Installers are usually plumbers, but in some areas like California, solar specialists also do installations. A qualified plumbing supply house may also perform installations. The installation requires knowledge of carpentry to provide roof support or mounting, electricity to install the control system, and plumbing to install the piping system and to tie it in to the storage tank and the existing domestic water supply. Always be sure the installation meets the requirements of the local building, plumbing and mechanical codes.

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Chapter 14

Duct and Conduit

Introduction

The general purpose of conduit, or duct, is to provide a clear, protected pathway for a cable, or for smaller conduits, sometimes called innerducts. Advances in cable technologies, as well as the expense of repairing sensitive cable materials like fiber optic cable, have driven preferences for protective conduit over that of direct burial. Polyethylene (PE) conduit provides mechanical protection to fragile cable materials like fiber optic and coaxial cables, as well as protection from moisture or chemicals and even, in some cases, animals. Furthermore, the permanent pathway provided by conduit also facilitates replacement projects or future installations of additional cable or duct.

Buried conduit evolved from terracotta tile, cast concrete and Transite to plastics in the 1960s. Originally, PVC was utilized, but ultimately, PE has emerged as the material of choice due to its distinct advantages in installation options, versatility and toughness.

PE conduit can be installed below ground by a variety of methods, including open trench, plowing, continuous trenching and directional drilling. Also, its flexibility and availability in continuous coiled lengths facilitates installation into existing conduits or ducts as innerduct. In addition PE conduit provides many above ground or aerial options.

Conduit Specifications

The following specifications are utilized by the industry for the production of Conduit and Raceways:

- **Telecommunication Conduits** – ASTM F2160 Standard Specification for Solid-Wall High Density Polyethylene (HDPE) Conduit Based on Controlled Outside Diameter (OD)

- **Power Conduits** – ASTM F2160 Standard Specification for Solid-Wall High Density Polyethylene (PE) Conduit Based on Controlled Outside Diameter (OD)
- **NEMA TC7 Smooth-wall Coilable Polyethylene Electric Plastic Conduit**
- **Electrical Conduits** – UL 651A Type EB and A Rigid PVC Conduit and PE Conduit – UL 651B Continuous Length PE Conduit
- **Premise Raceways** – UL 2024 Optical Fiber Cable Raceway

Applications

PE conduit serves two primary industries: communications (telephone, CATV, data transmission) and electrical (power transmission).

In the communications industry, the advent of fiber optic cable has had a tremendous impact due to its significantly higher data-carrying capacity, particularly due to the explosion of the Internet. In telecommunications service (phone, data transmission), fiber optic cable is used, along with traditional copper cable. In cable television service (CATV), fiber optic is also growing rapidly in addition to (or replacing) coaxial cable. This progression toward fiber optic cable has made the need for protection more critical, since these materials are highly sensitive to moisture and mechanical stress. Damage can be very expensive in terms of interrupted service and replacement costs. Also, these cables are installed in very long, continuous runs which require a clear, protected pathway, as well as a leak-free system for air-assisted ("blow-in") installations. In addition to fiber optic, coaxial cables have seen improvements to increase bandwidth, making these materials more mechanically sensitive.

In the electrical industry, a critical requirement is on maintaining uninterrupted service, as consumers and businesses are even less tolerant of power outages than they are of phone or CATV service interruptions. Although many direct-buried power cable systems are designed for 30- or 40-year lifetimes, they are susceptible to external influences like rock impingement and often require frequent repairs. Conduit is finding favor over direct burial in these applications due to improved protection, but it must be continuous and facilitate quick repair operations. PE conduit is used to carry both primary (substation to transformer) and secondary (transformer to end-user) cables. Some of these installations also contain fiber optic cables placed alongside the power cables to connect with load-monitoring sensors located throughout the network.

Advantages of PE Conduit

High Density Polyethylene (PE) is the most commonly used PE material for conduit. PE conduit delivers significant physical property advantages over other conduit materials:

- **Ductility** - tough, PE conduit will better resist brittleness with age or cold weather.
- **Low temperature impact resistance** – PE withstands low temperature impact better than any other material. This is illustrated by impact testing on PE conduit conditioned at 4ºF as compared to other materials conditioned at 73ºF.
- **Permanent flexibility** – PE conduit bends and flexes without breakage, even with ground heaves or shifts, over a wide range of temperatures.
- **Temperature versatility** – PE conduit can be installed over an ambient temperature range of -30ºF to 180ºF. Power conductors rated at 90ºC and medium voltage cable rated at 105ºC are permitted for use with PE Conduit.

Installation

Flexible PE conduit can be wound onto reels several thousand feet long, does not require manufactured bends, and can be easily navigated around unexpected obstructions (in the ground or within existing ducts), simplifying installation. The few joints that are required can be made reliably through a number of options.

PE conduit is suitable for all methods of duct and cable installation, including trenching, direct plow and installation into existing main pathways (conduit pulling, sliplining and pipe bursting). Also, the flexible nature of PE conduit facilitates directional bore installations to breach obstacles like rivers or highways. Cable can consistently be pulled or blown into PE duct in great distances and at fast rates due to its low coefficient of friction. Special PE products and accessories are also available for above ground or aerial applications.

Features

A variety of PE conduit products are available for special applications.

- **Multiple ducts** of different color/stripe combinations and sizes can be delivered on one common reel, for a more efficient installation.
- Pre-installed **Cable-in-Conduit (CIC)** saves time and labor by allowing one-step placement of both cable and duct. The integrity of the cable is protected during the installation process by the PE duct. Testing prior to and after the duct has been extruded around cable is performed to ensure no performance loss. Cable-in-Conduit can be provided with fiber, coaxial, twisted pair and electrical cables.
- **Corrugated** innerduct is flexible, lightweight with a low coefficient of friction.
- **Ribbed conduit** (longitudinally or spiral) provides friction reduction in cable installation.
- **Self-supporting duct** includes a suspension strand already built into the duct for greater dimensional stability and ease of installation in the aerial plant.

Deployment of ducts aerially allows for enhanced protection for the cable and allows for less costly cable repairs and capacity upgrade options.

Material Selection

The primary physical property advantages of PE conduit are flexibility, ductility and chemical resistance. Other physical attributes critical to the performance of PE conduit are tensile strength and stress crack resistance. However, the designing or specifying engineer should be aware that not all PE materials deliver the same level of performance in these areas, and it is critical to ensure that the material meets all the demands of the installation and service conditions. This section will briefly discuss these material considerations, but a more thorough discussion of PE technology is provided in the chapter on engineering properties of polyethylene in this Handbook.

Physical Properties

Cell Classification

The Cell Classification (ASTM D 3350) is a 6-digit numeric "code" which describes an PE conduit material's performance level in six key physical characteristics. This 6-digit classification often includes a single letter suffix representing a color or UV stabilizer category. This cell classification is used in specifications such as ASTM F2160 Standard Specification for Solid Wall High Density Polyethylene (PE) Conduit Based on Controlled Outside Diameter (OD). Each property is broken into 4-6 specific performance ranges.

Density – PE density generally has the greatest effect on many physical properties. For example, higher densities favor increased tensile strength and stiffness, while lower densities generally favor impact resistance, and flexibility and stress crack resistance. Density also affects coefficient of friction (COF – see Section 7), with higher density typically related to lower COF. Therefore, some degree of compromise may be necessary to balance properties required for a particular application.

Melt Index – Melt Index (MI), a measurement of a polymer's molten flow properties (ASTM D 1238), is related to molecular weight, or the length of the individual polymer chains. Generally, lower melt indices represent higher molecular weights while higher values indicate lower molecular weights. For any given PE resin, a lower melt index (higher molecular weight) will normally have superior physical properties.

Flexural Modulus – Flexural modulus is a measure of a plastic's stiffness, or its resistance to bending or deflection under applied load. In PE conduit, these stiffness characteristics generally affect load-bearing capability, bending radius, and tendency to ovalize (when coiled or bent). Flexural modulus should be taken into account when determining the appropriate wall thickness for an installation.

Tensile Strength/Yield Strength – Tensile yield strength, or the point at which a stress causes a material to deform beyond its elastic region (irreversible deformation), is a critical property for many conduit installation methods involving pulling (e.g., directional drilling). Yield strength can limit the rates or lengths of such installations (see page 7 Design Considerations), and it is an important consideration in determining allowable pull loads. It is important to note that both flexural modulus and tensile strength are affected by temperature (both decrease with increasing temperature).

Slow Crack Growth – ASTM D1693 Environmental Stress Cracking Resistance (ESCR) or ASTM F1473 Polyethylene Notched Tensile (PENT) can measure properties of slow crack growth. For PE conduit applications, ESCR is utilized. As one of the most important properties affecting the service life of PE conduit, stresses due to bends and rock impingement can cause inferior conduit materials to crack and fail, particularly at higher temperatures. ESCR is a laboratory test which measures a material's ability to resist cracking under these conditions. As mentioned above, higher densities generally have a negative effect on ESCR, and, as a general practice, base resins with densities below 0.950 have ESCR properties suitable for conduit applications.

Hydrostatic Strength Classification – The hydrostatic strength classification describes the material's resistance to failure under internal pressure; this property is primarily used for pressure piping applications and is not required for conduit. PE conduit materials are represented by a "0" (not pressure rated) in this category.

Other Important Physical Properties

Chemical Resistance – PE is highly resistant to a wide range of chemical agents even at elevated temperatures. However, when installing in potentially aggressive environments, the user should refer to PPI Technical Report TR-19, *Thermoplastic Piping for the Transport of Chemicals,* which provides chemical resistance data for PE with a wide range of chemicals.

Impact Resistance – Impact resistance is related to the pipe's ability to absorb impact and resist cracking during handling and installation, particularly in cold weather. An advantage of PE over many other materials is its ductility at low temperatures. For example, PE's glass transition temperature (the temperature below which it is more brittle and glassy) is well below 0°F, at approximately -166°F (~-110°C), while for PVC it is well above room temperature, at about 176°F (~80°C). Like ESCR, impact resistance is strongly influenced by density, with lower densities generally favoring greater impact resistance.

There are a number of impact tests for materials, like Izod or Charpy (see the chapter on engineering properties in this Handbook), but generally finished pipe and fittings are tested by a falling weight (tup) impact test (for example, ASTM D2444) at low temperature — typically -4°F (-20°C). This test, commonly used in Quality Assurance, is a pass/fail test, in which any cracking or breaking is considered a failure.

Stabilization

Unprotected PE, like virtually all other polymers, is vulnerable to degradation due to prolonged exposure to heat, oxygen or ultraviolet (UV) radiation, resulting in embrittlement and reduced service life. To prevent these damaging effects, PE conduit materials are typically formulated with a variety of stabilizing additives, ranging from antioxidants to UV stabilizers, to maintain required long-term performance. For a more in-depth discussion on both antioxidants and UV protection, see the chapter on engineering properties in this Handbook. Regardless of the type of UV protection used, the conduit must be adequately protected from UV attack to withstand normal storage conditions and special use intervals. Adequate protection for conduit destined for underground installation is to provide for at least one year's protection from outdoor storage. If longer storage times are possible or anticipated, the user may specify additional stabilization, or, preferably, should provide for a covered storage environment. Otherwise, if the conduit exceeds one year of UV exposure, it should be tested to ensure it meets all physical property requirements (cell classification, impact resistance) prior to installation.

The most common means for UV protection is to employ carbon black at a minimum loading of 2%. For long-term aerial exposure in self-supporting Figure-8 duct designs, due to the heightened mechanical stress level, the carbon black should be more finely divided and dispersed, having an average particle size of less than or equal to 20 nanometers, in accordance with ASTM F 2160.

PE non-black materials, however, require special stabilizers in addition to their normal pigments, generally UV blockers or Hindered Amine Light Stabilizers (HALS).

Colorants for Conduit

PE conduit is produced in a variety of solid and striped colors, which serve to help identify the duct for either its end use application (e.g., fiber optic cable, power, etc.) or owner. In determining the color of the conduit, its striping or the marking of the conduit or a combination thereof, it is recommended for safety reasons that the color yellow not be utilized since this is the uniform color code for natural gas applications.

Design Considerations

Conduit vs. Pipe

In general, plastic conduits and plastic pipes are very similar in structure and composition, but deployment is where they differ.

- Conduits do not have long-term internal pressure.

  External forces are unchecked; if ovalized during installation, it may not recover during service.

  Long-term stress rupture is not a factor. (Hydrostatic Design Basis is not required in material selection.)
- Conduit ID is chosen by cable occupancy, where internal clearances are critical; whereas, for piping applications, ID is based on volumetric flow requirements.
- Path of installation for conduit is very important – radius of curvature, vertical and horizontal path deviations (undulations) and elevation changes all significantly affect cable placement.

Cable Dimension Considerations

Determination of a conduit's dimensions begins with the largest cable, or group of cables or innerducts, intended for occupancy. From a functional viewpoint, selection of diameter can be broken down into the following general considerations:

1. The inside diameter of the conduit is determined by the cable diameter and placement method (pulling or air-assisted pushing).
2. Pulling cables into underground conduits requires sufficient free clearance and is typically further distinguished by classifying the cables into two groups: power and coax (short lengths) and fiber (long lengths). Additionally, electrical cable fill is controlled by the National Electric Code (Chapter 9), whereas, dielectric, or fiber optic cables, are not.
3. Long pulling lengths require low volume fill, i.e. 36% max.
4 Short pulling lengths may be filled up to 53%, or up to the latest NEC limitations for groups of cables.
5. Push-blow installation methods for long length fiber cables utilize higher volume fills, i.e. up to 70% max.
6. Innerducts are smaller diameter conduits, intended for placement into larger

conduits or casings. Their purpose is to subdivide the larger conduit space into discrete continuous pathways for incorporation of fiber optic cables. Diameters of conduits and innerducts are often specially designed to maximize the conduit fill.

Using these guidelines, one can determine the minimum ID of the conduit or innerduct. When over-sizing a conduit for power, coaxial or multi-pair telecom cables, the more room the better. This rule does not necessarily apply for push-blow methods of installation. Here, it is found to be more difficult to push a cable with additional clearance since a cable tends to form a helix, which transfers some of the axial load laterally into the wall causing friction. The air velocity moving over the cable can also be maximized with a minimum volume of air when the free volume is low. Higher air velocities result in improved drag forces on the cable, thus aiding with its placement.

Conduit Wall Determination

Conduit and duct products come in a wide range of sizes, spanning 1/4-inch (5mm) to 24-inch (610mm) bore casings. The standard dimension ratio, SDR, of a conduit is defined as the ratio of the average conduit diameter divided by the minimum wall thickness. Wall thickness typically ranges between SDR 9 to SDR 17. (Larger SDR numbers indicate a thinner wall thickness.)

Conventions exist that work off of either the average outside diameter (SDR) or the average inside diameter (SIDR). Internally sized (SIDR) are usually chosen when the inside diameter clearance must be very carefully controlled. This usually does not apply to most duct installations because, as noted above, the free clearance between the cable and the inner wall of the conduit is not usually that close. Bore casings, on the other hand, offer situations that can benefit from close ID control because many times several innerducts are tightly fit into a casing. In this latter case, the conduit wall can be increased or decreased relative to service conditions without jeopardizing the inside clearance fit. Internally sized dimension tables tend to preserve the minimum ID above the nominal conduit size, whereas, externally sized conduits often fall below the nominal ID as the wall thickness increases.

For most conduit installations, SDR sizing is utilized because the OD control lends itself to better joint formation using external couplers. This becomes very important when air-assisted placement methods are used for placing the cable. On the other hand, large diameter conduits (4 and above) typically undergo butt fusion as a means of joining.

Determination of the wall thickness becomes a function of either the method by which the conduit is placed, or the nature of environmental stresses that it will be exposed to over the service life. ASTM F 2160, *"Standards Specification for Solid Wall*

High Density Polyethylene (PE) Conduit Based on Controlled Outside Diameter (OD)", explains the conduit sizing systems fully.

Installation Method vs. Short-Term and Long-Term Stress

The viscoelastic nature of PE results in differences in the observed mechanical properties as a function of time (and/or temperature). The apparent stress/strain behavior of the material is time dependent under the influence of a sustained load. This is referred to as "creep" properties. In this regard, we can distinguish between "short-term" properties, such as those exhibited during a laboratory tensile test at a strain (stretching) rate of two inches per minute, as compared with "long-term" properties typical of conduit placement and sustained service loads.

Knowledge of the load-bearing capability of PE as a function of loading rate allows one to select appropriate strength values to substitute into design equations. Loads are applied to conduits both by the environment that they are placed into and by the placement means under which they are installed; the chief difference being the duration over which the load is applied. For example, a common means to install multiple conduits is to directly plow them into the ground using either a railroad plow or tractor-drawn plow. During this installation process, a certain amount of bending and tensile stress is encountered over a rather short period of time (only seconds to minutes). Whereas, after the plow cavity collapses about the conduit, the ground continues to settle upon stones that may be pressing directly against the conduit, thus setting up a long-term compressive load. For this application, we see that we would require both long-term and short-term moduli to assess the deflection resistance. Initially the conduit may offer resistance to ovalization, but in time, the resin may yield under the sustained load, resulting in a reduced pathway for the cable.

Numerous approaches to placing conduits have evolved over the years. Each method presents its own unique set of challenges with respect to the potential for conduit damage, or installation related predicaments. Perhaps one way to compare the potential sensitivity to damage of the various methods is the following table. Here the potential for damage is depicted by a numerical scale ranging from 0 to 5, where 5 is the most severe condition, resulting in yielding and permanent deformation of the conduit; 4 is the potential for loads greater than 75% of yield stress; 3 represents loads greater than 50%; 2 representing greater than 25%; 1 less than 25%, and 0 representing no significant load at all. The shaded areas depict the most severe condition.

TABLE 1
Relative Damage Sensitivity vs. Installation Method

Installation Method	Short-Term Loading				Long-Term Loading		Recommended SDR Range
	Tensile	Bending	Crushing	Impact	Crushing	Tensile	
Conduit*	3 - 5	3	2	1	1	1 - 2	9.0 – 13.5
Horizontal Bore	4 - 5	2	3 - 4	0	3 - 5	1	9.0 – 11.0
Direct Plow	2	3	4 - 5	1 - 2	4 - 5	1	9.0 –11.0
Continuous Trench	2	2	3 - 4	1 - 2	3 - 4	1	9.0 – 11.0
Open Trench	0	0	1 - 3	1	1 - 3	1	11.0 – 17.0
Aerial	1 - 2	3 - 5	2 - 3	1	1	2	11.0 – 13.5

* The term "conduit" in this chart refers to the placement of PE innerducts into a buried 4" to 6" PVC conduit typical of the underground telecom plant. The SDR recommendation range attempts to select safe SDR's based upon the potential for stressful conditions.

It should be noted that the above table is not intended to be representative of all conduits installed by these methods, but is indicative of what can happen when the wrong diameter, wall or material is used. Check with supplier for specific design recommendations.

Perhaps the most serious and least controlled problem for cable placement is that of ovalization or kinking of the conduit. This condition can be brought about through tensile yielding, severe bending, excessive sidewall loading, or probably more frequently, the crushing action of rocks in the underground environment. In direct plow or bore applications, one gets little feedback from the process to indicate that a potential problem is developing. For these applications, the most robust conduit design should be considered.

Below Ground Installations

Open Trench / Continuous Trenching

Conduits intended for buried applications are commonly differentiated into two classes, rigid and flexible, depending on their capacity to deform in service without cracking, or otherwise failing. PE conduit can safely withstand considerable deformation and is, therefore, classified as a flexible conduit.

Flexible conduits deform vertically under load and expand laterally into the surrounding soil. The lateral movement mobilizes the soil's passive resistance forces, which limit deformation of the conduit. The accompanying vertical deflection permits soil-arching action to create a more uniform and reduced soil pressure acting on the conduit. PE stress relaxes over time to decrease the bending moment in the conduit wall and accommodates local deformation (strain) due to imperfections in the embedment material, both in the ring and longitudinal directions.

The relationship between pipe stiffness, soil modulus (stiffness), compaction and vertical loading is documented by the work of Spangler and others. The pipe stiffness, as measured in ASTM D2412 and Spangler's Iowa formula provide a basis for prediction of conduit deflection as related to dimension ratio and resin modulus. It should be noted, however, that creep affects the pipe stiffness, so the long-term modulus should be used. Additional information pertaining to soil embedment materials, trench construction and installation procedures can be found in the chapter on "Underground Installation of Polyethylene Piping" in this Handbook.

Flexible conduit can occasionally fail due to stress cracking when localized forces (for example, from a large sharp rock) exceed the material's ability to relax and relieve stress. However, PE resins suitable for conduit applications should have adequate stress relieving properties to avoid these failures. Therefore, the design process should include consideration of the conduit resin's stress crack resistance, as well as the selection of appropriate embedment material and compaction.

Direct Plow

Flexible conduit materials need adequate compressive strength to safely resist the compressive stresses generated by external loading. However, the usual design constraint is not material failure due to overstraining, but, rather, excessive deflection or buckling under anticipated earth and ground water pressures. Deflection or buckling is more probable when the embedment material does not provide adequate side support. For example, pipe installed by directional drilling and plowing typically does not receive side support equivalent to that provided by the embedment material used in trench installations where bed and backfill can be "engineered" to provide a specific level of lateral support.

Plowing installations often encounter rocky soils, which would induce significant crush loads for conduits 2-inch diameter and smaller. In these cases, SDR 11 is the minimum wall thickness that should be used, and if rocky conditions were likely, SDR 9 would be more appropriate.

Pipe stiffness, as calculated per ASTM D2412, gives a measure of flexural stiffness of the pipe. Pipe stiffness equals the ratio of the applied load in units of lbs/lineal inch to the corresponding deflection in units of inches at 5% deflection. It should be understood, however, that although two conduits, 6-inch and 1.25-inch diameter, may possess the same pipe stiffness, the amount of soil load required to induce a 5% deflection in each is considerably different. As a result, the sensitivity of smaller diameter conduits to underground obstructions is that much greater. Another physical parameter for smaller conduits, crush strength, is often employed to establish limits of crush resistance. Unfortunately, there is no universally agreed upon criterion or test method for crush testing. Typically, the conduits are subjected to an increasing load, similarly applied as in ASTM D2412, but to a far greater deflection—on the order of 25 to 50% of the inside diameter. This deflection-limiting load is then reported on a per-foot basis.

Table 2 illustrates the difference in the load required to induce a 5% deflection in conduits having different diameters but common pipe stiffness values. These values were generated assuming a flexural modulus of 150,000 psi for the resin. Units for pipe stiffness are in pounds/inch of length/inch of deflection, whereas those for the crush are presented as pounds per foot. It is apparent that a fixed external load more easily deflects smaller diameter conduits. It is also important to remember that, in long-term loading, the resin will maintain only about 22 to 25% of its original modulus; thus, smaller thin-wall conduits can be quite susceptible to localized loads brought about by buried obstructions.

Conduit Network Pulling

In the telephone and electrical utility industries, the underground plant is often comprised of a network of 3", 4", and 6" conduit banks. These "rigid" conduits are composed of clay tile, cement conduit, or more recently, PVC constructions. They are usually separated by manhole vaults or buried pull-boxes. Distances between, and placement of manholes and pull-boxes is largely a function of the following constraints:

1. Location of branch circuit intersections
2. Lengths of cables (or innerducts) available on reels
3. Access to, or limited by physical obstructions
4. Path difficulty for placement of cable or innerducts
5. Surface environment
6. Method of cable placement (mid-assist access)

In addition, Department of Transportation (DOT) regulations often require additional protection and support structure for buried conduits in road bores and traffic areas. Although steel casings have been used in the past, it is becoming more prevalent to horizontally bore under roadways (or waterways) and pull back an PE casing into which PE innerducts are installed.

Pull placement of innerducts has obvious similarity to traditional cable placement methods. Several good references on this subject exist, including *Guide For Installation of Extruded Dielectric Insulated Power Cable Systems Rated 69KV Through 138KV,* *Underground Extruded Power Cable Pulling Guide, AEIC Task Group 28 and IEEE Guide Distribution Cable Installation Methods In Duct Systems.*

There are a number of variables that influence loading and selection of innerducts when pulling into conduit structures:

- Diameter of conduit and innerduct, and number of innerducts to be installed – clearance fit
- Length and direction changes of conduit run, sweeps
- Composition of conduit and coefficient of friction
- Jam combinations
- Pull speed and temperature
- Elevation and innerduct weight

Horizontal Directional Bore

For directional drilling the design process should include consideration of tensile forces and bend radii created during these processes. Flexible conduits installed in continuous lengths are susceptible to potential tensile failures when pulled into place, so allowable tensile forces should be determined to avoid neck-down from tensile yield. The engineer should also account for the conduit's allowable bend radius, especially on bends with no additional support given to the conduit, to prevent ovalization and kinking from installation. For additional information, please refer to the chapter on horizontal directional drilling in this Handbook.

TABLE 2
Pipe Stiffness (PS) vs. Crush Strength

Conduit Size	OD In.	SDR 9			SDR 11			SDR 13.5			SDR 15.5			SDR 17		
		Wall In.	PS Lb/in. in.	Crush Lb./6 in.	Wall In.	PS Lb/in. in.	Crush Lb./6 in.	Wall In.	PS Lb/in. in.	Crush Lb./6 in.	Wall In.	PS Lb/in. in.	Crush Lb./6 in.	Wall In.	PS Lb/in. in.	Crush Lb./6 in.
1	1.315	.146	1310	804	.120	671	433	.097	344	231	.085	220	151	.077	164	114
1.25	1.660	.184	1310	1020	.151	671	547	.123	344	292	.107	220	190	.098	164	144
1.5	1.900	211	1310	1160	.173	671	626	.141	344	33	.123	220	218	.112	164	165
2	2.375	.264	1310	1450	.216	671	782	.176	344	417	.153	220	272	.140	164	206
2.5	2.875	.319	1310	1760	.261	671	947	.213	344	50	.185	220	330	.169	164	249
3	3.5	.389	1310	2140	.318	671	1150	.259	344	615	.226	220	402	.206	164	304
4	4.5	.500	1310	2750	.409	671	1480	.333	344	790	.290	220	516	.265	164	390
6	6.625	.736	1310	4050	.602	671	2180	.491	344	1160	.427	220	760	.390	164	575

Table 2 is for comparative purposes only. Pipe stiffness values are based on 150,000-psi flexural modulus. Crush values are estimated from empirical data for 6" long conduit samples compression tested in accordance with ASTM D2412 to 50% deflection.

Installation Methods

This section discusses various conduit installation options in general terms and should not be interpreted as a step-by-step guide or "operations manual." The user should contact the equipment manufacturer for more detailed instruction, as operating procedures will vary with equipment.

NOTE: The consequences of striking gas or power lines (above and below ground) during installation can be dangerous, possibly deadly. Before digging, it is critical to ensure that all existing underground service lines (gas, water, power, etc.) in the vicinity are located and marked. It is recommended to contact the local "Call Before You Dig" agency to ensure these provisions are made. Furthermore, prior to installation, consult NEC, NFPA and NESC codes, as well as any applicable local codes.

General Considerations

Mechanical Stress

Regardless of the installation method, mechanical stress is of great concern during conduit placement. Exceeding the maximum allowable pulling tension or the minimum allowable bending radii can damage conduit. Consult the conduit supplier for allowable pulling tensions.

Pulling Tension

During conduit pulling placement, attention should be given to the number of sweeps, bends or offsets and their distribution over the pull.

Tail loading is the tension in the cable caused by the mass of the conduit on the reel and reel brakes. Tail loading is controlled by two methods. Using minimal braking during the pay-off of the conduit from the reel at times can minimize tension; no braking is preferred. Rotating the reel in the direction of pay-off can also minimize tail loading.

Breakaway swivels should be placed on the conduit to ensure that the maximum allowable tension for that specific conduit type is not exceeded. The swivel is placed between the winch line and pulling grip. A breakaway swivel is required for each conduit.

Bending Radii

Conduit is often routed around corners during placement, and pulling tension must be increased to complete the pull. It is important to determine the minimum radius to which the conduit can be bent without mechanically degrading the performance of the conduit. See Table 3.

TABLE 3
Minimum Bend Radius as a function of Diameter and Standard Dimension Ratio

		SDR 9		SDR 11		SDR 13.5		SDR 15.5		SDR 17	
Size	OD In.	Wall In.	Min. Radius In.	Wall In.	Min. Radius In.	Wall In.	Min. Radius In.	Wall In.	Min. Radius In.	Wall In.	Min. Radius In.
1	1.315	.146	15.4	.120	20.1	.097	25.9	.085	30.6	.077	34.1
1.25	1.660	.184	17.1	.151	22.3	.123	28.9	107	34.2	.098	38.1
1.5	1.900	.211	18.2	.173	23.8	.141	30.8	.123	36.4	.112	40.6
2	2.375	.264	20.0	.216	26.3	.176	34.2	.153	40.5	.140	45.2
2.5	2.875	.319	21.8	.261	28.0	.213	37.3	.180	44.3	169	49.5
3	3.500	.389	23.8	.318	31.4	.259	40.9	.226	48.5	.206	54.2
4	4.500	.500	26.4	.409	35.0	.333	45.8	.290	54.5	.265	61.0
6	6.625	.736	30.9	.602	41.3	.491	54.4	.427	64.9	.390	72.8

Ovalization is independent of tensile strength or modulus, but is controlled by diameter, wall thickness and bending radius. The radii listed above are estimated, as the minimum unsupported bending radius required producing a 5% ovalization. The values in the above table are calculated based on minimum wall thickness and are a first approximation to ovality in the bending conduit (actual bending radius may be slightly smaller). Ovality is calculated as: Ovality = [(Max. OD – Min. OD)/ Avg. OD] x 100.

Underground Installation

Generally, the three primary underground installation (or "underground plant") methods are trenching, plowing and boring, described in general terms below.

Trenching Methods

As with all methods, there are many variations on trenching installations, but generally the two main variations are the traditional "open trench" method and "continuous" trenching.

Open Trench/Continuous Trench

As the name implies, open trench installations involve digging an open trench and laying the conduit directly into the trench, often along with embedment material to protect the conduit from damage due to the surrounding soil. This installation is accomplished with specialized trenching machines that cut the trench and remove the soil in a single action and can be used to place multiple conduits over long or short distances. This technique, more common in pressure pipe or PVC installations, is described in more detail in the chapter on underground installation in this Handbook.

In Continuous trenching, conduit payoff moves along with the trenching process.

Digging the Trench

The trench should be dug as straight, level and rock free as possible. Avoid curves smaller than the conduit's allowable bend radius. Undercut inside corners to increase the radius of the bend. Should there be a rapid grade change, use back-fill to support the conduit.

Excavate the trench to the desired depth, and remove all rocks and large stones from the bottom of the trench to prevent damage to the conduit. Push some clean fill (fine material, without stones) into the trench to cushion the conduit as it is installed in the trench.

Supplemental trenches should be made to all offset enclosure locations. Trench intersections should be excavated to provide adequate space to make sweeping bends in the conduit.

Fill the trench and compact as required. Tamp the trench to provide compaction that will prevent the trench backfill from settling.

Placing the conduit

An important consideration for open-trench installations of PE conduit is that conduit should be straightened to remove any residual "coil memory," which can create a tortuous path for the cable and create significant challenges to cable installation. Conduit pay off can be accomplished by pulling the conduit into the trench from a stationary reel or by laying the conduit into the trench from a moving reel, usually attached to a trailer.

Spacers should be used when placing multiple ducts in a trench. Spacers prevent the ducts from twisting over and around each other. By keeping the ducts in straight alignment, cable-pulling tensions are reduced. When water is present in the trench, or when using extremely wet concrete slurry, floating of the conduit can be restricted through the use of the spacers.

Backfilling

It is best to place the best quality soil directly on and around the conduit. DO NOT place large rocks directly on the conduit. Allow at least 2 – 4 inches (5 – 10 cm) of clean, uniform soil to cushion the conduit.

A good practice to insure long-term protection of underground facilities is to utilize sand for padding the conduit. It provides a more stable environment for the conduit, prohibiting damage from rocks and allowing water to drain away from conduit easily. More importantly is the protection it can provide during future excavation near your facilities. The apparent change in soil condition provides warning that there is a utility buried there. This should not replace the practice of placing warning tape, but rather should serve as a supplement.

During backfill, warning tape should be placed typically 1 to 3 feet above the conduit.

Plowing

Plowing is the preferred installation for long continuous runs where space permits, for example, in rural areas. Plowing installations use a plow blade (pulled by a tractor or mounted to a railroad car) to split the earth and place the cable at the required depth through a feed tube located directly on the plow blade. The key distinction between plowing and continuous trenching is that trenching involves the actual removal of soil from the trench, whereas plowing only displaces soil while laying in the conduit.

Consult the equipment manufacturer for specific recommendations on plow blade and feed tube designs. It is strongly recommend to have a professionally engineered single or double feed tube plow blade with a tube at least 0.5 inch (1.25 cm) larger than the largest conduit size and a radius no smaller than the minimum bend radius of the largest conduit size. It is recommended that DR 11 or DR 9 be used, depending on conditions and conduit diameter.

Local regulation may require that warning tape be plowed in with the cable. Most plow manufacturers make plow blades that bury cable and tape at the same time.

Plowing Variations

There are several variations of plowing installations. A few are described briefly below:

- **Vibratory Plowing** – This method uses a vibrating blade and may allow use of a smaller tractor than that used for static plowing.
- **Rip and Plow** – This method may be required when significant obstructions (for example, roots) are anticipated and uses an additional lead plow (without conduit) to rip the ground and clear obstructions several hundred yards ahead of the primary plow with conduit.
- **Pull Plows Method** – Instead of installing from a reel traveling with the plow, conduit is pulled from a stationery reel behind the plow through the plowed trench.

Directional Bores

Directional boring allows the installation of conduit under obstacles that do not allow convenient plowing or trenching installations, for example rivers or highways. This unique installation method, which capitalizes on a primary strength of PE conduit — its flexibility, can be accomplished over very long distances.

Directional boring is accomplished using a steerable drill stem to create a pathway for the conduit. The equipment operator can control the depth and direction of the boring. A detailed discussion of this installation method is presented in the chapter on "Polyethylene Pipe for Horizontal Directional Drilling" in this Handbook. Also, consult the equipment supplier for detailed operating procedures and safety precautions.

It is recommended that DR 11 or DR 9 be used, depending on conditions and conduit diameter.

Installation into Existing Conduit

Conduit (or multiple conduits) is often pulled into existing conduit systems as innerduct.

NOTE: ALWAYS test and ventilate manholes prior to entering into them and follow OSHA confined space requirements.

Proofing

An important step that should be taken prior to this type of installation is "proofing" the existing conduit to ensure that all obstructions are cleared and that conduit continuity and alignment is good. It is recommended that a rigid mandrel roughly 90% of the inner diameter of the conduit be used to perform the proof. Proofing conduit is typically performed by pushing a fiberglass fish with a rigid mandrel attached to the end of it through the conduit. Any problem areas should be felt by the person pushing the fiberglass fish and should then be marked on the fish so that the distance to the problem is recorded and if necessary can be located for repair with greater ease. If the fiberglass fish makes its way through the conduit without any difficulties experienced, then the conduit has "proofed out," and no repairs should be necessary.

Before placement of the innerduct inside the conduit can be started, it is important to have all of the necessary equipment to protect the innerduct. The use of sheaves, bending shoes, rolling blocks (45 and 90 degrees) and straight pulleys are required for protection of the innerduct during installation. It is important that they all meet the proper radius for the innerduct size. The use of a pulling lubricant will greatly reduce the tension and stress on the innerduct when pulling innerduct into an existing conduit. Ball bearing swivels are needed for attaching the winch line to the innerduct harness system.

Mid-Assists

On long routes and routes with many turns in them it is important to consider the selection of mid-assist locations. There are different ways of providing mid-assist for innerduct pulls. Typically the use of a winch is required such as a capstan or vehicle drum winch. The introduction of mid-assist capstan winches has made innerduct pulling an easier task, requiring less manpower and communication than traditional drum winching involves. More importantly it provides greater production capabilities.

After Pulling

The stress of pulling innerduct through existing conduit will vary with the length of the route and the number of turns it has to make, as well as the condition of the conduit it is being pulled into and the amount of lubrication used. The effects of the stress will cause the innerduct to elongate (or stretch) in proportion to the amount of stress, but should be less than 2% of the total length placed. Due to this effect, it is important to pull past the conduit system slightly to compensate for recovery to the original length. An allowance of at least one hour needs to be given for the innerduct to "relax" before cutting and trimming it.

Above Ground/Aerial

There are many applications for aerial conduit, which include but are not limited to road crossings, rail crossings, trolley line crossings, and water crossings. They provide for efficient means of supporting cable that can easily be replaced and/or allow for the addition of cables without requiring encroachment in often hazardous or difficult to access spaces.

A critical consideration for aerial applications is UV protection. For this reason, only conduit materials with special carbon black pigments can be used, since constant direct exposure to UV radiation significantly shortens the lifetime of unprotected PE conduit (see Material Selection in this chapter).

Installation

The two preferred methods for aerial installation of conduit are the back-pull/stationary reel method and the drive-off/moving reel method. Circumstances at the construction site and equipment/manpower availability will dictate which placement method will be used.

Design consideration must be given to the expansion/contraction potential of PE conduit. This consideration is more important when lashing conduit than with the use of self-supporting conduit.

Installation – Back-Pull/Stationary Reel Method

The back-pull/stationary reel method is the usual method of aerial conduit placement. This method is also best suited for locations where the strand changes from the field side of the pole to the street side of the pole and where there are excessive obstacles to work around. The conduit is run from the reel up to the strand, pulled back by an over lash cable puller that only travels forward and is held aloft by the cable blocks and rollers. Once the section of conduit is pulled into place it is lashed and then cut.

Installation – Drive-Off/Moving Reel Method

The drive-off/moving reel method may realize some manpower and timesaving in aerial conduit placement and lash-up. This method is used where there is existing strand and is on one side of the poles, typically roadside. In it, the conduit is attached to the strand and payed off a reel moving away from it. The conduit is being lashed as it is pulled.

Self-Supporting Conduit

Installation of self-supporting conduit can be accomplished by both of the above methods, the difference being that the support strand is an integral part of the conduit. This product approach not only simplifies installation by eliminating the step of independently installing a support strand, but it improves the controllability of the expansion-contraction properties of the conduit.

Installation – Over-lashing Existing Cable

Over-lashing conduit onto existing cable plant is similar to installing conduit onto new strand. However, there are some unique aspects.

A sag and tension analysis should be performed to see if the new cable load will overwhelm the strand. Also, over-lashing conduit on top of sensitive coaxial cables may influence the cables signal carrying capability due to rising lashing wire tensions that may result from contraction-induced movement of the conduit. It is best to seek the help of engineering services in planning an aerial plant.

Joining Methods

Introduction

Conduit can be joined by a variety of thermal and mechanical methods. Since conduit does not experience any long-term internal pressure and acts only as a pathway for power or other cables, the owner of the system may be tempted to neglect the importance of specifying effective couplings. However, an integral part of any conduit system is the type and quality of joining method used. Proper engineering design of a system will consider the type and effectiveness of these joining techniques.

The owner of the conduit system should be aware that there are joint performance considerations that affect the system's reliability well beyond initial installation. Some of those might include:

- **Pull out resistance**, both at installation and over time due to thermal contraction/expansion, must be considered. This is critical for "blow-in" cable installations, which will exert an outward force at joints, less so for pulling installations, which will tend to exert the opposite force.
- **Pressure leak rates**, for "blow-in" installations at pressures of 125 to 150 psig. Consideration must be given to how much leakage can be tolerated without reducing the distance the cable can consistently be moved through the conduit.
- **Infiltration leakage**, allowing water and/or silt to enter the conduit over time, can create obstacles for cable installation and repair or cause water freeze compression of fiber optic cables.
- **Corrosion resistance** is important as conduit systems are often buried in soils exposed to and containing alkali, fertilizers, and ice-thawing chemicals, insecticides, herbicides and acids.
- **Cold temperature brittleness resistance** is required to avoid problems with installation and long-term performance in colder climates.

General Provisions

PE-to-PE joints may be made using heat fusion, electrofusion or mechanical fittings. However, mechanical couplings are often preferred over fusion joints, due to the internal bead of a butt fusion joint, which can interfere with cable installation. PE conduit may be joined to other materials in junction boxes or other hardware utilized by communication and electrical industries, by using mechanical fittings, flanges, or other types of qualified transition fittings. The user may choose from many available types and styles of joining methods, each with its own particular advantages and limitations for any joining situation encountered. Contact with the various manufacturers is advisable for guidance in proper applications and styles available for joining as described in this section.

Mechanical Fittings

PE conduit can be joined by a variety of available styles of mechanical fittings, each with its own particular advantages and limitations in any given application. This section will not address these advantages or limitations but will only offer general descriptions of many of these fitting types and how they might be utilized. ASTM F 2176, *"Standard Specification for Mechanical Couplings Used on Polyethylene Conduit, Duct and Innerduct,"* establishes performance requirements for material, workmanship, and testing of 2-inch and smaller mechanical fittings for PE conduit. PPI recommends that the user be well informed about the manufacturer's recommended joining procedure, as well as any performance limitations, for the particular mechanical connector being used.

Barbed Mechanical Fittings

Barbed fittings are available in various materials and configurations for joining conduit sizes 2-inch and smaller. None of these fittings are offered with sealing capabilities. Installation involves pressing the fitting over ends of the conduit to be joined using a special tool. The inside of these fittings contain sharp, inward-facing barbs which allow the conduit to be pressed in, yet dig into the conduit and resist removal when pulled.

Threaded Mechanical Fittings

Threaded mechanical fittings are available in various materials and configurations for conduit sizes 2-inches and smaller. Some are designed with sealing capabilities while others are not. Internal thread designs of these fittings are typically tapered similar to pipe threads, with a left-hand thread on one end and a right-hand thread on the other to cut thread paths on the conduit's outer surface. This thread design allows the operator to thread the fitting onto the ends of both conduit sections simultaneously. Some variations of threaded fittings may also be pressed on the conduit ends and used as barbed fittings. The user should consult the fitting manufacturer to determine if this alternate installation method is recommended.

Compression Fittings

As with the other mechanical fittings, compression fittings are also available in numerous designs – some designs for conduit as large as 8-inch and others for only 2-inch and below. While compression fittings used in PE pressure piping industries, such as water or gas, require internal stiffeners, conduit systems typically do not, because stiffeners may create obstacles for cable being blown through the conduit. For any fitting style being considered, consult the fitting manufacturer for available sizes and written instructions for use.

Expansion Joints

Expansion joints are designed primarily for aerial conduit installations. The primary purpose of this fitting design is to absorb thermal expansion and contraction in the conduit system created by ambient temperature changes, which can be extreme in these above ground installations. System designers should determine the number of expansion joints required based on the expansion length provided by the fitting and a calculation of the pipe's overall thermal expansion factor for the overall length of above ground installation.

Heat Fusion

The principle of heat fusion is to heat two surfaces to a designated temperature and fuse them together by application of a force sufficient to cause the materials to flow together and mix. When fused in accordance with the manufacturer's recommended procedure and allowed to cool to nearly ambient temperatures, the joint becomes as strong or stronger than the conduit itself in both tensile and pressure properties.

Three primary heat fusion methods used in joining PE conduit are butt, socket and electrofusion. Butt and socket fusion joints are made using "hot irons" designed specifically for PE joining, and electrofusion supplies heat internally by electric current applied to a special fitting containing a wire coil. More specific information on heat fusion joining practices can be found in the chapter on "Joining" in this Handbook, as well as in ASTM F 2620 for the hot iron methods (butt and socket fusion) and in ASTM F 1290 for electrofusion.

PPI recommends that the user precisely follow the qualified fusion procedures established by the manufacturer of the particular heat fusion and joining equipment being used.

Butt Fusion Joining

Butt fusion joints are produced without need of special fittings, using specially developed butt fusion machines, that secure, face and precisely align the conduit for the flat face hot iron (not shown) fusion process. It should be noted that the butt fusion process produces an internal bead of equal or larger size than the visible outer bead. If internal restrictions are a concern for the cable installation, alternative-joining methods may be more appropriate.

Socket Fusion Joining

This technique requires the use of specially designed hot irons to simultaneously heat both the external surface of the pipe and the internal surface of the socket coupling. Specially designed hand tools are available to maintain alignment and stab depth of the hot irons until the materials reach fusion temperature. These tools also help secure the heated conduit end and coupling as the joint is made. Design requirements for socket fusion can be found in ASTM D 2683 for fittings and in ASTM F 1056 for socket fusion tools. As with butt fusion, socket-fused joints may have an internal bead that can interfere with cable placement.

Electrofusion Joining

Electrofusion is somewhat different from the hot iron fusion method described previously, the main difference being the method by which heat is applied. Electrofusion involves the use of a special electrofusion fitting with an embedded wire coil. Electrical current supplied to the wire coil by an electrofusion control box generates the heat for fusion. Special training in equipment use and maintenance may be needed. For additional information consult the chapter on "Joining" in this Handbook.

Repair Operations

Repair joints, as the name implies, are often designed specifically for use in repair situations. The nature of the damage will often dictate what types of joints are needed for repairs. For example, one type of design, a clamp-on style may be preferred when damage is limited and removal of the cable for repair is not necessary. However, in more severe damage situations, where new cable and conduit sections must be installed, many of the joining methods described earlier in this section may be suitable. Ultimately, the type of repair fitting or joint installed should maintain the integrity of the conduit system, prevent infiltration and provide sufficient resistance to thermal expansion/contraction.

Cable Installation

Installing cable-in-conduit or innerduct can be accomplished in a number of ways. These include:

1. Pulling cable into the conduit using a pull line or rope
2. Blowing cable into the conduit using specialized equipment that installs the cable in conjunction with a high volume jet of air
3. Pre-installed in the conduit by the conduit manufacturer (cable-in-conduit)

Pulling Cable into Conduit

The traditional method of installing cable-in-conduit has been to attach a pull line (or rope) to the cable and pull the cable into the conduit. This placement method requires equipment to do the actual pulling, to apply lubricants to reduce friction, and devices that measure the amount of tension being applied to the cable.

Conduit may be supplied with a preinstalled pull line. This line is either a twisted rope or a woven tape. These pull lines come in a wide variety of tensile strengths that range from 500 - 6000 pounds-force. Pull lines are also available pre-lubricated to reduce friction.

Pull tapes are available with sequential footage marks. This type of tape is useful in determining the progress of the cable pull.

Empty conduit would require a pull line to be installed. Blowing a pull line directly or blowing a lightweight line through the conduit using compressed air accomplishes this. This line is then used to pull a pull line or a winch line into the conduit to pull the cable.

A winch mechanism with a take-up reel is used to pull the pull line with the cable attached. The winch should have a tension meter to monitor the amount of tension being placed on the cable during the pull. This monitor will reduce the risk of damaging a sensitive fiber optic cable during the pull. Check with the cable manufacturer to determine the amount of tension a cable can safely withstand.

The use of cable lubricants is strongly recommended. Cable lubricants reduce the amount of friction during a pull and therefore allow longer cable pulls and reduce the risk of damage to a cable during the pull.

When the cable is attached to the pull line, it is recommended that a swivel be used between the two. This swivel will allow the cable and pull line to move independently in the conduit during the pull and prevent unnecessary twisting of the cable or pull line.

On very long pulls the use of mid-assists is common. Mid-assist equipment can be as simple as a person pulling on the cable midway or it can be a capstan type device that provides a controlled amount of pulling tension to the cable to reduce the tension on the cable and increase the possible length of the pull.

If the conduit is in a manhole, protective devices are needed to guide the cable into the manhole and then into the conduit. These guides protect the cable from scraping on metal or concrete surfaces that could damage the cable sheath.

Cable Blowing or Jetting

In recent years the practice of pulling cable has frequently been replaced with a newer method that uses compressed air to blow the cable into the conduit. Cable blowing requires specialized equipment produced by a number of manufacturers that utilize high volume air compressors. There are two categories of air-assisted cable placement: Low Volume/High Pressure, and High Volume/Low Pressure. In the first case a dart seal is attached to the end of the cable and compressed air is introduced into the duct building pressure behind the seal, thus forcing the dart forward and creating a tensile pull on the end of the cable. At the same time, the cable is pushed into the conduit through a manifold seal using a tractor pusher. The cable then experiences simultaneous push and pull forces. In the second case, the cable is tractor fed into the conduit, again through a manifold seal, but this time has no dart seal. Instead, cable progress is based on the viscous drag of high volume air alone. In these methods of cable installation, much longer lengths of cable can be placed than traditional cable pulling methods, and the tension applied to the cable is significantly reduced.

When blowing cables into conduit, the use of corrugated conduit is not recommended. Corrugated conduit causes turbulence of the air that disrupts the flow of air in the conduit and thus reduces the distance a cable can be blown.

The conduit should also be capable of withstanding the pressure of the air being introduced. Generally the maximum pressure used is in the range of 125 psi.

Caution should be exercised when using compressed air to pressurize the conduit as a loose joint can lead to injury due to the conduit/joint exploding.

Cable Installed by the Conduit Manufacturer (Cable-in-Conduit)

Some producers of conduit have the capability of installing cable while the conduit is being extruded. Each conduit producer has specific size and length limits, and it is necessary to discuss with the producer the type of cable you desire to be installed: its size, type of material and lengths.

Most producers can lubricate the conduit during this process to allow easy movement of the cable in the conduit for future removal and replacement.

Cable can be tested prior to and following installation to guarantee the integrity of the cable. Check with the conduit producer for specific information on testing the cable.

Friction in Conduit Systems

Friction is a critical limiting factor in determining the type and length of cable installation. Although very little information on cable installation is provided in this guide, this section has been made available as a background reference on frictional properties.

Definitions

Friction: the nature of interaction occurring between two surfaces. The basis of friction has its roots in the mechanical and physical-chemical makeup of the interface created by bringing together two surfaces.

Coefficient of friction, COF: the ratio of the force required to move a body relative to the normal, or clamping force, acting to keep the bodies together.

Static COF: the ratio of forces required to bring about the onset of motion between two bodies at rest with each other.

Kinetic COF: the ratio of forces acting on a body already in motion. It is essentially a measure of the effort required to keep the body in motion.

Friction Reduction

Friction reduction can be promoted by reducing mechanical interactions, grounding electrostatic charges, reducing polar interactions, selecting dissimilar polymers, and employing methods and mechanisms which act to dissipate heat. Although many times little can be done to control the composition of cable jacket materials, choices can be made to select friction-reducing conduit designs and lubricating mechanisms.

The use of lubricants is strongly recommended during the placement of the conduit or cable, or may be included in the manufacturing process of the conduit. Typical lubrication methods would include:

Water-soluble lubricants are available in many different forms including low viscosity free-flowing petuitous liquids, creamy consistencies, and stiff gels. Low viscosity liquids are best suited for placement of long lengths of lightweight cables, such as fiber cables. Heavier, cream-like consistencies are useful on lightweight power conductors. Stiff gels are used in vertical applications in buildings, or where high sidewall loads are expected in placement of heavy power cables or innerducts.

Polymeric water-soluble lubricants are commonly used in the field to lubricate the placement of cable, or of the conduits themselves. In this case the lubricant is applied either ahead of, or in conjunction with, the advancing cable. Water-soluble polymer chemistries include a number of different enhancements including surface wetting and cling, modification via fatty acids or their derivatives, or by inclusion of various friction-reducing oils, including silicones.

Conduits may be **pre-lubricated** during the manufacturing process by incorporation of lubricants directly onto the conduit inner wall, or via a lubricant-modified coextruded layer. The most common type of lubricant used for this type of application is silicone polymer, although other agents such as mineral oils, fatty acid derivatives and glycols have also found use.

Prelubrication finds particular value with fiber cable push-blow systems. Because the sidewall loads with these techniques are quite low compared with pulling, and the distances so great, the viscous drag contributed by water-soluble lubes can be detrimental. The ultra-light amount of lubricants employed by factory pre-lubrication methods can be a real advantage.

Geometry of the inner surface of the conduit can also play a role in friction reduction. As the normal load increases, the COF is found to decrease, unless the surface is damaged in such a way so as to increase the contact area, or heat is allowed to build up at a rate faster than it can be conducted away. Ribs formed on the inner conduit wall are a common design feature to reduce friction.

Longitudinal ribbing results in a reduction of the contact surface between the cable and the conduit wall from an area to a line of contact. Decreasing the area of contact under the same sidewall load results in a higher localized normal force. Within a limited range of sidewall loads, the COF is found to go down – at least until the loading causes localized damage to the jacket sheath.

Spiral ribbing further reduces the contact area from a line to a series of points. In addition, because the advancing cable is alternately on and off the ribbing, there is an opportunity for cooling and re-lubrication. Constantly changing the direction of the spiral eliminates the tendency to accumulate spiral-induced torque in the cable.

Transverse ribbing, or corrugated profiles, results in similar friction reducing geometries. However, there is a tendency for field-added lubrication to be scraped off the cable by the corrugations. In addition, the high degree of flexibility requires careful placement of the duct to reduce the buildup of friction due to path curvature.

Field Effects of Friction

Burn-through results when the winch line or cable develops so much frictional heat that it melts its way through the conduit wall. There are a number of factors that exacerbate this condition including: sidewall load, pull speed, conduit and pull-line materials of construction.

Aside from lubrication, sidewall loading may not be easily reduced; however, speed of pulling is controllable by the operator. Because PE and other thermoplastics are such good insulators, frictional heat build-up can go unchecked. Slower pull speeds combined with water-based lubricants can help reduce the rate of heat accumulation.

PVC elbows are commonly used for transitions out of the underground plant. Unfortunately, PVC not only has a higher COF than PE conduit (due largely to hydrogen bonding to the fillers), but also tends to soften with the onset of heating at a much faster rate (due to plasticizers). PE conduit on the other hand, has lower inherent COF (about 0.35 vs. >0.40 for PVC), as well as higher heat capacity due to its semi-crystalline nature.

Pull-line construction also plays a significant role in burn-through. Polypropylene ropes or even PE pull-lines exhibit low COF at low sidewall loads, but rapidly cut through both PVC conduit and PE conduit when the load increases. The tendency for these materials to soften, combined with high structural similarity (to PE), limit the pull load range over which they may be used. Polyester and polyaramid pull lines, particularly in tape form, offer greater protection from burn through.

Sidewall loading results any time a cable or pull-line is pulled about a sweep or bend. Dividing the tension in the pull-line by the radius of the bend may approximate the magnitude of the load. Obviously, the smaller the radius is, the greater the magnitude of load.

Speed, as noted above, is a critical variable in the operator’s hands that can often spell the difference between success and failure. Speeds, which are too low, can result in a lot of mechanical interaction, whereas an excessively high speed results in heat build-up.

Compatibility, in conjunction with high sidewall loading, can be a problem – not only for higher relative friction, but also is a key determinant in burn-through.

Contamination with inorganic soils roughens the surfaces of both conduit and cable jacket, thus increasing the mechanical interaction between them. In addition, the embedment of small particles increases hydrogen bonding with water that may be in the conduit, further enhancing the interaction of jacket with conduit.

Placement Planning

Curvature in the conduit run is the greatest deterrent to long pulls. Some curvature is unavoidable due to path layout, e.g. elevation changes, direction changes, etc. On the other hand, sloppy installation techniques can introduce more curvature than would otherwise be planned. For example, open trench work without proper tensioning and bedding can lead to installations that severely limit cable placement.

Equations for calculation of accumulated frictional drag have been derived and can be found in Appendix A. These are combinations of straight section and exponential sweeps. If the cable has appreciable weight, the transition to sweep up or sweep down results in significant differences. In addition, for multiple conductor power cables, certain combinations of cable multiples and free volume result in locking configurations.

Push-blow techniques are also greatly affected by friction. As noted above, pre-lubricated ducts, or very light applications of silicone emulsions, produce the best results. Techniques that rely on air predominantly to accelerate the cable work best with lightweight cables. As cable weight increases, systems with greater pushing power and piston seals provide improved performance.

Insert sizing is different for pulling vs. push-blow installations. In pulling cables, the greater the free volume in the conduit, the better, and maximum fill ratios based on cable and duct diameters are around 60 percent. On the other hand, maximum fill ratios in push-blow installations are closer to 85 percent fill. The reason for this is that if the cable is not allowed to deflect laterally, it can assume a greater axial load. The more free volume existing in the conduit during pushing, the easier it is to deflect, and having done so, the greater the curvature, and the greater the accompanying sidewall loads.

Placement planning for fiber cable installation is critical because the cable lengths are so long. Typically, one would locate a point along the route possessing similar accumulated frictional drag in either direction. Part of the cable is then installed to one end of the run, then the cable is figure-eighted to recover the opposite free end. The free end is then installed into the other end of the run. It is not uncommon to place 3,000 to 6,000 feet over any given span, and to gang placement equipment at mid-assist intervals along the path to deliver over 20,000 feet continuously in one direction. Using proper combinations of conduit design, installation method, lubrication and placing equipment, it is possible for crews to install over 40,000 feet of cable per day.

Special Applications

Corrugated Duct

Corrugated conduit has properties that generally make it easier to work with in difficult and confined environments. Primarily, this is a result of the lack of memory with corrugated and greater flexibility vs. smooth wall conduit. The lack of memory also provides a corrugated conduit that, when installed as an innerduct (inside of another larger conduit), does not spiral and therefore has lower friction when cables are pulled through it.

The greater degree of flexibility makes corrugated conduit easier to handle when used in confined spaces and other restricted environments.

Corrugated conduit is not appropriate for use in direct buried applications because of its limited crush resistance and the difficulty of laying it in a straight path. Corrugated conduit is also not appropriate for use when cables are to be installed using air-assisted placement. Corrugated conduit is relatively thin-walled and may not be able to handle the air pressure of air-assisted placement. The corrugations create air turbulence that is counterproductive to the air-assisted placement systems and significantly reduce the distance cables can be blown through it.

Corrugated conduit should not be installed using directional drilling equipment due to limited tensile strength and the fact that the corrugations will create significant friction during the pullback that will likely cause the conduit to separate.

The ASTM standards that cover SIDR and SDR designs do not apply to corrugated duct. Corrugation equipment varies from producer to producer, and inside and outside diameter may vary from each source of supply. All corrugated conduit specifications are per the producer only. Generally a minimum ID is specified and a maximum OD.

Corrugation design (or profile) greatly affects the properties of the conduit such as crush resistance and tensile strength. Tooling used to produce corrugated conduit does not allow the producer to change the profile or dimensions without costly retooling.

Check with the source of supply for detailed dimensional and performance specifications.

Bridge Structures

Bridge structures can range from a simple conduit placed in the bridge structure when the bridge is built to a major retrofit of an existing bridge that does not contain a conduit or structure in place to secure a single conduit or conduits. Bridge structures, new or old, require specially designed support systems to ensure structural integrity and meet all federal, state and local requirements.

When installing conduit on bridges, it is important to incorporate into the design the expansion and contraction of the bridge. Expansion joints must be installed in the conduit to prevent the conduit from either separating or bending and kinking due to bridge movement. As an alternative to expansion joints, use of a serpentine path have been proven effective in reducing expansion/contraction issues.

Underwater

The term underwater is also referred to as marine, or submarine, applications. The three basic methods of placing a structure conduit are laying the conduit on the bottom, plowing and jetting the conduit into the sub-aqueous terrain, or drilling under the waterway. Each method has it's own unique requirements based on the type of waterway, length, environmental issues, and federal, state and local requirements. There may be instances when all three types of application will be required on the same installation.

Conduit placed on the bottom of waterways should be black to prevent UV damage. For a complete discussion of underwater installations, see the chapter on marine installations in this Handbook.

Premise (Flame Retardant)

In addition to using conduit for installing fiber optic/communication cables in the underground, there are a few other very specialized applications for conduit type products.

With the growing market for data communications systems within buildings, there has been a concurrent growth in the use of fiber optic/communication cables in buildings as well. These installations typically place fiber optic/communication cables in the same cable trays and vertical risers as other communications cables and electrical cables.

Designers and installers have been concerned about identifying and protecting these fiber optic/communication cables. Manufacturers have responded with the development of several types of conduit for building use, or as it is known in the industry, premise wiring.

Premise wiring generally uses plenum air spaces, vertical riser shafts and general-purpose areas to run cables throughout buildings. The types of conduit developed were specifically for these environments. Because fiber optic/communication premise wiring falls into areas generally thought of as electrical, the National Electric Code and Underwriters Laboratories have addressed the characteristics needed by conduits to be safely used in building wiring.

Initial development produced the Plenum Raceway, a specialized conduit that meets stringent Underwriters Laboratories (UL 2024) requirements for minimum flame spread and smoke generation. Plenum Raceway is a corrugated conduit made from plastic materials that do not support flame and produces almost no smoke. At this time PVDF is the material of choice for Plenum Raceway. Products for plenum air spaces are required to carry a Listing Mark to verify that the product has been tested and meets the requirements for installation in the plenum environment.

A riser raceway was developed for premise wiring applications in riser shafts. Riser Raceway meets the Underwriters Laboratories (UL 2024) requirements for vertical flame spread. Riser Raceway is also a corrugated conduit, which is currently produced from either PVC or Nylon materials. Products for riser locations are required to carry a Listing Mark to verify that the product has been tested and meets the requirements for installation in the riser environment. Plenum Raceways are permitted to be placed in a riser application.

A general-purpose raceway was developed for premise wiring applications in general purpose applications. General Purpose Raceway meets the Underwriters Laboratories (UL 2024) requirements for flame spread. General Purpose Raceway is typically a corrugated conduit, which is currently produced from either PVC or Nylon materials. Products for general-purpose locations are required to carry a Listing Mark to verify that the product has been tested and meets the requirements for installation in the riser environment. Plenum and Riser Raceways are permitted to be placed in a general-purpose application.

The uses of Plenum or Riser Raceways do not eliminate the use of a Plenum or Riser rated cable.

As the use of fiber optic/communication cables in premise wiring increases there will likely be other specific needs that may generate other types of conduit for use in building wiring systems.

Electrical/Building Code (Conduit Entry Issues)

Electrical/Building Code regulations vary greatly regarding the placement of conduit into a building. Codes require the use of conduit constructed of a material that is listed for use in specific building areas, and these codes prohibit the use of PE conduit beyond a specific distance after entry through an exterior wall. The greatest variation in local code is the location of the transition from PE conduit to a conduit that meets the code requirement (distance from the exterior of the wall). Check your local codes for local amendments.

Armored (Rodent and Mechanical Protection)

When placing cables in the underground there is occasionally concern about the ability of the conduit to protect the cable(s) inside. Concerns usually are for crush resistance and resistance to cutting and gnawing by animals.

This need led to the development of armored conduit. Armored Conduit is standard PE conduit that has been wrapped with a second layer of metal and jacketed to provide a barrier to the problem of gnawing by animals. Armored Conduit also protects against cuts and abrasions from accidental strikes by persons digging nearby.

Multi-Cell Conduit

Multi-cell conduits are designed to meet special needs and unique job situations. There are a number of designs available to meet most of these special needs. Multi-cell conduit can be a product that is installed as an innerduct inside of existing conduits designed to maximize the available space in a vacant or occupied conduit, or it can be a fully assembled conduit with internal conduits that when installed provides a multi-channel conduit without the need to install any other innerducts. Some multi-cell designs can be direct buried like PE conduit using standard installation methods (plowing or open trenching).

Summary

The information contained in this chapter should help the reader to understand the fundamental properties of polyethylene (PE) conduit. A basic understanding of these properties will aid the engineer or designer in the use of PE conduit and serve to maximize the utility of the service into which it is ultimately installed.

While every effort has been made to present the fundamental properties as thoroughly as possible, it is obvious that this discussion is not all-inclusive. For further information concerning PE conduit, the reader is referred to a variety of sources including the pipe manufacturers' literature, additional publications of the Plastics Pipe Institute and the references at the end of this chapter.

References

ASTM International, D 1238, Standard Test Method for Flow Rates of Thermoplastics by Extrusion Plastometer.

ASTM International, D 1693, Standard Test Method for Environmental Stress-Cracking of Ethylene Plastics.

ASTM International, D 2444, Standard Test Method for Determination of the Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight).

ASTM International, D 2683, Standard Specification for Socket-Type Polyethylene Fittings for Outside Diameter-Controlled Polyethylene Pipe and Tubing.

ASTM International, D 3350, Standard Specification for Polyethylene Plastics Pipe and Fittings Materials.

ASTM International, D 3485, Standard Specification for Smooth-Wall Coilable Polyethylene (PE) Conduit (Duct) for Preassembled Wire and Cable.

ASTM International, F 1056, Standard Specification for Socket Fusion Tools for Use in Socket Fusion Joining Polyethylene Pipe or Tubing and Fittings.

ASTM International, F 1290, Standard Practice for Electrofusion Joining Polyolefin Pipe and Fittings.

ASTM International, F 1473, Standard Test Method for Notch Tensile Test to Measure the Resistance to Slow Crack Growth of Polyethylene Pipes and Resins.

ASTM International, F 2160, Standard Specification for Solid Wall High Density Polyethylene (PE) Conduit Based on Controlled Outside Diameter (OD).

ASTM International, F 2176, Standard Specification for Mechanical Couplings Used on Polyethylene Conduit, Duct and Innerduct.

ASTM International, F 2620, Standard Practice for Heat Fusion Joining of Polyethylene Pipe and Fittings.

AEIC Task Group 38.

Guide for Installation of Extruded Dielectric Insulated Power Cable Systems Rated 69KV -138KV.

IEEE Guide Distribution Cable Installation Methods in Duct Systems.

National Electrical Code (NEC), Chapter 9.

National Electrical Manufacturers Association, NEMA TC 7, Smooth-Wall Coilable Polyethylene Electrical Plastic Conduit.

Plastics Pipe Institute, Inc., *Handbook of Polyethylene Pipe.*

Plastics Pipe Institute, Inc., TR19, Thermoplastic Piping for the Transport of Chemicals.

Underground Extruded Power Cable Pulling Guide.

Underwriters Laboratories, Inc. UL 651A.

Underwriters Laboratories, Inc., UL 651B, Continuous Length PE Conduit.

Underwriters Laboratories, Inc., UL 2024, Optical Fiber Cable Raceway.

Appendix A

Calculation of Frictional Forces

Reference – *Maximum Safe Pulling Lengths for Solid Dielectric Insulated Cables – vol. 2: Cable User's Guide*, EPRI EL=3333-CCM, Volume 2, Research Project 1519-1, Electric Power Research Institute.

Calculations of Pulling Tensions

The following formulae can be employed to determine pulling tensions for a cable installation. Each equation applies to a specific conduit configuration. In order to use the formulae, the cable pull should be subdivided into specific sections. The configuration of each section should be identifiable with one of the graphical depictions accompanying the equations.

The mathematical expression associated with each of the accompanying sketches will yield the cumulative tension (T_2) on the leading end of the cable(s) as it exits from a specified section when T_1 is the tension in the cable entering that section.

The maximum tension obtained when pulling in one direction often differs from that obtained when pulling in the opposite direction due to the location of the bends and the slope of the pull. Therefore, the required tension should be calculated for both directions.

A listing of the symbols employed and their definitions are as follows:

DEFINITIONS OF SYMBOLS

Symbols	Definition	Units
T_1	Section incoming cable tension	Pounds
T_2	Section outgoing cable tension	Pounds
R	Inside radius of conduit bend	Feet
W	Total weight of cables in conduit	Pounds/foot
Θ	Angle subtended by bend for curved sections or angle of slope measured from horizontal for inclined planes	Radians
Θ_a	Offset angle from vertical axis	Radians
Θ_b	Total angle from vertical axis	Radians
K	Effective coefficient of friction	—
L	Actual length of cable in section	Feet
D’	Depth of dip from horizontal axis	Feet
2s	Horizontal length of dip section	Feet

FIGURE 1 PULLING TENSION FORMULAE FOR CABLE IN CONDUIT

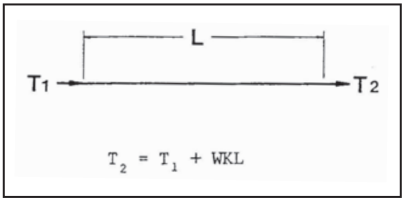


Figure 1.1 Straight Pull

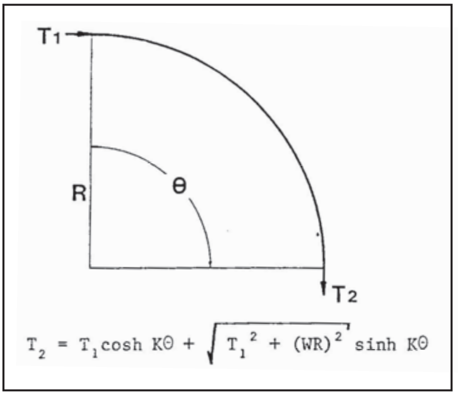


Figure 1.2 Horizontal Bend Pull

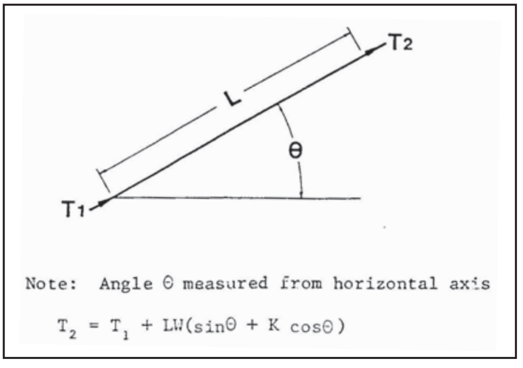


Figure 1.3 Slope - Upward Pull

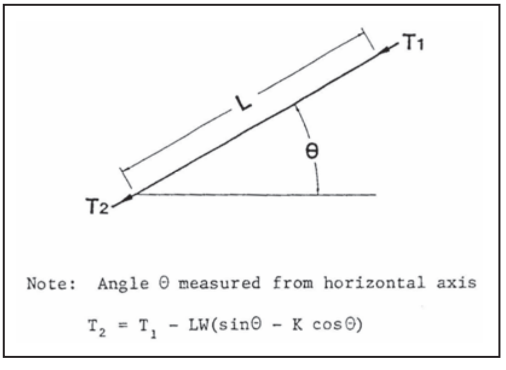
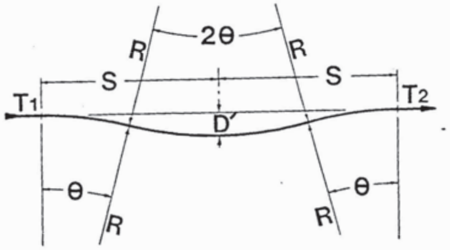


Figure 1.4 Slope - Downward Pull



$$\Theta = \frac{2D'}{S}$$

$$R = \frac{S^2}{4D'}$$

$$T = T_1\varepsilon^{K\Theta} + RW(\varepsilon^{K\Theta} - 1)$$

(Use coefficient of friction corresponding to SWBP < 150 lbs/ft in the equation above.)

Where D′ is small compared to S (i.e. $\tan \Theta/2 = \sin \Theta/2 = D'/S$)

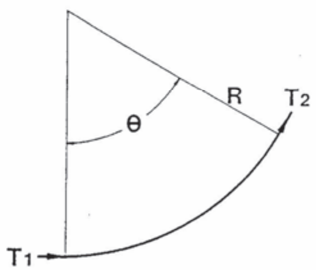
For $T > RW$

$$T_2 = T_1\varepsilon^{4K\Theta} + RW[\varepsilon^{4K\Theta} - 2\varepsilon^{3K\Theta} + 2\varepsilon^{K\Theta} - 1]$$

For $T \leq RW$

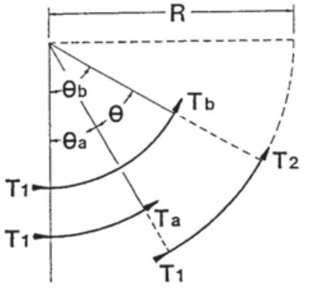
$$T_2 = T_1 + WK2S$$

Figure 1.5 Vertical Dip Pull (Small Angle)



$$T_2 = T_1\varepsilon^{K\Theta} - \frac{WR}{1+K^2}[2K \sin\Theta - (1-K^2)(\varepsilon^{k\Theta} - \cos\Theta)]$$

Figure 1.6a Concave Bend - Upward Pull, for Angle Θ Measured from Vertical Axis



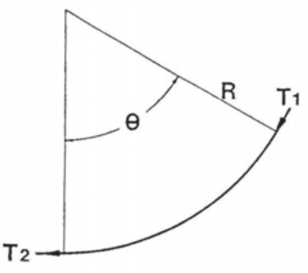
$$\Theta = \Theta_b - \Theta_a$$

$$T_a = T_1\varepsilon^{K\Theta_a} - \frac{WR}{1+K^2}\left[2K\sin\Theta_a - (1-K^2)(\varepsilon^{K\Theta_a} - \cos\Theta_a)\right]$$

$$T_b = T_1\varepsilon^{K\Theta_b} - \frac{WR}{1+K^2}\left[2K\sin\Theta_b - (1-K^2)(\varepsilon^{K\Theta_b} - \cos\Theta_b)\right]$$

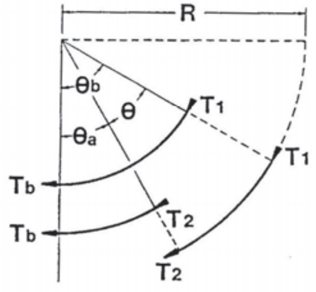
$$T_2 = T_b - T_a + T_1$$

Figure 1.6b Concave Bend - Upward Pull, for Angle Θ Offset from Vertical Axis by Angle Θ_a (Derived from Figure 1.6a, above)



$$T_2 = T_1\varepsilon^{K\Theta} - \frac{WR}{1+K^2}\left[2K\varepsilon^{K\Theta}\sin\Theta + (1-K^2)(1-\varepsilon^{K\Theta}\cos\Theta)\right]$$

Figure 1.7a Concave Bend - Downward Pull, for Angle Θ Measured from Vertical Axis

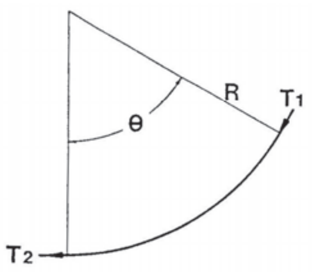


$$\Theta = \Theta_b - \Theta_a$$

$$T_b = T_1 \varepsilon^{K\Theta_b} - \frac{WR}{1+K^2} [2K\varepsilon^{K\Theta_b} \sin\Theta_b + (1-K^2)(1-\varepsilon^{K\Theta_b} \cos\Theta_b)$$

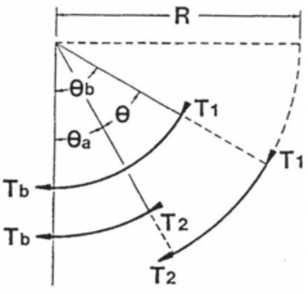
$$T_2 = \left(\frac{T_b + \frac{WR}{1+K^2} [2K\varepsilon^{K\Theta_a} \sin\Theta_a + (1-K^2)(1-\varepsilon^{K\Theta_a} \cos\Theta_a)]}{\varepsilon^{K\Theta_a}} \right)$$

Figure 1.7b Concave Bend - Downward Pull, for Angle Θ Offset from Vertical Axis by Angle Θ_a (Derived from Figure 1.7a, above)



$$T_2 = T_1 \varepsilon^{K\Theta} - \frac{WR}{1+K^2} [2K\varepsilon^{K\Theta} \sin\Theta + (1-K^2)(1-\varepsilon^{K\Theta} \cos\Theta)]$$

Figure 1.8a Concave Bend - Downward Pull, for angle Θ Measured from Vertical Axis

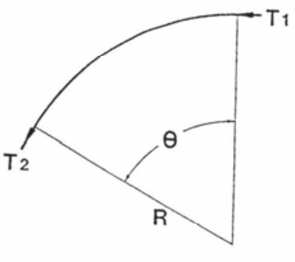


$$\Theta = \Theta_b - \Theta_a$$

$$T_b = T_1 \varepsilon^{K\Theta_b} - \frac{WR}{1+K^2}\left[2K\varepsilon^{K\Theta_b}\sin\Theta_b + (1-K^2)(1-\varepsilon^{K\Theta_b}\cos\Theta_b)\right]$$

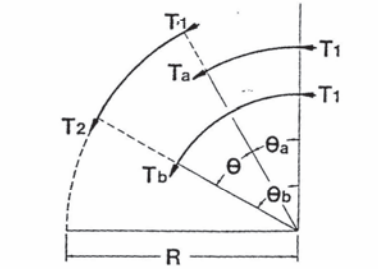
$$T_2 = \left(\frac{T_b + \frac{WR}{1+K^2}\left[2K\varepsilon^{K\Theta_a}\sin\Theta_a + (1-K^2)(1-\varepsilon^{K\Theta_a}\cos\Theta_a)\right]}{\varepsilon^{K\Theta_a}}\right)$$

Figure 1.8b Concave Bend - Downward Pull, for angle Θ Offset from Vertical Axis by Angle Θ_a (Derived from Figure 1.8a, above)



$$T_2 = T_1 \varepsilon^{K\Theta} + \frac{WR}{1+K^2}\left[2K\sin\Theta - (1-K^2)(\varepsilon^{K\Theta} - \cos\Theta)\right]$$

Figure 1.9a Convex Bend - Downward Pull, for Angle Θ Measured from Vertical Axis



$$\Theta = \Theta_b - \Theta_a$$

$$T_a = T_1 \varepsilon^{K\Theta_a} + \frac{WR}{1+K^2} \left[2K \sin\Theta_a - (1-K^2)(\varepsilon^{K\Theta_a} - \cos\Theta_a)\right]$$

$$T_b = T_1 \varepsilon^{K\Theta_b} + \frac{WR}{1+K^2} \left[2K \sin\Theta_b - (1-K^2)(\varepsilon^{K\Theta_b} - \cos\Theta_b)\right]$$

$$T_2 = T_b - T_a + T_1$$

Figure 1.9b Convex Bend - Downward Pull, for Angle Θ Offset from Vertical Axis by Angle Θ_a (Derived from Figure 1.8a, above)

Chapter 15

General Guidelines for Repairing Buried PE Potable Water Pressure Pipes

Introduction

Traditional piping systems have gasket-sealed bell and spigot joints every 20 feet, which can be a potential maintenance and repair point at each connection. Metallic pipes are subject to corrosion which can require constant maintenance over the life of the pipes. A heat fused high density polyethylene (PE) pipeline is not only corrosion and chemical resistant but the leak free joints at 40 to 50 foot intervals are as strong as the pipe itself which provides a maintenance free system except for infrequent unforeseen third party damage. If PE is damaged by a third party, repair methods may be required to bring the piping system back into service as soon as possible. This document will provide general guidelines for repairing PE. They should be useful in establishing procedures and/or specifications for various repair methods to PE piping systems.

For above ground repairs, when the pipe can be moved, the damage can be cut out and replacement pipe can be butt fused or electro-fused into the system.

Figure 1 Above Ground Repair with Fusion Machine

However constrained installations, such as buried pipes, may not allow such movement. Permanent repairs of constrained pipes may require techniques and fittings that do not require longitudinal movement such as spool or flanged assemblies, mechanical or electrofusion couplings, etc.

Caution: Be sure to follow OSHA safety guidelines when uncovering and repairing buried pipelines.

Natural Gas Polyethylene Piping Systems

In this application, only those persons qualified pursuant to a gas company's Operator Qualification program shall make repairs.

Plastic piping systems may be damaged during installation or through third party damage by others once in service. The repair or replacement must be made in accordance with requirements of DOT 49 CFR 192.311. All imperfections or damaged sites that would impair the serviceability of the plastic pipe (significant scratches, gouges or flaws) must be removed or repaired.

Mechanical or electrofusion couplings appropriate for plastic gas piping systems are frequently used for economical and convenient replacement of damaged plastic pipe segments. The gas flow is stopped; the damaged section cut out and replaced with a mechanical repair fitting or a new segment using either two couplings or a fusion joint and a coupling. Joints fabricated from mechanical fittings used in replacement must be designed to restrain the pipe against pullout forces and, if metallic fittings are utilized, be protected against corrosion.

Full encirclement type band clamps have been successfully used with plastic pipe to make repairs. ASTM F 1025 "Standard Guide for Selection and Use of Full Encirclement Type band clamps for Reinforcement or Repairs of Punctures or Holes in Polyethylene Gas Pressure Pipe" provides guidance regarding use of this fitting for repair and reinforcement of polyethylene pipe. The important consideration is that the clamp permanently exerts limited unit-bearing pressure on the plastic pipe since it is not possible to install metal stiffeners inside the plastic pipe in this application. A soft gasket formulation with waffle-type inner surface would generally be preferred for this application. In all cases, the method used should follow procedures that have been established and qualified by test.

Full encirclement type band clamps in compliance with the guidelines of ASTM F 1025 are acceptable for temporary repairs of polyethylene pipe.

Before placing in service, test segments of plastic pipe that are installed to replace damaged sections of mains and services according to the operator's procedures. Leak test all tie-in joints and the squeeze-off areas at system pressure after the repair is complete. If recommended by the manufacturer, any anti-static fluid should be rinsed from the piping using water. If, in a dig-in situation or a plastic service other than a low pressure service, it appears that the pipe or casing was pulled or moved, and that damage could have occurred at locations along the service other than those inspected or repaired, leak-test the entire service at 100 psig for a minimum of 5 minutes per the operator's procedures. Leak- test low –pressure services at 10 psig for a minimum of 5 minutes per the operator's procedures. If additional damage is found, replace the service.

Municipal and Other Polyethylene Piping Systems

Temporary Field Repairs with Full Circle Band Clamp

Many system operators will have full circle band clamps in their specifications as a repair option. In general these types of repair clamps have proven to be a great method of temporary repair, especially in emergency situations.

Some general design considerations for the successful use of full circle band clamps are as follows:

- Full Circle Band Clamps are recommended for repairs only where the pipe is able to maintain its structural integrity. Consider repairs only to a clean-cut round hole or deep scratches or gouges of maximum dimension, less than the nominal diameter of the pipe divided by three. Do not use band clamps when the pipe has cracks, jagged punctures, long tears, or deep scratches or gouges which could propagate outside the clamp under anticipated field loads.
- Do not exceed the manufacturer's recommended maximum operating parameters such as temperature and pressure.
- The installer should always follow the clamp manufacturer's recommend installation guidelines. Whenever possible, use a product that has been specifically designed for use with polyethylene pipe.
- The manufacturer should always be consulted on the use of their product on polyethylene pipe if the clamp was not manufactured specifically for use with polyethylene pipe.
- Pipe movement due to thermal expansion, thermal contraction and creep, as well as, surge events must be considered when repairing polyethylene pipe with a full circle band clamp.
- Generally, full circle band clamps are intended for use in underground applications. If your application is of a different nature, contact the manufacturer of the band clamp.

If the band clamp is to be used as a permanent repair, contact the fitting manufacturer for the suitability of use as a permanent repair.

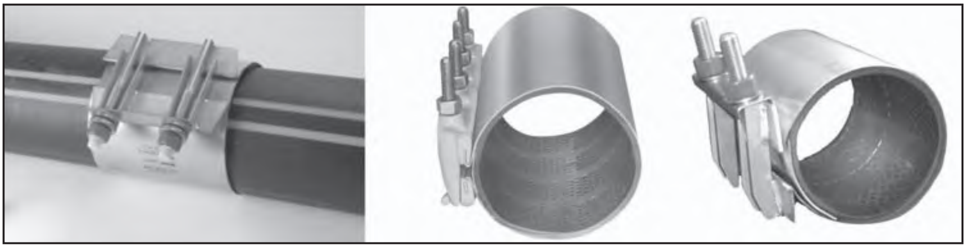


Figure 2 Full Circle Band Clamps

Permanent Field Repairs

Small Field Repairs

Saddle Fusion Repair

If the size of the puncture damage is very small (1inch or smaller puncture on one pipe wall), a capped off Tapping Tee or High Volume Tapping Tee or patch can be saddle fused to the main over the damaged area, provided the water flow can be stopped and the repair area kept dry during the repair process. Before adding the patch or fitting, drill a small hole at each end of the damage to prevent the crack from propagating further.

Then, butt fuse a cap on the service outlet of the Tapping Tee selected for the repair. Turn off the water and prepare the surface area around the damage for the saddle fusion process (see PPI Generic Saddle Fusion Procedure TR-41). Saddle fuse the fitting over the damaged area using the Generic Procedure and allow the joint to cool. Wait 30 minutes, turn the water back on.

Figure 3 Saddle Fusion Repair

Electrofusion Patch Repair

An electrofusion patch can also be used to repair small puncture damage in the pipe (3 inches or smaller puncture in one wall of the pipe) as long as the water flow can be stopped and the repair area kept dry during the repair process. Use the manufacturer's recommended electrofusion procedure and equipment for saddle fusion.

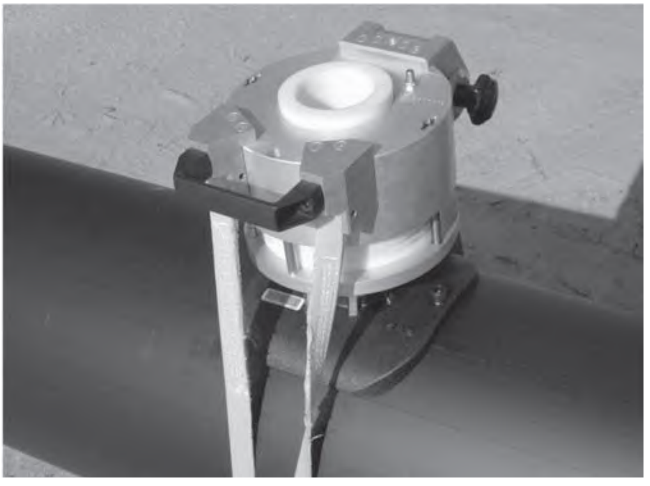


Figure 4 Electrofusion Patch Repair

Mechanical Fitting Repair

In some cases where the damage is slight but has severed the pipe, the line can be shut off and a small section of the pipe cut out to install a mechanical coupling in the damaged area (see Figures 5, 6, & 7). Contact the coupling manufacturer for the size of damage that can be repaired. A certain amount of the piping system will need to be exposed to allow the pipe to be bent for the installation of the coupling.

Some couplings are self restrained and others are not. Some require a stainless steel stiffener inside the PE pipe and some do not.

For damage to small diameter water service lines (2 inches and smaller), mechanical compression fittings appropriate for PE pipe or tubing are commonly used for the repair. Water flow is stopped, generally using a pinch off tool, and the damaged area evaluated. If it is a small cut or hole, the pipe can be cut in the damaged area and a compression fitting installed between the pipe ends. As required for larger pipe sizes, this method may require a certain amount of the piping system be exposed to allow the pipe to be bent for the installation of the coupling. If the damage is more extensive, a section of pipe is cut out and replaced with a replacement piece of pipe and two compression fittings.

It is recommended that all couplings used with PE should have a stiffener installed to increase the sealing capability of the coupling by minimizing the effects of creep and dimensional changes due to temperature variations (see "Stiffener Installation Guidelines" section in this chapter). It is also recommended that, if the coupling does not provide its own restraint, then external restraints should be utilized on each side of the fitting to prevent pullout due to the thermal expansion or the Poisson effect of the pipe (see "Restraint Methods" section in this chapter). Mechanical fittings have different design advantages and accommodate different sizes. Contact the mechanical fitting manufacturer for more information. Several manufacturers make mechanical fittings specifically for use with PE, including Mueller, Elster Perfection, Victaulic, Dresser, JCM, Ford, Romac, Cascade Water Works and Smith-Blair.

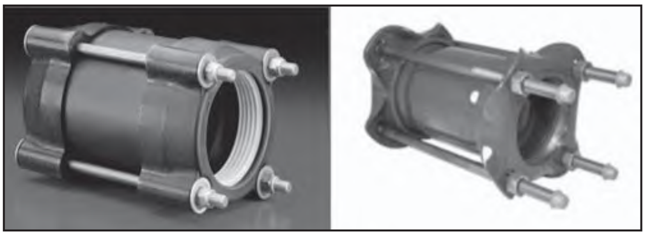


Figure 5 Mechanical Couplings

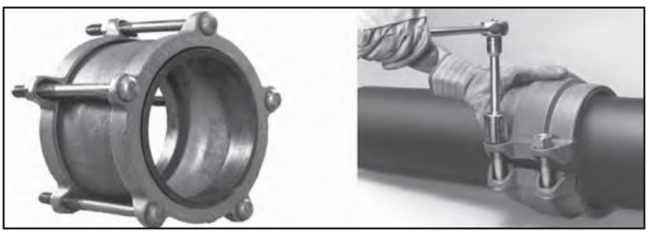


Figure 6 Mechanical Couplings

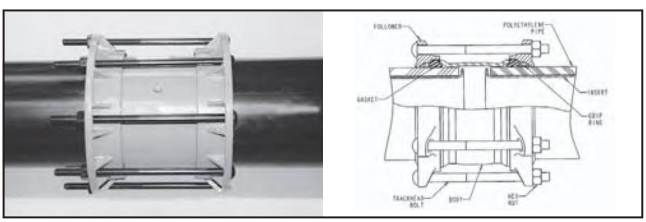


Figure 7 Mechanical Couplings

Large Field Repairs

Mechanical Fitting Repair

If the damage to the pipeline cannot be repaired with a single mechanical coupling as described above, two mechanical fittings can be used by cutting out the damaged pipe (Figure 8 & 9) and making up an assembly with two mechanical fittings and a properly sized and length of polyethylene pipe in the middle. Again, install per the fitting manufacturer's instructions. (Figure 10) A repair to larger pipes requires joining devices for the size of pipe being repaired. However, the various types of joining devices discussed in this section may not be available for all pipe sizes. Contact the joining device manufacturer or supplier for availability and applicability with polyethylene pipe.

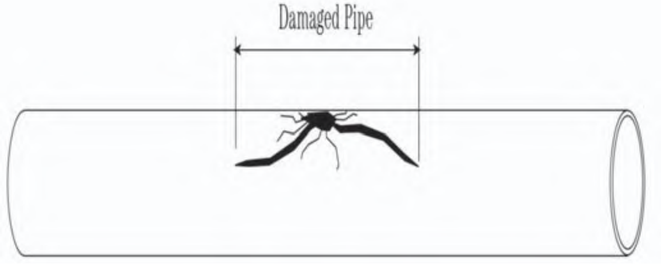


Figure 8 Damaged Pipe

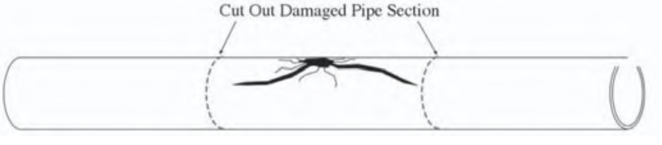


Figure 9 Cut out Damaged Section of Pipe

A saw is needed to cut out the damaged pipe and to cut the replacement section between the cut ends. A wrench is also needed to tighten the bolts. After the damaged section is examined, it can be removed. Damaged PE pipe is usually cut using a dry chain saw. Measure the distance between the cut pipe ends and cut an PE replacement section approximately ½-inch shorter than that length. Install the insert stiffeners in both ends of the existing PE pipes and in both ends of the replacement section.

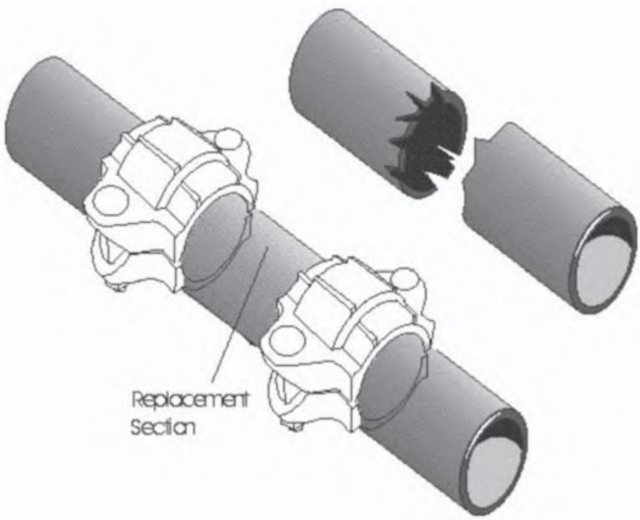


Figure 10 Mechanical Coupling Repair Assembly

Slide the couplings over the replacement section of the pipe and drop the assembly between two cut ends. Then slide the couplings between the replacement section and the cut ends and tighten the bolts using the manufacturer's procedures.

Caution: Make sure to provide restraints or anchors for the PE pipe if the mechanical couplings are not self restrained. Failure to follow this procedure could result in the pipe pulling out of the coupling (see "Mechanical Restraint" section in this chapter).

As noted above, it is recommended that all PE pipe ends used with mechanical couplings have a stiffener installed to increase the sealing capability of the coupling by minimizing the effects of creep and dimensional changes due to temperature variations (see "Stiffener Installation Guidelines" section in this chapter).

Repairs with Solid Sleeves

Repairs can be made using a mechanical joint (MJ) solid sleeve along with insert stiffeners, restraint device, gasket and tee bolts. A saw is needed to cut out the damaged pipe and to cut the replacement section of PE pipe. A wrench is also needed to tighten bolts. The pipe, gasket and solid sleeve must be cleaned before final tightening of the bolts.

The benefit of this repair method is that it can be made in a wet environment with no special equipment. This is basically the same repair method used for PVC and ductile iron pipe with the addition of insert stiffeners used with PE pipe. The parts are MJ sleeve or sleeves, glands, restraint ring, gasket, extra pipe if large area is damaged, gaskets and tee bolts.

Figure 11 Restraint fitting placed on PE pipe

After cleaning the contact surfaces, and installing a stiffener in existing PE pipe ends and in the ends of the replacement HPDE pipe section, slide the restraint ring and gland over pipe followed by a gasket as shown above. The drawing below shows a typical layout of parts needed to make a repair.

In a repair situation, the MJ sleeve is connected on both ends to PE pipe. The solid sleeve can make up small sections of pipe. If the damaged pipe is longer than the span of a single sleeve, two solid sleeves are used to replace damaged pipe.

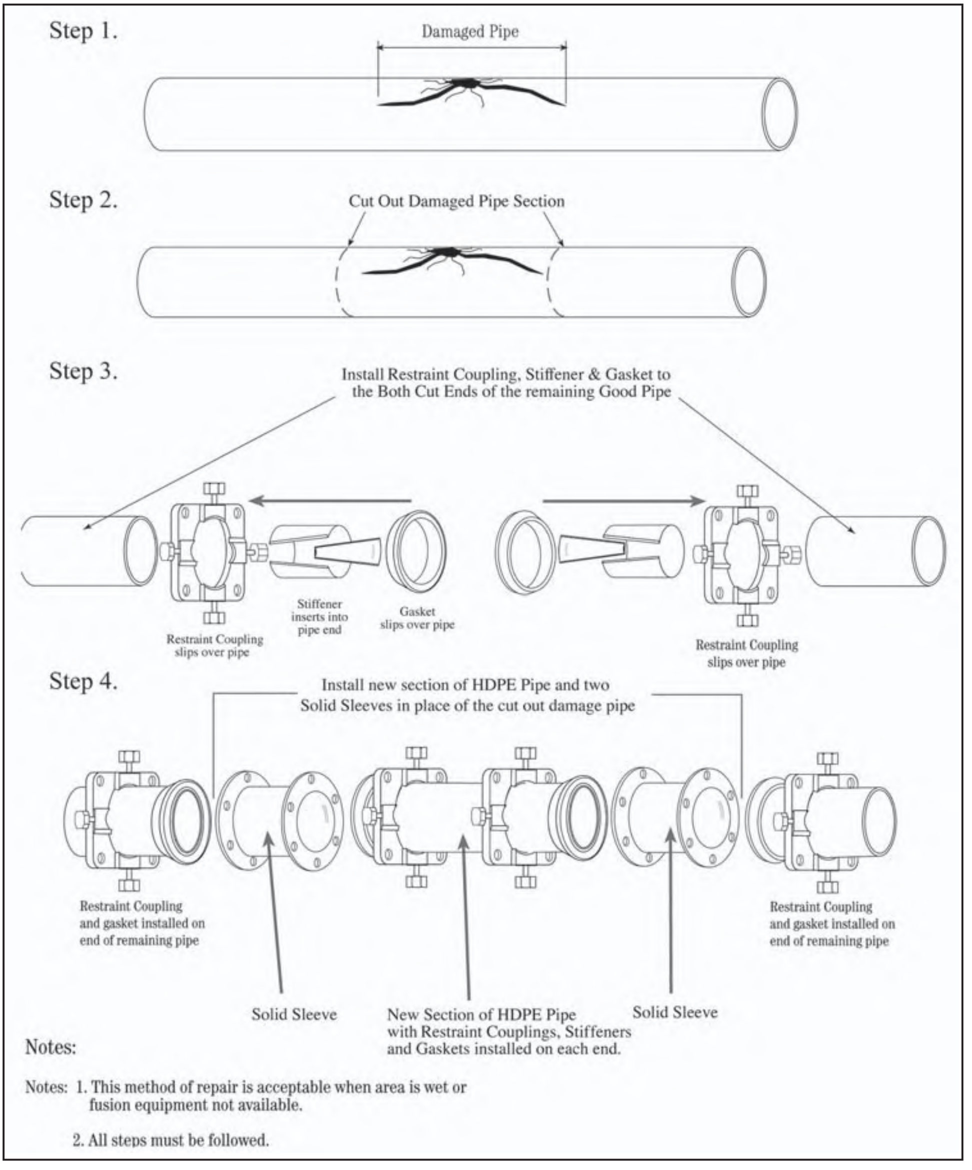


Figure 12 Solid Sleeve Repair Assembly

Flange Adapter Spool Repair

Once pipeline damage has been reported, the size of the pipeline and the DR needs to be established. The correct flange adapter and backup ring size is selected and (4) are required for the repair (see Table 1). The water valve is then shut off and the area excavated and planking installed.

Cut the damaged pipe from the piping system. Make sure that the length removed is long enough for the flange adapter spool assembly to be installed. (See Table 1)

Caution: Butt or Electro-fusion joints cannot be made with water flowing through the pipes. Make sure the water valve shuts-off the water flow 100% and make sure no water is flowing. If a small amount of water is flowing, a towel or pneumatic bladder can be inserted in the valve end to dam up the water long enough to make the butt fusion joint. Be sure to remove this item before making the final connection.

A butt-fusion machine capable of fusing the pipe size is installed in the ditch on planking and clamped to the main pipe. A proper sized flange adapter/back-up ring assembly is installed in the movable jaw. Face the pipe and the flange adapter end to mechanical stops. Remove the pipe chips from the area and align the pipe ends. Using the pipe manufacturer's recommended butt fusion procedures, fuse the pipe to the flange adapter/back-up ring assembly and allow the joint to cool under pressure.

When this joint is cool, remove the fusion machine from the pipe and install the fusion machine's fixed end on the other end of the pipe. Install the proper sized flange adapter/back-up ring assembly in the movable jaw. Face the pipe and the flange adapter end to mechanical stops. Remove the pipe chips from the area and align the pipe ends. Using the pipe manufacturer's recommended butt- fusion procedures, fuse the pipe to the flange adapter/back-up ring assembly and allow the joint to cool under pressure. Also, refer to PPI TR-33.

Once the flange adapters have been fused to the existing pipe ends, measure the inside distance between the flanges. Using the pipe manufacturer's recommended butt fusion procedures, fuse the other two flange adapter/back-up ring assemblies to a piece of pipe with the same OD, DR and specification as the existing pipe to produce an assembly that matches the inside distance between the flanges on the existing pipe. Install the spool piece between the two flanged pipe ends. Bolt the assembly together using the manufacturer's recommended guide for alignment and bolt torque. This will result in a fully restrained joint that does not require thrust blocks or thrust restraints (see Figure 13).

TABLE 1
Minimum Recommended Length of Pipe to Remove for Repair Spool

Pipe Size	Minimum Length of Pipe to be Cut Out for Repair
4” IPS/DIPS	4-5’
6” IPS/DIPS	4-5’
8” IPS/DIPS	5’
10” IPS/DIPS	5’
12” IPS/DIPS	5’
14” IPS/DIPS	5’
16” IPS/DIPS	5’
18” IPS/DIPS	5’
20” IPS/DIPS	5’
22” IPS/DIPS	5’
24” IPS/DIPS	6’

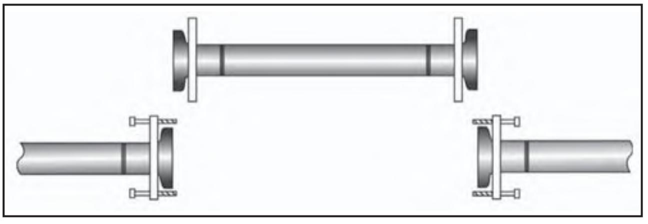


Figure 13 Flange Adapter Repair Spool

Electrofusion Spool Repair

This method is very similar to the Flange Adapter Spool Assembly method, but uses different fusion technology to produce a permanent leak free connection. Instead of butt fusing the pipe ends to flange adaptors, electrofusion couplings are used to connect the replacement spool of pipe to the existing undamaged pipe. Consult the electrofusion manufacturer for the detailed joining procedure to follow in making this joint. Here are some general guidelines for follow.

Resistance wires are imbedded into the inside diameter of the electro-fusion couplings to facilitate the fusion joining of the pipe. Fusion is accomplished by energizing the coupling using a processor attached to the fitting. The processor provides the proper amount of energy required to achieve a proper fusion joint.

When damage has been detected, isolate the damaged area by closing valves or utilizing squeeze off tooling. Excavate the damage and determine the extent of the damage. Confirm the size and DR of the pipe to be repaired. The water valve is then shut off and the area excavated and planking installed.

Caution: Make sure the water valve shuts the water flow off 100% with no water flowing. Butt or Electrofusion joints cannot be made with water flowing through the pipes.

Caution: Pipe diameter and surface condition – Before making electrofusion coupling joints, the user must first determine that the pipe diameter and OD surface condition are suitable for electrofusion joining. Consult the electrofusion coupling manufacturer's instructions for diameter and surface damage limits.

Caution: Joining by qualified persons – Large diameter electrofusion joining is performed only by persons that have personally received training in large diameter electrofusion from the electrofusion coupling manufacturer.

Remove the damaged section of pipe, cutting the ends as square as possible. Cut a spool of the repair pipe to the same length as the removed section of pipe.

On pipe sizes larger than 8" or if the pipe is out of round, it is recommended that a re-rounding tool be installed beyond the area to be scraped. This will help in the scraping process and in the installation of the electro-fusion coupling.

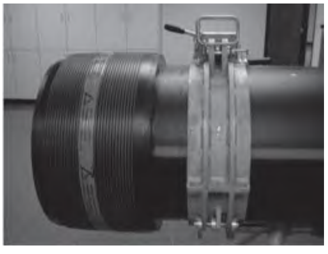


Figure 14 Hydraulic Re-Rounding Clamp Installed

Figure 15 Mechanical Re-Rounding Clamp Installed

Prepare the ends of the spool piece by removing all of the oxidized material from the outside diameter, using a scraper tool. Do not use grinders, emery cloth or other abrasive materials or tools, as they do not completely remove the oxidation.

Prepare each end for the full length of the electrofusion coupling.

Install the couplings completely on each end of the spool piece. Prepare the existing pipe ends in the same manner. Position the spool and move the couplings over the existing pipe ends to be repaired. Provide support for the couplings and the pipe and eliminate any misalignment and stress from the repair area. Using the Electrofusion manufacturers recommended procedures, attach the control box to the fittings and fuse the couplings to both ends of the spool and pipe. This will result in a fully restrained joint that does not require thrust blocks or thrust restraints.

Always follow the manufacturer's installation instructions when installing electrofusion fittings. When making a large diameter pipe repair, refer to the Plastics Pipe Institute Technical Note TN-34.

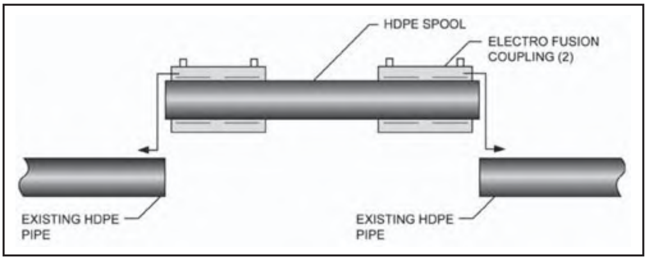


Figure 16 Electrofusion Repair Spool

Stiffener Installation Guidelines

When using a mechanical connection for repair that grips on the OD of the PE pipe, it is recommended that a stiffener be added to the ID of the pipe to insure a good connection between the coupling and the pipe. Check the pipe for toe in, which is an inward curvature of the pipe ends due to residual stress. If it is severe, cut the pipe back to remove it. If possible, have some means to press the stiffener into place. Lubricant will minimize the insertion effort required. A detergent or silicone grease is recommended.

There are two types of stiffeners available on the market. One type is a fixed diameter stiffener that matches the ID of the pipe being repaired (see Figure 17). Caution should be used when using fixed diameter stiffeners to be sure they are sized properly to obtain the proper press fit in the PE pipe. These are mainly used with smaller diameter service lines.

Figure 17 Fixed Diameter Stiffener for PE pipe

The other type of stiffener is a split ring stiffener (see Figure 18). These are normally made of stainless steel and provide a thin yet strong pipe wall reinforcement without disturbing the flow characteristic of the pipe. The easy installation instructions are shown below.

Figure 18 Split Ring Stiffener for PE pipe

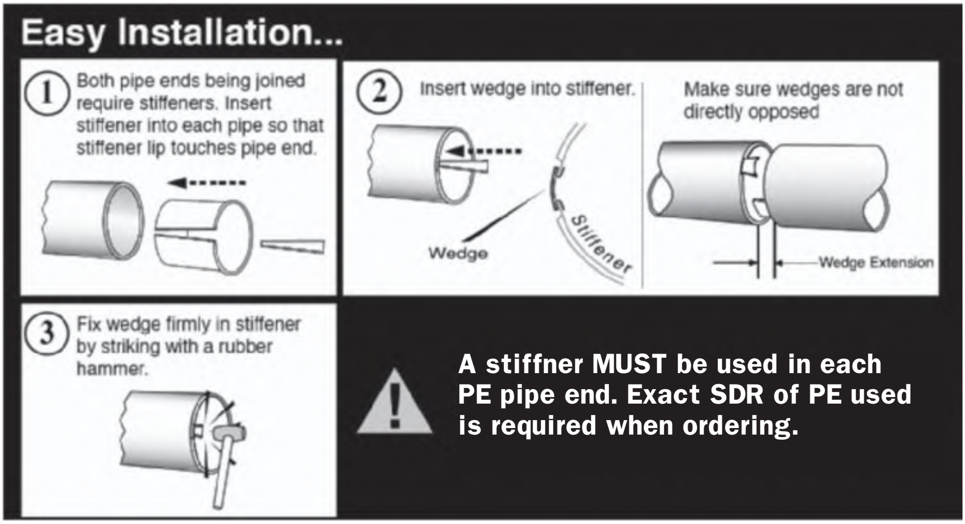


Figure 19 Install Split Ring Stiffener in PE pipe

Restraint Methods

Mechanical Repair Fitting Restraint

The most common method of restraining a mechanical repair fitting is to add a back-up flange to each pipe and electro-fuse the appropriate number of Flex Restraints to each end of the mechanical fitting. The number of Flex Restraints fused to each end depends on the pipe diameter (contact the fitting manufacturer for proper assembly instructions). Once the Flex Restraints have been cooled properly, the mechanical components such as the sleeve, glands, gaskets and bolts can be installed per the manufacturer's procedures to complete the restraining process.

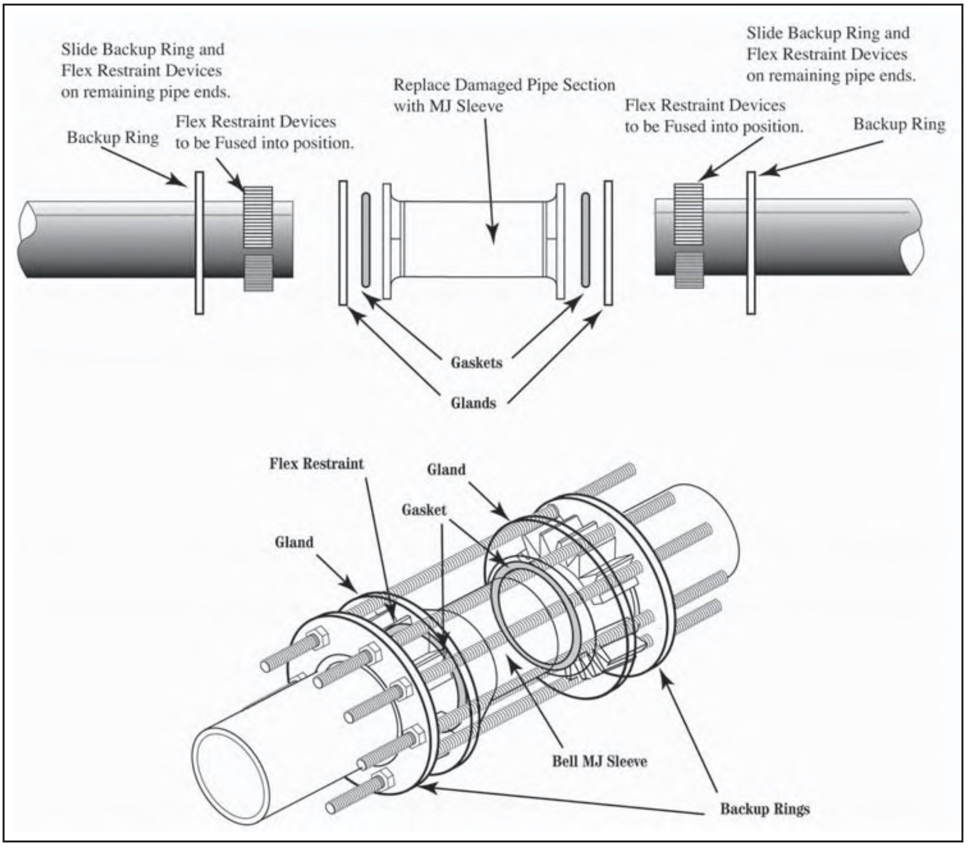


Figure 20 Mechanical Repair Fitting Restraint

Mechanical Coupling Restraint

When the damage is small and a mechanical coupling will satisfy the repair, it may need to be restrained. This is accomplished by using flex restraints (or mechanical restraints) and back up rings on both sides of the coupling. In this situation, the proper quantity of flex restraint couplings are electro-fused to the PE pipe on each side of the coupling (contact the fitting manufacturer for proper assembly instructions). Two backup rings are used with all-thread rods to restrain the connection. Consult the restraint harness manufacturer for the proper assembly procedure.

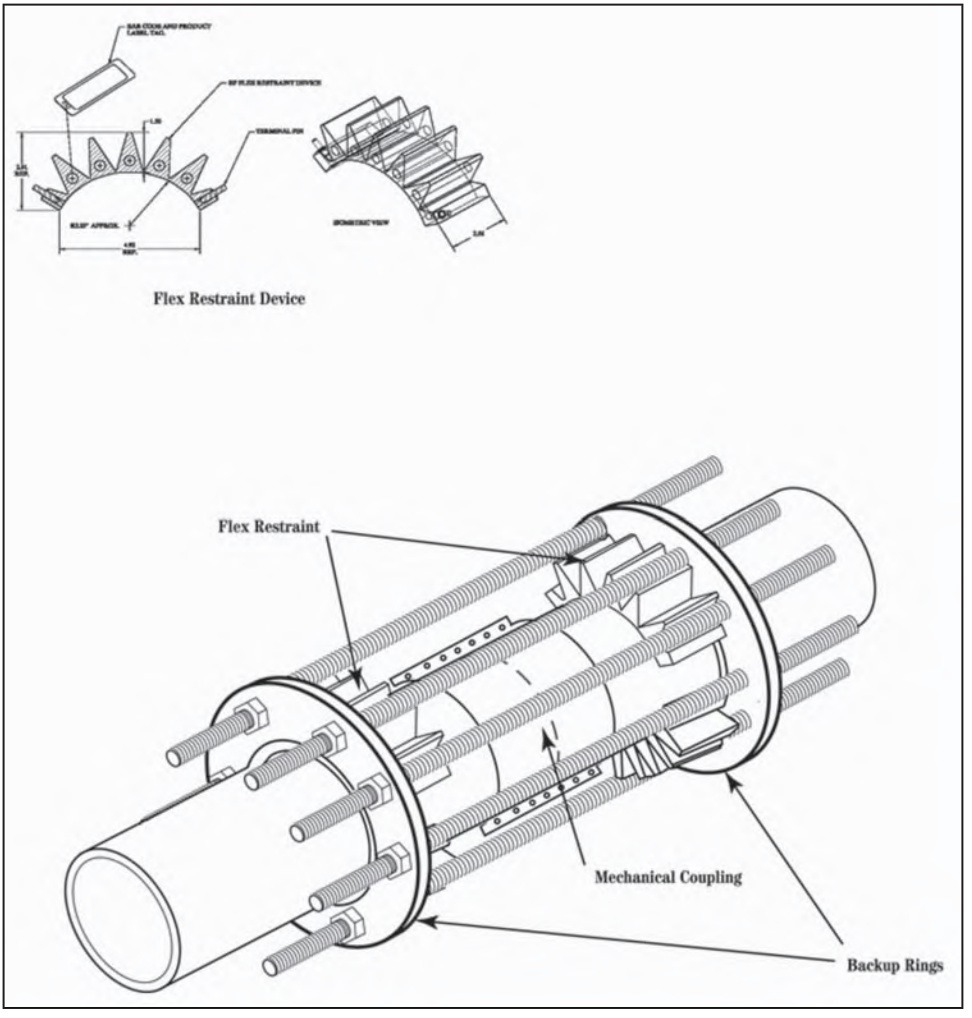


Figure 21 Mechanical Coupling Restraint

Repair Clamps

Third party damage to PE or any pipe material is always a possibility. Repairs can be made by cutting out the damaged section of pipe and replacing the section by use of heat fusion or mechanical fitting technology discussed earlier. Within limits, repairs can also be made with clamp-on repair saddles as depicted in Figure 22. Such devices do have limitations for use. They are intended only to repair locally damaged pipe such as gouges or even punctures of the pipe wall. A clamp length of not less than 1½" times the nominal pipe diameter is recommended. The procedure is basically to clean the pipe area where the clamp will be placed, and bolt the clamp in place according to the fitting manufacturer's instructions. As with all fittings, limitations on use should be verified with the fitting manufacturer.

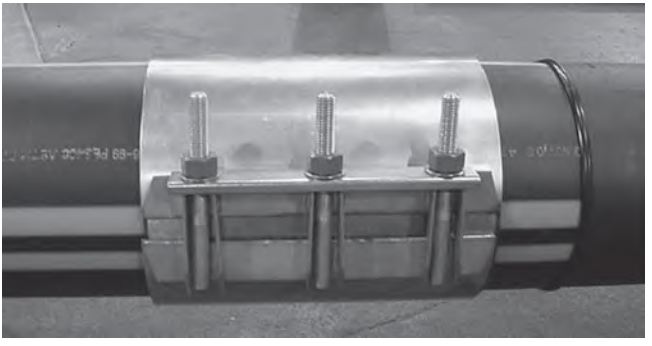


Figure 22 Mechancial Clamp-on Repair Saddle

Squeeze-off

Regardless of the joining method applied in the installation of PE pipe, it may become necessary to shut off the flow in the system. With PE pipe materials, squeeze-off of the pipe with specially-designed tools is a common practice for gas applications. Use squeeze-off tools per ASTM F 1563 and follow the squeeze-off procedures in ASTM F 1041.

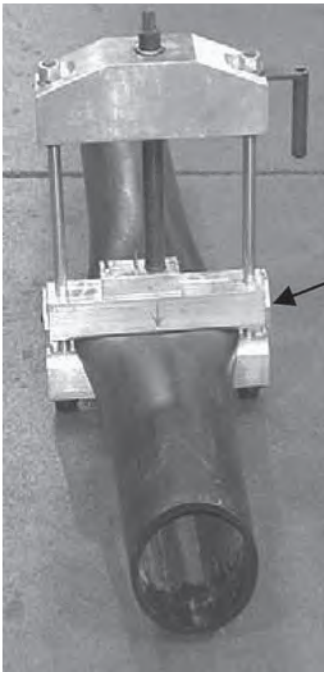


Figure 23 Squeeze-Off Tool

Chapter 16

Pipe Bursting

Introduction

Underground service utilities in many American cities have been in place for over 100 years. While existing systems have functioned well beyond reasonably anticipated service life, underground systems are mostly deteriorated and need costly maintenance and repair. Common problems involve corrosion and deterioration of pipe materials, failure or leakage of pipe joints, and reduction of flow due to mineral deposits and debris build up inside the pipe. Damage to existing pipes can also occur by ground movements due to adjacent construction activity, uneven settlement or other ground instability. This leads to infiltration and inflow (I&I) increase in sewer systems. In water systems, it leads to flow and pressure reductions, persistent leakage (up to 30 percent of water provided in some systems), pipe bursts, and poor water quality. These problems tend to increase with the age of the network where maintaining this large network of underground sewer, water, and gas pipelines is difficult and costly. The above problems are compounded by the significant negative impacts (of open cut repair or replacement projects) on the daily life, traffic, and commerce of the area served by and along the pipeline in question.

Pipe bursting is a well-established trenchless method that is widely used for the replacement of deteriorated pipes with a new pipe of the same or larger diameter. Pipe bursting is an economic pipe replacement alternative that reduces disturbance to business and residents when it is compared to the open cut technique. Pipe bursting is especially cost-effective if the existing pipe is out of capacity, deep, and/or below the ground water table (GWT). Replacing an old pipe with a larger one is termed upsizing. One-size upsizing is replacing the old pipe with a pipe one standard size larger, for example replacing 8” pipe with 10” one. Similarly, two-size upsizing is replacing the old pipe with a pipe two standard sizes larger, e.g. replacing 8” pipe with 12” one.

Pipe bursting conventionally involves the insertion of a cone shaped bursting head into an old pipe. The base of the cone is larger than the inside diameter of the old pipe and slightly larger than the outside diameter of the new pipe to reduce friction and to provide space for maneuvering the pipe. The back end of the bursting head is connected to the new Polyethylene (PE) pipe and the front end is attached to a cable or pulling rod. The new pipe and bursting head are launched from the insertion shaft and the cable or pulling rod is pulled from the pulling shaft, as shown in Figure 1. The bursting head receives energy to break the old pipe from one of the following sources: a pulling cable or rod, a hydraulic source, or an air compressor. The energy breaks the old pipe into pieces and expands the diameter of the cavity. As the bursting head is pulled through the old pipe debris, it creates a bigger cavity through which the new pipe is simultaneously pulled from the insertion shaft. There are many variations to this conventional layout that are presented later in the chapter.

History

Pipe bursting was first developed in the UK in the late 1970s by D. J. Ryan & Sons in conjunction with British Gas, for the replacement of small-diameter, 3- and 4-inch cast iron gas mains (Howell 1995). The process involved a pneumatically driven, cone-shaped bursting head operated by a reciprocating impact process. This method was patented in the UK in 1981 and in the United States in 1986; these patents expired in April, 2005. When it was first introduced, this method was used only in replacing cast iron gas distribution lines; it was later employed to replace water and sewer lines. By 1985, the process was further developed to install up to 16-inch outer diameter (OD) medium-density polyethylene (MDPE) sewer pipe. Replacement of sewers in the UK using sectional pipes as opposed to continuously welded PE pipe was described in a paper by Boot et al. (1987). Up to 2006, approximately 9,000 miles of PE pipe has been installed by bursting (Najafi, 2006). Currently, pipe bursting is used to replace water lines, gas lines, and sewer lines throughout the world.

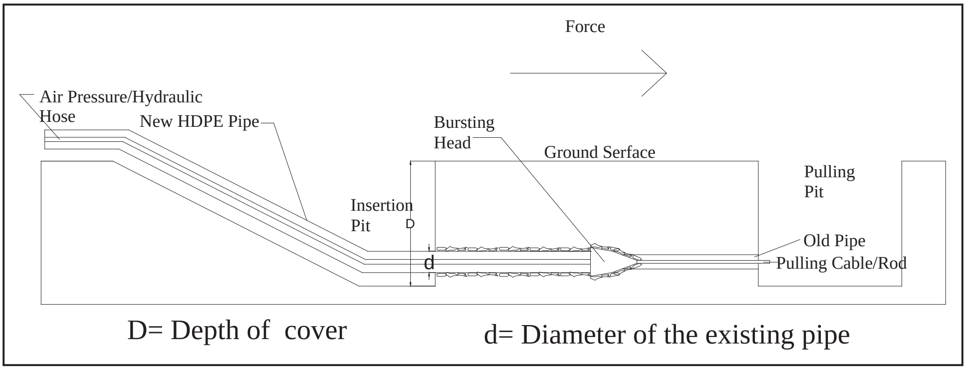


Figure 1 The Pipe Bursting Operation Layout

Pipe Bursting and Trenchless Pipe Replacement Systems

Existing old pipes can be replaced by one of several trenchless techniques developed up to date. There are three basic methods of pipe bursting: pneumatic, hydraulic, and static pull. In addition, there are proprietary trenchless pipe replacement systems that incorporate significant modifications to the basic pipe bursting technique. The basic difference among these systems is in the source of energy and the method of breaking the old pipe and some consequent differences in operation that are briefly described in the following paragraphs. The selection of a specific replacement method depends on soil conditions, groundwater conditions, degree of upsizing required, type of new pipe, construction of the existing pipeline, depth of the pipeline, availability of experienced contractors, and so on.

Pneumatic Bursting Systems

The most common pipe bursting method is the pneumatic system. In the pneumatic system, the bursting tool is a soil displacement hammer driven by compressed air and operated at a rate of 180 to 580 blows per minute. It is similar to a pile-driving operation going horizontally. The percussive action of the hammering cone-shaped head is also similar to hammering a nail into the wall; each hammer pushes the nail a short distance as shown in Figure 2. With each stroke, the bursting tool cracks and breaks the old pipe, the expander on the head - combined with the percussive action of the bursting tool, push the fragments and the surrounding soil providing space to pull in the new PE pipe. The expander can be frontend (attached to the frontend of the hammer) for pipes smaller than 12” or back-end (attached to the backend of the hammer) for pipes larger than 12”. The frontend expander allows withdrawing the hammer through the PE pipe after removing the expander from the existing manhole at the pulling shaft without damaging the manhole. The tension applied to the cable keeps the bursting head aligned with the old pipe, keeps the bursting tool pressed against the existing pipe wall, and pulls the new PE pipe behind the head. An air pressure supply hose is inserted through the PE pipe and connected to the bursting tool. The bursting starts once (1) the head is attached to the new pipe, (2) the winch cable is inserted through the old pipe and attached to the head, (3) the air compressor and the winch are set at a constant pressure and tension values. The process continues with little operator intervention until the head reaches the pulling shaft at which point it is separated from the PE Pipe.

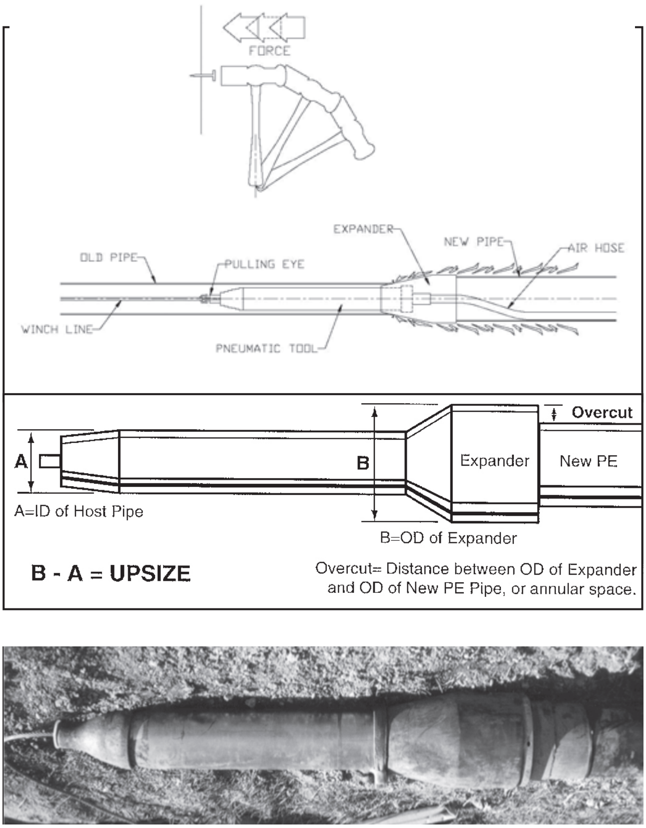


Figure 2 The Bursting Head of the Pneumatic System

Static Bursting Systems

The second common method of pipe bursting is the static pull system. In the static pull system, a larger tensile force is applied to the cone-shaped expansion head through a pulling rod assembly or cable inserted through the existing pipe. The cone transfers the horizontal pulling force into a radial force -- breaking the old pipe and expanding the cavity providing space for the PE pipe as shown in Figure 3. The steel rods, each is about four feet long, are inserted into the old pipe from the pulling shaft. The rods are connected together using different types of connections. When the rods reach the insertion shaft, the bursting head is connected to the rods and the PE pipe is connected to the rear of the head. A hydraulic unit in the pulling shaft pulls the rods one rod at a time, and the rod sections are removed. The process continues until the bursting head reaches the pulling shaft, where it is separated from the PE pipe. If cable is used instead of rod, the pulling process continues with minimum interruption, but the tensile force of a cable compared to a rod section is limited.

Pipe Splitting

The North American Society for Trenchless Technology (NASTT) defines *pipe splitting* as a replacement method for breaking an existing pipe by longitudinal slitting. At the same time a new pipe of the same or larger diameter may be drawn in behind the splitting tool (NASTT 2008). Pipe splitting is used to replace ductile material pipes, which does not fracture using the above-cited bursting techniques. The system has a splitting wheel or cutting knives that slit the pipe longitudinally at two more lines along the side of the pipe. An example of splitting head is shown in Figure 4.

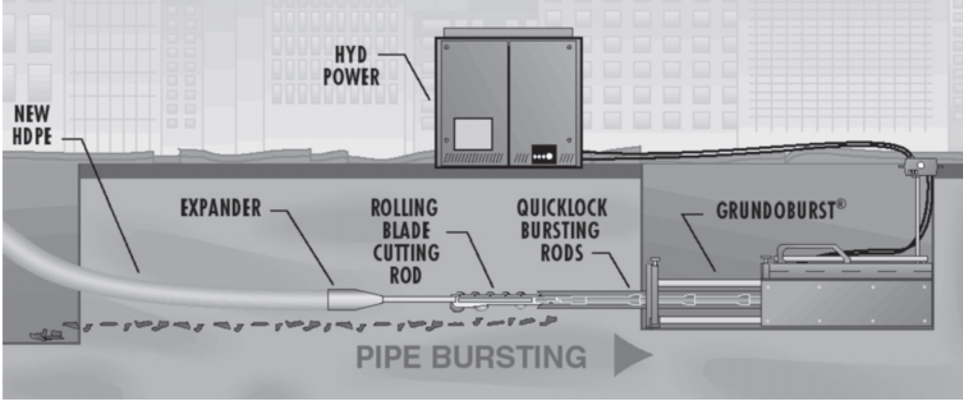


Figure 3 The Static Pull Bursting Head with Accessories to Cut Reinforcing Steel in RCP

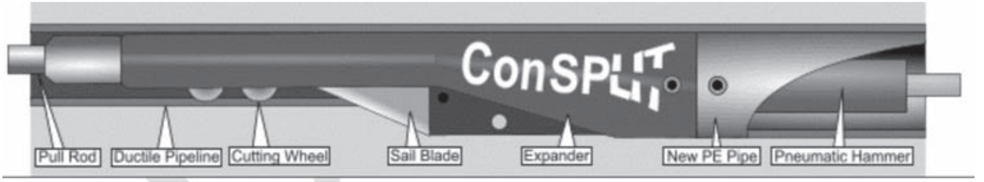


Figure 4 Pipe Splitting Head (PIM Corporation 2007)

Pipe Reaming

Pipe reaming is pipe replacement technique that uses a horizontal directional drilling (HDD) machine with minor modification. After pushing the drill rods through the old pipeline and connecting the rods to a special reamer (see Figure 5), the new PE pipe string is attached to the reamer via a swivel and towing head. As the drill rig rotates and simultaneously pulls back, the old pipe is grinded and replaced by the new PE pipe. Removal of the old pipe is accomplished by mixing the grinded material with the drilling fluid and transferring it to an exit point for removal via a vacuum truck. Directional drilling contractors or utility contractors who use an HDD rig can add inexpensively modified reamers of various types for different pipe materials and ground conditions. Pipe reaming is limited to non-metallic pipeline replacement. According to Nowak (Hayward 2002), the surrounding environmental conditions (groundwater, sand, rock, concrete encasement, etc) that prohibit other procedures are not obstacles to successful installations.

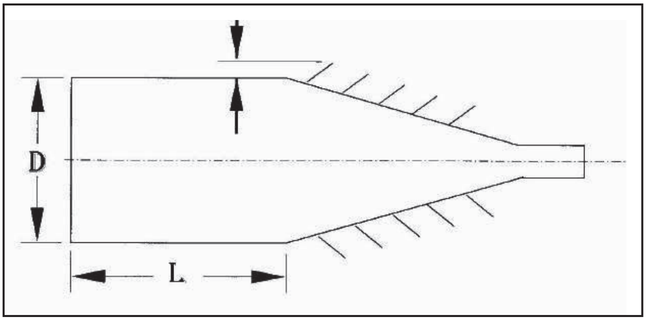


Figure 5 Reaming Head

Impactor Process

The patented Impactor process is another system that combines the HDD with pipe bursting as shown in Figure 6. The bursting head (Impactor) receives air through the HDD stems. The HDD is connected to the air supply and positioned to drill out to an entry manhole. Then the HDD stem is pushed through old pipe to the next manhole and drilled back to the entry manhole. The Impactor device, after it is attached to the drill stem and to the replacement pipe, is pulled into the old pipe. While pulling back, the Impactor system is activated and bursts the old pipe. The combined actions - of pulling using the HDD rig and of hammering of the Impactor device - breaks up the old pipe and replace it with the new pipe. The Impactor system can reduce excavation and overcomes blocked old pipes.

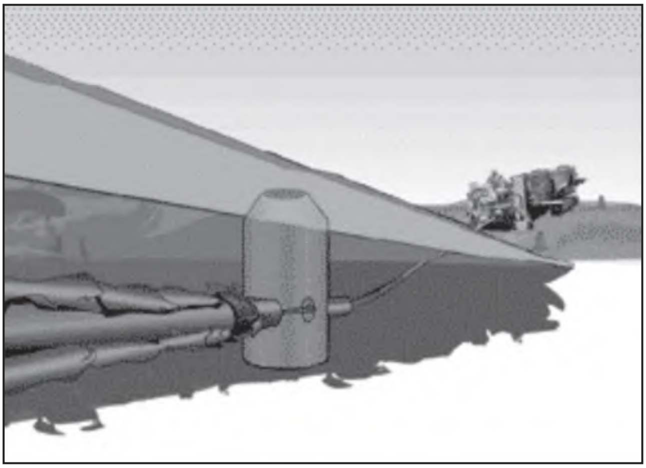


Figure 6 The Impactor Process Combines HDD with Pipe Bursting

Old Pipe Material

In most bursting applications, the old pipe is made of a rigid material such as vitrified clay pipe (VCP), ductile iron, cast iron, plain concrete, asbestos, or some plastics. Reinforced concrete pipe (RCP) was successfully replaced when it was not heavily reinforced or if it was substantially deteriorated. The diameter of the old pipe typically ranges from 2 inches to 30 inches, although the bursting of larger diameters is increasing. A length of 300 to 400 feet is a typical length for bursting; however, much longer runs were completed with bursting systems that are more powerful. In addition, some point repairs on the old pipe, especially repairs made with ductile materials, can make the process more difficult.

New Pipe Material

High-and medium-density polyethylene (HDPE and MDPE) have been the most-used replacement pipes for pipe bursting applications. The main advantages of PE pipe are its continuity, flexibility, and versatility. The continuity, which is obtained by butt fusing together long segments in the field, reduces the possibility of stopping the process. The flexibility allows bending the pipe for angled insertion in the field. In addition, it is a versatile material that meets all the other requirements for gas, water, and wastewater lines. The smoother interior surface (relative to other pipe material) reduces the friction between the flow and the pipe wall, which allow higher flow speed and increased flow capacity. The PE pipe does not erode, rotten, corrode, or rust; it also does not support bacteriological growth. The relatively higher thermal expansion coefficients are the main issue with PE pipes, but when the PE pipe is installed and restrained appropriately, the pipe expands and contracts without any damage. When used in pipe bursting applications, the friction between the soil and the pipe is reduced.

The internal surface of the PE pipe is smoother than those of the concrete or clay pipes. For gravity applications, after some algebraic manipulation to the following Chezy-Manning equation, it is can be demonstrated that the flow capacity of the PE is 44% more than those of the concrete or clay pipes considering the internal diameter for the old clay or concrete pipe equals that of the replacement PE pipe.

$$Q = \frac{1.49}{n} A(r_H)^{2/3} \sqrt{S}$$

WHERE

Q **= the flow quantity**
n **= Manning roughness coefficient**
A **= the area of the pipe**
r_H **= hydraulic radius**
S **= the slope of the energy line, which is parallel to the water surface and pipe invert if the flow is uniform.**

The n value ranges for clay or concrete pipes between 0.012 and 0.015 (on average about 0.013), and it is about 0.009 for PE (Lindeburg 1992).

In addition to PE, other new pipe materials can be ductile iron, VCP, or RCP. However, these pipes cannot be assembled into a single pipe string prior to bursting operation; but they can be jacked into position behind the bursting head or kept compressed by towing them via a cap connected to the cable or rod that passes through the pipes. Therefore, the static pull system is the only bursting system that can be used with these pipes. The joints of these pipes must be designed for trenchless installations.

When is Pipe Bursting a Preferred Solution?

For repair and replacement, conventional techniques have involved open cut excavation to expose and replace the pipe. Alternatively, the pipeline can be rehabilitated by inserting a new lining or replaced by pipe bursting. There are several pipe lining technologies available such as cured in place pipe, deform and reform, and slip lining. The main advantage of the lining methods over pipe bursting is the need for small or no access excavation to the pipeline. In contrast, pipe bursting has the advantage of increasing the pipe capacity by more than 100%.

The unique advantage of pipe bursting over pipe lining techniques is the ability to upsize the service lines. A 15% and 41% upsizing doubles the capacity of the sewer and water lines respectively. The technique is most cost advantageous compared to the lining techniques when (1) there are few lateral connections to be reconnected within a replacement section, (2) the old pipe is structurally deteriorated, and (3) additional capacity is needed.

For pressure applications, 41% increase in the inside pipe diameter double the cross sectional area of the pipe and consequently double the flow capacity of the pipe. For gravity applications, after some algebraic manipulation to the above-mentioned Chezy-Manning equation, it shown that a 15% and 32% increase in the inside diameter of the pipe combined with the smoother pipe surface can produce a 100% and 200 % increase in the flow capacity, respectively.

Pipe bursting has substantial advantages over open cut replacements; it is much faster, more efficient, and often less expensive than open cut especially in sewer applications due to high depths that usually gravity sewer pipes are installed. The increased sewer depth requires extra excavation, shoring, and dewatering which substantially increases the cost of open cut replacement. The increased depth has a minimal effect on the cost per foot for pipe bursting as shown in Figure 7 (Poole et al 1985). Specific studies carried out in the US have shown that pipe bursting cost savings are as high as 44% with an average savings of 25% compared to open cut (Fraser et al 1992). This cost saving could be much more if the soil is hard rock because rock excavation is extremely expensive compared to pipe bursting. Additionally, open cut can cause significant damage to nearby buildings and structures (Atalah 2004).

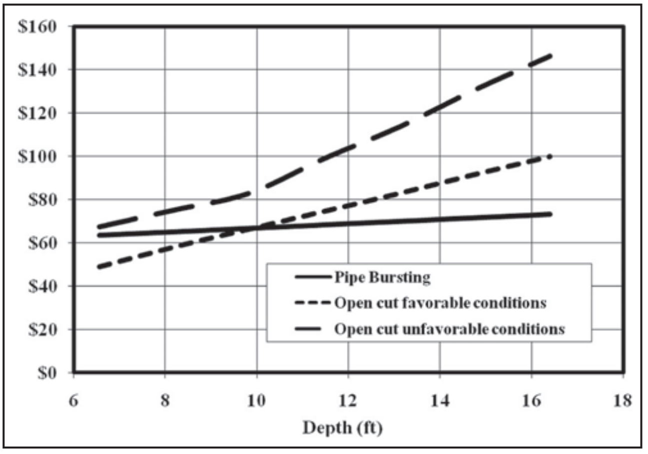


Figure 7 Cost Comparison Between Pipe Bursting and Open Cut Replacements (Poole et al 1985)

In addition to the direct cost advantage of pipe bursting over open cut, pipe bursting, as a trenchless technique, has several indirect cost savings. Less traffic disturbance, road or lane closing, time for replacement, business interruption, and environmental intrusion are some examples of these indirect cost savings. Pipe bursting has minimal interference with other utilities, and less safety hazards (for both operators and the public) due to reduced open excavation.

The unique advantage of pipe bursting over pipe lining techniques; such as cured-in-place pipe (CIPP), sliplining, and deform and reform, etc.; is the ability to upsize the service lines. A 15% and 41% upsizing doubles the capacity of the sewer and water lines respectively. The technique is most cost advantageous compared to the lining techniques when (1) there are few lateral connections to be reconnected within a replacement section, (2) the old pipe is structurally deteriorated, and (3) additional capacity is needed. Pipe bursting has the following additional advantages over open cut: (1) minimal disruption to traffic, (2) minimal interference with other utilities, (3) superior safety (for both operators and the public) due to reduced open excavation, and (4) substantial time savings.

Pipe Bursting Project Classification

National Association of Sewer Service Companies (NASSCO) classified bursting projects into three classifications in terms of difficulty; they are A – routine, B - moderately difficult to challenging, and C – challenging to extremely challenging. The projects are classified as A - routine if the depth is less than 12 feet, the existing pipe is 4-12 inch in diameter, the new pipe is same size as the old pipe or one diameter upsize, the burst length is less than 350 feet, the old trench is significantly wider than the diameter of the new pipe, and the soil is compressible outside trench (soft clay, loose sand). The projects are classified as B - moderately difficult to challenging if the depth is between 12 feet and 18 feet, existing pipe is between 12 to 20 inch, the diameter of the new pipe is two diameter upsize, the burst length is between 350 feet to 450 feet, the trench width less than 4 inch wider than new pipe diameter, or the soil is moderately compressible outside trench such as medium dense to dense sand, medium to stiff clay. The projects are classified as C – Challenging to Extremely Challenging if the depth is more than 18 feet, existing pipe is between 20 and 36 inch, the new pipe diameter is three or more diameter upsize, the length is more than 450 feet, the soil is incompressible outside trench, or the trench width is less than or equal to upsize diameter. Note that the degree of difficulty increases as more than one of the above criteria applies (Najafi 2007).

TABLE 1
Summary of NASSCO Pipe Bursting Classification

Criteria	A – Routine (all of the criteria below apply)	B - Moderately Difficult to Challenging	C – Challenging to Extremely Challenging
Depth	Less than 12 feet	12 ft to 18 ft	More than 18 ft
Existing Pipe	4”-12”	12” to 20”	20”-36”
New Pipe Diameter	Size for size or one diameter upsize	Two diameter upsize	Three or more diameter upsize
Burst Length	Less than 350 feet	350 feet to 450 feet	More than 450 feet
Trench Width	Relatively wide trench compared to upsized diameter	Trench width less than 4” wider than upsize diameter	Incompressible soils (very dense sand, hard clay or rock) outside trench
Soil	Compressible soils outside trench (soft clay, loose sand)	Moderately compressible soils outside trench (medium dense to dense sand, medium to stiff clay)	Constricted trench geometry (width less than or equal to upsize diameter)

Pipe Bursting Applicability and Limitations

Pipe bursting is used to replace water lines, sewer mains, and gas lines, as well as sewer lateral connections. Typical replacement length is between 300 feet and 500 feet; however, in favorable conditions, longer drives have been completed successfully. The size of pipes being burst typically range from 2 to 30”, although pipes of larger sizes can be burst. Pipe bursting is commonly performed size-for-size and one-size upsize above the diameter of the existing pipe. Larger upsize (up to three pipe sizes) have been successful, but the larger the pipe upsizing, the more energy needed and the more ground movement will be experienced. It is important to pay close attention to the project surroundings, depth of installation, and soil conditions when replacing an existing pipe especially in unfavorable conditions such as expansive soils, repairs made with ductile material, collapsed pipe, concrete encasement, sleeves, and adjacent utility lines.

On the other hand, pipe bursting has the following specific limitations: (1) excavation for the lateral connections is needed, (2) expansive soils could cause difficulties for bursting, (3) a collapsed pipe at a certain point along the old pipe may require excavation at that point to allow the insertion of pulling cable or rod and to fix the pipe sag, (4) point repairs with ductile material can also interfere with the replacement process, (5) if the old sewer line is significantly out of line and grade, the new line will also tend to be out of line and grade although some corrections of localized sags are possible, and (6) insertion and pulling shafts are needed specially for larger bursts.

Design Considerations

Pipe-bursting projects can be broken down to three phases: pre-design, design, and construction. The pre-design phase involves collecting information about the problem pipeline, investigating the alternative solutions, and ensuring that pipe bursting is the best solution. The design phase involves investigating the conditions of the old pipe and trench, nearby utilities and structures, determining shaft locations, bypass pumping requirements, and developing detailed drawing and specifications. The construction phase involves selecting the bursting system, lateral connections, submittals, shaft construction and shoring, bypass pumping, and restoration.

Pre-design Phase

At the pre-design and design phases, the ability to influence the cost of the project is the highest, and the cost of project modification is lowest, as shown in Figure 8. This is especially true for small jobs where the contractor’s cost savings (from design modification) is small in magnitude, and the benefits do not justify the risk of being responsible for the redesign and its consequences. Therefore, invested effort in this phase will pay dividends later.

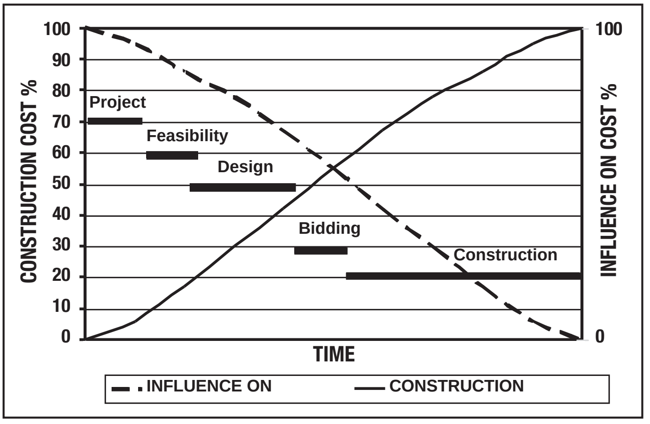


Figure 8 Ability to Influence Construction Cost Over Time (Project Management Institue Inc. 2004)

The pre-design phase involves collecting information about the old and new pipelines. The designer determines the maximum flow requirements for the future design life of the pipeline (considering the future economical developments and population growth trends), and then calculates the diameter of the new pipe. This phase also includes investigating potential solutions for the problem and collecting the relevant information to evaluate the valid solutions. For example, potential solutions may include installing another new line, lining the old pipe, replacing the pipeline via open cut, replacing it by pipe bursting, and so forth. If pipe bursting is the optimal solution, the design team proceeds to the design phase.

Many times open cut is the specified method of construction for most pipeline projects, and the bursting contractors offer pipe bursting as an alternative to open cut. This process may include preparation and submittal of two bids: one is based on open cut and the second is a value-engineering proposal based on pipe bursting. While this arrangement may increase the competition among bidding contractors, it increases the overall project cost (due to risk and contingency factors) for the project because (1) while the presented information in the contract document might be complete for the open cut method, it may be incomplete for estimating the cost of the bursting project and (2) this incomplete bid information increases the risk of problems during construction period that may lead to change orders and possible disputes that are more costly to resolve. It is believed that if the owner and the engineer select the methods of construction (for example open cut and pipe bursting) early during the design phase, the competition is maintained, bidding information is complete, and the risk of changes is reduced as illustrated in Figure 8.

Design Phase

The design phase starts with collecting further information about the old line, such as: the type of soil and backfill, current flow volume for bypass pumping, lateral connections, trench width, backfill compaction levels, and manhole locations. This phase also includes locating nearby utilities, investigating soil and trench backfill material, and developing risk assessment plans. The feasibility of pipe bursting as the optimal solution may need to be re-evaluated in light of the new collected information. The designer completes this phase with developing detailed drawing and specifications and complete bid documents which include listing of the needed submittals. The drawings should provide all relevant information, such as diameter and material type of existing pipe, existing plan view and profile, existing nearby utilities and structures (crossing and parallel), repair clamps, concrete encasement, fittings, and so forth. This information is collect through a CCTV or similar inspection of the old pipe.

Utility Survey

Surrounding utilities have significant impact on the success of the pipe bursting operation, and the design engineer should attempt to identify and locate these existing utilities. However, the *exact* location of these utilities must be identified during the construction phase through visual locating, such as vacuum potholing. The identification of nearby utilities by design engineer is critical for the following reasons:

- The presence of nearby utilities may steer the engineer to eliminate pipe bursting as a construction method.
- The existing utilities may affect the location of insertion and pulling/jacking shafts.
- Reduce or eliminate the risk of causing significant damage to these utilities.
- The contractors need to know the number of utilities that they need to expose to account for them in their bid.
- Consideration for protection of existing utilities from the ground movement of the bursting operation must be made early on to reduce the risk of service interruptions to the customers.
- Reduce the risk of injuries and fatalities to the workers and nearby people if these utilities are accidently damaged during bursting.

Site investigation should indicate the locations of many utilities; for example, sewer manholes indicate the presence of a sewer line and fire hydrants indicate the presence of a water line, etc. The engineer should contact the One-Call center for utilities marking, review the available as-built drawings from the different utility owners, and ideally consider geographic information system (GIS) data (if available), utility maps, and conducts surface and subsurface investigations to superimpose these utilities on plans and profiles.

Investigation of Existing Pipe and Site Conditions

Investigation of the old pipe condition assists in selecting the suitable rehabilitation technique and provides the exact location of the lateral connections. The conditions of the existing pipe may render pipe bursting as an unsuitable method for correcting the problem. The presence of sags in the line may require treatment for the sag prior to bursting. The host pipe (diameter, material, and conditions) and the diameter of the new pipe guide the contractor to select the appropriate bursting system type, size, and accessories during the bidding and construction phase. The site conditions and surface features may affect the locations of the insertion and pulling shafts, staging area for fused pipe, traffic control planes, and foot print for the needed bursting system components.

Insertion and Pulling Shaft Requirements

When planning for shaft locations, the engineer identifies spots where excavation is needed to replace manholes, valves, lateral connections, or fittings. These excavation spots are used as insertion or pulling shafts. However, if excavation at the manhole location is not feasible or needed, shaft excavation at other locations may be considered. In selecting the location of these shafts, the engineer has to consider the following issues:

- Sufficient staging area for the fused replacement pipe to avoid blocking driveways and intersecting roads.
- The shaft length should be long enough to allow alignment of the bursting head with old line and for the PE pipe to bend safely from the entry point to the ground surface.
- Space for the construction equipments such as backhoe, loader, crane, etc.
- Nearby flow bypass discharge spot or space to lay by pass lines without blocking driveways and intersecting roads.
- Traffic control around shafts.
- Soil borings close to these shafts.
- Discharge spots for dewatering if needed.
- Using the same shaft to insert or pull pipes more than once.

Generally, the engineer recommends locations for the insertion and pulling shaft but leaves the final determination to the contractor (through a submittal process) with the guidelines of minimizing excavation and disturbance to the surrounding environment.

Soil Considerations in Pipe Bursting

The soil and subsurface investigation is collecting the necessary information to properly design the project. It assists the contractor in submitting a proper bid by selecting the appropriate bursting system (type and size), shoring of the pulling and insertion shafts, dewatering system, compacting backfill material, etc. This proper decisions and biding increase the chances of success during the construction phase of the project.

The soil investigation activities include soil borings, standard penetration tests, groundwater level determinations, trench geometry investigation, and native soil and trench backfill material classifications. If the presence of washouts or voids around the existing pipe is suspected, Ground Penetrating Radar (GPR) survey may assist in determining locations and magnitude of these voids. Special attention should be given to the presence of major difficulties that may render pipe bursting not feasible such as the presence of rock, hard cemented dense soils, very soft or loose soils, reinforced concrete encasement, very narrow trench in hard soils or rock, or ductile point repairs. If contaminated soil is suspected, the type and extent of contamination should be identified and indicated in the contract documents. The contractor should be requested to take the necessary measures to handle and dispose of this contaminated soil.

The soil around the pipe (backfill and native soil) has to be compressible to absorb the diameter expansion. Compressible soils are the ideal soils for pipe bursting because the outward ground displacements will be limited to an area surrounding the pipe alignment as shown in Figure 9. Original backfill is the most suitable soil for bursting followed by (increasing difficulty) compressible clay, loose cobble, beach and running sand, densely compacted clay, then sandstone. Soils with long standup time allow the overcut (created by the expanded hole) to remain open for most of the bursting operation, thus reducing the friction force between the soil and the pipe. The overcut lowers the needed pulling forces and consequently the axial stress on the new pipe during installation. Somewhat less favorable ground conditions for pipe bursting involve densely compacted soils and backfills, soils below the water table and expandable soils. Special soils such as highly expansive soils or collapsible soils will also cause problems.

Pipe bursting below the groundwater table increases the difficulty of the bursting operations because the groundwater flows towards the insertion shaft requiring dewatering of the shaft. Also, in very soft or loose soils, significant ground movements may take place causing significant sags in the new line and damage to nearby structures. In sever situations, the soils particles migrate to the old pipe converting the bursting operation into a piercing operation. If the groundwater is lowered via any dewatering technique such as deep wells, well point system, or open sumps in the pulling and receiving shafts, the effective soil pressure will increase.

This will increase the vertical loads on the pipe causing increased friction, bursting and pulling force, and tensile stresses in the PE pipe. On the other hand, the presence of water reduces the coefficient of friction between the pipe and the soil, reducing the applied pulling force.

If the original soil borings (during the old pipe installation) are available, they should be reviewed and made part of the supplemental information available to the bidders. The determination of the trench geometry and backfill material and compaction is important for the designer and contractor.

Maximum Allowable Operating Pressure (MAOP)

For pressure applications such as water, gas, and force mains, the maximum allowable pressure should be determined based on the maximum surge pressure that pipe will be subject to and the maximum operating pressure for the pipe. The PE pipe should be designed to withstand the maximum allowable operating and surge pressures according to the design procedure shown in Chapter 6 in this Handbook. DR 17 is typically used for bursting pressure or gravity pipe unless a higher pressure rating is required. In short bursting runs where high tensile forces are not expected DR 21 can be used.

Risk Assessment Plan

Most underground and pipeline construction projects generally have some risks associated with the unknown subsurface conditions. The risks associated with pipe bursting include damage to nearby utilities and structures, failure to complete the project using pipe bursting, and time and/or budget overrun. There is risk of damage to nearby utilities, buried structures, and pavement if there are adverse soil conditions, improper construction techniques, design mistakes, inappropriate toning of utilities, etc. There are also many risks associated with flow bypass, dewatering, shoring, etc if the appropriate procedures were compromised. A list of additional risks that may stop the bursting operation and/or create problems include:

- Settlement at insertion/pulling pits if the density of the backfill exceeds that of native soil.
- Bursting through sharp curves.
- Concrete encasement or steel point repair inside existing pipe.
- Excessive bursting lengths.
- Damage to new pipe from sharp edge or fragments of existing pipe being burst/split.
- Damage to laterals from bursting of main line.

- The presence of rock under the existing pipe may create a 'bump' in the replacement pipe.
- Collapsed pipe.

Projects with class C classification-challenging to extremely challenging as indicated in Table 1- must be carefully examined in terms of required forces and ground displacements. Additionally, the depth of the old pipe affects the expansion of surrounding soil and consequently the extent of ground displacement around the pipe. If the pipe is shallow, damage to the pavement may take place. Saw cutting the pavement prior to bursting might be advisable. If the existing pipe is below the GWT, the difficulties increase. Insertion and pulling shafts grow larger and more complex as the depth increases.

If there are unacceptable sags in the existing sewer line, these sags need to be corrected before bursting. The sags can be corrected by local excavation, surface grouting, or grouting from within the pipe. Some reduction of sag magnitude may be expected (without corrective measures) from the bursting operation, but the extent to which the problem is corrected depends on the relative stiffness of the soil below the sagging section.

If there is erosion of the soil around the pipe, the bursting head and the following PE pipe will tend to deviate toward the void or lower density region. If there is a hard soil layer or rock close to the pipe, the bursting head will tend to displace towards the softer soil. In shallow conditions, the bursting head will deviate mostly upwards towards the ground surface. If the conditions change substantially along the length of the burst, this may cause some change in the grade and/or alignment of the pipe. When the grade is critical, these possibilities should be considered.

Most pipe bursting operations can be done safely if site and project conditions are known before bursting and appropriate measure are taken to address these conditions. There are well known solutions to all of the above mentioned risks and problems, and successful project engineers or construction managers identify these risks and develop a risk management plan to address these specific risks for this project. This plan includes quantification of the occurrence probability of the identified events and their associated impact or damage; it also includes measures to eliminate, mitigate, transfer, or undertake these risks. One of the general measures to mitigate the project risks is building and maintaining cooperative relationships among owners, engineers, contractors, equipment manufacturers, and pipe suppliers. Identifying and developing a realistic plan to manage and share risks appropriately is an important part of effectively communicating responsibilities, defining roles, and building a strong team. It is important to pay close attention to the project surroundings (surface and subsurface conditions) for unfavorable conditions and risks. These conditions require extra attention in order to ensure the safety of all involved people as well as surrounding facilities and infrastructure.

Ground Movement Associated with Pipe Bursting

The pipe bursting process creates a cavity in the soil around the pipe where the new pipe is pulled through. This cavity creates a compression plastic zone around the new pipe outlined by an elastic zone as shown in Figure 9.

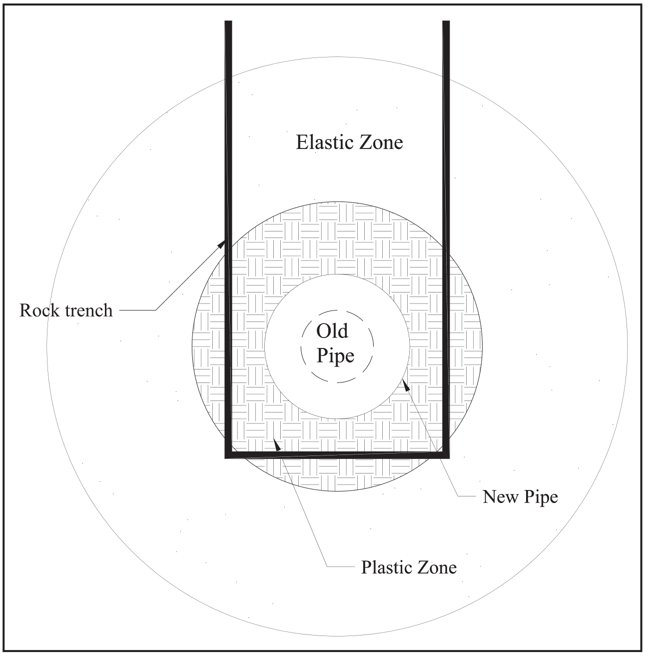


Figure 9 Cavity Expansion and the Plastic and Elastic Zones

The magnitude of the compression and the dimensions of these zones correlate with the amount of upsizing, the diameter of the pipe, and the type of soil (Atalah 1998). The author investigated the ground movements and vibrations associated with bursting small diameter pipes in soft soils (Atalah 1998) and with large diameter pipes in rock conditions (Atalah 2004) and developed guidelines for safe distance from existing nearby utilities, structures, and pavement. Large diameter bursting in rock conditions is applicable for upsizing 24″ in diameter reinforced RCP pipes with upsize percentage less than 50%. Small diameter bursting in soft soils refers to upsizing 8″ and 10″ in diameter VCP with upsize percentage less than 30%. The findings of these reports are summarized in Figure 10.

Figure 10 compares the peak particle velocity (PPS) of the soil versus the distance from the source of the vibration for different types of construction equipment and small diameter pipe bursting in soft soils and large diameter bursting in rock conditions. The PPS is the velocity of soil particles as they vibrate due to these construction activities. There is a strong correlation between the distance from the bursting head and the level of vibration for pneumatic bursting. As shown in Figure 10, the bursting vibration levels quickly fall to levels that do not cause damage to buildings. For structurally sound residential buildings, a safe distance (away from these structures) of eleven feet and eight feet are recommended for large diameter bursting in rock conditions and small diameter bursting in soft soils respectively. Safe distances of eight feet and four feet from nearby structurally sound commercial structures are recommended for bursting large diameter bursting in rock conditions and small diameter bursting in soft soils respectively. In addition, the statistical analysis indicates that the safe distance should be more than 7.5 feet from the buried structures. These pipes are mostly deep main lines installed in the right of way, which are usually far from the residential or commercial buildings.

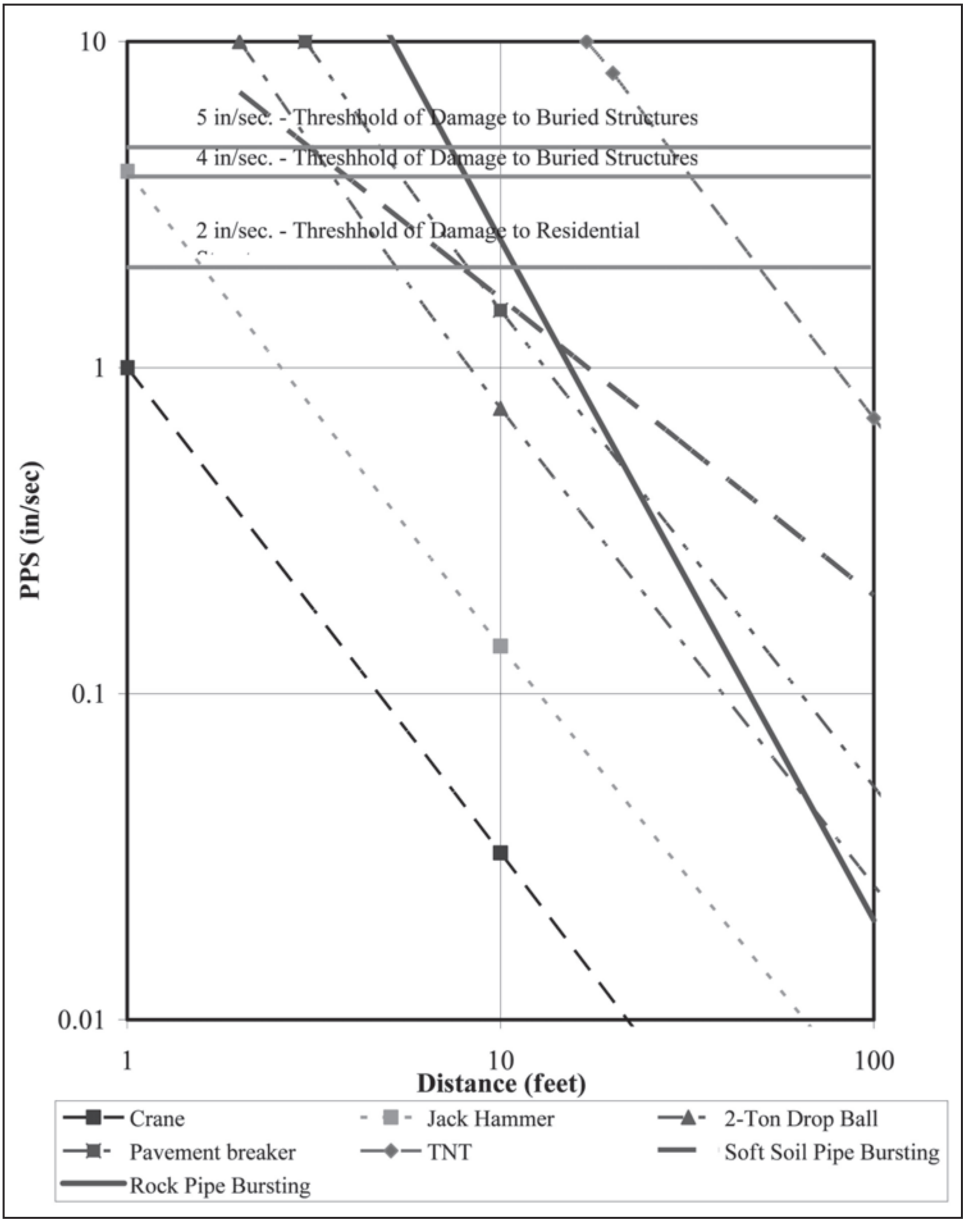


Figure 10 The Attenuation Lines of the PPS Versus Distance from the Source for Different Construction Pieces of Equipment (Wiss 1980) and the Attenuations of the 90% PI Upper Limit lines for the Pneumatic Bursting in Soft Soils (Atalah 1998) and Hard Soils (Atalah 2004).

Plans and Specifications

The contract documents typically include the contract agreement, general conditions, special conditions, project plans, specifications, geotechnical report, and CCTV records. The plans and specifications for pipe bursting projects should have all the required information for typical open cut water or wastewater pipeline projects plus the information listed in this section. The drawings should provide information about the existing site conditions and the required construction work. Description of site constraints (i.e., work hours, noise, etc.) and the procedures to review the CCTV data should be listed in the notes section in the drawings. The plans may also include information to show erosion and sediment control requirements, flow bypassing plans, and service connection and reinstatement details. Generally the plans should include:

- Limits of work; horizontal and vertical control references.
- Topography and survey points of existing structures.
- Boundaries, easements, and rights-of-way.
- Existing utilities, sizes, locations, and pipe materials.
- The verification requirements for existing utilities.
- Plan and profile of the design alignment.
- Existing point repairs, encasement, sleeves, etc.
- Construction easement and the allowable work areas around the insertion and pulling pits.
- Details for lateral connections and connections to the rest of the network.
- Restoration plans.
- Traffic control plans.
- Existing flow measurements for bypass pumping (Najafi 2007).

The technical specifications supplement the drawings in communicating the project requirements. Information to be included in the technical specifications should include:

General

- Minimum contractor qualifications.
- Permit matrix and responsibilities.
- Safety requirements with focus on confined space entry, flow bypass, and shoring.
- Scheduling requirements and construction sequence.
- Submittals.

Pipe and Manhole Materials

- Standards and tolerances for materials, wall thickness and class, testing and certification requirements.
- Construction installation instructions for pipe joining and handling.
- Fittings, appurtenances, and connection-adaptors.
- Acceptable material performance criteria and tests.

Construction Considerations

- Flow bypassing, downtime limits, and service reinstatement requirements.
- Spill and emergency response plans.
- Traffic control requirements.
- Erosion and sediment control requirements.
- Existing conditions documentation (e.g., photographs, videos, interviews).
- Protection plan for existing structure and utility (ground movement monitoring).
- Accuracy requirements of the installed pipe.
- Daily construction monitoring reports.
- Field testing and follow-up requirements for pipe joining, pipe leakage, disinfection, backfill, etc.
- Site restoration and spoil material disposal requirements (Najafi, 2007).

Submittals

In addition to the submittals needed for a traditional open cut projects, the submittals for pipe bursting projects usually include the following submittals: site layout plans, sequence of bursting, shoring design for all the excavations, bypass pumping plan, manufacturers' specifications of the selected bursting system and its components, dewatering plan, new pipe material, lateral connections material and plans, site layout plans, and so forth. The site layout plans would show the location of the insertion and pulling shafts, dimensions of shafts, traffic flow, safety and communication plan, storage space to store and lay the new pipe, and so forth. Lastly, the site restoration and clean-up plans should be included in the submittals

Quality Control/Quality Assurance Issues

The project specifications should state the quality control and assurance measures required to ensure that the project is executed according to the contract specifications. In addition to the quality control and quality assurance measures usually specified for a traditional open cut projects, there are a few measures that are specific to the pipe bursting operations. The project specifications should state the quality control and assurance measures required to ensure that the project is executed according to the contract specifications. These measures can take the form of tests, certifications, inspection procedures, etc. Extensive listing of the relevant required submittals, careful preparation of the submittals, and alert review and approval of the submittal are significant steps in the QC/QA program. The QC/QA program states the performance criteria for the product line and the acceptable tolerance from these criteria. For example, the invert of the new pipe should not deviate from the invert of the old pipe by more than a certain number of inches, the depth of sags in the line should not exceed one inch, and the difference in the vertical and horizontal dimensions of the new pipe diameter should not exceed 2%. The QC program should state how these performance criteria will be measured, tested, and checked. Some of these performance criteria that can be specified are post bursting CCTV inspection, pressure tests, and mandrel test. The surface and subsurface displacement-monitoring program should be outlined in the specifications along with the acceptable amount of ground movements. Certifications from the manufacturers of the bursting system, replacement pipe, and other material that these products meet the contract specifications based on tests conducted by the manufacturer or a third party may be required. For challenging projects, the presence of bursting system manufacturer representative at the jobsite may be required. The owner's quality assurance program should ensure that the field and management team of the contractor have the knowledge and the experience needed to complete the project successfully and able to respond appropriately to unforeseen problems.

Dispute Resolution Mechanisms

The contract should include different site conditions and unforeseen conditions clauses that allow contract time and amount adjustment if the conditions at site *materially* differ from the conditions expected and indicated in the bid documents. These clauses facilitate resolving disputes efficiently and quickly without negative impact on the project. If site conditions are significantly different than those described in the contract documents and the contractor or owner can show that the different conditions impacted the work, the contract value and duration should be adjusted accordingly. Conducting the proper surface and subsurface investigations, outlined earlier in this chapter, should minimize the occurrence of project disputes and possibility of work stoppage during the pipe bursting operations.

Maximum Allowable Tensile Pull

After the bursting head breaks the old pipe and creates a cavity in the ground, the winch pulls the new pipe through this cavity. For the pipe to be pulled, the pulling force has to exceed the friction between the outside surface of the pipe and the surrounding soils. When the coefficient of friction between soil and the pipe is high and the outside surface area of the pipe is large, high pulling forces are needed to overcome this high friction resistance. The high pulling force generates high tensile stresses on the replacement pipe. If the allowable tensile strength of the pipe is less than the anticipated tensile stresses on the pipe, actions to reduce friction must be adopted to avoid excessive strains in the pipe. Examples of these actions are increasing the diameter of the bursting head by about an inch to create about half an inch of overcut around the pipe, and injecting bentonite and/or polymer lubrication into the annular space behind the bursting head to reduce the frictional forces. If these actions are not sufficient to rectify the problem, shorter bursting run and relocation of the insertion or pulling shafts must be considered. Friction force calculations need to be conducted before bursting operation starts to avoid over stressing the pipe. It is much easier and less costly to incorporate the above-mentioned corrective actions before bursting than during bursting.

Typical safe pull tensile stress values for MDPE and HDPE are given in Table 2. Consult the manufacturer for specific applications. The values are given as a function of the duration of continuous loading. For pipe temperatures (not outside air temperatures) other than 73ºF, multiply the value in Table 2 by the temperature compensating multipliers found in Table B.1.2 of the Appendix to Chapter 3. The Safe Pull Load at 12 hours is given for many pipe sizes and DR's in Chapter 12, Tables 4 and 5 (3xxx material) and Tables 6 and 7 (4xxx material).

TABLE 2
Safe Pull Tensile Stress @ 73ºF

	Typical Safe Pull Stress (psi) @ 73ºF		
Duration (Hours)	**PE2xxx (PE2406)**	**PE3xxx (PE3408)**	**PE4xxx**
0.5	1100	1400	1500
1	1050	1350	1400
12	850	1100	1150
24	800	1050	1100

Note: The safe pull stress is the stress at 3% strain. For strains less than 3% the pipe will essentially have complete strain recovery after pullback. The stress values in Table 2 were determined by multiplying 3% times the apparent tensile modulus from the Appendix to Chapter 3 adjusted by a 0.60 factor to account for the high stress level during pullback.

Estimating the pulling force to break the old pipe and overcome friction resistance between the new PE and the surrounding soil is very difficult and currently there is no accurate method to calculate it. Many site and project factors interact to make developing an accurate and reliable model very difficult; among these factors: the strength of the old pipe, the type of backfill material, the type of native material, degree of upsize, bursting system, the amount of overcut, the presence of sags along the line, etc. Comparisons between the actual pulling forces and the calculated forces using the Terzaghi's Silo Theory that is used in calculating the jacking force in pipe jacking operations is presented later in this chapter.

Atalah et al (1998) instrumented two PE pipe with strain gauges and measured the strain in the pipe due to the pipe bursting process. They also calculated the friction resistance between the pipe and the soil using Terzaghi's silo theory. Figure 11 presents a comparison between the maximum stresses recorded in the pipe against calculated pipe stresses. The stress was calculated on the basis that the soil collapsed around the pipe and exerted a normal pressure on the pipe related to its depth below the ground surface similar to the frictional drag on jacking pipe. The assumptions for ground pressure and frictional resistance followed the typical assumptions for pipe jacking calculation presented in Atalah 1994 and Atalah 1996.

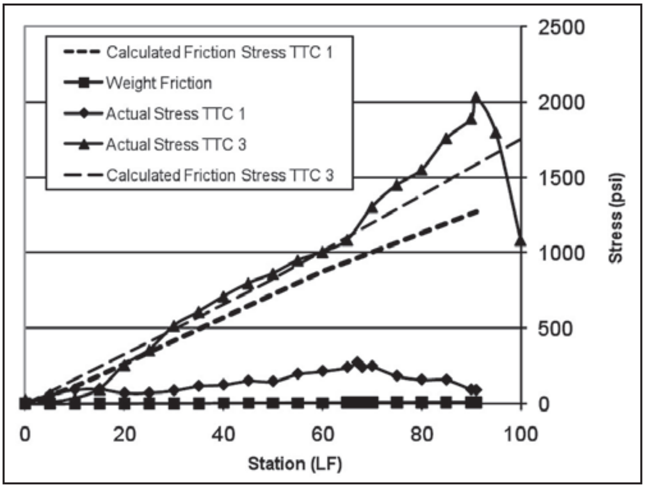


Figure 11 Actual Stress vs. Calculated Stress for TTC Test Site #1 and 3

As shown in the Figure 11 in TTC test site 1, there was substantially less frictional drag on the pipe than would be expected from a fully collapsed soil around the pipe. This indicated that the hole remained at least partially open during the replacement process. The cavity around the pipe stayed open during and possibly after the bursting because the nominal overcut was about 0.7 inch and the hammering action of the head compressed the surrounding soil. For the TTC test site 3, the measured data correlated well with the stresses that were generated from a collapsed soil around the replacement pipe over its full length. It is not clear why the friction on the pipe in this test is so much more than on the pipe in TTC Test Site #1 which had a larger upsizing. The following are the conclusions from these pipe stress measurements:

- Appear to match the range of stresses measured
- Measures to retard the collapse of soil around the replacement pipe will lower stresses in the replacement pipe

- None of the stresses measured exceeded about two-thirds of the yield stress of the PE pipe
- The level of stress in the replacement pipe was actually less for the pipe with larger upsizing percentage so there is not a direct relationship between upsizing percentage and replacement pipe stress
- The magnitude of the stress cycling in the replacement pipe during installation is small compared with the mean stress level

The pulling force must overcome the penetration resistance at the bursting head and the friction resistance along the outside surface of the pipe. The friction equals the outside surface area of the pipe times the soil pressure on the pipe times the friction coefficient between the soil and the pipe surface. A more detailed discussion about estimating the jacking force on jacking pipes is presented in Atalah 1994 and 1996. The frictional resistance, R, is calculated as follows:

$$R = \mu \times V$$

WHERE

μ = coefficient of friction.

V = the force perpendicular to the contact surface calculated using the Terzaghi's Silo Theory

There are two techniques to reduce the pulling force through the pipe: oversize cut and lubrication of the outside surface of the pipe. Oversize cut at the face reduces the puling force if the soil is highly stable. In unstable soil, oversize cut must be made nevertheless to allow lubricating the outside surface of the pipe, but it should be minimized. Lubrication around the whole perimeter of the pipe and along the whole length of the drive significantly reduces the friction resistance.

Permitting Issues

Permits from all the affected parties should be secured before the start of the bursting phase. Some of these permits could be secured by the owner and its representatives, and rest should be secured by the contractor. The permits responsibilities should be outlined in the specifications and stated on the drawings. Permits to burst under the road and to modify the regular traffic flow according to the project traffic control plan should be secured from owner of the affected road if the pipe crosses underneath a road. If the pipe crosses underneath a runway, taxiway, drainage ditch, irrigation channel or canal, and railroad track, permits should be secured from the owners of these facilities. Communications with the affected residents should take place before bursting to inform them about road closures, night or weekend work, service disruptions, driveway blockings and so on.

Typical Bidding Form For a Pipe Bursting Project

In addition to providing the owner with the total price of the project to compare the different bids, the bid form should provide the contractor and the owner with a mechanism for fair pricing and payment system based on the progress during construction. The unit prices in the form can also be used to resolve disputes amicably. It is recommended that the bursting is measured in linear feet and segmented by classification or sections from manhole to manhole or from insertion to pulling shaft. Segmentation by run or bursting class provides the owner and the contractor with fairer pricing mechanism and reduces and resolves disputes. Table 3 shows an example of a typical bid form for a pipe-bursting project (Bennett and Ariaratnam 2005).

TABLE 3
Example of Pipe Bursting Bid Form (Bennett and Ariaratnam 2005)

Item No.	Description	Quantity	Unit	Unit price	Total Price
1	Mobilization/Demobilization		LS		
2	Pipe Cleaning and Pre CCTV Inspection		LF		
3	Pipe Bursting of Exist. 6" VCP with New 9.05" O.D., SDR 17 PE Pipe (4'-8' Deep) from MH 1 to MH 6		LF		
4	Pipe Bursting of Exist. 12" Class 250 Cast Iron Pipe with New 21.6" O.D. PE Pipe (8'-12' Deep)		LF		
5	Pipe Bursting of Exist. 24" RCP with New 30" VCP (12'-16' Deep) from MH 10 to MH 16		LF		
6	Pipe Bursting of Existing 4" Service Lateral with New 4.5" O.D., SDR 17 PE Pipe (4'-8' Deep)		LF		
7	4" Lateral Connection to 9.05 O.D. SDR 17 PE Pipe (8'-12' Deep)		EA		
8	6" Lateral Connection to Exist. MH		EA		
9	New PE Pipe Connection at MH		EA		
10	Furnish & Install 48" Dia. MH		EA		
11	Manhole Renewal		VF		
12	Cleaning, Testing and Post CCTV of New Sewer		LS		
13	Replacement of Unsuitable Trench Backfill Material		LS		
14	Bypass Pumping		LS		
15	Traffic Control		LS		
16	Pavement, Sidewalk and Curb Installation		LS		
17	Landscaping and Surface Restoration on Private Property		LS		

Please note that the lateral connections are accounted as a separate bid items and segmented by depth. Cleaning, testing, and post CCTV of the sewer line is a separate bid item. By pass pumping can be priced as a lump sum or measured by each run.

Selection of Pipe SDR

The PE pipes are available with iron pipe sized (IPS) or ductile iron pipe sized (DIPS) outside diameters. PE pipes are extruded with fixed outside diameter with variance in the inside diameter controlled by the Standard Dimensional Ratio (SDR) as shown in following equation:

$$SDR = \frac{\text{Pipe O.D.}}{\text{Wall Thickness of Pipe}}$$

The PE pipe should withstand the internal pressure requirements of the water or the force main line, overburden dead and live loads, and pulling forces during the bursting phase. The SDR of the PE pipe is a major factor in the ability of the pipe to withstand the installation forces and service pressures. Experience has shown that SDR 17 is sufficient for gravity sewer applications, and thinner wall pipes with SDR of 19 or 21 can be used in shorter and smaller diameter applications. Thinner wall pipes tend to stretch excessively during bursting. For pressure applications, if the maximum allowable design pressure is less than 100 psi, SDR of 17 is sufficient. If the maximum allowable design pressure is more than 100 psi, the allowable pressure governs the needed SDR. If the allowable pressure is 150 psi, PE pipe with SDR 11 meets needed pressure requirements.

In most trenchless applications, but not always, the pipe that withstands the pulling stresses during installation can withstand the vertical overburden and traffic pressures. The pipe stresses caused by construction are higher than those caused by vertical pressures. However, each application is different; it is possible that a specific application can require a different SDR. An engineering analysis is suggested for very deep or very shallow installations. Deep installations may be subject high overburden pressures, and shallow installations may be subject to high concentrated traffic loads that the pipe has to withstand.

Section 2 of Chapter 6 in this Handbook presents how to calculate the live loads on the pipe and stress distribution of live load with depth using the Timoshenko and Boussinesq equations to calculate the live load at the centerline of the pipe. The over burden pressure in trenchless applications can be calculated using the Terzaghi's Silo Theory.

Terzaghi's Silo Theory

Terzaghi established a calculation model to estimate the normal pressure acting on the pipe from vertical load and soil arch action. Terzaghi's theory presents the load on the pipe in a similar form to that of the horizontal earth pressure theory. The following equation gives the normal pressure on the pipe (P) as a function of soil density (w), depth of cover to center-line of the pipe (H), vertical live load at the pipe level (PL) and coefficient of soil load (k).

$$P = k\,(wxH + P_L)$$

The coefficient of soil load (k)

$$k = \frac{1 - e^{-2K \times \tan\delta \times H / B}}{2K \times \tan\delta \times H / B}$$

WHERE
K **= soil lateral pressure coefficient**
δ **= angle of wall friction between pipe and soil**
B **= the influence width above the pipe.**

According to the German Association for Water Pollution Control (ATVA 161), the values of these variables are: K = 0.5, δ = 0.5F (angle of internal friction of soil) and B= 1.73d (the outside diameter of the pipe). Figure 12 presents the value of k as a function of F and the ratio H/d for K= 0.5. On the other hand, in Japan, K= 1, δ= F and b= δ(0.5+tan(45-F/2) are used in the above equation. Although ground water does not significantly influence the soil friction, the ATVA 161 specifies, for safety reasons, that the full soil load should be applied in case of jacking below the ground water table. If the surrounding soil is swelling soil, additional swelling pressure must be considered (Stein 89).

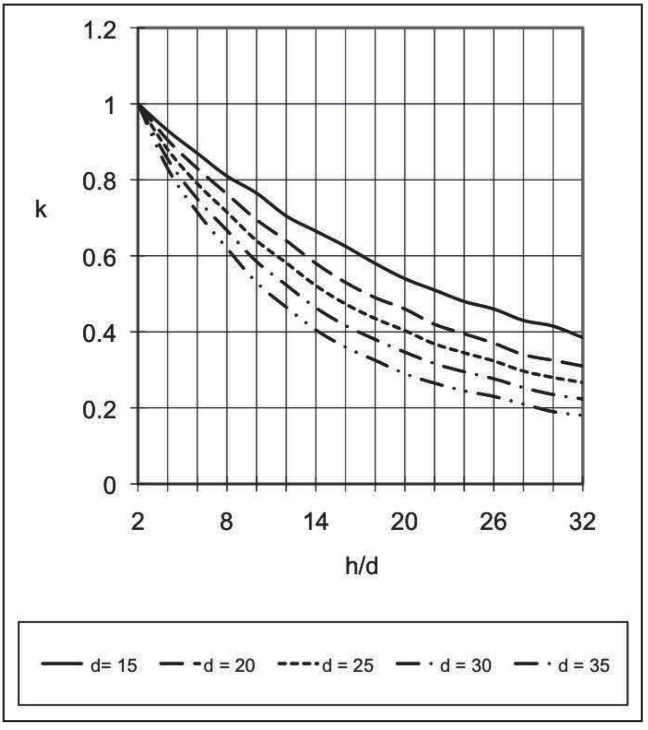


Figure 12 Reduction Factor k According to ATVA 161

Construction Considerations

Once the owner issues the notice to proceed, the contractor prepares the submittals for the project according to bid documents. Typically, the contractor takes the following steps:

- Pre-construction survey
- Cleaning or pigging of line, if needed
- Closed circuit TV inspection, if needed
- Excavations at services for temporary bypass
- Setting up temporary bypass or connections to customers
- Excavation of insertion and pulling shafts
- Fusion of PE
- Setting up the winch or hydraulic pulling unit and insertion of pulling cable or pulling rods inside the old pipe.
- Installation of hoses through the PE pipe to attach to bursting head (air supply hoses or hydraulic hoses for pneumatic or hydraulic systems respectively)

- Connection of bursting head to pulling cable or rod
- Pipe bursting and replacement with new pipe
- Removal of bursting head and hoses from the pipe
- Post installation inspection
- Pipeline chlorination if it is not pre-chlorinated (for water mains)
- Reconnection of services and reinstating manhole connections
- Site restoration

Butt fusion of PE replacement pipe is typically carried out prior to the bursting operation, so that all fused joints can be chlorinated (for water lines), checked, and tested. The pipe should not be dragged over the ground, and rollers, pipe cutouts, or slings should be used for both insertion and transportation of the pipe. The ends of water or gas pipes should be capped to prevent the entry of contaminants into the pipe.

Typical Pipe Bursting Operation Layout

The first step in planning the pipe bursting operation is the optimization of the locations of the insertion and pulling shafts by using the insertion shafts to insert the new pipe into two directions. This optimization reduces the amount of excavation, mobilization, and demobilization efforts. These shafts should be planned at manholes or lateral connections in sewer lines and at fire hydrants or gate valves in water applications. The length of the run between the insertion and pulling shafts should not generate friction forces that exceed the capabilities of the bursting system and the tensile strength of the pipe. The next step is ensuring that the area around every shaft is sufficient for safe operation of the needed pieces of equipment and material staging. The insertion shaft has a flat section and sloped section; the flat portion has to be long enough to allow aligning the centerlines of the bursting head with that of the old pipe. The slopped section has to be long enough to allow the PE pipe to bend without any negative impact on the pipe (i.e. accommodate the bending radius requirements of the pipe). PE pipes can be cold bent to a radius of 25 to 30 times the OD of the pipe depending on its SDR. Because of the pipe's ability to bend, the lay down area of the pipe prior to insertion does not necessarily have to be in line with the existing pipe. For example for an 18" PE pipe with an SDR of 17, the minimum length of the insertion shaft is a horizontal length of 12 times the diameter of the new pipe (18 feet) plus a sloped length of 2.5 times the depth of the shaft as shown in Figure 13 (Bennett and Ariaratnam 2005). The width of the pit depends on the pipe diameter and required working space around the pipe. The pulling pit must be large enough to allow for operation of the winch or pull-back device, along with removal of the bursting head.

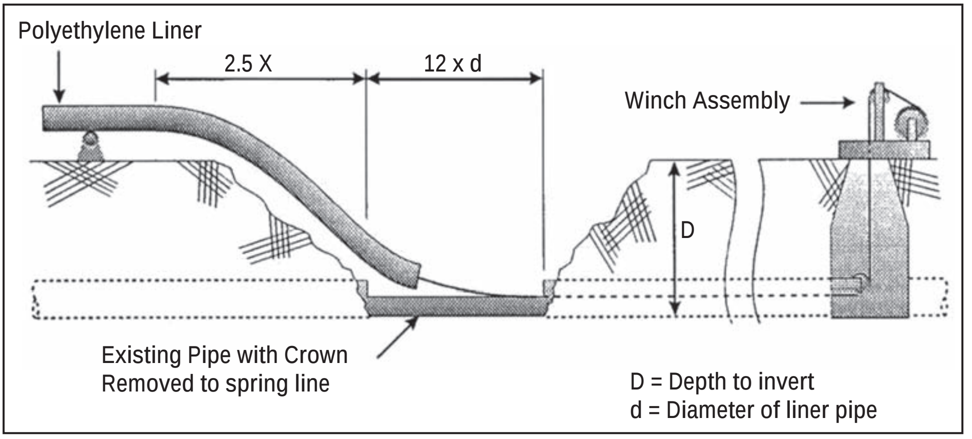


Figure 13 Insertion Shaft Dimensions for PE Pipe with SDR 17 (Bennett and Ariaratnam 2005)

Acceptable arrangements for traffic control, based on DOT and local government regulations, and for stretching the fused PE pipe with minimum inconvenience to nearby residents and businesses must be carefully considered. The flow bypass pumping and pipes layout should be also planned and considered. If dewatering needs arise, safe and proper flow discharge plans are required. The contractor submits the jobsite layout plan that reflects the intended method of construction and addresses the above mentioned considerations. The contractor does not start bursting before the engineer reviews and approves the jobsite layout plan, and the site inspector enforces the adherence to this plan unless there is a reason for the deviation approved by engineer or owner. If contaminated soil is excavated, the contractor should take the necessary measures to handle and dispose of this contaminated soil.

Shoring The Insertion and Pulling Shafts.

Proper shoring of the insertion and pulling shafts is essential for the safety of the workers and the safety of the surrounding environment. The trench shoring or bracing should be constructed to comply with OSHA standards. Some of the available means of shoring these shafts are: trench box, solder pile and lagging, steel sheet piles, corrugated pipes, etc. Also, if space is available, sloping the sides of the shaft to provide stability is an option. The judgment and the supervision of a competent person (as defined by OSHA) or a qualified geotechnical engineer is needed to ensure safe shoring.

In the pulling shafts, the winch will thrust against manhole wall or one side of the pulling shaft. This side has to be able to withstand the pressure coming from the pulling winch. Therefore, a thrust block or structure is needed to distribute the force over a larger area. In the static pull applications, the contractor should construct a thrust block against which the pulling system thrusts during pulling and bursting. The thrust block, shoring, and soil behind the shoring must be able to withstand the stresses from the pulling system. The passive earth pressure of the soil has to exceed the stresses generated by the pulling system with an acceptable factor of safety.

Matching System Components to Reduce Risk of Failure

One of the most critical activities before bursting is to ensure that the bursting system has sufficient power to burst the old run from the insertion shaft to the pulling shaft. The system must be able to overcome the friction between the soil and the outside surface of the new pipe and the soil with reasonable margin of safety to overcome unforeseen repair sleeves, clamps, etc.

The contractor should adhere to the sizing guidelines stated in the operations manual issued by the bursting system manufacturer to match the system with the needs of the job. The bursting system manufacturer should be consulted if there is any doubt regarding the adequacy of the system for that specific run in that particular conditions (soil, depth, type of pipe, etc.). Lubricating the outside surface of the pipe with polymer or bentonite (depending on the type of soil) can dramatically reduce the coefficient of friction between the pipe and the soil, and consequently, reduce the needed pulling force. In addition, the bursting system components should be appropriately matched to the need of the project; for example, the winch capacity is matched with the bursting head size and the conditions of the job.

Toning for Utilities

The contractor should do its due diligent to identify, locate, and verify the nearby underground utilities prior to digging the shafts and bursting. The contractor must contact the one state call center to have representatives of the nearby utilities come to the site and mark the existing utilities on the ground surface. Then the contractor has to verify the exact location and depth of these utilities via careful excavation. Manual excavation may be needed for the last few inches from the existing utilities to avoid damaging this utility. Vacuum excavation is an excellent tool to expose utilities with minimum surface excavation and minimum risk to the existing utility.

The underground utilities that are in moderate condition are unlikely to be damaged by vibrations at distances of greater than 2.5 feet from the bursting head in small (less than 12 inch in diameter) typical pneumatic pipe bursting operations (Atalah 1998). According to Atalah (2006), this safe distance for large diameter bursting (up to 24 inch) is about seven feet. Rogers (1995) reported that ground displacements are unlikely to cause problems at distances greater than 2-3 diameters from the pipe alignment. Utilities that are closer to the bursting head than these distances should be exposed prior to bursting so the vibration from the bursting operation would be isolated or reduced before it reaches the utility in question.

By Pass Pumping Considerations

One of the objectives of the bursting team (owner, engineer, contractor, etc.) is to minimize customers' service interruptions for water and gas applications and continuation of flow for sewer applications. The key for achieving this objective is the bypass pumping system. For water applications, the system should be able to deliver the needed flow volume with the specified pressure to the customers. For gravity applications, the system should be able to adequately pump the upstream flow and discharge it to the manhole downstream of the run being burst. The plan should ensure that the bypass system has adequate pumping capacity to handle the flow with emergency backup pumps to ensure no interruption to existing services. The bypass pipes and fittings should have sufficient strength to withstand the surge water pressures. Contractual arrangements between the owner and contractor should be made regarding third party damage due to the disconnection and reconnection of the water lines without fault of the contractor.

Dewatering Considerations

The pulling and the insertion shafts should be dry during installation to avoid disturbing the sub-grade in the shaft. Therefore, if rain is expected or the pipe invert is slightly below the GWT in clay soil, installation of a dewatering sump pump at one corner of the shaft is needed. Ditches crossing the shaft, sloped towards the sump, lined with filter fabric, and filled with gravel may be needed to direct the water towards the sump. If the pipe invert is significantly below the GWT in sandy or silty soils, more elaborate dewatering system is recommended such as well point system, deep wells, or larger sump and pump system. As the water level is drawn down, soil particles travel with the water towards the dewatering system undermining utilities and structures. As it is the case with every dewatering system, the contractor should take all necessary measure to prevent the migration of the soil particles from underneath nearby buildings and utilities. The discharge flow volume in this case is expected to be large; therefore, a suitable discharge in compliance with the EPA requirements is needed. If sump pump is used, preliminary treatment of flow to reduce the sediments may be needed before discharging into water streams.

Ground Movement Monitoring Program

The safety of nearby buildings and structures is paramount as it is the case in deep open cut installations. The safety of nearby structures can be compromised if the structures are subject more ground movements or vibration than what they can withstand. Referring to extremely challenging pipe bursting operations (class C—see Table 1), preconstruction survey and monitoring of the ground movement is advisable if there are nearby structures. A preconstruction survey of all nearby buildings and structures that documents all existing cracks, cosmetic problems, and structural deficiencies is recommended prior to any work on site. The elevations of carefully planned settlement points (on nearby buildings and on the ground surface) around the insertion and pulling shafts should be surveyed prior to bursting, during bursting, and after bursting. These preconstruction surveys and elevations monitoring can significantly reduce the risk of unmerited law suits to the contractor and the owner.

Pipe Connection to the Manhole

The thermal elasticity of the PE material causes changes in the pipe length; one inch change in length per 100 ft of pipe for each 10°F temperature change. Therefore, in extreme hot or cold weather when there is significant difference between the temperature of the deep soil and the ambient air temperature, it is recommended to allow the pipe to rest for 12 to 24 hours prior to tie-ins. Also when pipe has been pulled to a significant portion of its allowable tensile load, it may be prudent to let the pipe rest as well before connecting to other pipes, fittings, manholes, and lateral connection. This allows the pipe to rebound from any stretch that may have occurred during bursting. Chapter 9 presents in more detail the PE pipe joining procedures.

In most pipe bursting applications, the sewer line is old and deteriorated and so are the manholes along the line. It is economical on the long run in most cases to replace the old deteriorated manholes and use their location as pulling or insertion shafts. When existing manholes are replaced with new ones, connections to PE pipe can be made using flexible rubber manhole connectors called boots. A pipe clamp is used to tighten the boot around the PE pipe as shown in Figure 14.

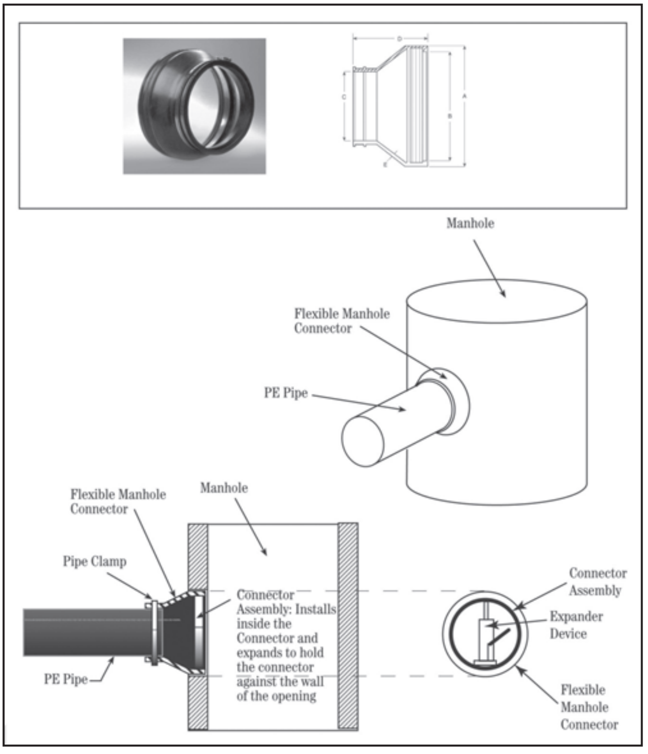


Figure 14 Connecting PE Pipe to New Concrete Manhole

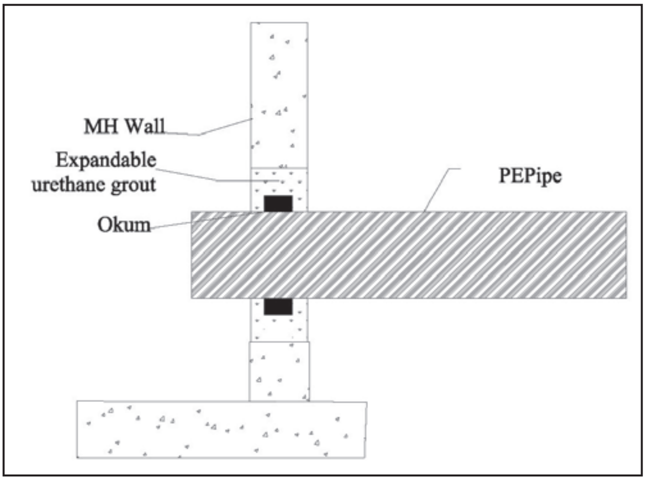


Figure 15 Connecting PE Pipe to Old Manhole

If the old manhole is in reasonable conditions and it is economical to use it after bursting, the manhole benching is removed and the pipe opening is enlarged to allow the passage of the bursting head. Expandable urethane grout and oakum can be used to create a seal between the exiting pipe opening and the PE pipe as shown in Figure 15. The compression allows pipe movement.

Frequently, when pipe bursting the inlets and outlets of the manhole are damaged, the resulting inlet or outlet is no longer round. A low shrink polymer cement grout is used to repair the damage. To get a good seal to the PE pipe, special PVC fitting with bell end and sand adhered to the outer surface (as shown in Figure 16) is used. The grout bonds to the manhole and the rough sandy surface of the PVC fitting giving a good seal. The gasket between the PVC fitting and the PE pipe allows the PE pipe to move if expansion or contraction occurs. The PVC fitting requires PE pipes with SDR of 21 or lower.

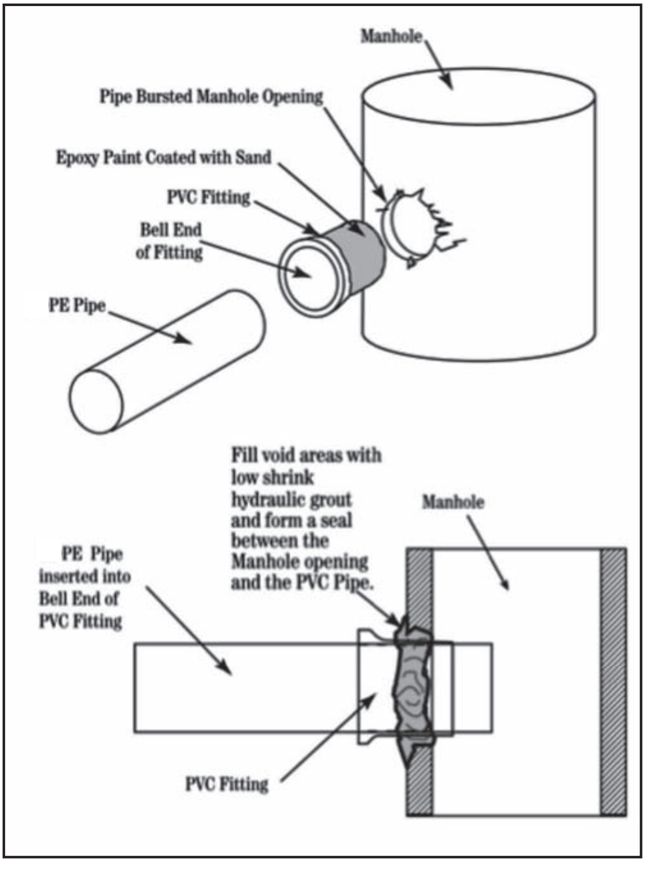


Figure 16 Connecting PE Pipe toOld Manhole with Damaged Inlets/Outlet

Pipe Connection to Other Pipes

PE pipes are joined to other PE fittings by heat fusion or mechanical fittings. They are joined to other material by means of compression fittings, flanges, or other qualified transition fittings (PPI).

Pipe Bursting Water Mains

The most common materials for existing water mains are cast iron, ductile iron, and PVC. All three can be replaced by pipe bursting but each requires a different piping burst approach. Cast iron pipe is a relatively brittle material, and therefore, basic pipe bursting system is sufficient. PVC pipes require multi-blade cutting accessories in front of the bursting head to facilitate cutting the pipe. Ductile iron pipe is not brittle; therefore, pipe splitting is the most suitable bursting system.

Valves are connected to PE pipe using mechanical joint (MJ) adapters, which is butt fused to the PE pipe. A gland ring is then used to make a restrained connection to ductile iron valves. Figure 17 shows connections to PVC or ductile iron pipes can be made using a female MJ connector, which is butt fused to the PE pipe. This connection provides a restrained connection.

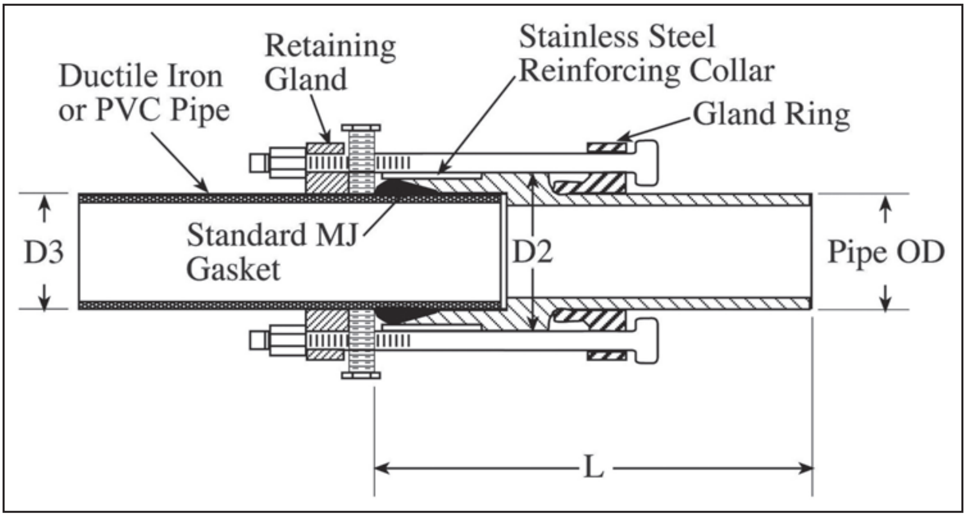


Figure 17 Connection to Existing PVC or DI Pipes Using Female MJ Adapter

Service connections can be attached to PE pipe using mechanical saddle connections or electrofusion saddles. Figure 18 shows an electrofusion saddle with a cutter attached; it is easy to hot tap PE pipe lines.

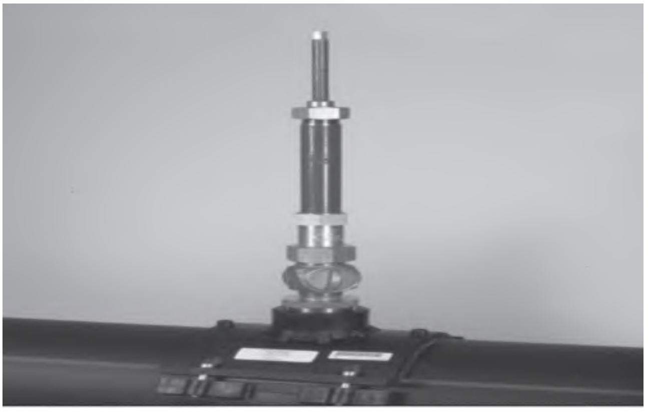


Figure 18 Electrofusion Saddle with a Cutter Attached

During installation, a temporary above ground PE pass is installed to continue to supply water to the home owners while the main line is under construction. Figure 19 shows an example of above ground PE bypass pipe.

The PE pipe can be pre-chlorinated prior to bursting to reduce the overall installation time and inconvenience to the home/business owners.

Figure 19 Example of Above Ground PE Bypass Pipe

Service Connections

The lateral connections and material plan stated in the submittal list should explain the proposed material and connection procedures. Video inspection of the original sewer line normally provides the location of service connections. In replacing water and gas lines, metal detectors can be used. Standard practice is to locate and expose services prior to pipe bursting. Service connections can be made with Inserta Tee®, specially designed fusion fittings, or strap-on saddles.

Figure 20 Inserta Tee® Fittings for Sewer Lateral Connections

For sewer applications, after service connections are excavated, a "window" is cut in the PE pipe wall, and then one of the above fittings connects the new PE pipe to the lateral connection. Inserta Tee® connection is a three piece service connection consisting of a PVC hub, rubber sleeve, and stainless steel band as shown in Figure 20. Inserta Tee® is compression fit into the cored wall of a mainline and requires no special tooling. Inserta Tees® are designed to connect 4 inch through 15 inch services to all known solid wall, profile, closed profile, and corrugated pipe. The PE lateral connection options are fusing a lateral PE pipe to the main line and Electrofusion sewer saddle. Fusing a lateral PE to the main PE line requires curved iron that allows heating the ends of both pipes. This connection require highly skilled fusion worker because it is usually made in small muddy space. Electrofusion saddle is mounted on the opening for fusion with the main line as shown in Figure 21. Careful considerations are needed to ensure that all exposed surfaces are cleaned and maintained in an acceptable condition for the fusion operation. Strap-on saddles use a PE or PVC saddle that are lined with a rubber layer; the saddle is trapped around the main line using a stainless steel strap as shown in Figure 21. After testing and inspecting the line and the connection, the excavation is backfilled and line returns to service. More service connections details for gravity and pressure applications are presented in Chapter 9 in this Handbook.

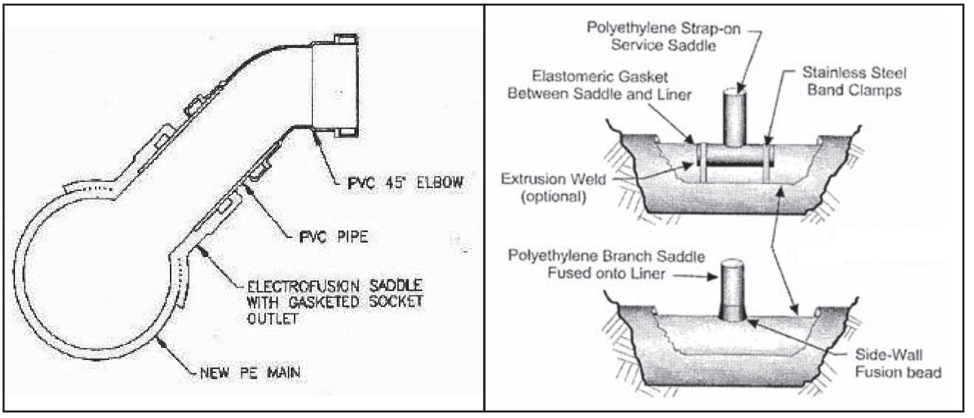


Figure 21 Pipe Fusion and Strap On Saddle Lateral Connections

Groves on the Outside Surface of the Pipe

One common misconception about bursting is that the existing pipe fragments from the old pipe can damage PE pipe during bursting. British Gas conducted study on bursting cast iron pipes and concluded that there was no damage to the PE. The pipe bursting research conducted at Louisiana Tech University and Bowling Green State University indicated the groves are very shallow and narrow when bursting clay, asbestos, and concrete pipes. The widest grove was 0.07 inch and depth of the deepest grove was 0.03 inch with no damage to the PE. CI, clay, concrete, and asbestos pipes generally break off without sharp shards that do not puncture PE (Atalah 1998 and 2004). The exception to this rule occurs when trying to significantly upsize ductile iron (DI) pipe. It is recommended to limit PE pipe to size-on-size bursting or a single upsize when bursting DI pipes. If larger upsize of DI pipe is required, PE pipes with harder outside shell similar to ones shown in Figure 22 can be used. If the PE will be dragged for a long distance over rough pavement, the contractor can reduce the risk of scratching the pipe by placing it on cut-outs of old PE or PVC to keep the pipe higher than the pavement. Sometimes the contractor needs to press on the PE with bucket of the excavator to ensure that the PE pipe is aligned with the old pipe at the entry point in the insertion shaft because the shaft is not long enough. Welding wheels similar to the one shown in Figure 23 reduces the risk of groves or scratches on the PE pipe. When the head end of the pipe reaches the pulling shaft, the pipe should be inspected for surface damage. Surface scratches or defects in excess of 10% of the wall thickness should be rejected.

As-Built Drawing

As built drawings are usually required for any underground utility construction as well as pipe bursting projects. The bursting contractor should mark the new line, manholes, ancillary structure information on a copy of the plans marked as and dedicated to the as-built. On these plans, the contractor should document any changes to the original layout of the underground utilities and structures that took place during the construction phase. For example, rerouting any utility due to the excavation of the shafts, reconfiguration of other utilities needed for bypass pumping, etc. should be marked on the as-built drawings. These changes shown on the as-built drawings should be verified and used to update the as-built electronic files for the locality.

Figure 22 Protecting the PE Pipe from Shards

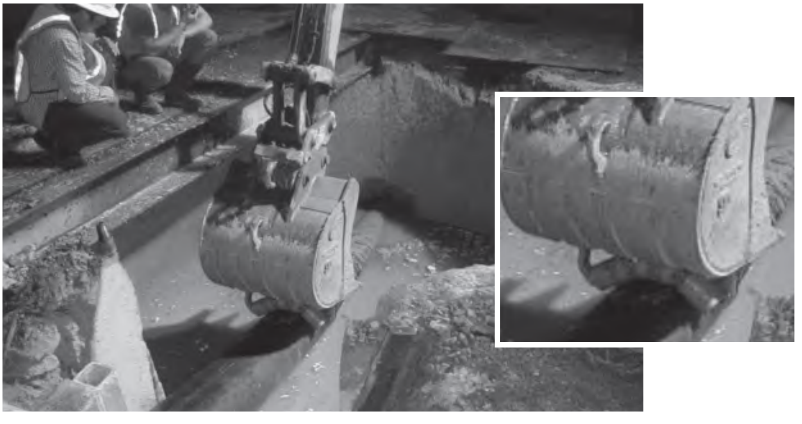


Figure 23 Protecting the PE Pipe from Groves Using Welded Wheels on the Bucket

Contingency Plan

An important submittal is the contractor's contingency plan. Most contractors have contingency plans that include planned corrective actions if certain events take place. Pipe bursting projects require adding a few specific additions to this standard contingency plan. Some of these specific events that are unique to pipe bursting and need to be addressed include:

- There is more than allowable ground movement or vibration
- The bursting progress is slow or the bursting head is stuck
- Problem with the bypass system and with diverting and reconnecting the services to the customers
- Damage to existing waterline, gas line, sewer line, power cable
- Dewatering problem in the insertion or pulling shaft or at lateral connection pits.

Safety Considerations

The standard safety procedures, adhered to in typical open cut construction, should be followed in bursting projects. Additionally, the workers should understand the components of the bursting system and how they work with special attention to the moving parts in the system. The involved workers should be trained on and equipped with the needed tools for confined space entry because the workers work in live sewers during flow bypass and diversion, which takes place mostly inside a manhole. The winch should thrusts against a thrust block that (along with the soil behind it) should withstand the forces of the winch. The stability of the soil behind the thrust block should not be compromised. During the flow bypass, the upstream pipe will be plugged; these plugs should be braced and preferably remotely inflated and deflated. Prior to bursting, the contractor has to ensure that there is no unforeseen gas line or power line close to bursting head.

Cost Estimating

Estimating pipe bursting projects for bidding purposes needs to be detailed, methodical, and systematic as it is the case for open cut installations. For each run, the contractor has to estimate the labor, material, and equipment needed for excavation and shoring of shafts, shaft bottom stabilization (concrete or gravel), bursting system set up, pipe fusion, lateral connection excavation, bypass pumping, bursting, service reconnection, shaft backfill, surface restoration, and potential dewatering.

As shown in Figure 7, the cost per foot of pipe bursting installations are less than that of open cut in unfavorable situations. The figure also shows that that cost is less than that of open cut in favorable conditions if the depth of cut is more than 10 feet.

Bennett and Ariaratnam (2005) presented Table 4 which shows the unit cost from several pipe bursting projects with different sizes and upsize percentages in North America.

TABLE 4
Example Unit Cost from Various Pipe Bursting Projects

Project #	Existing to New Pipe Information	Length	Overall Cost/LF
1	6” VCP to 8” PE	8,500 LF	$80
2	8” conc. to 12” PE	350 LF	$200
3	8” conc. to 14” PE	700LF	$215
4	10” PVC to 16” PE	520 LF	$230
5	12” AC Pipe to 14” PE	2640 LF	$160
6	24” RCP to 24” VCP	521 LF	$380

In 1999, the Trenchless Technology Center surveyed several municipalities and contractors for bidding prices per linear foot. The bid prices ranges for size to size replacement using pipe bursting for different pipe diameters are shown in Figure 24. The bid prices ranges for upsizing less than 20% and upsizing larger than 20% using pipe bursting replacement of different diameters pipes are shown in Figure 25 (Simicevic and Sterling, 2001).

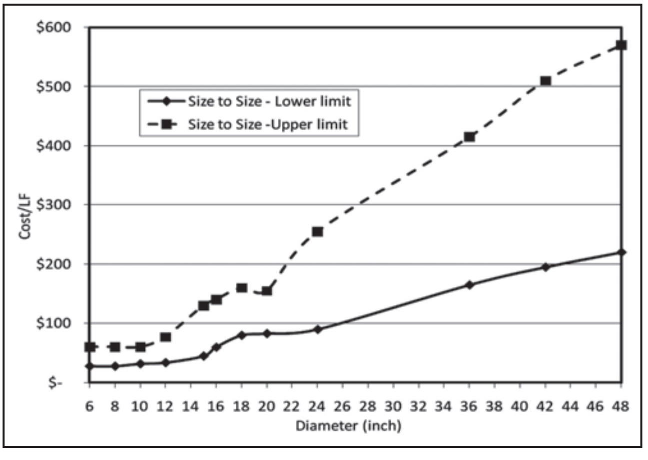


Figure 24 The Bid Prices Ranges for Size to Size Replacement for Different Pipe Diameters

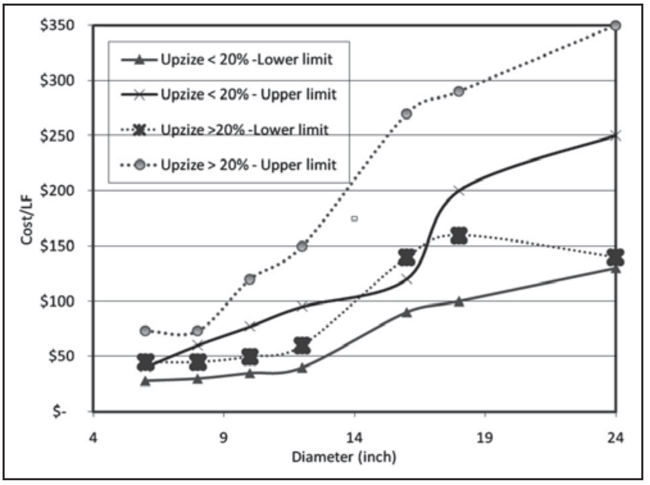


Figure 25 The Bid Price Ranges for Upsizing Less than 20% and Upsizing Larger than 20% Using Pipe Bursting Replacement of Different Diameter Pipes

Potential Problems and their Possible Solutions

The best option for dealing with the pipe bursting problems is avoiding them or reducing the probability of their occurrence by properly following the design and construction precautions mentioned thus far in this chapter. However, if some of these precautions are not followed or unforeseen conditions occur, this section attempts to provide actions that help avoid these troubles or correct them when they occur. Some of the potential problems associated with pipe bursting include sag correction, soil displacement, protecting utilities, bursting system selection problems, unforeseen obstacles, and site restrictions.

If the sewer line has excessive sags in it, these sags have to be repaired prior to bursting using any of the earlier – discussed techniques. However, if they were discovered after bursting, the contractor can fix the sag by digging this spot and improving the soil under the pipe. Replacement of a section of pipe may be needed at this excavation. If the excavation at this spot is not feasible, grouting and stabilizing the soil underneath the pipe can be a solution.

If excessive ground movement is anticipated very close to an existing structure, a ground movements and vibrations monitoring plan should be developed. If dangerous movements are observed, slowing the rate of bursting is mandated. If the movement is still high, bursting should be halted until analysis of the causes and corrective options is studied (including the option of abandoning the pipe bursting method). If there is a gas line, water line, or sewer line that is too close to the bursting head and is at risk of damage, exposing the line reduces this risk significantly. The excavation to expose this utility should be done using means that do not damage the line such as vacuum or manual excavation. If the pipe is shallow and there is a high risk of damaging the surface pavement, saw cutting the pavement prior to bursting prevents the spreading of the damage to the rest of the pavement. Later on, the pavement over the trench can be replaced.

If the bursting is significantly slower than expected, the contractor should investigate the reason and study the available corrective actions. Here some potential reasons for slow bursting:

The bursting system does not have sufficient power relative to the bursting applications (upsize percentage, large diameter, length, etc.). If this problem takes place shortly after the start of the run, the solution is replacing the system with a more powerful one. If it takes place close to the pulling shaft, continue until the bursting head reach the pulling shaft and replace the system before the next run if the reason of the slow down is not a repair ductile clamp or a fitting. Also in this case, consider shorting the length of the runs. If this problem takes place in the middle of the run at location where excavation is feasible, dig shaft on top of the bursting head and replace the system. The new shaft can be an insertion shaft for the remainder of the run.

Certain components or accessories of the system (for example, the winch, air compressor, hydraulic components, cutting accessories in front of bursting head, etc) are under sized or unmatched. Adding accessories in front of the bursting head to cut PVC fitting, ductile clamps or fittings, etc. reduces the potential of stopping or slowing the bursting. Upsizing these components (within the allowable range of that system) is the recommended solution. Matching the system and its components and accessories with the needs of the bursting jobs may solve the problem.

There are obstacles such as ductile repair fittings, concrete encasement, or change in the existing pipe material along the line. If the obstacle is close to the pulling shaft, continue bursting slowly until the head reaches the pulling shaft. If the obstacle is far from the pulling shaft, rescue shaft to remove the obstacle, change the bursting head, or add/change cutting accessories.

The soil around the pipe is flowing or running and is causing excessive friction. Lubrication of outside surface of the pipe with suitable lubricant is an effective way to reduce required pulling force on the PE pipe by reducing the friction between the pipe and the soil. The key to apply this solution is setting a lubrication manifold and lubrication line before bursting start to pump the lubrication during bursting.

Breaking the old pipe in running soil below the GWT fills the pipe with dirt so that the operation turns from bursting to piercing. The first step is to make sure that bursting head did not damage any nearby water line then dewater the site.

It is critical that the contractor ensure that the replacement pipe meets the specification before, during, and after bursting. Adhering to the quality control and quality assurance plans during the manufacturing and shipping to the site along with proper unloading of the pipe reduces risk of pipe failure. It is recommended that the pipe fusion is performed by certified and well trained workers under appropriate supervision to reduce the risk of pipe failure later when repair is difficult and costly. For pressure application, the PE pipe should be inspected and pressure tested before bursting.

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Credit

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Abbreviations

ABS	Acrylonitrile Butadiene Styrene
AGA	American Gas Association
ANSI	American National Standards Institute, (formerly USASI, formerly ASA)
ASA	American Standards Association (see ANSI)
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials; now just ASTM International.
AWWA	American Water Works Association
CPPA	Corrugated Plastic Pipe Association
CTS	Copper Tubing Size
DIPS	Ductile Iron Pipe Size
DOT	Department of Transportation, a bureau of the Federal Government
DR	Dimension Ratio
ESC	Environmental Stress Cracking
ESCR	Environmental Stress Cracking Resistance
HDB	Hydrostatic Design Basis
HDBC	Hydrostatic Design Basis Category
HDPE	High Density Polyethylene
HDS	Hydrostatic Design Stress
IPS	Iron Pipe Size
ISO	International Standards Association
LPG	Liquefied Petroleum Gas
LTHS	Long-Term Hydrostatic Strength
MDPE	Medium Density Polyethylene
MRS	Minimum Required Strength
MSS	Manufacturers Standardization Society of the Valve and Fitting Industry
NFPA	National Fire Protection Association
NPGA	National Propane Gas Association
NSF	National Sanitation Foundation
NTSB	National Transportation Safety Board
OPS	Office of Pipeline Safety, a branch of the U.S. Department of Transportation
PA	Polyamide (nylon)
PB	Polybutylene
PE	Polyethylene
PEX	Crosslinked Polyethylene
PPI	Plastics Pipe Institute
RCP	Rapid Crack Propagation
RTRP	Reinforced Thermosetting Resin Pipe
SCG	Slow Crack Growth
SDR	Standard Dimension Ratio
SPE	Society of Plastic Engineers
SPI	Society of the Plastics Industry, Inc.
TSI	Transportation Safety Institute

Glossary

Abrasion - Wear or scour by hydraulic traffic.

Abrasion and Scratch Resistance - Ability of a material to resist the infliction of damage in the form of scratches, grooves and other minor imperfections.

Abutment - A wall supporting the end of a bridge or span, and sustaining the pressure of the abutting earth.

Acceptance - By the owner of the work as being fully complete in accordance with the contract documents.

Action - A positively charged ion which migrates through the electrolyte toward the cathode under the influence of a potential gradient.

Addenda - Written or graphic instruments issued prior to the execution of the agreement, which modify or interpret the contract documents, drawings and specifications, by addition, deletions, clarifications or corrections.

Additive - A substance added in a small amount for a special purpose such as to reduce friction, corrosion, etc.

Aerial Sewer - An unburied sewer (generally sanitary type) supported on pedestals or bents to provide a suitable grade line.

Aerobic - Presence of unreacted or free oxygen (0_2).

Aggressive - A property of water which favors the corrosion of its conveying structure.

Aggressive Index (AI) - Corrosion index established by the American Water Work Association (AWWA) Standard C-400; established as a criterion for determining the corrosive tendency of the water relative to asbestos-cement pipe; calculated from the pH, calcium hardness (H), and total alkalinity (A) by the formula Al = pH + log.$^{(A \times H)}$

Agreement - The written agreement between the owner and the contractor covering the work to be performed; the contract documents are attached to and made a part of the agreements. Also designated as the contract.

Alkalinity - The capacity of a water to neutralize acids; a measure of the buffer capacity of a water. The major portion of alkalinity in natural waters is caused by (1) hydroxide, (2) carbonates, and (3) bicarbonates.

Anaerobic - An absence of unreacted or free oxygen [oxygen as in H_2O or Na_2SO_4 (reacted) is not "free"].

Angle of Repose - The angle which the sloping face of a bank of loose earth, gravel, or other material, makes with the horizontal.

Anode - (opposite of cathode) The electrode at which oxidation or corrosion occurs.

Apparent Tensile Strength - A value of tensile strength used for comparative purpose that is determined by tensile testing pipe rings in accordance with ASTM D 2290. This differs from true tensile strength of the material due to a bending moment induced by the change in contour of the ring as it is tested. Apparent tensile strength may be at yield, rupture or both.

Apparent Tensile Yield - The apparent tensile strength calculated for the yield condition.

Application for Payments - The form furnished by the engineer which is to be used by the contractor in requesting progress payments, and an affidavit of the contractor that progress payments theretofore received from the owner on account of the work been applied by the contractor to discharge in full all of the contractor's obligations stated in prior applications for payment.

Approval - Accept as satisfactory.

Aqueous - Pertaining to water; an aqueous solution is a water solution.

Areaway - A paved surface, serving as an entry area basement or subsurface portion of a building, which is provided with some form of drainage that may be connected to a sewer line.

ASTM - American Society of Testing and Materials and technical organization formed for the development of standards on characteristics and performance of materials, products, systems and services, and the promotion of related knowledge.

Available Water - Water necessary for the performance of work, which may be taken from the fire hydrant nearest the worksite, given conditions of traffic and terrain which are compatible with the use of the hydrant for performance of work.

Backfill Density - Percent compaction for pipe backfill (required or expected).

Base (course) - A layer of specified or selected material of planned thickness, constructed on the subgrade (natural foundation) or subbase for the purpose of distributing load, providing drainage or upon which a wearing surface or a drainage structure is placed.

Base Resin - Plastic materials prior to compounding with other additives or pigments.

Batter - The slope or inclination from a vertical plane, as the face or back of a wall.

Bedding - The earth or other material on which a pipe or conduit is supported.

Berm - The space between the toe of a slope and excavation made for Bedding – The earth or other material on which a pipe or conduit is supported.

Bid - The offer or process of the bidder submitted on the prescribed form setting forth the prices for the work to be performed.

Bidder - Any person, firm, or corporation submitting a bid for the work.

Biological Corrosion - Corrosion that results from a reaction between the Pipe material and organisms such as bacterial, algae, and fungi.

Bituminous (coating) - Of or containing bitumen; as asphalt or tar.

Bonds - Bid, performance and payment bonds and other instruments of security furnished by the contractor and his surety in accordance with the contract documents and in accordance with the law of the place of the project.

Boring - An earth-drilling process used for installing conduits or pipelines, or obtaining soil samples for evaluation and testing.

Bridge - A structure for carrying traffic over a stream or gully, or other traffic ways including the pavement directly on the floor of the structures. A structure measuring 10 ft. or more in clear span.

Bridge Plank (deck or flooring) - A corrugated steel sub-floor on a bridge to support a wearing surface.

Brittle Failure - A pipe failure mode that exhibits no visible (to the naked eye) material deformation (stretching, elongation, or necking down) in the area of the break.

Brittleness Temperature - Temperature at which 50% of the tested specimens will fail when subjected to an impact blow.

Building Sewer - The conduit which connects building wastewater sources, to the public or street sewer, including lines serving homes, public buildings, commercial establishments, and industrial structures. The building sewer is referred to in two sections: (1) the section between the building line and the property line, frequently specified and supervised by plumbing or housing officials; and (2) the section between the property line and the street sewer, including the connection thereto frequently specified and supervised by sewer, public works, or engineering officials (Referred to also as “house sewer,” “building connection,)’ “service connection,” or “lateral connection”).

Buoyancy - The power of supporting a floating body, including the tendency to float an empty pipe (by exterior hydraulic pressure).

Burst Strength - The internal pressure required to cause a pipe or fitting to fail within a specified time period.

Butt Fusion - A method of joining polyethylene pipe where two pipe ends are heated and rapidly brought together under pressure to form a homogeneous bond.

Bypass - An arrangement of pipes and valves whereby the flow may be passed around a hydraulic structure or appurtenance. Also, a temporary setup to route flow around a part of a sewer system.

Bypass Pumping - The transportation of sewage which flows around a specific sewer pipe/line section or sections via any conduit for the purpose of controlling sewage flows in the specified section or sections without flowing or discharging onto public or private property.

Caisson - A watertight box or cylinder used in excavating for foundations or tunnel pits to hold out water so concreting or other construction can be carried on.

Camber - Rise or crown of the center of a bridge, or Bowline through a culvert, above a straight line through its ends.

Cantilever - The part of a structure that extends beyond its support.

Carbon Black - A black pigment produced by the incomplete burning of natural gas or oil, that possesses excellent ultraviolet protective properties.

Catastrophic Rainfall Event - Rainfall event of return frequency far in excess of any sewerage design performance criteria typically, say, a 20 to 200 year storm.

Cathode - The electrode of an electrolytic cell at which reduction is the principal reaction (Electrons flow toward the cathode in the external circuit). Typical cathodic processes are cations taking up electron and being discharged, oxygen being reduced, and the reduction of an element or group of elements from a higher to a lower valence state.

Cathodic Corrosion - An unusual condition (especially with Al, Zn, Pb) in which corrosion is accelerated at the cathode because the cathodic reaction creates an alkaline condition which is corrosive to certain metals.

Cathodic Protection - Preventing corrosion of a pipeline by using special cathodes (and anodes) to circumvent corrosive damage by electric current. Also a function of zinc coatings on iron and steel drainage products - galvanic action.

Cavitation - Formulation and sudden collapse of vapor bubbles in a liquid; usually resulting from local low pressures - as on the trailing edge of a propeller; this develops momentary high local pressure which can mechanically destroy a portion of a surface on which the bubbles collapses.

CCTV - Closed circuit television.

Cell - Electrochemical system consisting of an anode and a cathode immersed in an electrolyte. The anode and cathode may be separate metals or dissimilar areas on the same metal. The call includes the external circuit which permits the flow of electrons from the anode toward the cathode (See Electrochemical Cell).

Cell Classification - Method of identifying thermoplastic materials, such as polyethylene, as specified by ASTM D 3350, where the Cell Classification is based on these six properties for PE are: Density, Melt Index, Flexural Modulus, Tensile Strength at Yield, Environmental Stress Crack Resistance, and Hydrostatic Design Basis.

Cellar Drain - A pipe or series of pipe which collect wastewater which leaks, seeps, or flow into subgrade parts of structures and discharge them into a building sewers or by other means dispose of such wastewater's into sanitary, combined or storm sewers (Referred to also as "basement drain").

Change Order - A written order to the contractor authorizing an addition, deletion or revision in the work, within the general scope of work of the agreement, authorizing an adjustment in the agreement price or agreement time.

Chemical Resistance - Ability to render service in the transport of a specific chemical for a useful period of time at a specific concentration and temperature.

Chimney - The cylindrical, variable height portion of the manhole structure having a diameter as required for the manhole frame. The chimney extends from the top of the corbel or cone to the base of the manhole frame and is used for adjusting the finished grade of the manhole frame.

Circumferential Coefficient of Expansion and Contraction - The fractional change in circumference of a material for a unit change in temperature. Expressed as inches of expansion or contraction per inch of original circumference per °F.

Coefficient of Thermal Expansion and Contraction - The fractional change in length of a material for a unit change in temperature.

Cofferdam - A barrier built in the water so as to form an enclosure from which the water is pumped to permit free access to the area within.

Cohesive Soil - A soil that when unconfined has considerable strength when air-dried, and that has significant cohesion when submerged.

Cold Bend - To force the pipe into a curvature without damage, using no special tools, equipment or elevated temperatures.

Collector Sewer - A sewer located in the public way collects the wastewater's discharged through building sewers and conducts such flows into larger interceptor sewers and treatment works. (Referred to also as "street sewer.")

Combined Sewer - A sewer intended to serve as both a sanitary sewer and a storm sewer, or as both an industrial sewer and a storm sewer.

Compaction - The densification of a soil by means of mechanical manipulation.

Composite Pipe - Pipe consisting of two or more different materials arranged with specific functional purpose to serve as pipe.

Compound - A mixture of a polymer with other ingredients such as fillers, stabilizers, catalysts, processing aids, lubricants, modifiers, pigments, or curing agents.

Compounding - The process where additives and carbon black are homogeneously mixed with the base polyethylene resin in a separate and additional process to produce a uniform compound material for polyethylene pipe extrusion.

Compression Gasket - A device which can be made of several materials in a variety of cross sections and which serves to secure a tight seal between two pipe sections (e.g., "0" rings).

Conductivity - A measure of the ability of a solution to carry an electrical current. Conductivity varies both with the number and type of ions the solution carries.

Conduit - A pipe or other opening, buried or aboveground, for conveying hydraulic traffic, pipelines, cables or other utilities.

Consolidation - The gradual reduction in the volume of a soil mass resulting from an increase in compaction.

Contamination - The presence of a substance not intentionally incorporated in a product.

Contract Documents - The Agreement, Addenda, Instructions to Bidders, Contractor's Bid, the Bonds, the Notice of Award, the General Conditions, the Supplementary Conditions, Special Conditions, Technical Conditions, the Specifications, Drawings, Drawing Modifications, and Notice to Proceed, all make up the Contract Documents.

Contract Price - The total moneys payable to the Contractor under the Contract Documents.

Contract Time - The number of calendar days stated in the Agreement for the completion of the work.

Contracting Officer - The owner (guarantee) - The Individual who is authorized to sign the contract documents on behalf of the owner's governing body.

Contractor - The person, firm or corporation with whom the owner has executed the agreement.

Corbel or Cone - That portion of a manhole structure, which slopes upward, and inward from the barrel of the manhole to the required chimney or frame diameter. "Corbel" refers to section built of brick or block, while "cone" refers to a precast section.

Core Area - That part of a sewer network containing the critical sewers, and other sewers where hydraulic problems are likely to be most severe and require detailed definition within a flow simulation model.

Corrosion - The destruction of a material or its properties because of a reaction with its (environment) surroundings.

Corrosion Fatigue - Fatigue type cracking of metal caused by repeated or fluctuating stresses in a corrosive environment characterized by shorter life than would be encountered as a result of either the repeated or fluctuating stress alone or the corrosive environment alone.

Corrosion Index - Measurement of the corrosivity of a water (e.g. Langelier Index, Ryznar Index, Aggressive Index, etc.)

Corrosion Rate - The speed (usually an average) with which corrosion progresses (it may be linear for a while); often expressed as though it was linear, in units of mdd (milligrams per square decimeter per day) for weight change, or mpy (milligrams per year) for thickness changes.

Corrosion Resistance - Ability of a material to withstand corrosion in a given corrosion system.

Corrosion-erosion - Corrosion which is increased because of the abrasive action of a moving stream; the presence of suspended particles greatly accelerates abrasive action.

Cracks - Crack lines visible along the length and/or circumference.

Crazing - Apparent fine cracks at or under the surface of a plastic.

Creep - The dimensional change, with time, of a material under continuously applied stress after the initial elastic deformation. The time dependent part of strain due to a constant stress.

Crew - The number of persons required for the performance of work at a site as determined by the contractor in response to task difficulty and safety considerations at the time or location of the work.

Critical Pressure - The minimum internal compressed gas pressure at which rapid crack propagation (RCP) can be sustained along a section of plastic pipe.

Critical Sewers - Sewers with the most significant consequences in the event of structural failure.

Crosslink - The formation of a three dimensional polymer by means of interchain reactions resulting in changes in physical properties.

CTS – Copper tube sizing convention for PE tubing.

Density, Base Resin – The mass per unit volume at a standardized temperature of 23°C of a base resin prior to compounding with additives and modifiers.

Density, Pipe Compound - The mass per unit volume of a compound at standardized temperature of 23°C. Note this is pipe compound density, not base resin density.

Design Coefficient (DC) - A number greater than 1.00 that when divided into the Minimum Require Strength (MRS) establishes the maximum design stress of the product for the application. The DC takes into consideration the variables in resin and processing involved in the production of plastic pipe. The user needs to also consider other variables such as: shipping, handling, installation and service of properly installed thermoplastic pressure piping systems.

Design Factor (DF) - A number less than 1.00 that takes into consideration the variables in resin and processing as well as the variables involved in the shipping, handling, installation and service of properly installed thermoplastic pressure piping systems.

Design Stress – (ISO12162) Allowable stress (MPa) for a given application. It is derived by dividing the MRS by the design coefficient C then rounding to the next lower value in the R-20 series (ISO 3). (For HDB rated materials see Hydrostatic Design Stress).

Dimension Ratio (DR) - The ratio of pipe diameter to wall thickness. It is calculated by dividing the specified outside diameter of the pipe, in inches, by the minimum specified wall thickness, in inches. Specifying PE pipes with the same DR regardless of O.D. assures all pipes will have the same design pressure assuming the PEs have the same HDB rating. The standard dimension ratio (SDR) is a common numbering system that is derived from the ANSI preferred number series R-10.

Dimple - A term used in tight fitting pipeline reconstruction, where the new plastic pipe forms an external departure or a point of expansion slightly beyond the underlying pipe wall where unsupported at side connections. The dimples are used for location and reinstatement of lateral sewer service.

Ductile Failure - A failure mode that exhibits material deformation (stretching, elongation, or necking down) in the area of the break.

Easement - A liberty, privilege, or advantage without profit which the owner of one parcel of land may have in the hand of another. In this agreement, all land, other than public streets, in which the owner has sewer system lines or installations and right of access to such lines or installations.

Easement Access - Areas within an easement to which access is required for performance of work.

Effluent - Outflow or discharge from a sewer us sewage treatment equipment.

EHMWHD - Extra High Molecular Weight High Density as originally noted in ASTM D1248, Grade P34 materials were specifically EHMW high-density polyethylene materials.

Elastic Modulus - A measure of the stress buildup associated with a given strain.

Electrofusion - A heat fusion joining process where the heat source is an integral part of the fitting.

Elevated Temperature Testing - Tests on plastic pipe above 23°C (73°F) for HDB rated materials and 20°C (68°F) for MRS rated materials.

Elongation – (strain) The increase in length of a material stressed in tension.

Embankment (or fill) - A bank of earth, rock or other material constructed above the natural ground surface.

Embrittlement - Loss of ductility of a material resulting from a chemical or physical change.

Emergency Repair - A repair that must be made while the main is pressurized, or flowing.

End Section - Flared attachment on inlet and outlet of a culvert to prevent erosion of the roadbed improve hydraulic efficiency, and improve appearance.

Endurance Limit - The maximum stress that a material can withstand for an infinitely large number of fatigue cycles (See Fatigue Strength).

Energy Gradient - Slope of a line joining the elevations of the energy head of a stream.

Energy Head - The elevation of the hydraulic gradient at any section, plus the velocity head.

Engineer - The person, firm or corporation named as such in the contract documents; the "Engineer of Record".

Environment - The surroundings or conditions (physical, chemical, mechanical) in which a material exists.

Environmental Stress Crack Resistance (ESCR) - The resistance to crack or craze under the influence of specific chemicals and stress and/or mechanical stress.

Environmental Stress Cracking – Under certain conditions of temperature and stress in the presence of certain chemicals, polyethylene may begin to crack sooner than it would at the same temperature and stress in the absence of those chemicals. The susceptibility to crack or craze under the influence of specific chemicals, stress, and/or mechanical stress.

Epoxy - Resin formed by the reaction of bisphenol and epichlorohydrin.

Equalizer - A culvert placed where there is no channel but where it is desirable to have standing water at equal elevations on both sides of a fill.

Erosion - Deterioration of a surface by the abrasive action of moving fluids. This is accelerated by the presence of solid particles or gas bubbles in suspension. When deterioration is further increased by corrosion, the term "Corrosion-Erosion" is often used.

Erosion Corrosion - A corrosion reaction accelerated by the relative movement of the corrosive fluid and the metal surface.

ESCR - Environmental Stress Crack Resistance. The ability to resist environmental stress cracking when tested under standards such as ASTM F 1248 and F 1473.

Ethylene Plastics - Plastics based on polymers of ethylene or copolymers of ethylene with other monomers, the ethylene being in greatest amount by mass.

Exfiltration - The leakage or discharge of flows being carried by sewers out into the ground through leaks in pipes, joints, manholes, or other sewer system structures; the reverse of "infiltration."

Existing Linear Feet - The total length of existing sewer pipe in place within designated sewer systems as measured from center of manhole to center of manhole from maps or in the field.

Experimental Grade (E) - A PPI HSB recommended rating that is valid for a limited duration, given to those materials covered by data that do not yet comply with the full requirements of the Standard Grade, but satisfy the applicable minimum preliminary data requirements which are detailed in TR-3.

Extrusion - A process whereby heated or unheated plastic forced through a shaping orifice becomes one continuously formed piece.

Fabricated Fittings – Large diameter polyethylene fittings fabricated by fusing together special shapes to create reducer fittings, tees, ells and bends.

Fatigue - The phenomenon leading to fracture under repeated or fluctuating stresses having a maximum value less than the tensile strength of the material.

Fatigue Strength - The stress to which a material can be subjected for a specified number of fatigue cycles.

Field Orders - A written order issued by the engineer clarifies or interprets the contract documents in accordance with the terms of the contract or orders minor changes in the work in accordance with the terms of the contract.

Filter - Granular material or geotextile placed around a submarine pipe to facilitate drainage and at the same time strain or prevent the admission of silt or sediment.

Flash Point - Temperature at which a material begins to vaporize.

Flexible - Readily bent or deformed without permanent damage.

Flexural Modulus - The ratio, within the elastic limit, of the applied stress in the outermost fibers of a test specimen in three point static flexure, to the calculated strain in those outermost fibers (ASTM D 790).

Flexural Strength – (Flexural Modulus of Rupture) – The maximum calculated stress in the outermost fibers of a test bar subjected to three point loading at the moment of cracking or breaking (ASTM D 790). The maximum stress in the outer fiber of a test specimen at rupture.

Flow Attenuation - The process of reducing the peak flow rate, in a sewer system, by redistributing the same volume of flow over a longer period of time.

Flow Control - A method whereby normal sewer flows or a portion of normal sewer flows are blocked, retarded, or diverted (bypassed) within certain areas of the sewer collection system.

Flow Reduction - The process of decreasing flows into a sewer system or of removing a proportion of the flow already in a sewer system.

Flow Simulation - The modeling of flow in surface water or combined sewer systems using a dynamic digital model.

Fold and Form Pipe - A pipe rehabilitation method where a plastic pipe manufactured in a folded shape of reduced cross-sectional area is pulled into an existing conduit and subsequently expanded with pressure and heat. The reformed plastic pipe fits snugly to and takes the shape of the ID of the host pipe.

Fouling - An accumulation of deposits. This term includes accumulation and growth of marine organisms on a submerged metal surface and also includes the accumulation of deposits (usually inorganic) on heat exchanger tubing.

Foundation Drain - A pipe or series of pipes which collect groundwater from the foundation or footing of structures and discharge it into sanitary, storm, or combined sewers, or to other points of disposal for the purpose of draining unwanted waters away from such structures.

Fracture Mechanics - A quantitative analysis for evaluating structural reliability in terms of applied stress, crack length, and specimen geometry.

Fractures - Cracks visibly open along the length and/or circumference of the conduit with the pieces still in place.

Galvanic Cell - A cell consisting of two dissimilar metals in contact with each other and with a common electrolyte (sometimes refers to two similar metals in contact with each other but with dissimilar electrolytes; differences can be small and more specifically defined as a concentration cell).

General Corrosion - Corrosion in a uniform manner.

Glass Transition Temperature - The temperature below which a plastic is more brittle and glassy.

Gradation - Sieve analysis of aggregates.

Grade - Profile of the center of a roadway, or the invert of a culvert or sewer. Also refers to slope, or ratio of rise or fall of the grade line to its length. (Various other meanings.)

Gradient - See Grade.

Grain - A portion of a solid metal (usually a fraction of an inch in size) in which the atoms are arranged in an orderly pattern. The irregular junction of two adjacent grains is known as-a grain boundary; also a unit of weight, 1/7000th of a pound; also used in connection with soil particles i.e. = grain of sand.

Granular - Technical term referring to the uniform size of grains or crystals in rock.

Graphitization (graphitic corrosion) - Corrosion of gray cast iron in which the metallic constituents are converted to corrosion products, leaving the graphite flakes intact, Graphitization is also used in a metallurgical sense to mean the decomposition of iron carbide to form iron and graphite.

Groin - A-jetty built at an angle to the shoreline, to control the waterflow and currents or to protect a harbor or beach.

Ground Water Table (or level) - Upper surface of the zone of saturation in permeable rock or soil. (When the upper surface is confined by impermeable rock, the water table is absent.)

Grout - A fluid mixture of cement, and water (and sometimes sand), that can be poured or pumped easily; also encompasses chemical mixtures recognized as stopping water infiltration through small holes and cracks.

Grouting - (1) The joining together of loose particles of soil in such a manner that the soil so grouted becomes a solid mass which is impervious to water, (see also PIPE JOINT SEALING) (2) The process of flowing a cement/water grout (without sand) into the annular space between a host pipe and a slipline pipe.

Haunch - That portion of the pipe barrel extending below the pipe springline.

Haunching - The act of placing embedment material below the springline.

Head (Static) - The height of water above any plane or point of references (the energy possessed by each unit of weight of a liquid, expressed as the vertical height through which a unit of weight would have to fall to release the average energy posed). The standard inch-pound unit of measure is feet of water. The relation between pressure in psi and feet of head at 68°F is 1 psi = 2.310 ft of head.

Headwall - A wall (of any material) at the end of a culvert or, drain to serve one or more of the following purposes: protect fill from scour or undermining; increase hydraulic efficiency, divert direction of flow, and serve as a retaining wall.

Height Of Cover (HC) - Distance from crown of a culvert or conduit to the finished road surface, or ground surface, or the base of the rail.

High-Density Polyethylene (HDPE) - A plastic resin made by the copolymerization of ethylene and a small amount of another hydrocarbon. The resulting base resin density, before additives or pigments, is greater than 0.941 g/cm.

Holiday - Any discontinuity or bare spot in a coated surface.

Hoop Stress - The circumferential force per unit areas, psi, in the pipe wall due to internal pressure.

Hydraulic Cleaning - Techniques and methods used to clean sewer lines with water e.g. water pumped in the form of a high velocity spray and water flowing by gravity or head pressure. Devices include high velocity jet cleaners, cleaning balls, and hinged disc cleaners.

Hydraulic Gradient or Hydraulic Grade Line - An imaginary line through the points to which water would rise in a series of vertical tubes connected to the pipe. In an open channel, the water surface itself is the hydraulic grade line.

Hydraulic Radius - The area of the water prism in the pipe or channel divided by the wetted perimeter. Thus, for a round conduit flowing full or half full, the hydraulic radius is d/4. Another term sometimes used for this quantity is hydraulic mean depth.

Hydraulics - That branch of science or engineering which treats water or other fluid in motions.

Hydrocarbon, Gaseous - An organic compound made up of the elements of carbon and hydrogen that exists as a gas at ambient conditions (14.7 psi, 73.4T).

Hydrocarbon, Liquid - An organic compound made up of the elements of carbon and hydrogen that exists as a liquid at ambient conditions (14.7 psi, 73.4"F).

Hydrogen Blistering - Subsurface voids produced in a metal by hydrogen absorption in (usually) low strength alloys with resulting surface bulges.

Hydrogen Induced Cracking (HIC) - A form of hydrogen blistering in which stepwise internal cracks are created that can affect the integrity of the metal.

Hydrogen ion (pH) - Refers to acidity or alkalinity of water or soil. An ion is a charged atom or group of atoms in solution or in a gas. Solutions contain equivalent numbers of positive and negative ions.

Hydrogen Stress Cracking - A cracking process that results from the presence of hydrogen in a metal in combination with tensile stress. It occurs most frequently with high strength alloys.

Hydrostatic Design Basis (HDB) – One of a series of established stress values specified in Test Method D 2837 "Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials" for a plastic compound obtained by categorizing the LTHS determined in accordance with Test Method D 2837. HDB refers to the categorized LTHS in the circumferential, or hoop direction, for a given set of end use conditions. Established HDBs are listed in PPI TR-4.

Hydrostatic Design Stress HDB (HDS_{HDB}) – The estimated maximum tensile stress (psi) in the wall of the pipe in the circumferential orientation due to internal hydrostatic pressure that can be continuously applied with a high degree of certainty that failure of the pipe will not occur.
HDS_{HDB} = HDB X DF

Hydrostatic Design Stress MRS (HDS_{MRS}) – The estimated maximum tensile stress (psi) in the wall of the pipe in the circumferential orientation due to internal hydrostatic pressure that can be continuously applied with a high degree of certainty that failure of the pipe will not occur. HDS_{MRS} = MRS/C

I. D. –Inside diameter of pipe or tubing.

Ignition Temperature - Temperature at which the vapors emitted from a material will ignite either without exposure to a flame (self-ignition) or when a flame is introduced (flash ignition).

Impact - Stress in a structure caused by the force of a vibratory, dropping, or moving load. This is generally a percentage of the live load.

Impact Strength - The ability of a material to withstand shock loading.

Impervious - Impenetrable. Completely resisting entrance of liquids.

Inert Material - A material which is not very reactive, such as a noble metal or plastic.

Infiltration - The water entering a sewer system, including building sewers, from the ground, through such means as defective pipes, pipe joints, connections, or manhole walls. Infiltration does not include, and is distinguished from inflow.

Infiltration/Inflow - A combination of infiltration and inflow wastewater volumes in sewer lines, with no way to distinguish the basic sources, and with the effect of usurping the capacities of sewer systems and facilities.

Inflow - The water discharged into a sanitary sewer system, including service connections from such sources as roof leaders, cellar, yard, area drains, foundation drains, cooling water discharges, drains from springs and swampy areas, manhole catch basins, storm waters, surface runoff, street washwaters and/or drainage. Inflow does not include and is distinguished from infiltration.

Ingredient – Any chemical, mineral, polymer or other ingredient that has been added to a resin composition for the purpose of imparting certain desired processing or product performance properties.

Inhibitor - (1) A chemical substance or combination of substances which, when present in the environment, prevents or reduces corrosion without significant reaction with the components of the environment. (2) A substance which sharply reduces corrosion, when added to water, acid, or other liquid in small amounts. (3) A chemical additive that delays the chemical reaction in epoxy resin systems.

Injection Molding - The process of forming a material by melting it and forcing it, under pressure, into the cavity of a closed mold.

Insert Stiffener - A length of tubular material, usually metal, installed in the ID of the pipe or tubing to reinforce against OD compressive forces from a mechanical compression type fitting.

Inspector - The owner's on-site representative responsible for inspection and acceptance, approval, or rejection of work performed as set forth in these specifications.

Inspector (Construction Observer, Resident Inspector, Construction Inspector, Project Representative) - An authorized representative of the engineer assigned to observe the work and report his findings to the engineer.

Interaction - The division of load carrying between pipe and backfill and the relationship of one to the other.

Intercepting Drain - A ditch or trench filled with a pervious filter material around a subdrainage pipe.

Interceptor Sewer - A sewer which receives the flow of collector sewers and conveys the wastewaters to treatment facilities.

Intergranular Stress Corrosion Cracking (IGSCC) - Stress corrosion cracking in which the cracking occurs along grain boundaries.

Internal Corrosion - Corrosion that occurs inside a pipe because of the physical, chemical, or biological interactions between the pipe and the water as opposed to forces acting outside the pipe, such as soil, weather, or stress conditions.

Internal Erosion - Abrasion and corrosion on the inside diameter of the pipe or tubing due to the fluid or slurry that is being transported.

Internal Pipe Inspection - The television inspection of a sewer line section. A CCTV camera is moved through the line at a slow rate and a continuous picture is transmitted to an above ground monitor. (See also PHYSICAL PIPE INSPECTION.)

Inversion - The process of turning a fabric tube inside out with water or air pressure as is done at installation of a cured in place pipe.

Invert - That part or a pipe or sewer below the spring line - generally the lowest point of the internal cross section.

Invert Level (elevation) - The level (elevation) of the lowest portion of a liquid-carrying conduit, such as a sewer, which determines the hydraulic gradient available for moving the contained liquid.

Ion - An electrically charged atom (e.g., Na^+, Al^{+3}, Cl^-, S^{-2}) or group of atoms known as "radicals" (e.g. NH_4, SO_4, PO_4).

Ionization - Dissociation of ions in an aqueous solution (e.g., H2CO3 —> H+ + HCO3 or H20 —> H+ + OH-).

IPS – Iron pipe sizing convention for PE pipe.

Jacking (for conduits) - A method of providing an opening for drainage or other purposes underground, by cutting an opening ahead of the pipe and forcing the pipe into the opening by means of horizontal jacks.

Joint, Butt-Fused - A thermoplastic pipe connection between two pipe ends using heat and force to form the bond.

Joint, Electrofused – A joint made with an Electrofusion fitting in which the heating source is an integral part of the fitting.

Joint, Flanged - A mechanical joint using pipe flanges, a gasket, and bolts.

Joint, Heat-Fused - A thermoplastic pipe connection made using heat and usually force to form the fusion bond.

Joint, Mechanical - A connection between piping components employing physical force to develop a seal or produce alignment.

Joint, Saddle-Fused - A joint in which the curved base of the saddle fitting and a corresponding area of the pipe surface are heated and then placed together to form the joint.

Joint, Socket-Fused - A joint in which the joining surfaces of the components are heated, and the joint is made by inserting one component into the other.

Joints - The means of connecting sectional lengths of sewer pipe into a continuous sewer line using various types of jointing materials. The number of joints depends on the lengths of the pipe sections used in the specific sewer construction work.

Kip - A force unit equal to 1000 pounds.

Lateral - Any pipe connected to a sewer.

Linear Foot - Being one foot to the length of a sewer line.

Long-Term Strength - The hoop stress in the wall of the pipe is sufficiently low that creep (relaxation) of the materials is nil and assures service life in excess of 50 years.

Long-Term Hydrostatic Strength (LTHS) - The hoop stress that when applied continuously, will cause failure of the pipe at 100,000 hours (11.43 years). This is the intercept of the stress regression line with the 100,000-h coordinate as defined in ASTM D 2837. Note –The typical condition uses water as the pressurizing fluid at 23°C (73°F).

Low-Density Polyethylene Plastics (LDPE) - Polyethylene plastics, having a standard density of 0.910 to 0.925 g/cm^3.

Lower Confidence Limit (LCL) - A calculated statistical value used in ASTM D 2837 to determine the suitability of a data set for use in determining LTHS and HDB.

Lower Confidence Limit of the Predicted Hydrostatic Strength (σLPL)(ISO 9080) - A quantity in MPA, with the dimension of stress, which represents the 97.5% lower confidence limit of the predicted hydrostatic strength at temperatures T and time t.

LP-Gas – Liquid petroleum gas, permitted to be piped in PE piping, in vapor phase, Maximum Allowable Operating Pressure only at pressures ≤ 30 psig.

MAG PIPE – Magnetically detectable polyethylene pipe.

Major Blockage - A blockage (structural defect, collapse, protruding service connection, debris) which prohibits manhole-to-manhole cleaning, TV inspections, pipe flow, or rehabilitation procedures.

Manhole Section - The length of sewer pipe connecting two manholes.

Manning's Formula - An equation for the value of coefficient c in the Chezy Formula, the factors of which are the hydraulic radius and a coefficient of roughness: an equation itself used to calculate flows in gravity channels and conduits.

Maximum Allowable Operating Pressure - The highest working pressure expected and designed for during the service-life of the main.

Maximum Allowable Operating Pressure (MAOP) – In USA Regulation for gas piping, the highest allowed pressure, in psig, as determined in accordance with US CFR, Title 49, Part 192.121 and as represented in the following: $MAOP = 2 \times HDB_T \times 0.32 / (DR-1)$

Mechanical Cleaning - Methods used to clean sewer lines of debris mechanically with devices such as rodding machines, bucket machines, winch-pulled brushes, etc.

Mechanical Fitting - Fitting for making a mechanical joint to provide for pressure integrity, leak tightness, and depending on category, as defined in ASTM F 1924, resistance to end loads and pull-out.

Median Barrier - A double-faced guardrail in the median or island dividing two adjacent roadways.

Medium Density Polyethylene Plastics (MDPE) - Those branched polyethylene plastics, having a standard density of 0.926to 0.940 g/cm^3.

Melt Flow - A measure of the molten material's fluidity.

Melt Flow Rate - The quantity of thermoplastic material in grams that flows through an orifice during a 10-minute time span under conditions as specified by ASTM D 1238.

Melt Index - A measurement of a polymer's molten flow properties (ASTM D 1238), is related to molecular weight, or the length of the individual polymer chains. Generally, lower melt indices represent higher molecular weights while higher values indicate lower molecular weights. For any given PE resin, a lower melt index (higher molecular weight) will normally have superior physical properties.

Melt Viscosity - The resistance of the molten material to flow.

Melting Point - That temperature at which the plastic transitions to a completely amorphous state.

Minimum Required Pressure (MRP) – One of a series of established pressure values for a plastic piping component (multilayer pipe, fitting, valve, etc.) obtained by categorizing the long-term hydrostatic pressure strength in accordance with ISO 9080.

Minimum Required Strength (MRS) – (ISO 12162) The lower confidence limit in accordance with ISO 9080 at 20°C for 50 years with internal water pressure, rounded down to the next smaller value of the R-10 series or of the R-20 series conforming to ISO 3 and ISO 497, and categorized in accordance with ISO 12162, "Thermoplastic materials for pipes and fittings for pressure applications – Classification and designation – Overall service (design) coefficient."

Modification - (1) A written amendment of the contract documents signed by both parties. (2) A change order. (3) A written clarification or interpretation issued by the engineer in accordance with the terms of the contract. (4) A written order for a minor change or alteration in the work issued by the engineer pursuant to the terms of the contract. A modification may only be issued after execution of the agreement.

Modulus of Elasticity (E) - ASTM D 638 The ratio of stress (nominal) to corresponding strain below the proportional limit of a material.

Molecular Weight Distribution - The ratio of the weight average molecular weight (M_w) to the number average molecular weight (M_n). This gives an indication of the distribution.

Molecular Weight, Number Average (abbreviation M_n) - The total weight of all molecules divided by the number of molecules.

Molecular Weight, Weight Average (abbreviation M_w) - The sum of the total weight of molecules of each size multiplied by their respective weights divided by the total weight of all molecules.

Moment of Inertia - Function of some property of a body or figure - such as weight, mass, volume, area, length, or position, equal to the summation of the products of the elementary portions by the squares of their distances from a given axis.

Moment, Bending - The moment which produces bending in a beam or other structure. It is measured by the algebraic sum of the products of all the forces multiplied by their respective lever arms.

Multilayer Pipe – (Composite Pipe). **TYPE 1:** A pressure rated pipe having more than one layer (bonded together) in which at least 60% of the wall thickness is polymeric material that has an HDB (Hydrostatic Design Basis) or MRS (Minimum Required Strength), from which the pressure rating of the pipe is determined by pipe size and pipe wall construction.

Multilayer Pipe – (Composite Pipe). **TYPE 2:** A pressure rated pipe having more than one layer (bonded together) where at least 60% of the wall thickness is polymeric material, where the pipe pressure rating is determined by pipe size and pipe wall construction, and this pipe rating is listed by a PDB (Pressure Design Basis) or MRP (Minimum Required Pressure).

Multilayer Pipe – (Composite Pipe). **TYPE 3:** Non-pressure rated pipe comprising more than one layer in which at least 60% of the wall thickness is polymeric material.

Neutral Axis - An axis of no stress.

Nominalize - To classify a value into an established range or category.

Non-Pressure Pipe - Pipe designed for gravity-conveyed medium which must resist only intermittent static pressures and does not have a pressure rating.

Non-Uniform Corrosion - Corrosion that attacks small, localized areas of the pipe. Usually results in less metal loss than uniform corrosion but causes more rapid failure of the pipe' due to pits and holes.

Notch Sensitivity - The extent to which an inclination to fracture is increased by a notch, crack, scratch, or sudden change in cross-section. NOTE: The SDB is used only for a material intended for molding applications. The SDB shall not be used for pipe applications.

Notice of Award - The written notice by owner to the apparent successful bidder stating that upon compliance with the conditions precedent to be fulfilled by him within the time specified, the owner will execute and deliver the agreement to him.

Notice to Proceed - A written notice given by the owner to the contractor (with a copy to the engineer) fixing the date on which the contract time will commence to run and on which contractor shall start to perform his obligations under the contract documents.

Nylon (Polyamides) - Plastics based on resins composed principally of a long-chain synthetic polymer amide, which has recurring amide groups as an integral part of the main polymer chain.

O.D. – Outside diameter of pipe or tubing.

Odorants - To enhance safety, the fuel gas industries add chemical compounds to their gases, with a unique odor, to alert the user if a leak occurs. This odor is designed to be readily detectable when the fuel gas mixes with the atmosphere at low concentrations. The compounds used as odorants usually consist of aliphatic mercaptans, such as propyl and tertiary butyl mercaptan, and sulfides, such as thiopane or dimethyl sulfide at ordinary temperatures. Most gas odorants are liquids at full concentrations, and, in this state, might be harmful to some plastic pipe materials. However, in the small amounts sufficient to odorize a gas they are in the vapor state and cause no harm to plastic piping.

Outfall (or outlet) - In hydraulics, the discharge end of drains and sewers.

Out-of-Roundness - The allowed difference between the maximum measured diameter and the minimum measured diameter (stated as an absolute deviation).

Ovality - (%) - ((max_measured_O.D.) - (min_measured_O.D.) ÷ (average_O.D.)) x 100

Overflow - (1) The excess water that flows over the ordinary limits of a sewer, manhole, or containment structure. (2) An outlet, pipe, or receptacle for the excess water.

Owner - A public body of authority, corporation as partnership, or individual for whom the work is to be performed.

Oxidation - Loss of electrons, as when a metal goes from the metallic state to the corroded state.

Parapet - Wall or rampart, breast high. Also, the wall on top of an abutment extending from the bridge seat to the underside of the bridge floor and designed to hold the backfill.

Pascal's Law - Pressure exerted at any point upon a confined liquid is transmitted undiminished in all directions.

Pavement, Invert - Lower segment of a corrugated metal pipe provided with a smooth bituminous material that completely fills the corrugations, intended to give resistance to scour, erosion, and to improve flow.

PE - Polyethylene

PE 2406 – Medium-density polyethylene with ESCR in accordance with ASTM D1693 equal to or greater than 600 hours or a PENT value per ASTM D1473 equal to or greater than 10 hours and a hydrostatic design basis of 1250 psi.

PE 3408 – High-density polyethylene with ESCR in accordance with ASTM D1693 equal to or greater than 600 hours or a PENT value per ASTM D1473 equal to or greater than 10 hours and a hydrostatic design basis of 1600 psi.

PE 80 – A polyethylene classified by the ISO MRS system as having a minimum required strength of 8.0 MPa (1160 psi) in accordance with ISO 12162.

PE 100 - A polyethylene classified by the ISO MRS system as having a minimum required strength of 10.0 MPa (1450 psi) in accordance with ISO 12162.

PENT - The common name given for a test to determine the slow crack resistance of PE materials by placing a razor-notched tensile bar under a constant tensile load of 2.4 MPa at 80°C in accordance with ASTM F 1473.

Perched Water Table - In hydrology, the upper surface of a body of free ground water in a zone of saturation, separated by unsaturated material from an underlying body of ground water in a differing zone of saturation.

Periphery - Circumference or perimeter of a circle, ellipse, pipe-arch, or other closed curvilinear figure.

Permeability - Penetrability

PEX – Crosslinked polyethylene

pH - A measure of the acidity or alkalinity of a solution. A value of seven is neutral. Numbers lower than seven are acid, with the lower numbers more acid. Numbers greater than seven (up to 14) indicate alkalinity, with the higher numbers more alkaline.

Physical Pipe Inspection - The crawling or walking through manually accessible pipelines. The logs for physical pipe inspection record information of the kind detailed under TELEVISION INSPECTION. Manual inspection is only undertaken when field conditions permit this to be done safely. Precautions are necessary.

Pile, Bearing - A member driven or jetted into the ground and deriving its support from the underlying strata and/or by the friction of the ground on its surface.

Pipe - Nominal Weight - The pipe or tubing weight, expressed in pounds per 100 feet, calculated in accordance with PPI TN-7 by using the nominal diameter, and the nominal wall thickness of the pipe.

Pipe Joint Sealing - A method of sealing leaking or defective pipe joints which permit infiltration of groundwater into sewers by means of injecting chemical grout into and/or through the joints from within the pipe.

Pipeline Reconstruction - The insitu repair of an existing pipeline that has suffered loss of pressure integrity or has been structurally damaged. The liner becomes the principal pressure containment or structural element of the insitu composite pipe structure.

Pipeline Rehabilitation - The insitu repair of an existing pipeline, which has become corroded or abraded, by insert renewal of a liner which rehabilitates the bore of the pipeline but does not contribute significantly to increased pressure capability or increased structural strength, yet does improve flow efficiency/hydraulics.

Pitting - Highly localized corrosion resulting in deep penetration at only a few spots.

Pitting Factor - The depth of the deepest pit divided by the "average penetration" as calculated from weight loss.

Planting Piping - Installation procedure that digs a trench and lays the pipe in one step.

Plastic - A polymeric material that contains as an essential ingredient one or more organic polymeric substances of large molecular weight, is solid in its finished state, and, at some stage in its manufacture or processing into finished articles (See Thermoplastic and Thermoset).

Plastic Pipe - A hollow cylinder of a plastic material in which the wall thicknesses are usually small when compared to the diameter and in which the inside and outside walls are essentially concentric and which follows the O.D. sizing convention of steel pipe (IPS) or the sizing convention of ductile iron pipe (DIPS).

Plastic Tubing - A particular size of smooth wall plastic pipe in which the outside diameter is essentially the same as the corresponding size of copper tubing (CTS) or other tubing sizing conventions.

Plate - A flat-rolled iron or steel product.

Plough-in Piping - Installation procedure that splits the earth and pulls the pipe into position.

Poly (Vinyl Chloride) (PVC) - A polymer prepared by the polymerization of vinyl chloride as the sole monomer.

Polyester - Resin formed by condensation of polybasic and monobasic acids with polyhydric alcohols.

Polyethylene - A ductile, durable, virtually inert thermoplastic composed of polymers of ethylene. It is normally a translucent, tough solid. In pipe grade resins, ethylene-hexene copolymers are usually specified with carbon black pigment for weatherability.

Polymer - A substance consisting of molecules characterized by the repetition (neglecting ends, branch junctions, and other minor irregularities) of one or more types of monomeric units.

Polymerization - A chemical reaction in which the molecules of a monomer are linked together to form polymers. When two or more different monomers are involved, the process is called copolymerization.

Ponding - (1) Jetting or the use of water to hasten the settlement of an embankment - requires the judgment of a geotechnical engineer. (2) In hydraulics, ponding refers to water backed up in a channel or ditch as the result of a culvert of inadequate capacity or design to permit the water to flow unrestricted.

PPI (Plastic Pipe Institute) - A trade organization whose Membership is composed of manufacturers of plastic pipe, fittings, and valves; plastic materials for piping; metallic fittings for plastic piping: and equipment that is used for fabricating, joining or installing plastic piping.

Precipitation - Process by which water in liquid or solid state (rain, sleet, snow) is discharged out of the atmosphere upon a land or water surface.

Pressure Class (PC) – (AWWA C906) The design capacity to resist working pressure up to 80°F (27°C) maximum service temperature, with specified maximum allowances for reoccurring positive surges above working pressure.

Pressure Design Basis (PDB) – One of a series of established pressure values for a plastic piping component (multilayer pipe, fitting, valve, etc.) obtained by categorizing the long-term hydrostatic pressure strength determined in accordance with an industry test method that uses linear regression analysis. Although ASTM D 2837 does not use "pressure values", the PPI Hydrostatic Stress Board uses the principles of ASTM D2837 in plotting log pressure vs. log time to determine a "long-term hydrostatic pressure strength" and the resulting "Pressure Design Basis" for multilayer pipe that is listed in PPI TR-4.

Pressure Pipe - Pipe designed to resist continuous pressure exerted by the conveyed medium.

Pressure Rating - Estimated maximum internal pressure that allows a high degree of certainty that failure of the pipe will not occur.

Pressure Rating, HDB (PR_{HDB}) - The estimated maximum pressure (psig) that the medium in the pipe can exert continuously with a high degree of certainty that failure of the pipe will not occur. $PR_{HDB} = 2\ (HDB)\ (DF)/(DR-1)$

Pressure Rating, MRS (PR_{MRS}) - The estimated maximum pressure (bar) that the medium in the pipe can exert continuously with a high degree of certainty that failure of the pipe will not occur. $PR_{MRS} = 20\ (MRS)/(DR-1)\ C$

Pressure, Surge - The maximum positive transient pressure increase (commonly called water hammer) that is anticipated in the system as the result of a change in velocity of the water column.

Pressure, Working - The maximum anticipated sustained operating pressure, in pounds per square inch gauge, applied to the pipe or tubing, exclusive of surge pressures.

Primary Properties - The properties used to classify polyethylene materials.

Profile - Anchor pattern on a surface produce by abrasive, blasting or acid treatment.

Project - The entire construction to be performed as provided in the contract documents.

PSF - Pounds per square foot. PSF= $lb/in^2 \times 144$

PSI - Pounds per square inch.

PSIG – Pounds per square inch gauge.

Pull-in Piping - Also referred to as insert renewal; installation procedure whereby pipe is pulled inside old mains and service lines to provide the new main or service line.

Quality Assurance Test - A test in a program that is conducted to determine the quality level. DISCUSSION—Quality assurance includes quality control, quality evaluation, and design assurance. A good quality assurance program is a coordinated system, not a sequence of separate and distinct steps.

Quality Control Test - A production, in-plant test that is conducted at a given test frequency to determine whether product is in accordance with the appropriate specification(s).

Quick Burst Test - (ASTM D 1599) An internal pressure test designed to produce rupture (bursting) of a piping component in 60-70 seconds determined in accordance with ASTM D 1599.

Radian -An arc of a circle equal in length to the radius; or the angle at the center measured by the arc.

Radius of Gyration - The distance from the reference at which all of the area can be considered concentrated that still produces the same moment of inertia. Numerically it is equal to the square root of the moment of inertia, divided by the area.

Rainfall - Precipitation in the form of water (usage includes snow).

Rapid Crack Propagation (RCP) – A running-crack failure associated with lower temperatures and compressed gas media, initiated by a significant impact. Cracks, once initiated, run at high speed (300 to 1400 ft/sec) and result in cracks many feet in length.

Rate Process Method (RPM) – A three coefficient mathematical model for calculating plastic piping performance projections at use conditions – see TN-16.

Reduction - Gain of electrons, as when copper is electro-plated on steel from a copper sulfate solution (opposite of "Oxidation").

Regression Analysis - An evaluation of the long-term hoop stress data. A linear curve is calculated using the least Squares method to fit the logarithm of hoop stress versus the logarithm of the resulting hours-to-failure.

Regulator - A device for controlling the quantity of sewage and storm water admitted from a combined sewer collector line into an interceptor, pump station or treatment facility, thereby determining the amount and quality of the flow discharged through an overflow device to receiving waters or other points of disposal.

Rehabilitation - All aspects of upgrading the performance of existing sewer systems. Structural rehabilitation includes repair, renovation and renewal. Hydraulic rehabilitation covers replacement, reinforcement, flow reduction or attenuation and occasionally renovation.

Reinforcement - The provision of an additional sewer which in conjunction with an existing sewer increases overall flow capacity.

Renewal - Construction of a new sewer, on or off the line of an existing sewer. The basic function and capacity of the new sewer being similar to those of the old.

Renovation - Methods by which the performance of a length of sewer is improved by incorporating the original sewer fabric, but excluding maintenance operations such as isolated local repairs and root or silt removal.

Repair - Rectification of damage to the structural fabric of the sewer and the reconstruction of short lengths, but not the reconstruction of the whole of the pipeline.

Replacement - Construction of a new sewer, on or off the line of an existing sewer. The function of the new sewer will incorporate that of the old, but may also include improvement or development work.

Reprocessed Plastic - A thermoplastic prepared from usually melt processed scrap or reject parts by a plastics processor, or from non-standard virgin material or non-uniform virgin material.

Resin Impregnation (wet-out) - A process used in cured-in-place pipe installation where a plastic coated fabric tube is uniformly saturated with a liquid thermosetting resin while air is removed from the coated tube by means of vacuum suction.

Resins - An organic polymer, solid or liquid: usually thermoplastic or thermosetting.

Retaining Wall - A wall for sustaining the pressure of earth or filling deposited behind it.

Revetment - A wall or a facing of wood, willow mattresses, steel units, stone or concrete placed on stream banks to prevent erosion.

Reworked Plastic - A plastic from a manufacturer's own production that has been reground or pelletized for reuse by that same manufacturer.

Reynolds Number - A dimensionless quantity named after Osbourne Reynolds who first made know the difference between laminar and turbulent flow. The practical value of the Reynolds Number is that it indicated the degree of turbulence in a flowing liquid. It depends on the hydraulic radius of the conduit, the viscosity of the water and the velocity of flow. For a conduit of a given size, the velocity is generally the major variable and the Reynolds Number will increase as the velocity of flow increases.

Right Bank - That bank of a stream which is on the right when one looks downstream.

Ring Compression - The principal stress in a confined thin circular ring subjected to external pressure.

Rip Rap - Rough stone of various large sizes placed compactly or irregularly to prevent scour by water or debris.

Roadway (highway) - Portion of the highway included between the outside lines of gutters or side ditches, including all slopes, ditches, channels and appurtenance necessary to proper drainage, protection and use.

Roof Leader - A drain or pipe that conducts storm water from the roof of a structure downward and thence into a sewer for removal from the property, or onto the ground for runoff or seepage disposal.

Roughness Coefficient - A factor in the Kutter, Manning, and other flow formulas representing the effect of channel (or conduit) roughness upon energy tosses in the flowing water.

Runoff - That part of precipitation carried off from the area upon which it falls. Also, the rate of surface discharge of the above. That part of precipitation reaching a stream, drain or sewer. Ratio of runoff to precipitation is a "coefficient" expressed decimally.

Saddle Fitting - A fitting used to make lateral connection to a pipe in which a portion of the fitting is contoured to match the OD of the pipe to which it is attached.

Samples - Physical examples which illustrate materials, equipment or workmanship and establish standards by which the work will be judged.

Sanitary Sewer - A sewer intended to carry only sanitary and industrial wastewaters from residences, commercial buildings, industrial parks, and institutions.

Scaling - (1) High temperature corrosion resulting in formation of thick corrosion product layers. (2) Deposition of insoluble materials on metal surfaces, usually inside water boilers or heat exchanger tubes.

SDR (Standard Dimension Ratio) - The ratio of the average outside diameter to the minimum wall thickness. A common numbering system that is derived from the ANSI preferred number series R-10.

Secondary Stress - Forces acting on the pipe in addition to the internal pressure such as those forces imposed due to soil loading and dynamic soil conditions.

Section Modulus - The moment of inertia of the area of a section of a member divided by the distance from the center of gravity to the outermost fiber.

Sectional Properties - End area per unit of widths, moment of inertial, section modulus, and radius of gyration.

Seepage - Water escaping through or emerging from the ground along a rather extensive line or surface, as contrasted with a spring, the water of which emerges from a single spot.

Serviceability of The Piping System - Continued service life with a high degree of confidence that a failure will not occur during its long-term service.

Sewer Cleaning - The utilization of mechanical or hydraulic equipment to dislodge, transport, and remove debris from sewer lines.

Sewer Interceptor - A sewer which receives the flow from collector sewers and conveys the wastewaters to treatment facilities.

Sewer Pipe - A length of conduit, manufactured from various materials and in various lengths, that when joined together can be used to transport wastewaters from the points of origin to a treatment facility. Types of pipe are: Acrylonitrile-butadiene-styrene (ABS): Asbestos-Cement (AC); Brick Pipe (BP); Concrete Pipe (CP); Cast Iron Pipe (CIP): Polyethylene (PE); Polyvinylchloride (PVC); Vitrified Clay (VC).

Sewer, Building - The conduit which connects building wastewater sources to the public or street sewer, including lines serving homes, public buildings, commercial establishments and industry structures. The building sewer is commonly referred to in two sections: (1) the section between the building line and the property line, frequently specified and supervised by plumbing or housing officials; and (2) the section between the property line and the street sewer, including the connection thereto, frequently specified and supervised by sewer, public works, or engineering officials. (Referred to also as "house sewer," "building connection," or "service connection.")

Shaft - A pit or wall sunk from the ground surface into a tunnel for the purpose of furnishing ventilation or access to the tunnel.

Sheeting - A wall of metal plates or wood planking to keep out water, soft or runny materials.

Shop Drawings - All drawings, diagrams, illustrations, brochures, schedules, and other data which are prepared by the contractor, a subcontractor, manufacturer supplier or distributor and which illustrate the equipment, materials or some portion of the work as required by the contract documents.

Siphon (Inverted) - A conduit or culvert with a U or V shaped grade line to permit it to pass under an intersecting roadway, stream or other obstruction.

Site - Any location where work has been or will be done.

Site Access - An adequately clear area of a size sufficient to accommodate personnel and equipment required at the location where work is to be performed, including roadway or surface sufficiently unobstructed to permit conveyance of vehicles from the nearest paved roadway to the work location.

Skew (or Skew Angle) - The acute angle formed by the intersection of the line normal to the centerline of the road improvement, with the centerline of a culvert or other structure.

Slide - Movement of a part of the earth under force of gravity.

Slit-Type Failure - A form of brittle failure that exhibits only a very small crack through the wall of the pipe with no visible material deformation in the area of the break.

Slow Crack Growth (SCG) – the slow extension of the crack with time.

Smooth Radius Bend - A contoured sweep or bend with no sharp or angular sections.

Social Costs - Costs incurred by society as a result of sewerage works and for which authorities have no direct responsibility. These include unclaimed business losses due to road ensures and the cost of extended journey times due to traffic diversions.

Socket Fusion Joint - A joint in which the joining surfaces of the components are heated, and the joint is made by inserting one component into the other.

Softening Temperature - There are many ways to measure the softening temperature of a plastic. The commonly reported Vicat Softening Temperature method is to measure the temperature at which penetration of a blunt needle through a given sample occurs under conditions specified in ASTM D 1525.

Solar Radiation - The emission of light from the sun, including very short ultraviolet wavelengths, visible light, and very long infrared wavelengths.

Solubility - The amount of one substance that will dissolve in another to produce a saturated solution.

Spalling - The spontaneous chipping, fragmentation, or separation of a surface or surface coating.

Span - Horizontal distance between supports, or maximum inside distance between the sidewall of culverts.

Special Conditions - When included as a part of the contract documents. Special conditions refer only to the work under this contract.

Specific Gravity - The density of a material divided by the density of water usually at 4°C. Since the density of water is nearly 1 g/cm, density in g/cm and specific gravity are numerically nearly equal.

Specifications - Those portions of the contract documents consisting of written technical descriptions of materials, equipment, construction systems, standards and workmanship as applied to the work.

Spillway - (1) A low-level passage serving a dam or reservoir through which surplus water may be discharged; usually an open ditch around the end of a dam, a gateway, or a pipe in a dam. (2) An outlet pipe, flume or channel serving to discharge water from a ditch, ditch check, gutter or embankment protector.

Spring Line - A line along the length of the pipe at its maximum width along a horizontal plane. The horizontal midpoint of a sewer pipe.

Springing Line - Line of intersection between the intrados and the supports of an arch. Also the maximum horizontal dimension of a culvert or conduit.

Spun Lining - A bituminous lining in a pipe, made smooth or uniform by spinning the pipe around its axis.

Stabilizer - An ingredient used in the formulation of some plastics to assist in maintaining the physical and chemical properties of the materials at their initial values throughout the processing service life of the material.

Standard Dimension Ratio (SDR) - A specific ratio of the average specified outside diameter to the minimum specified wall thickness for outside diameter-controlled plastic pipe, the value of which is derived by adding one to the pertinent number selected from the ANSI Preferred Number Series 10. Specifying PE pipes with a given SDR regardless of O.D. assures all pipes will have the same design pressure assuming the PEs have the same HDB rating.

Standard Grade (S) - A PPI HSB recommended rating that is valid for a five-year period, given to those materials that comply with the full data requirements of TR-3.

Standard Thermoplastic Material Designated Code - In this designation system, which is widely used by major national product standards, the plastic is identified by its standard abbreviated terminology in accordance with ASTM D 1600, "Standard Terminology Relating to Abbreviations, Acronyms, and Codes for Terms Relating to Plastics", followed by a four or five digit number. The first two or three digits, as the case may be, code the material's ASTM classification (short-term properties) in accordance with the appropriate ASTM standard specification for that material. The last two digits of this number represent the PPI recommended HDS (0.5 design factor) at 73ºF (23ºC) divided by one hundred. For example, PE 2406 is a grade P24 polyethylene with a 630-psi design stress for water at 73.4°F (23°C). The hydrostatic design stresses for gas are not used in this designation code.

Strength Design Basis (SDB) - Refers to one of a series of established stress values (specified in Test Method D 2837) for a plastic molding compound obtained by categorizing the long-term strength determined in accordance with ASTM Test Method F 2018, "Standard Test Method for Time-to-Failure of Plastics Using Plane Strain Tensile specimens".

Stress Crack - An internal or external crack in a plastic caused by tensile or shear stresses less than the short-term tensile strength of the material. The development of such cracks is frequently related to and accelerated by the environment to which the material is exposed. More often than not, the environment does not visibly attack, soften or dissolve the surface. The stresses may be internal, external, or a combination of both.

Stress Relaxation - The decay of stress with time at constant strain.

Sustained Pressure Test - A constant internal pressure test for an extended period of time.

Tensile Strength at Break - The maximum tensile stress (nominal) sustained by the specimen during a tensile test where the specimen breaks.

Tensile Strength at Yield - The maximum tensile stress (nominal) sustained by the specimen during a tensile test at the yield point.

Thermal Stabilizers - Compounds added to the plastic resins when compounded that prevent degradation of properties due to elevated temperatures.

Thermoplastic - A plastic, such as PE, that can be repeatedly softened by heating and hardened by cooling through a temperature range characteristic of the plastic, and that in the softened state can be shaped by flow into articles by molding or extrusion.

Thermoset - A material, such as epoxy, that will undergo or has undergone a chemical reaction by the action of heat, chemical catalyst, ultraviolet light, etc., leading to an infusible state.

Thermosetting - Resins that are composed of chemically cross-linked molecular chains, which set at the time the plastic is first formed; these resins will not melt, but rather disintegrate at a temperature lower than its melting point, when sufficient heat is added.

Threading - The process of installing a slightly smaller pipe or arch within a failing drainage structure.

Toe Drain - A subdrain installed near the downstream toe of a dam or levee to intercept seepage.

Toe-in - A small reduction of the outside diameter at the cut end of a length of thermoplastic pipe.

Tuberculation - Localized corrosion at scattered locations resulting in knob-like mounds.

Ultraviolet Absorbers (Stabilizers) - Compounds that when mixed with thermoplastic resins selectively absorb ultraviolet rays protecting the resins from ultraviolet attack.

Underdrain - See subdrain.

Uniform Corrosion - Corrosion that results in an equal amount of material loss over an entire pipe surface.

UV Degradation - Sunlight contains a significant amount of ultraviolet radiation. The ultraviolet radiation that is absorbed by a thermoplastic material may result in actinic degradation (i.e., a radiation promoted chemical reaction) and the formation of heat. The energy may be sufficient to cause the breakdown of the unstabilized polymer and, after a period of time, changes in compounding ingredients. Thermoplastic materials that are to be exposed to ultraviolet radiation for long periods of time should be made from plastic compounds that are properly stabilized for such conditions.

Velocity Head - For water moving at a given velocity, the equivalent head through which it would have to fall by gravity to acquire the same velocity.

Vinyl Plastics – Compositions of polymers and ingredients that are based on polymers of vinyl chloride, or copolymers of vinyl chloride with other monomers, the vinyl chloride being in the greatest amount by mass.

Virgin Plastic - A plastic material in the form of pellets, granules, powder, floc, or liquid that has not been subjected to use or processing other than that required for its initial manufacture.

Voids - A term generally applied to paints to describe holidays, holes, and skips in the film. Also used to describe shrinkage in castings or welds.

Wale - Guide or brace of steel or timber, used in trenches and other construction.

Water Table - The upper limit of the portion of ground wholly saturated with water.

Watershed - Region or area contributing to the supply of a stream or lake; drainage area, drainage basin, catchment area.

Weatherability - The properties of a plastic material that allows it to withstand natural weathering; hot and cold temperatures, wind, rain and ultraviolet rays.

Wetted Perimeter - The length of the perimeter in contact with the water. For a circular pipe of inside diameter "d", flowing full, the wetted perimeter is the circumference, d. The same pipe flowing half full would have a wetted perimeter of d/2.

Work - Any and all obligations, duties and responsibilities necessary to the successful completion of the project assigned to or undertaken by contractor under the contract documents, including all labor, materials, equipment and other incidentals, and the furnishing thereof.

Working Pressure (WP) - The maximum anticipated, sustained operating pressure applied to the pipe exclusive of transient pressures.

Working Pressure Rating (WPR) - The capacity to resist Working Pressure (WP) and anticipated positive transient pressure surges above working pressure.

Written Notice - The term "notice" as used herein shall mean and include all written notices, demands, instructions, claims, approvals, and disapproval required to obtain compliance with contract requirements. Written notice shall be deemed to have been duly served if delivered in person to the individual or to a member of the firm or to an officer of the corporation for whom it is intended, or to an authorized representative of such individual, firm or corporation, or if delivered at or sent by registered mail to the last business address known to him who gives the notice. Unless otherwise stated in writing, any notice to or demand upon the owner under this contract shall be delivered to the owner through the engineer.

Yield Point (ASTM D 638) - The stress at which a material exceeds its elastic limit. Below this stress, the material will recover its original size and shape on removal of the stress. The first point on the stress-strain curve at which an increase in strain occurs without an increase in stress.

Yield Strength (ASTM D 638) – The stress at which a material exhibits a specified limiting deviation form the proportionality of stress to strain. Unless otherwise specified, this stress will be the stress at the yield point, and when expressed in relation to the tensile strength, shall be designated as Tensile Strength at Yield or Tensile Stress at Yield.

Organizations and Associations

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www.aashto.org

ACS **American Chemical Society**
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www.acs.org

AGA/PMC **American Gas Association**
Plastic Materials Committee
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Washington, DC 20001
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www.aga.com

ANSI **American National Standards Institute**
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New York NY 10036
(212) 642-4900
www.ansi.org

APC **American Plastics Council**
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1-800-2-HELP-90
www.americanplasticscouncil.org

API **American Petroleum Institute**
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ASTPHLD **Association of State and Territorial Public Health Laboratory Directors**
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AWWRF **American Water Works Research Foundation**
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(708) 799-4981
www.bocai.org

CABO **The Council of American Building Officials**
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CERF **Civil Engineering Research Foundation**
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CSA **Canadian Standards Association**
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DOT/OPS **U.S. Department of Transportation**
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DOT/TSI **U.S. Department of Transportation**
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GTI **Gas Technology Institute**
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GRI **Geosynthetic Research Institute at Drexel University**
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HSB **Hydrostatic Stress Board**
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www.iapmo.org

ICBO **International Conference of Building Official**s
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Whittier, CA 90601
(213) 699-0541
www.icbo.org

IGSHPA **International Ground Sourced Heat Pump Association**
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(405) 744-5175
www.igshpa.okstate.edu

ISO **International Standard Organization**
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www.ansi.org

ISO/SC4 **International Standards Organization**
Secretariat for Subcommittee SC4 "Gas"
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NACE **National Association of Corrosion Engineers**
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www.naco.org

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www.nassco.org

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NCSL **National Conference of State Legislatures**
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www.ncsl.org

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NWRA **National Water Resources Association**
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PPFA **Plastic Pipe and Fittings Association**
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PVRC **Pressure Vessel Research Council of the Welding Research Council**
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Municipal Advisory Board
Established May 1, 2008 at the University of Texas, Arlington

MAB Generic Electrofusion Procedure for Field Joining of 12 Inch and Smaller Polyethylene (PE) Pipe

First edition approved by Municipal Advisory Board on Nov. 5, 2015, in Casselberry, FL.

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CONTENTS

FOREWORD

This procedure was developed by the Municipal Advisory Board and published with the technical help of the members of the PPI (Plastics Pipe Institute, Inc.). The members have shown their interest in quality products by assisting independent standards-making and user organizations in the development of standards, and also by developing reports on an industry-wide basis to help engineers, code officials, specifying groups, and users.

The purpose of this technical report is to provide important information available to the Municipal Advisory Board (MAB) on particular aspects of polyethylene pipe electrofusion to engineers, users, contractors, code officials, and other interested parties. More detailed information on its purpose and use is provided in the document itself.

This report has been prepared by Municipal Advisory Board members and associates as a service to the industry. The information in this report is offered in good faith and believed to be accurate at the time of its preparation, but is offered "as is" without any express or implied warranty, including WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. Consult the manufacturer for more detailed information about the particular joining procedures to be used with its piping products. Any reference to or testing of a particular proprietary product should not be construed as an endorsement by the Municipal Advisory Board, or the Plastics Pipe Institute, Inc., which do not endorse the proprietary products or processes of any manufacturer. The information in this report is offered for consideration by industry members in fulfilling their own compliance responsibilities. Municipal Advisory Board and the Plastics Pipe Institute, Inc., assume no responsibility for compliance with applicable laws and regulations.

The Municipal Advisory Board serves as an independent, non-commercial adviser to the M & I Division of the Plastics Pipe Institute. Once adopted, MAB intends to revise this report from time to time, in response to comments and suggestions from users of the report. Please send suggestions of improvements to Camille Rubeiz at crubeiz@plasticpipe.org.

ACKNOWLEDGEMENTS

The Municipal Advisory Board would like to acknowledge the excellent contributions of the MAB Electrofusion Task Group for developing and leading this project:

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10. **Greg Scoby, PE**, City of Palo Alto, CA (past) and Crossbore Consultants, CA
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HISTORY

In 2014, representatives of the Municipal Advisory Board (MAB) requested assistance in creating greater uniformity in the joining procedures utilized by municipal utilities in the electrofusion of polyethylene (PE) piping products for water and waste water applications. Users reported the proliferation of similar but slightly varying joining procedures from individual electrofusion fitting and equipment producers. The slight differences in the various procedures made it more difficult for system operators and installers to qualify persons with appropriate training and experience in the use of these procedures. It was even more difficult for system operators to inspect for and enforce that proper joining procedures were being followed.

In response to this request, MAB established a task group to develop a generic electrofusion procedure for the joining of polyethylene piping and a guide for inspection to ensure that proper procedures are in place and being followed. The result of that task group effort is this document.

In the spirit of complying with the above request, companies that manufacture electrofusion products and equipment reviewed existing procedures, agreed on common best practices, and combined experiences and knowledge to educate and train installers. Thus, this publication provides a uniform electrofusion joining procedure to provide greater consistency, and to facilitate the pipeline operator's efforts to qualify the installer, reduce cost, and simplify inspections. Refer to Appendix A for a list of electrofusion companies that endorsed these generic practices for use with their fittings.

SCOPE

The program undertaken by the MAB Task Group combined common installation practices shared by multiple manufacturers into a single format. The goal is to provide clear direction and common procedures for proper pipe preparation, fitting-to-pipe assembly, and installation of electrofusion fittings on 12 inch or smaller pipe. An additional goal is to provide clear inspection criteria for installer qualification, installation acceptance by inspection, and answers to frequently asked questions. The size range was limited to 12 inch or smaller due to differences in installation procedures for larger diameters, commonly accepted as 14 inch or larger. For installation of larger electrofusion couplings, the user can reference PPI TN-34 *INSTALLATION GUIDELINES FOR ELECTROFUSION COUPLINGS 14 INCH AND LARGER.*

The Municipal Advisory Board hopes that the inherent value of greater uniformity will provide all the incentive necessary for companies to evaluate the procedure as a first option for electrofusion joining of its PE piping products. Use of this procedure is obviously not mandatory, and every electrofusion fitting producer, equipment manufacturer, and pipeline operator retains the option of developing different procedures for its particular products and pipelines. However, MAB believes that its work in developing this procedure as a candidate for widespread acceptance throughout the industry will lead to greater efficiency, simplicity, and understanding in this area and promote the use of effective, qualified procedures for electrofusion joining of PE pipe.

I. INTRODUCTION

Electrofusion joining of PE pressure pipe has been commonly used in North America for over 30 years. ASTM standard specifications for materials (ASTM D3350), performance (ASTM F1055), and installation practice (ASTM F1290) have been in publication for many years. All electrofusion fittings should be marked to indicate that they meet the design and performance requirements of ASTM F1055 before being considered for use. Additional markings may be included to indicate that other performance and health effect requirements are satisfied, such as AWWA C906 and NSF 61. Since each fitting manufacturer may have slightly varying geometrical designs, and each manufacturer is responsible for establishing safe installation temperature limits, it is also common that installation instructions can vary from one manufacturer to another. Although instructions can vary, all fitting designs share some common requirements for installation and all manufacturer's instructions include these same requirements.

Proper installation techniques, installer understanding of and training to these techniques, and effective examination before installation are key to a successful installation. This document provides detailed instructions for each key step to a successful installation, why each step is important, and how to tell if the requirements of each step have been accomplished.

II. JOBSITE PREPARATION

All heat fusion joining methods require that there is no water flowing or standing in the pipe that can reach the fusion surfaces. De-watering of the site may be required to prevent ground water from reaching the fusion and contaminating the surfaces to be joined. Dewatering can be accomplished using portable pumps (Fig. II-a) in moderate conditions.

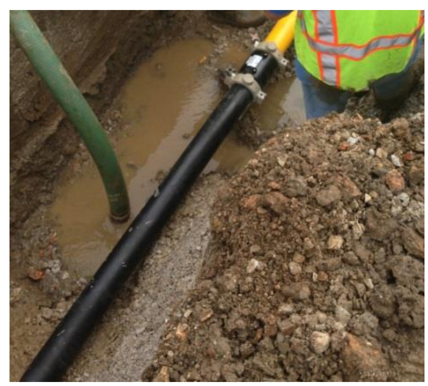


Figure II-a – Submersible pump

In repair or cut-in situations, flowing water in the pipe may be present due to leakage of valves. Flowing water in contact with the fusion surfaces during the assembly or fusion cycle must be avoided as it can contaminate and hinder the fusion process and/or cause voids and pockets in the fusion surfaces as the moisture turns into expanding steam during the fusion process. PE squeeze-off tools can be used to control flow of water in cases where a valve is not present or will not shut off completely; refer to ASTM F1041. Some practical temporary methods for accomplishing this, while avoiding the need to disinfect the line, are the use of organic absorbent materials, such as bread, which can later be flushed from the system at downstream hydrants. Dry ice placed in the pipe upstream of the fusion location will temporarily freeze small amounts of flowing water until the fusion process can be completed. In smaller diameter pipes inflated latex balloons also provide good temporary stoppage of trickling water. The balloon will burst during pressure testing and can be flushed from the system at a downstream outlet.

Electrofusion fittings can be installed in ambient temperatures as recommended by the manufacturer. A typical qualified temperature range for installation is 14°F minimum to 113°F maximum. Some manufacturers have lower and/or higher temperature limits and will state their qualified range in the technical specifications, contact the fitting manufacturer to verify.

III. FITTING STORAGE AND HANDLING

Electrofusion fittings are packaged in sealed plastic bags as protection against accumulation of dust, dirt, and contamination. The bag should remain in place during normal handling and should only be removed during installation. Fittings are also typically boxed to protect against other sources of degradation, such as oxidation due to UV exposure over long periods of storage. Fittings should always be stored indoors in their original packaging until installation.

Black electrofusion fittings contain a 2% to 3% carbon black additive to protect against other UV effects and if stored indoors in their original packaging have a virtually unlimited shelf life.

⚠ **Fittings with an unknown storage history or that have been exposed to questionable storage conditions should be evaluated through destructive testing of sample fusions. If fusion quality is shown to be affected, the fittings in question should not be installed.**

Fittings should be inspected for damage before installing to ensure that connection points such as terminal pins have not been damaged from handling, that there is no visible damage to fusion surfaces or heating wires, and that no foreign materials are present on or near the fusion surfaces.

Fittings can be cleaned if incidental contact is made with the fusion surface. A suitable cleaning agent that contains no additives to hinder the fusion process must be used. 96% or greater concentration of Isopropyl alcohol, with no additional additives except water, is universally accepted as a good cleaning agent. Other cleaning agents may be acceptable and the fitting manufacturer should be consulted in case of questions.

⚠ **DO NOT USE DENATURED ALCOHOL – Denatured alcohols may contain additives that can prevent fusion and should not be used.**

IV. REQUIRED TOOLS

Proper tools are essential to a successful electrofusion installation. Tools include devices for measuring, marking, cutting, scraping, cleaning, clamping (which includes aligning and securing), re-rounding, and power delivery. At minimum, the following items should be accessible during installation:

A. Measuring: A tape measure (Fig. IV-a) or ruler for measurement of insertion (stab) depth of pipe ends inside a coupling. A circumferential wrap Pi tape for measurement of pipe diameter is also recommended.

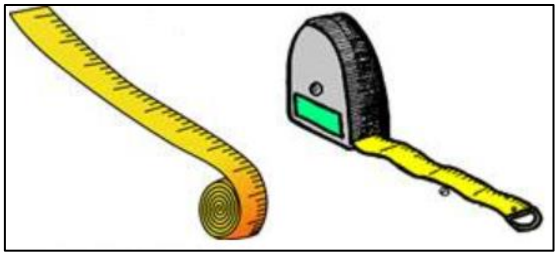


Figure IV-a –Measuring Tape

B. Marking: A permanent visible marker. Markers should be visible on the pipe color (Fig. IV-b) being used. For black pipe, a silver colored Sharpie®, or equivalent, permanent marker works well. The marker dries fast and contains no oils or other ingredients that could accidentally contaminate a prepared pipe surface. Marks are needed to locate insertion depths and to use as a guide for pipe scraping effectiveness.

⚠ **Markers that are slow-drying or contain oils that could be spread onto fusion surfaces should not be used.**

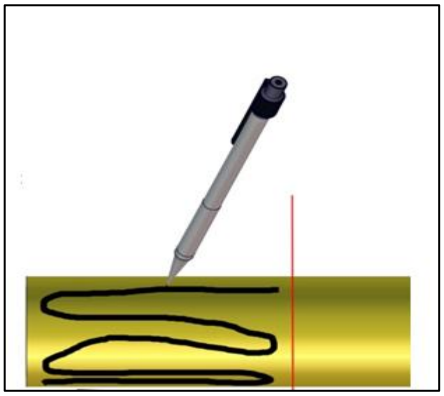


Figure IV-b - Marking

C. Cutting: Devices that deliver a relatively clean and square cut (±3 degrees) on the pipe ends are recommended. Many suitable types of pipe cutters are commercially available that can be used for diameters of 12 inch and smaller (Fig. IV-c).

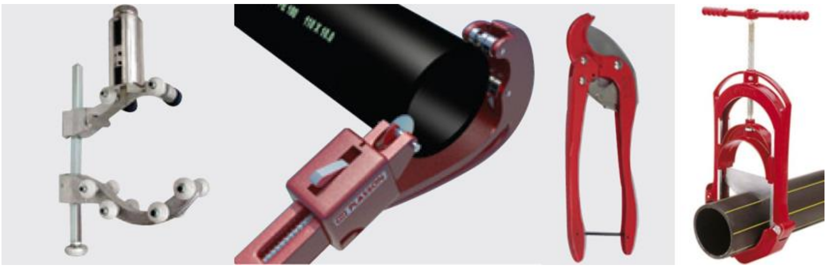


Figure IV-c – Pipe cutters (rotational, ratcheting, and guillotine style)

✅For larger diameters, a suitable saw (without lubricants) and a guide or guide marks can be used; reciprocating saws, circular saws with a coarse-tooth blade, hot saws, chop saws, and chain saws are commonly used for larger pipes with appropriate safety precautions and personal protective equipment. Cutting marks can made around the pipe using a 2 inch or wider strap or encirclement clamp as a guide so that the pipe can then be cut along the line as shown in Fig. IV-d.

Figure IV-d – Marking and cutting larger diameter pipes

D. Measuring pipe:

1. Diameter**:** Electrofusion fittings are designed for use on pipe made to standard diameters in dimensions for Iron Pipe Size (IPS), Copper Tube Size (CTS), and Ductile Iron Pipe Size (DIPS). Pipe that is outside of the diameter tolerance band of the appropriate pipe standard should not be used. The following table (Table IV-a) can be used for reference when measuring pipe diameter to ensure that the pipe is within tolerance.

Table IV-a – Standard Pipe and Tubing Dimensions

IRON PIPE SIZE (IPS) ASTM D3035/F714		
PIPE SIZE	Nominal Diameter (inches)	Tolerance (±)
3/4 IPS	1.050	0.004
1 IPS	1.315	0.005
1 1/4 IPS	1.660	0.005
1 1/2 IPS	1.900	0.006
2 IPS	2.375	0.006
3 IPS	3.500	0.016
4 IPS	4.500	0.020
6 IPS	6.625	0.030
8 IPS	8.625	0.039
10 IPS	10.750	0.048
12 IPS	12.750	0.057

COPPER TUBE SIZE (CTS) ASTM D2737		
TUBING SIZE	Nominal Diameter (inches)	Tolerance (±)
3/4 CTS	0.875	0.004
1 CTS	1.125	0.005
1 1/4 CTS	1.375	0.005
1 1/2 CTS	1.625	0.006
2 CTS	2.125	0.006

DUCTILE IRON PIPE SIZE (DIPS) ASTM F714		
PIPE SIZE	Nominal Diameter (inches)	Tolerance (±)
3 DIPS	3.960	0.018
4 DIPS	4.800	0.022
6 DIPS	6.900	0.031
8 DIPS	9.050	0.041
10 DIPS	11.100	0.050
12 DIPS	13.200	0.059

(NOTE: For sizes larger than 12 inch, See PPI TN-34)

2. Roundness: Polyethylene is a flexible material. Pipe roundness (Fig III-e) can be affected by a number of conditions to include manufacturing process conditions, coiling, storage/stacking, and soil load if buried.

The condition of pipe roundness can be expressed in two ways, “out-of roundness” or “ovality”, while both are referencing the same basic condition, it can sometimes be confusing:

- Out-of-roundness is the difference in the maximum measured diameter minus the minimum measured diameter. The pipe can be measured with a tape measure or calipers to find the maximum (d1) and minimum (d2) diameter points. The out-of-roundness is calculated as d1- d2 as measured in the field.

- Ovality is the difference between the maximum and minimum measured outside diameters expressed as a percentage. Ovality is calculated as $(d1 – d2) / D_{average} \times 100$.

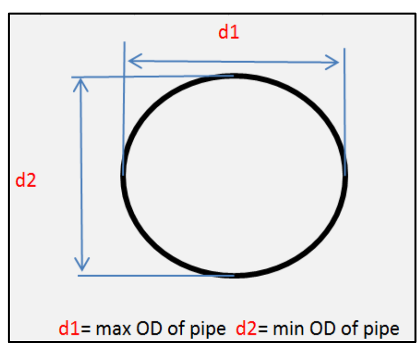


Figure IV-e - Roundness Measurement

If severe enough, pipe out-of-roundness can have a negative effect on electrofusion joint quality. If the pipe is out-of-round, and is not corrected, the amount of gap between the pipe and fitting can be too large for the melt expansion to close and increase the difficulty of sliding the fitting onto the pipe.

Most often, 2" IPS and smaller diameter tubing is flexible enough that the coupling and alignment clamps will provide the necessary rounding forces and no other re-rounding device is needed.

For sizes equal to or larger than 3" IPS / DIPS, re-rounding clamps may be needed on either side of an electrofusion fitting to ensure that the gap between the pipe and fitting is not too large. Table IV-b can be used for guidance when re-rounding clamps are used:

Table IV-b – Maximum Out-of-Roundness (IPS/DIPS)

PIPE SIZE	d1 - d2
3"	.0625 or 1/16"
4"	.0625 or 1/16"
6"	.125 or 1/8"
8"	.125 or 1/8"
10"	.125 or 1/8"
12"	.125 or 1/8"

Pipe scratches and/or gouges: Installation of pipe can cause surface scratches or gouges. Smaller scratches from dragging or normal handling are not problematic and will normally be removed during the pipe preparation process by scraping.

⚠ **Gouges that are deeper than the scrape depth may also require extra attention when scraping the pipe to ensure that any debris or contaminates embedded in the gouges are removed; use of a hand tool to scrape the gouge may be necessary. If the gouge exceeds 10% of the pipe wall thickness, that pipe section should be cut out and replaced to maintain the maximum pressure rating of the pipe.**

V. PIPE PREPARATION

Scraping: Pipe preparation is perhaps the most important and least understood aspect of making a sound electrofusion joint. Improper pipe preparation is overwhelmingly the leading cause of unsuccessful electrofusion joint attempts because the installer may not completely understand the goal of pipe scraping, which is to remove a thin layer of the outer pipe surface (see trouble-shooting section for more details) to expose clean virgin material beneath.

Pipe surfaces exhibit surface oxidation from the extrusion process, transportation, and outdoor exposure. Surface oxidation is a normal chemical reaction that results in a physical change to the molecular structure of the polymer chains on the pipe surface. Oxidation acts as a physical barrier and therefore those surfaces cannot be heat fused. Simply roughing the pipe surface is not sufficient. In order to achieve fusion, this layer must be removed. Even new pipe must be properly scraped before a fusion will be successful.

The outer oxidation layer on a pipe surface is very thin. It does not increase in depth of more than a few thousandths of an inch even over long periods of exposure, so regardless of the amount of time the pipe has been stored before scraping, the scraping depth requirement is the same. An adequate minimum amount of material that must be removed (Fig. V-a) is just seven one-thousandths of an inch (.007”). That thickness is approximately the same as two sheets of ordinary paper.

Figure V-a - Scraping Measurement

Sand paper, emory cloth, or other abrasives should never be used to prepare a pipe surface for electrofusion. Abrasives have been proven to be ineffective for electrofusion because they don’t adequately remove material, they can redistribute contaminates on the surfaces, and because they can leave behind a grit residue that forms another barrier that will also prevent fusion.

There are many tools that can be used for pipe scraping, however they are not all the same and care must be used depending on the type of tool selected. The only tools used for surface preparation are those that are specifically designed for electrofusion scraping and peeling:

Examples of acceptable tools that “peel” the pipe surface to a controlled depth are most commonly referred to as “peelers” (Fig. V-b).

Figure V-b – Acceptable “Peelers”

- Tools with serrated blades are also available (Fig. V-c); these tools physically scrape the pipe surface by pulling the serrated blade across the pipe in a perpendicular position. Serrated blades sometimes mask the pipe surface by leaving behind score marks that make it difficult to visually tell if all of the original surface material has been removed.

Figure V-c - Examples of serrated type blade scrapers

- ✓ It is strongly recommended that, no matter what type of tool is used, witness marks should be made on the pipe surface with a permanent marker prior to scraping so that any marking that remains after scraping is evidence that areas were missed or that more scraping is required.

- Another type of tool is referred to as a "hand scraper". **These scrapers are not recommended** (Fig. V-d) due to inconsistent surface preparation and difficulty in mastering skills required for uniform surface preparation.

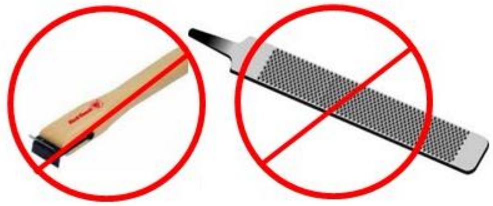


Figure V-d – Not Recommended "Hand Scrapers"

⚠ **Wood rasps and metal files are not acceptable scraping tools.**

VI. FITTING CLAMPING

Electrofusion fittings generate significant pressure from thermal expansion during the melt phase of the fusion process. This melt pressure is an integral part of the fusion process and a designed function of the fitting and fusion parameter. Polyethylene is also a thermoplastic that softens when heated. As a result, all electrofusion fittings shall be installed with the use of alignment and restraining clamps. (Fig. VI-a)

Figure VI-a - Fitting Clamps

Use clamps on all coupling installation that will restrain the pipe ends from moving and keep the pipes in alignment. Some coupling clamp designs also serve to re-round the pipe when placed on either side of the fitting.

Saddles require clamps to secure the fitting to the main to prevent movement, restrain against generated melt pressure, and in some cases to form the fitting to the contour of the main. Saddles are designed to be used with a particular clamping device. Clamping devices are typically not interchangeable from one fitting design or main size to another. In some cases clamping devices may be a part of the fitting (commonly referred to as under-parts) that are intended to remain in place after fusion (Fig. VI-b). Specific instructions for clamping and/or fastener tightening are provided by the fitting manufacturer and must be followed.

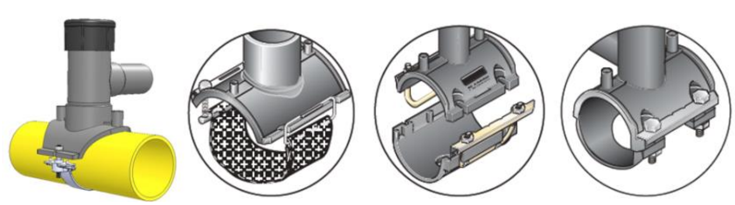


Figure VI-b - Integral saddle clamps that remain in place after fusion

Other designs include a clamp that is re-usable (Fig. VI-c) and is removed after the fitting is cooled.

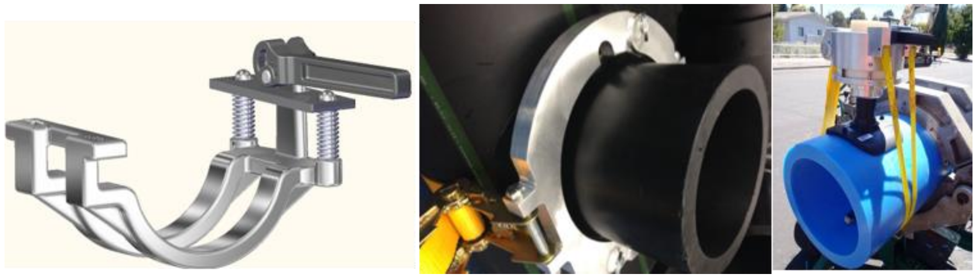


Figure VI-c - Reusable saddle clamps

Note: Consult manufacturer for nylon type strap tools that are intended for multiple use regarding frequency of strap replacement interval.

VII. CONTROL BOX

Electrofusion control boxes, sometimes referred to as processors, perform vital functions during the fusion process. The control box provides carefully regulated voltage for the required fusion cycle time resulting in the designed energy required for fusion. During the fusion process, the control box also monitors the power being supplied to the fitting and can detect certain assembly or fitting errors such as shorted heating coils or short-stabbed pipe ends.

When using the fitting barcode, the control box checks the ambient air temperature and automatically adjusts the fusion time for that temperature if the fitting barcode requires it.

Adjustment of the fusion time for higher or lower ambient temperature is referred to as "temperature compensation". Not all fittings require temperature compensation, but all barcodes contain two characters that define whether the feature is used or not. If in doubt, use the barcode.

Let the control box acclimate to the jobsite weather conditions for minimum period of 15 minutes to ensure that it accurately measures ambient temperatures before beginning the fusion process.

The control box will terminate a fusion process when any defined protocol is out of range and will display an error message. Control boxes have a list of error message definitions affixed to the unit for reference if an error occurs. A record of each fusion, as well as the result of the fusion cycle, is stored and is downloadable via a USB connection. Displayed error codes are unique to each manufacturer- refer to manufacturer's user manual for interpretation.

Control box fusion cables tips can be changed or adapted to fit the size of the connecting pins on the electrofusion fitting. There are two sizes of fitting connecting pins, 4.7mm and 4.0mm.

The control box manufacturer recommends regular calibration intervals, typically every 1 to 3 years, to ensure that all monitored parameters are measured accurately and the control box is functioning normally. Units that are past their calibration interval will normally alert the operator at power-up, but will continue to function when acknowledged.

VIII. POWER REQUIREMENTS

Control boxes are typically available in 120v or 240v versions. The control box monitors the energy input from the power source to ensure that fluctuations from the generator are within designed tolerances and alerts the installer when parameters fall out of range. Control boxes are typically tolerant to small fluctuations in input voltage or frequency, however not all generators or inverters are equal. When an assembly is known to have been completed correctly, and there is an error or failure, the cause can usually be traced to the power supply. It is important to ensure that the power supply is in good working order and capable of supplying the required energy for the fitting being fused.

Each electrofusion fitting has an integral heating coil that requires a defined amount of energy input to achieve the designed results. Heating coils are engineered specifically for a fitting size or configuration and power requirements will vary from one manufacturer to another for the same size fitting. The fitting manufacturer can provide specific requirements for its particular products, but Table VIII-a can be used as a guide for most fittings that are commonly available:

Table VIII-a – Input Power Requirements

FITTING TYPE	FITTING SIZE	GENERATOR MINIMUM (WATT)	BREAKER MINIMUM 120v / 240v	EXTENSION CORD 25 ft.	EXTENSION CORD 50 ft.
SOCKET*	3/4" to 2"	2500	15 / 15 AMP	#10/3	#8/3
SOCKET*	3" to 12"	5000	30 / 20 AMP	#10/3	#8/3
SADDLE	ALL	2500	15 / 15 AMP	#10/3	#8/3

*Socket includes couplings, tees, elbows, reducers, and caps.

Extension cords can be used, however the wire gage should not be less than that shown in Table (VIII-a) for the maximum length.

Consult the control box manufacturer for further details on recommended generator or inverter needs. Note: Do not use a welding generator to power the fusion processor.

CAUTION: The rated capacity of a generator is less than the peak generator capacity; use the lower of the two stated capacities. Capacity is further reduced by the age of the generator. The generator governor control must be turned off and the warmed up generator running at full speed before fusion begins to provide constant generator electrical output. Users must verify/qualify the output of generator on a minimum annual basis, or at the start of each contractor's project and approved/tagged accordingly. Generators are a potential source of inadequate fusion due to inadequate power supply. Verify the performance of generators by test sets such as http://www.sotcher.com/Load_Bank_Generator_Test_Sets

IX. FUSION PARAMETERS

Fusion parameters such as fusion time, voltage, and cooling time, can be entered into the control box by various means:

A. All electrofusion fittings have a barcode attached that contains all of the information needed by the control box to perform the fusion process. Barcodes contain additional information about the fitting manufacturer, fitting size, fitting resistance, and temperature correction values if required by the fitting manufacturer.

   1. Codes are displayed on the fitting label in an interleaved barcode format that can be read by a barcode wand or hand-held scanner. Bar code scanners should be kept clean to insure proper working order.

   2. Because of limitations in the number of characters allowed by the barcode standard, DIPS fittings may not accurately display sizing standard (DIPS) on EF processor. DIPS sizes may display as the metric (mm) equivalent, or as IPS. Consult EF processor or fitting manufacturer for further information.

   3. The 24-digit numerical value is also printed on the label, either directly above or below the barcode (Fig. IX-a) that can be entered into the control box in in the event that the code cannot be scanned.

EF COUPLING 1 CTS FT30sCT5M 12062462

951320308152401207030114

Figure IX-a – Barcode with Numerical Value

B. Identification resistors (Fig. IX-b) are supplied in some fitting designs that can be read by a compatible control box to automatically set the fusion time, voltage, and cooling time. The resistor pin is usually identified by a colored insert in the center of the pin that can be matched to a colored end of the control box cable.

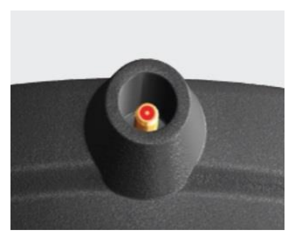


Figure IX-b – Identification Resistor

C. Manual entry of fusion time and voltage entry may be possible if printed on the fitting label (Fig. IX-c). The fusion time is typically preceded by the word "WELD" or "FUSE" and displayed in seconds. The voltage is displayed and followed by "V". It is always preferable to use the bar code method. All PE EF fittings are manufactured using PE 4710/PE100 and must be fusible to the piping system.

EF CPLG,8,IPS,,BLK,PE3408/PE4710,CEC,4.
7R,40V,FUSE 500S,COOL 20M,,,ASTM
D2513/F1055 – GAS,AWWA C906 FM 1613 CL200

Figure IX-c – Label for Manual Entry of Fusion Values

X. ELECTROFUSION INSTALLATION TRAINING PROCEDURES

A. COUPLING INSTALLATION:

1.) Cut the pipe ends (Fig X-a) squarely and evenly. (±3 degrees)

Figure X-a – Cut Pipe Ends

2.) Clean the pipe ends (Fig. X-b) by removing dirt, mud, and other debris. Clean water can be used for initial cleaning of pipe surfaces prior to scraping. Clean the pipe for a length far enough beyond the area to be fused to ensure that remaining debris on the pipe surface will not be transferred to the area to be prepared during handling. Dry with a clean cotton towel.

Figure X-b – Clean Pipe Ends

3.) Measure and mark the stab depth on the pipe ends (Fig. X-c). If stab depth marks are not indicated on the outside of the coupling, measure the total length of the coupling to be installed and make a mark on both pipe ends equal to ½ the length of the coupling. This mark is used as visual indication by the installer that the pipe ends are correctly inserted to the center of the coupler. Check the pipe surface for any embedded debris that may cause damage to scraping tools, and once more make sure that the outer pipe surface is clean and free of any dirt or mud that could re-contaminate the scraped pipe surfaces. Mark the entire pipe surface to be scraped with longitudinal and/or circumferential lines.

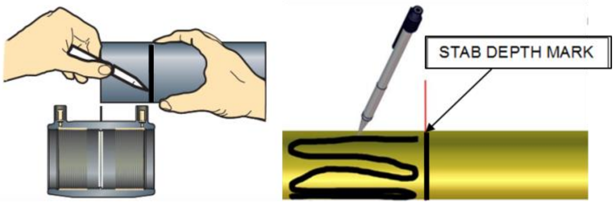


Figure X-c- Measure and mark Stab Depth

When making a repair, or in situations where the coupling must slide completely over one of the pipe ends, scrape that pipe end for the entire length of the coupling (Fig. X-d).

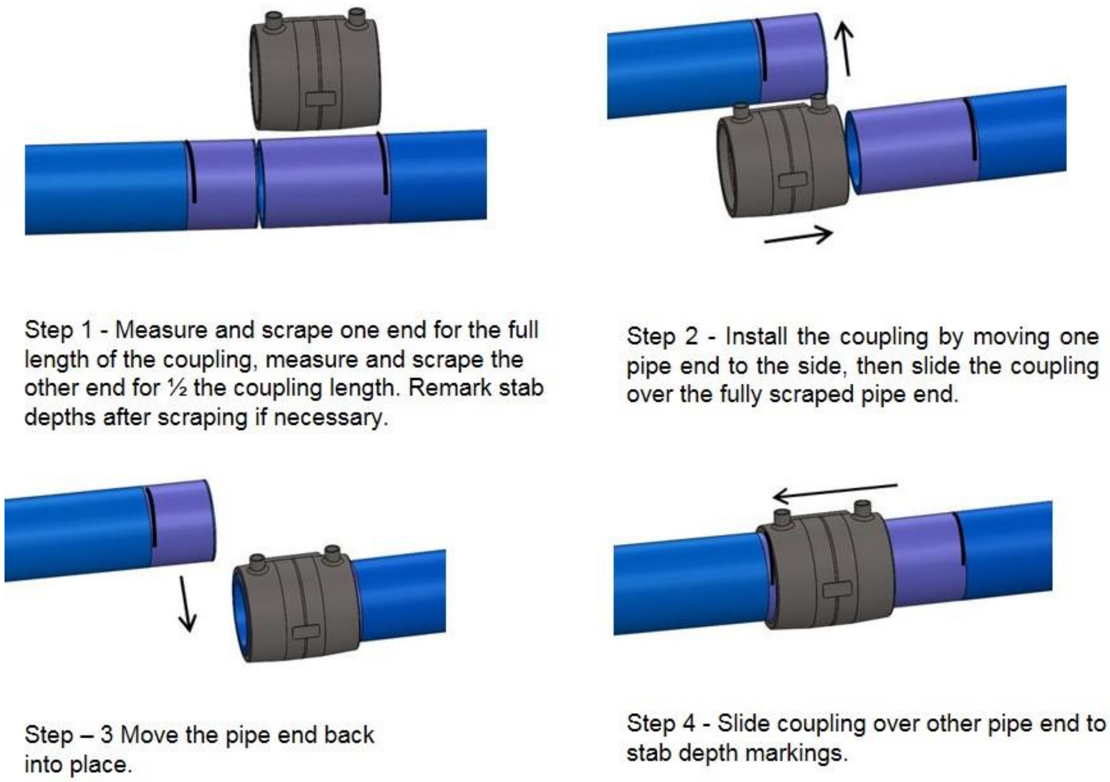


Figure X-d – Repair of Couplings Over Entire Pipe End

4.) Scrape the outside of the pipe surface to remove oxidation and other contaminates (Fig. X-e). Use an appropriate scraping tool as described in the PIPE PREPARATION section of this guide. Scrape the pipe surface until the outer layer or "skin", at least .007" thick, of the pipe has been removed to expose a clean, virgin pipe material. Remove longitudinal or circumferential markings made in step 3. Inspect the entire scraped area to ensure total scraping coverage.

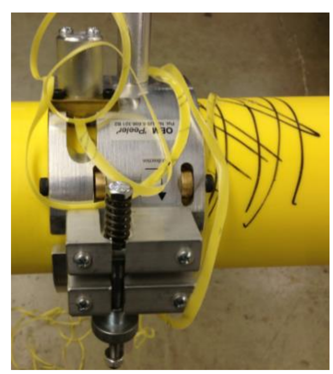


Figure X-e – Pipe Scrapping

⚠ **While not common, it is possible to remove too much surface material by repeated scraping. Removal of .020" on 4" or smaller, or .040" on larger sizes is the maximum. Use caution if scraping multiple times to ensure that the pipe OD is not reduced to the point that the gap between the pipe and fitting is too large.**

5.) Avoid touching the scraped pipe surface or the inside of the coupling as body oils and other contaminates can affect fusion joint performance. If the surfaces become contaminated, clean thoroughly with a clean, lint free towel and a minimum 96% concentration of isopropyl alcohol and allow to dry before assembling. Do not use alcohol with any additives other than water.

⚠ **CAUTION: AVOID ALL POSSIBLE RECONTAMINATION OF THE PREPARED SURFACE.**

⚠ **Do not use Denatured Alcohol.**

6.) Slide the coupling over the scraped pipe ends to the stab depth markings. If the pipe is out of round, a clamp can be used to re-round before sliding the coupling onto the pipe. If needed, a block of wood can be placed over the coupling end and a hammer can be used to drive the coupling onto the pipe. Use caution that the connecting pins are not damaged.

Note: Pipe ends should be beveled on the outer edges when installing couplings that incorporate bare exposed heating wires to prevent snagging of wires on pipe edge.

When one of the pipes to be joined has limited movement capability, it may be necessary to slide the coupling onto the pipe for its full depth before placing the other pipe in place. If the full coupling must be placed on one pipe end, that pipe end should be cleaned and scraped for the full depth of the coupling to avoid contamination. The depth mark on the opposite pipe can be used for centering the coupling assuming that the two pipe ends are in contact (Fig X-f).

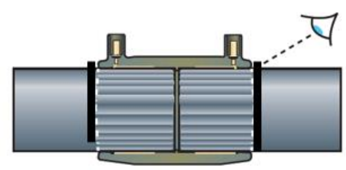


Figure X-f – Center Couplings Between Depth Marks

7.) Clamp the pipe ends to align and secure the assembly (Fig. X-g).

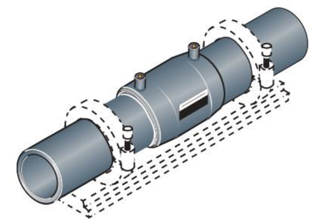


Figure X-g – Clamp and Secure

8.) Connect the fitting to the control box (Fig. X-h), enter the fusion parameters (bar code scan the fitting), and fuse the joint. See “Fusion Parameter” section for details.

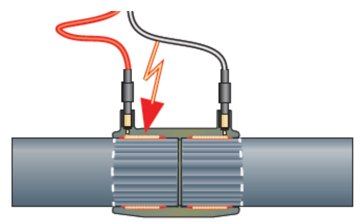


Figure X-h – Connect Fitting to Control Box

9.) Mark the time of day on the fitting when the fusion cycle has ended.

10). Allow the fused fitting and pipe assembly to remain clamped and undisturbed for the minimum recommended cooling time.

⚠ **Cooling is a vital part of the fusion process. Proper cooling times must be observed and fused joints should not be disturbed until the proper cooling time has elapsed. See "clamping" section of this guide for further details.**

B. SADDLE INSTALLATION:

1.) Clean the pipe (Fig. X-i) by removing dirt, mud, and other debris. Clean water can be used for initial cleaning of pipe surfaces prior to scraping. Clean the pipe for a length far enough beyond the area to be fused to ensure that remaining debris on the pipe surface will not be transferred to the area to be prepared during handling.

Figure X-i – Clean Pipe

2.) Mark the area on the pipe where the saddle is to be installed (Fig. X-j). This mark is used by the installer to indicate the approximate size of the area to be prepared. Check the pipe surface for any embedded debris that may cause damage to scraping tools, and once more make sure that the outer pipe surface is clean and free of any dirt or mud that could re-contaminate the scraped pipe surface. Mark the entire pipe surface to be scraped with longitudinal and/or circumferential lines.

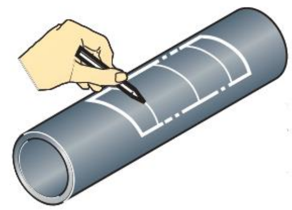


Figure X-j – Mark Installation Area

3.) Scrape the outside of the pipe surface (Fig. X-k) to remove oxidation and other contaminates. Use an appropriate scraping tool as described in the PIPE PREPARATION section of this guide. Scrape the pipe surface until the outer layer or "skin", at least .007" thick, of the pipe has been removed to expose a clean, virgin pipe material. Remove longitudinal or circumferential markings made in step 3. Inspect the entire scraped area to ensure total scraping coverage.

Figure X-k – Scrape Pipe

4.) Avoid touching the scraped pipe surface or the fitting fusion surface as body oils and other contaminates can affect fusion joint performance. If the surfaces become contaminated, clean thoroughly with a clean, lint free towel and a minimum 96% concentration of isopropyl alcohol and allow to dry before assembling. Do not use alcohol with any additives other than water.

⚠ **CAUTION: AVOID ALL POSSIBLE RECONTAMINATION OF THE PREPARED SURFACE.**

⚠ **Do not use Denatured Alcohol.**

5.) Place the saddle over the scraped pipe surface (Fig. X-l). Ensure that the fitting fusion surface is only in contact with the <u>scraped</u> pipe surface.

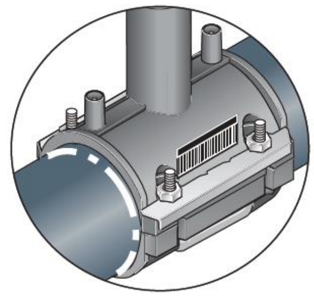


Figure X-l – Place Saddle Over Scraped Surface

6.) Secure the saddle-to-pipe assembly with the appropriate clamping mechanism required by the fitting manufacturer. If bolts are used in the clamping device, make sure they are tightened in the proper sequence and the required amount of torque /engagement per the manufacturers' instructions. See "clamping" section of this guide for further details.

⚠ **Use only the clamps provided or required by the fitting manufacturer. Clamps from one manufacturer's fitting are not interchangeable with another's.**

7.) Connect the fitting to the control box (Fig. X-m), enter the fusion parameters, and fuse the joint. See "Fusion Parameter" section for details.

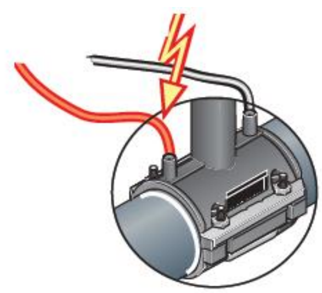


Figure X-m – Connect Fitting to Control Box

8.) Allow the fused fitting and pipe assembly to remain undisturbed for the minimum recommended cooling time.

⚠ **Do not tap saddle fittings until after observance of minimum cooling time**

9.) Mark the time of day on the fitting when the fusion cycle has ended. If required by the pipeline owner, include installer and installation information such as the date, operator identification number, fusion ID card number, contractor name, fusion machine identification number, etc.

⚠ **Cooling is a vital part of the fusion process. Proper cooling times must be observed. See “clamping” section of this guide for further details.**

C. INSTALLATION INSPECTION CHECKLIST:

1. SQUARE CUT (±3 Degrees)
The square-ness of the cut can be checked (if needed) by placing a square at the end of the pipe at its longest point and measuring the resulting gap between the square and shortest point of the cut (Fig. X-n). Table (X-a) indicates the resulting maximum measured gap when the cut angle is approximately 3 degrees from square.

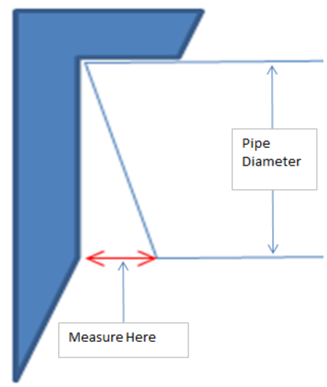


Figure X-n – Check for Square-ness

Table X-a – Maximum Measured Gap

Pipe or tubing size	Gap between square and pipe end to result in approximately 3 degree angled cut
1/2 CTS / IPS to 1 1/4 CTS / IPS	1/16"
1 1/2 & 2 CTS / IPS	1/8"
3 IPS / DIPS	3/16"
4 IPS / DIPS	1/4"
6 IPS / DIPS	3/8"
8 IPS / DIPS	1/2"
10 IPS / DIPS	9/16"
12 IPS / DIPS	5/8"

2. SCRAPING
A properly scraped pipe has a thin outer layer of the pipe surface removed to expose clean virgin PE material for fusion. Visual indicators can be very helpful to ensure that all of the surface has been scraped, and that an adequate amount has been removed. Marking the pipe surface with a permanent marker is a simple and effective step. Using the pipe print line as a depth indicator is also useful, but should not be used as the only means to determine that proper scraping has been accomplished. (Refer to Fig. X-o and Fig. X-p for correct and incorrect scraping.)

Mark insertion depth | Mark entire surface to scrape | Scrape surface | Marks completely removed

Figure X-o - Correct Scraping

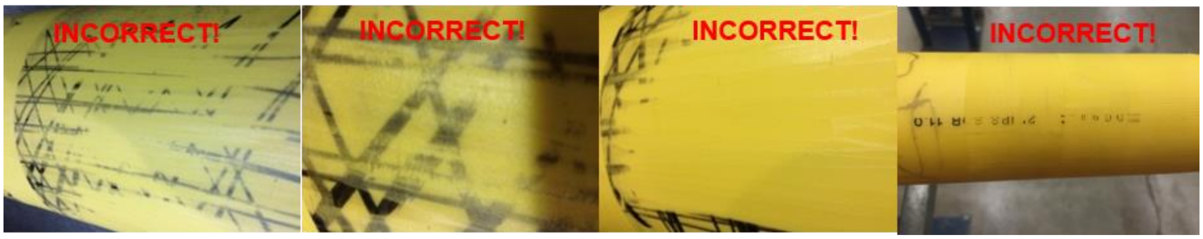


Figure X-p - Incorrect Scraping! Improper surface preparation / Not enough material removed, marks still visible.

3. CLAMPING/ASSEMBLY/ALIGNMENT
   Clamps are necessary to ensure that the pipe ends are properly aligned and rounded, that no external stresses are exerted on the fitting or assembly, that no movement occurs during the melt and cooling phases, and that saddle fittings are held in place with the correct amount of pressure (Fig. X-q)

Stab depth is correct | Alignment clamps used | Appropriate saddle clamp used

Figure X-q

4. FUSION
   - Ensure that the generator or power source is adequately sized for the fitting being fused.
   - Ensure that the power source has an adequate supply of fuel to complete the fusion cycle.

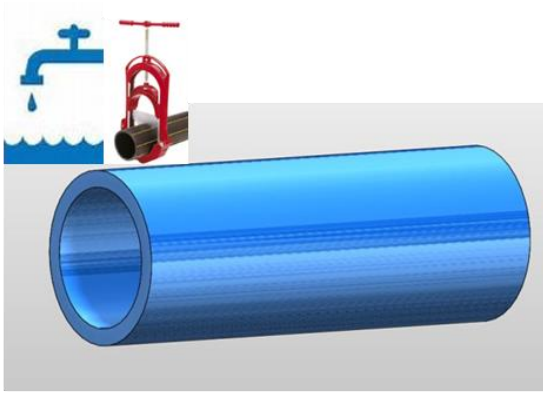
- Ensure that any extension cords are appropriately sized for the fitting being fused. See previous comments on generator.

5. CLAMPING
Ensure that the proper clamps are in use and that the joint assembly is properly aligned.

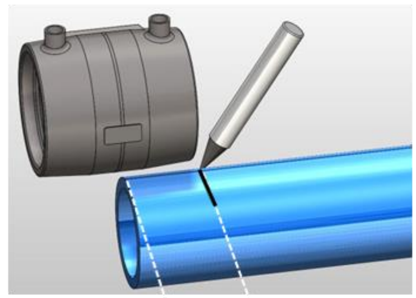
6. COOLING
Mark the time on or near the fitting to indicate when the minimum cooling time has elapsed. This will prevent inadvertent movement or removal of the assembly and/or clamps. If required by the pipeline owner, include installer and installation information such as the date, operator identification number, fusion ID card number, contractor name, fusion machine identification number, etc.

⚠ **Do not allow pipe and fitting to be moved or exposed to stress before the minimum cooling time has elapsed!**

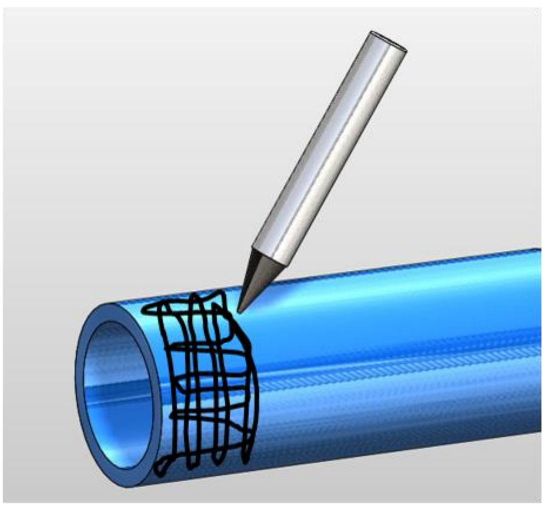
XI. FIELD GUIDE FOR ELECTROFUSION COUPLING INSTALLATION



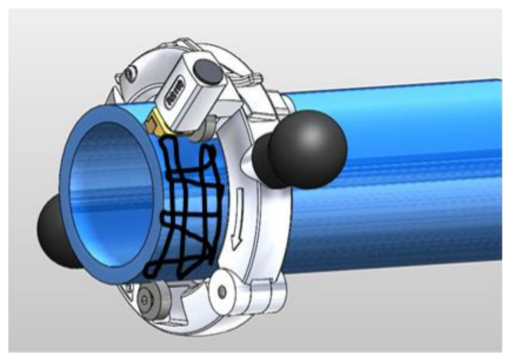
1. Clean pipe ends with clean water and cut as squarely (± 3 degrees) as possible.



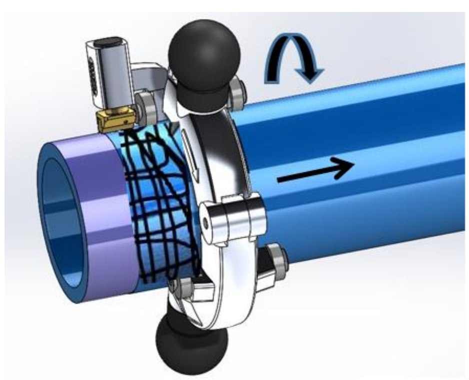
2. Measure and mark the stab depth on both pipe ends



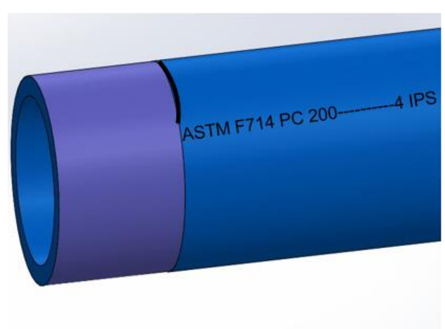
3. Mark the pipe surface to be scraped in a criss-cross pattern.



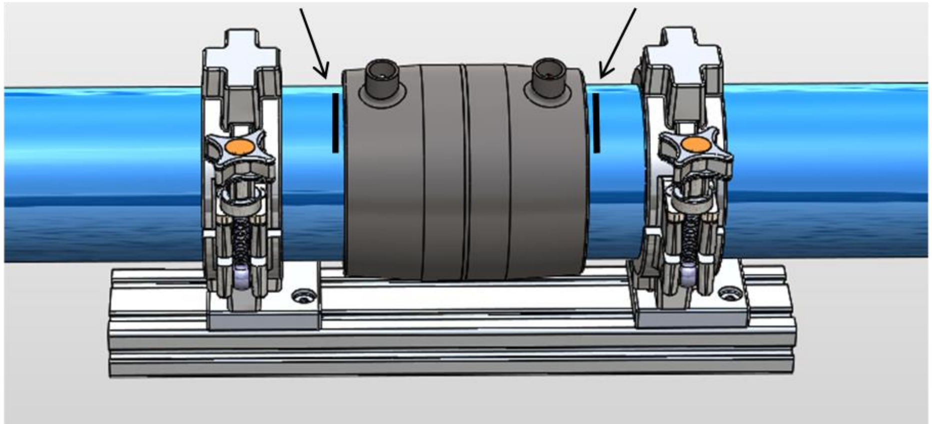
4. Mount the scraper over the area to be scraped.



5. Scrape or peel the pipe to remove the surface layer and expose clean virgin pipe beneath.

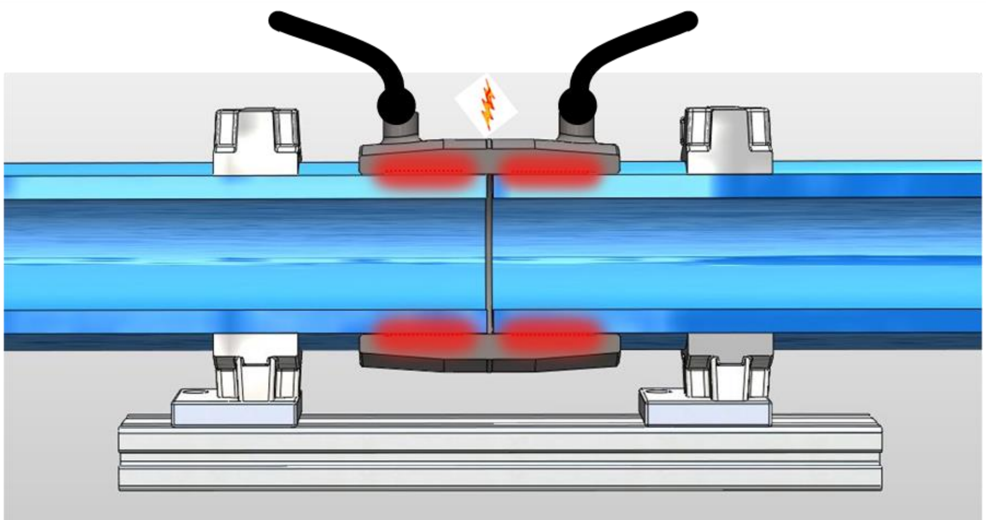


6. Inspect the scraped pipe surface thoroughly to ensure that all marks are removed and that only virgin pipe surface is exposed.



7. Clean surfaces with Isopropyl alcohol if necessary, avoid touching cleaned surfaces.

8. Insert the pipe ends to the stab depth marks made in step one.
Secure in alignment clamp with coupling centered between stab depth marks.

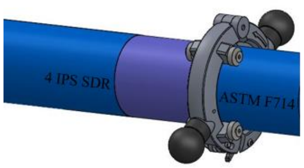


9. Connect the control box leads to the fitting and fuse the joint. Do not move or disturb joint for the recommended cooling time. Mark time of day on fitting when fusion cycle ends.

XII. FIELD GUIDE FOR ELECTROFUSION SADDLE INSTALLATION

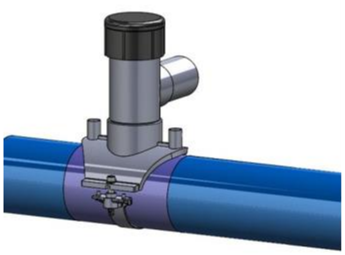
1. Mark position of saddle on pipe.

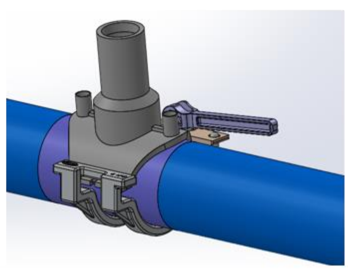
2. Mark pipe surface in area to be scraped.



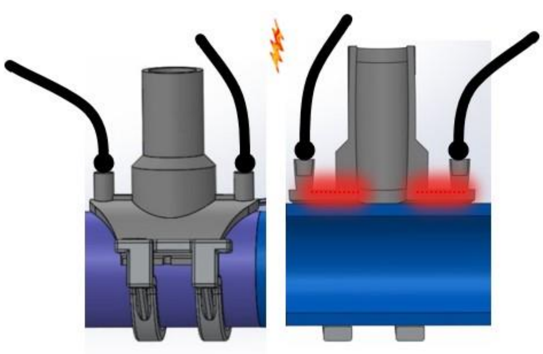
3. Scrape or peel the pipe to remove the surface layer and expose clean virgin pipe beneath.

4. Inspect the scraped pipe surface thoroughly to ensure that all marks are removed and that only virgin pipe surface is exposed.





5. Clean surfaces with Isopropyl alcohol if necessary, avoid touching cleaned surfaces. Clamp saddle to the scraped pipe using only the clamp provided or recommended by the fitting manufacturer.



6. Connect the control box leads to the fitting and fuse the joint. Do not move or disturb the joint for the recommended cooling time. Mark the time of day on fitting when fusion cycle ends. Picture to left shows clamps to pipe and picture to right shows EF.

XIII. FREQUENTLY ASKED QUESTIONS

A. What pipes can be fused with electrofusion fittings?
   1. Electrofusion fittings are compatible with pipe dimensions conforming to ASTM D2513, F714 and D3035.
   2. Fittings are typically compatible with pipes with a SDR or DR range of 9 to 17. Other wall thickness ranges and pressure ratings may also apply. Consult the specific fitting manufacturer for details.
   3. Electrofusion fittings are fusible to PE 2406/2708 and PE3408/3608/3708/3710/4710 pipes.

B. What are the power requirements?
   1. A reliable source of AC power is necessary for a successful fusion.
      a. Generator – well maintained generator meeting the capacity requirements shown in the Table under "POWER REQUIREMENTS".
         i. Generator should have enough fuel to complete the electrofusion cycle.
         ii. The governor/economy switch should be off so that the throttle is opened all the way in anticipation of the power draw at the start of the fusion cycle.
      b. Provide output voltage in the range that meets the specifications of the applicable processor model.
      c. Operate within a frequency range of 50 to 60 Hertz.
      d. A matching outlet is needed to mate with the plug equipped on the electrofusion processor. 110V/120V models – 30 Amp, 125 Volt, NEMA L5 twist lock.

C. Can I use an extension cord with my processor?
   1. The use of extension cords should be avoided;
      a. In the event an extension cord must be used a 25 foot cord should have a wire gage of #10/3 and a 50' cord should have a wire gage of #8/3.

D. Can I use a pigtail with my electrofusion processor? Not for field installations.

E. What are the most common electrofusion failures?
   1. Electrofusion has proven to be an extremely reliable joining system. The most common reasons for failure account for more than 95% of all fusion failures:
      a. Contamination – poor pipe preparation
         i. Poor scraping
         ii. Dirt, mud, dust
         iii. Grease, oils
         iv. Moisture
         v. Hands (body oil, sunscreen, etc.)
         vi. Solvents, unsuitable wiping fluids
         vii. Unclean or unsuitable wiping rags
         viii. Over Scraping

b. Geometry – pipe out of round or not cut square
   i. Alignment Errors
      a) Pipe Mis-Stab – pipe not cut square and pipe ends not being centered in the fitting.
      b) Short Stab – can result from improper insertion of the pipe or movement during weld due to incorrect restraint
      c) Excessive Gap – excessive gap between pipe and fitting due to pipe out of roundness, undersized pipe or over scraping of pipe surface.
      d) Pipe Movement during Fusion Cycle – due to external forces or forces induced by the welding process, when the pipes are not clamped properly.
      e) Movement – pipe not properly restrained during fusion process
      f) Unusual conditions - Contact EF manufacturers if smoke or melt flow outside the fitting is observed.

c. Removal of clamping equipment before observance of minimum cooling times.

F. Can I use sandpaper, dragon skin or emory cloth to clean the PE pipe?

1. No, it is very important to note that abrasive materials such as sand paper, dragon skin or emory cloth should never be used in place of an approved scraping tool. Abrasive materials have been proven to be ineffective in the removal of sufficient amounts to surface material needed to achieve an electrofusion bond and in fact have been shown to impede the electrofusion process. See “SCRAPER” section of this document.

⚠ **Wood rasps, metal files, or paint scrapers are not acceptable for cleaning PE pipe.**

G. Why does the fitting need to observe the entire cooling time prior to pressure test or backfill?

1. One of the most misunderstood and often ignored components of the entire electrofusion process is the cooling phase. It is often assumed that if the fitting is cool enough to touch it must be cool enough to remove the restraint device or even pressure test the connections. The cooling phase is critical to the success of the electrofusion process and careful attention should be given to insure that the stated cooling times are properly adhered to (refer to fitting manufacturer for specific fitting cooling times).
2. When current is applied to the fitting the plastic in the fitting and on the pipe surface begins to melt and form a melt pool. With continued application of current the melt pool deepens at the pipe and fitting interface which in turn forces internal pressure to build up. After the heating phase, the melt pool re-solidifies. This process is known as co-crystallization between the melted pipe and fitting material. The cooling phase provides a controlled environment between the pipe and fitting where solidification can effectively take place. This cooling phase begins immediately following the termination of current being supplied to the fitting and continues for a period of time beyond the point where the PE polymer re-solidifies (also known as clamping time). This allows ample time for the fusion area to regain the strength and flexibility it exhibited prior to fusion. Any movement or external stresses

applied to the fused area during this cooling phase may result in a compromised fusion joint.

H. Do I need to use clamps?
1. Electrofusion couplings:
   a. Electrofusion couplings (regardless of manufacturer) require the pipe to be restrained or sufficiently supported on each side of the pipe to restrict movement during the fusion and cooling process and alleviate or eliminate sources of stress and/or strain until both the fusion cycle and the cooling cycle are completed.
   b. To achieve this we recommend the use of some form of pipe restraint and/or support for the primary purpose of controlling and eliminating any movement of the fitting due to fusion pressures generated during the fusion process and/or any external forces exerted on the pipe or fitting. The basis for using a pipe restraint system and/or support when joining two pieces of PE pipe with an electrofusion coupling is to:
      i. Minimize potential short stab, mis-stab or binding situations
      ii. Ensure proper cold zone contact with the prepared fusion area so that sufficient interfacial pressure is built up
      iii. Eliminate unwanted loss of molten material from the fusion zone
2. Electrofusion saddles
   a. Electrofusion saddle fittings include tapping tees, branch saddles, corp saddles and others. Installation of an electrofusion saddle requires the use of recommended restraint systems for the purpose of:
      i. Holding the fitting in place during the fusion process
      ii. Eliminating fitting movement due to material expansion
      iii. Ensuring proper cold zone contact with the prepared fusion area so that sufficient interfacial pressure is built up

⚠ **To ensure good joint integrity during the fusion process and recommended cooling time, the joint must remain stationary and free from stress and strains.**

I. Can electrofusion fittings be re-fused if I have a power related failure?
1. Electrofusion fittings can be re-fused only in the event of an input power interruption.
   a. Fusion leads were detached during fusion
   b. Generator runs out of gas
   c. Other circumstances that results in processor input power interruption
2. Recommended procedure for re-fusing fittings:
   a. Fitting should remain in restrained position
   b. Fittings should be allowed to cool to ambient temperature
   c. Fitting should be reconnected to the processor
   d. Fitting should be completely refused for the entire fitting fusion time

⚠ **This re-fusion procedure should only be used for fusions that terminated due to input power reasons. <u>Fittings that fault for any other reason should be removed or abandoned.</u>**

XIV. OPERATOR TRAINING AND QUALIFICATION GUIDELINES

A. Scope

1. This section applies to the Generic Electrofusion Procedure for Field Joining of Polyethylene (PE) Pipe and specifies the method of testing the knowledge and skill of an operator who is authorized to perform electrofusion joining to polyethylene pipe up to 12” in diameter. The examination of an operator is essential for the assurance of the operator’s skills and quality of electrofusion work. The application of this section is intended to ensure that the examination is carried out according to a uniform and standard test method.

B. Training and Qualification

1. Any operator that performs or inspects electrofusion joints on polyethylene (PE) pipe should successfully complete an annual electrofusion training program or more frequently if required.
2. During the test, the operator shall demonstrate practical skill and knowledge of electrofusion joints on PE pipe.
3. The test will be carried out in two parts under the direction of the utility or operator qualifying organization.
    a. The operator will answer questions relevant to electrofusion qualification testing. The questions will be presented to the operator in written form. The written test will be a True/False and/or multiple choice questionnaire. The operator must answer all questions correctly! 100% is the only passing grade.
    b. The operator will perform a minimum of two electrofusion joints adhering to the Generic Electrofusion Procedure. A 2 inch or larger coupling and 2 inch or larger main size saddle type fitting are recommended. This will qualify the operator for electrofusion joining up to and including 12 inch.
        i. The utility or operator qualifying organization will provide a suitable environment for qualification testing of the operator. The utility or operator qualifying organization will supply the operator with all necessary fittings and tools for electrofusion joining and testing. At owners’ discretion, Contractors should supply all tooling, power supplies, fittings and pipe similar to actual field conditions so the Owner can inventory tooling, verify quality of tooling and generator performance including any extension cords intended for work. A controlled environment is not a field condition.
        ii. Owner shall witness the entire fusion procedure and all required steps to perform fusion. If anything is skipped or inadequately performed including observing cooling time rejection of the operator is required and the prepared fitting will not be failure tested. If and only if all of the required steps are conducted, all of the required tooling is used and in good working order and proper cooling time observed is the fitting failure tested.
        iii. The fuser will make and submit electrofusion joints for approval via the attached destructive testing procedures in Section D.

4. Individuals who successfully complete both sections of the testing will be qualified to perform electrofusion joints on polyethylene piping up to and including 12 inch.
   Operators must requalify annually, or more frequently if any failures are encountered since the last qualification. Fusion failures are defined as connections not allowed to be put into service. If a fitting fails during fusion or by observance after installation but before being put into service it does not count as a joint failure (it is okay and encouraged for the fuser to cut out bad joints).

C. Electrofusion Joint Failures
   1. Electrofusion joint failures that are detected during air pressure tests or connection bubble tests are subject to the provision set forth in Section E.
   2. The utility or pipeline owner may elect to perform additional testing or require the electrofusion joint (saddle only) to be abandoned in place or cut out at its discretion.

D. Destructive Testing Procedures for Electrofusion Fitting Qualification
   The following test methods are useful as an evaluation of bonding strength and fusion quality between the pipe and fitting. These procedures are based on requirements from ASTM F1055 Standard *Specification for Electrofusion Type Polyethylene Fittings for Outside Diameter Controlled Polyethylene Pipe and Tubing* Fusion Evaluation Test section. Refer to ASTM F1055 for more detailed test requirements. These tests can be used as user qualification criteria as defined in DOT CFR 49 Part 192.283 and 192.285. As these methods are destructive, they are only useful in determining joint quality of a fitting that was fused for the purpose of testing, and cannot be used for testing of fusions intended for service.

   1. Couplings:
      After all relevant information is gathered, the fitting should be cut and subjected to joint evaluation tests. Bend tests, peel tests, and crush tests are helpful in locating fusion weaknesses. It is desirable to obtain x-ray photographs of the fitting before dissection to locate any possible contact points of the fusion coil.

      To prepare a specimen for crush testing, it is necessary to cut the pipe and coupling longitudinally in half as near to the centerline of the pipe and coupling as possible. It is desirable to leave at least 3"(75mm) to 5"(125mm) of pipe length at each end of the coupler.

      Place a specimen half in a vise so that the outermost wire of the fusion zone is approximately 1 1/4" (32mm) from the vise jaws. (Fig. XIIV-a)

Close the vise jaws until the pipe walls meet. (Fig. XIIV-b) Repeat this process for each end of both halves of the coupling.

Inspect the crushed specimens for separation of the pipe and fitting in the fusion zone. Some minor separation (up to 15% measured as shown in the following examples) may be seen at the outermost region of the fusion zone, this does not constitute failure. Ductile failure of the pipe, fitting, or PE insulation around the wires is acceptable. There should be no separation at the fusion interface of the pipe and fitting. Passing (Fig. XIIV-c) and failing (Fig. XIIV-d) results are shown in the photographs.

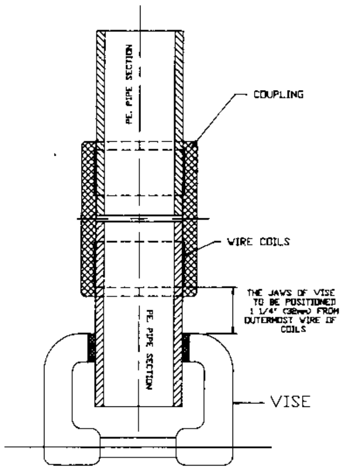


Figure XIV-a

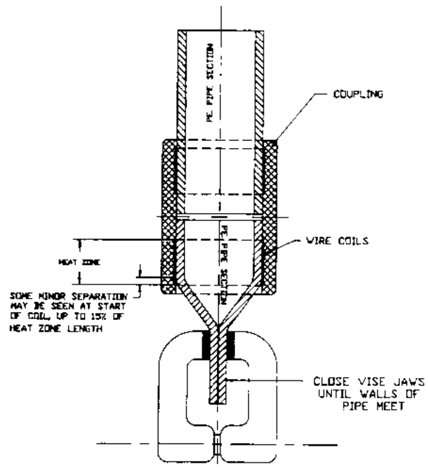


Figure XIV-b

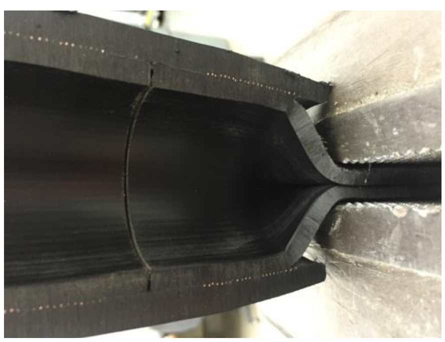


Figure XIV-c - Pass

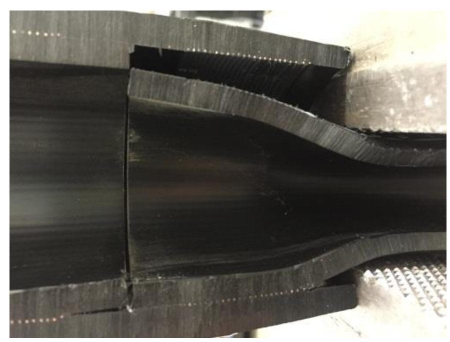


Figure XIV-d- Fail

2. Saddles/Tapping Tees

Tapping tees should be left intact for crush testing. Pipe lengths can be cut to the edges of the fitting base.

Place the pipe and fitting into a vise (or suitable press) so that the jaws are within 1/2" (13mm) of the bottom of the saddle (Fig. XIV-e). Close the vise until the pipe walls meet **(**Fig**.** XIV-f).

Inspect the crushed specimens for separation of the pipe and fitting in the fusion zone. Some minor separation (up to 15%) may be seen at the outermost region of the fusion zone, this does not constitute failure. Ductile failure of the pipe, fitting, or PE insulation around the wires is acceptable. There should be no separation at the fusion interface of the pipe and fitting. Passing (Fig. XIV-g) and failing (Fig. XIV-h) results are shown in the photographs.

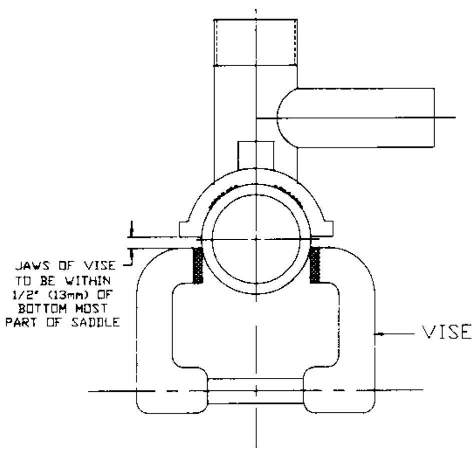


Figure XIV-e

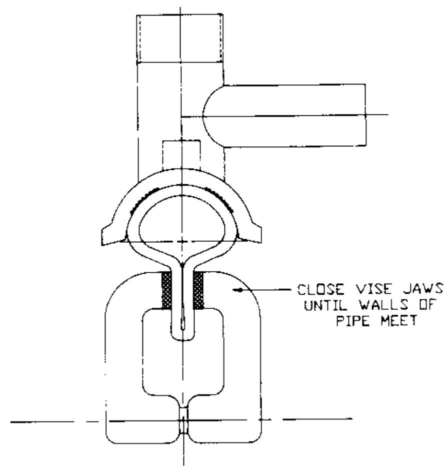


Figure XIV-f

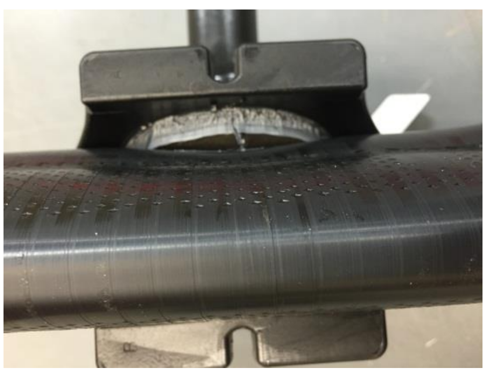


Figure XIV-g – Pass

Figure XIV-h - Fail

Further evaluations are possible by cutting the fusion area and surrounding pipe and fitting materials in thin longitudinal /cross sectional strips for bend tests. The strips are then placed into a vise and bent 90 degrees in both directions directly at the fusion interface and evaluated for separation. The same visual criteria are used for fusion evaluation tests as is used for crush tests (Fig. XIV-i).

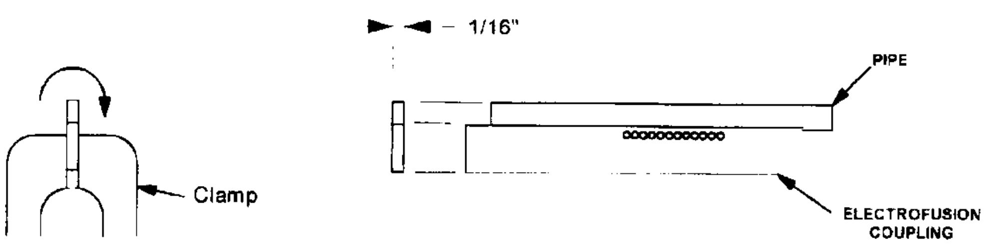


Figure XIV-i

Couplings should have four longitudinal strips cut from the fusion interface at 90° intervals as shown (Fig. XIV-j). The strips should be approximately 1/16"(1.5mm) to 1/8"(3mm) in thickness. The strips are then placed into a vise and bent 90 degrees in both directions directly at the fusion interface and evaluated for separation.

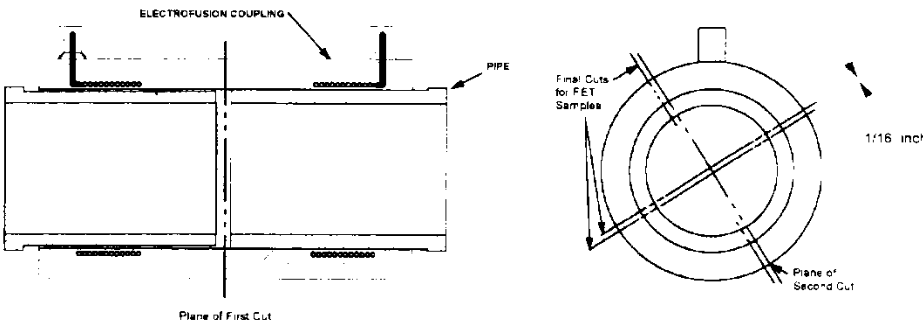


Figure XIV-j

Tapping Tees should have strips cut along the center line of the pipe (Fig. XIV-k) through the fitting fusion surface and a strip cut from the radial side of each half of the fitting, totaling 4 strips for each sample fusion made. The strips are then placed into a vise and bent 90 degrees in both directions directly at the fusion interface and evaluated for separation.

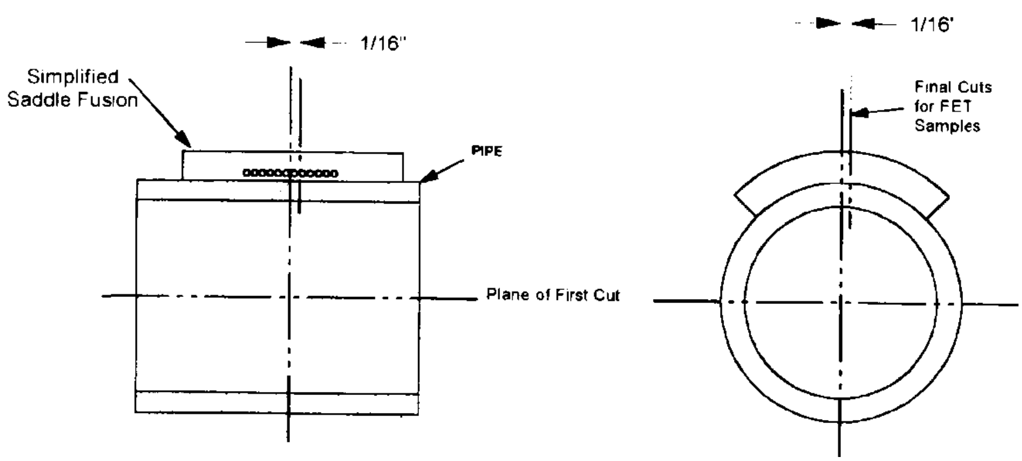


Figure XIV-k

E. Required Re-Qualification and Retraining
   Failed electrofusion joints determined to be caused by improper installation procedures may warrant retraining and/or qualification of the installer. If an operator has failed electrofusion joint(s) under the provision previously listed or is observed using non specified or faulty equipment or not strictly adhering to all fusion procedures that operator will be disqualified from making additional electrofusion joints and will require additional training and requalification before performing any additional fusion joining.

F. Test Result and qualification test certificate

1. The operator shall be presented with a completion certificate (or card) upon successful completion of the MAB Electrofusion Operator and Training & Qualification test valid for one year from date of issuance.
    a. Successful Completion
        i. Operator cannot miss any questions on the written test.
            a) Operator who misses two (2) questions or less can re-address the specific questions with the trainer and re-take written test in its entirety.
            b) Operator who misses more than two (2) questions must re-take both the written and re-submit two (2) additional test specimens for destructive testing.
        ii. Operators must pass the destructive testing on all submitted electrofusion joints.
2. Qualification Test Certificate
    a. Certificate shall contain the following:
        i. Operators Full Name
        ii. Date, Place of Training
        iii. Date of Issue
        iv. Expiration Date of Test Certificate
        v. Signature of Authorized Trainer
3. Failed electrofusion or written Test
    a. Operator shall undergo further education and training prior to re-taking the qualification test.

Appendix A – List of Electrofusion System Manufacturing Companies

The generic Electrofusion procedure has been endorsed by the following Electrofusion companies (listed alphabetically) for use with their Fittings. This list will be updated quarterly if needed.

1. **Agru America**	(800) 373-2478	http://agruamerica.com
2. **Georg Fischer Central Plastics**	(800) 654-3872	www.gfcp.com
3. **Integrity Fusion Products**	(770) 632-7530	http://integrityfusion.com
4. **IPEX Inc.**	(866) 473-9462	http://www.ipexinc.com/
5. **M.T. Deason Company**	(800) 633-7131	http://mtdeason.com
6. **Nupi Americas**	(281) 590-4471	www.nupiamericas.com
7. **Plasson USA**	(800) 241-4175	www.plassonusa.com
8. **Strongbridge-Tega**	(904) 278-7499	http://strongbridge.us/

Appendix B - Generic Electrofusion Operator Training & Qualification Section

DESTRUCTIVE TESTING

Operator Name:____________________ Date:______________________ Location:_________________

Electrofusion Coupling

Fitting Size:
Fitting Manufacturer:
Fitting Fusion Time:
Fitting Cooling Time:

PASS/FAIL:_________________________________

Electrofusion Saddle Fitting

Fitting Size:
Fitting Manufacturer:
Fitting Fusion Time:
Fitting Cooling Time:

PASS/FAIL:_________________________________

Authorized Trainer:_________________________ Date:_________________

Operator Training Card **Card No. #xxx**
(Operator Name)_________________________________
has successfully completed the training requirements for
qualifications to **fuse Electrofusion Fittings** according to
(Utility Name) Department Standards with no restrictions.

Insert Photo

I have instructed and tested the above in all requirements and procedures related to installation of Electrofusion Fittings according to **(Utility Name)** Department Standards.

Authorized Instructor Date Issued Expiration Date

Appendix C – Sample Test

The following is a sample written qualification test.

Users should modify this test to address their unique operating environment.

Generic Electrofusion Operator Training & Qualification Section

Operator Name: ____________________ **Date:** ______________________

Location: ________________

All Questions should be answered with either T for True or F for False. The operator must answer all questions correctly! 100% is the only passing grade.

1. The purpose of scraping is to remove the oxidized layer of PE pipe from the pipe surface prior to electrofusion.
   a. True
   b. False
2. For out of round pipe it is acceptable to scrape the high points until the pipe fits into the electrofusion coupling.
   a. True
   b. False
3. Sand paper, dragon skin, emory cloth, and other abrasives are acceptable for scraping.
   a. True
   b. False
4. If the pipe becomes re-contaminated after scraping it is acceptable to use Isopropyl Alcohol for cleaning purposes.
   a. True
   b. False
5. It is acceptable to perform an electrofusion with a slight trickle of water running across the fusion area.
   a. True
   b. False
6. In case of an input power interruption only, an electrofusion fitting can be refused for the entire fusion time after it has been allowed to cool completely.
   a. True
   b. False
7. Pressurizing, testing, and backfill can be performed immediately after the electrofusion has been completed.
   a. True
   b. False
8. Pipe ends can be cut to within 10° of being completely square.
   a. True
   b. False

9. A 2500 watt generator is recommended for fusing electrofusion couplings (12" and smaller).
   a. True
   b. False
10. Slow drying markers that contain oils should not be used when marking the pipe for scraping.
   a. True
   b. False
11. If the electrofusion coupling is to be pushed completely over one pipe, it is necessary to scrape the entire length of the coupling onto one of the pipes.
   a. True
   b. False
12. A standard metal file is acceptable for scraping the pipe surface.
   a. True
   b. False
13. There is no need to support hanging pipe ends during fusion.
   a. True
   b. False
14. Operators must re-qualify annually or if they make any bad joint.
   a. True
   b. False
15. Observance of pipe printline under saddle fitting fusion area after scraping is acceptable.
   a. True
   b. False
16. A gouge or scratch in the pipe of more than 10% of the wall thickness is acceptable.
   a. True
   b. False
17. An electrofusion joint should not be started if the processor incorrectly identifies the fitting fusion parameters.
   a. True
   b. False
18. Alignment clamps should be used only if the pipes do not line up.
   a. True
   b. False
19. The generator should be checked prior to electrofusion to make sure it is full of gas.
   a. True
   b. False
20. Electrofusion fittings should be kept in original packaging until installed.
   a. True
   b. False

Number Correct: _______

Authorized Trainer: ________________________ **Date:**________________

Municipal Advisory Board

Established May 1, 2008 at the University of Texas, Arlington

MAB Generic Electrofusion Procedure for Field Joining of 14 Inch to 30 Inch Polyethylene (PE) Pipe

(MAB-02-2017)

First edition approved by MAB on November 30, 2017 at the Arlington Water Utilities, Texas
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CONTENTS

FOREWORD
This procedure was developed by the Municipal Advisory Board (MAB) and published with the help of the members of the Plastics Pipe Institute, Inc. (PPI).

The purpose of this technical report is to provide important information on particular aspects of larger diameter polyethylene pipe electrofusion to engineers, users, contractors, code officials, and other interested parties. More detailed information on its purpose and use is provided in the document itself.

This report has been prepared by MAB members and associates as a service to the industry. The generic information in this report is offered in good faith and believed to be accurate at the time of its preparation, but is offered "as is" without any express or implied warranty, including WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. Consult the manufacturer for more detailed information about the particular joining procedures to be used with its piping products. Any reference to or testing of a particular proprietary product should not be construed as an endorsement by the MAB or PPI, which do not endorse the proprietary products or processes of any manufacturer. The information in this report is offered for consideration by industry members in fulfilling their own compliance responsibilities. MAB and the PPI assume no responsibility for compliance with applicable laws and regulations.

The MAB serves as an independent, non-commercial adviser to the Municipal & Industrial (M & I) Division of the PPI. Once adopted, MAB will consider revising this report from time to time, in response to comments and suggestions from users of the report. Please send suggestions of improvements to Camille George Rubeiz, PE, F.ASCE at crubeiz@plasticpipe.org.

ACKNOWLEDGEMENTS
The MAB would like to acknowledge the excellent contributions of the MAB Electrofusion Task Group for developing and leading this project:

1. **Marisa Boyce, PE** EBMUD, CA
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4. **Holly Link** Colorado Springs Utilities, CO
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12. **Dave Stewart** City of Lago Vista, TX
13. **Ryan Taylor, PE** Citizens Energy Group, IN
14. **Jeff Wright** Georg Fischer Central Plastics, OK

HISTORY

In 2014, representatives of the Municipal Advisory Board (MAB) requested assistance in creating greater uniformity in the joining procedures utilized by utilities in the electrofusion of polyethylene (PE) piping products for water and waste water applications. Users reported the proliferation of similar but slightly varying joining procedures from individual electrofusion fitting and equipment producers. The slight differences in the various procedures made it more difficult for system operators and installers to qualify persons with appropriate training and experience in the use of these procedures. It was even more difficult for system operators to inspect for and enforce that proper joining procedures were being followed. To address these issues, MAB established a task group and then published in 2015 the *MAB Generic Electrofusion Procedure for Field Joining of 12 Inch and Smaller Polyethylene (PE) Pipe*.

In 2016 and following the successful implementation and use of the above-referenced electrofusion document, MAB established a new task group to develop this generic procedure for installing larger diameter (14 inch to 30 inch) electrofusion fittings per the sizes shown in AWWA C906-15. Due to the magnification and multitude of installation procedures of large diameter electrofusion fittings, the MAB agreed to create this new document. Based on the results of the survey of the large diameter electrofusion manufacturers, the MAB TG (Task Group) unanimously agreed to take a conservative approach and adopt the most stringent installation requirements so that the document could be used with any product regardless of the manufacturer. This conservative approach may not be justified in all cases and the user of this document is encouraged to contact the electrofusion fitting manufacturer to obtain specific advice for the fittings being used.

In the spirit of complying with the above request, companies that manufacture larger diameter (14 inch to 30”) electrofusion products and equipment manufacturers reviewed existing procedures, agreed on common leading practices, and combined experiences and knowledge to educate and train installers. Thus, this publication provides a uniform electrofusion joining procedure to provide greater consistency, and to facilitate the pipeline operator’s efforts to qualify the installer, and simplify inspections. Refer to Appendix A for a list of electrofusion companies that endorsed these generic practices for use with their large diameter electrofusion fittings.

SCOPE
The program undertaken by the MAB TG combined common installation practices shared by multiple manufacturers into a single format. The goal is to provide clear direction and common procedures for proper pipe preparation, fitting-to-pipe assembly, and installation of electrofusion fittings 14 inch to 30 inch diameters; refer to the manufacturer for larger sizes. An additional goal is to provide clear inspection criteria for installer qualification, installation acceptance by inspection, and answers to frequently asked questions. This document replaces PPI TN-34. For installation of 12 inch and smaller pipe diameters refer to MAB Generic Electrofusion Procedure Manual for Field Joining of 12 Inch and Smaller Polyethylene (PE) Pipe (MAB-1-2015).

INTRODUCTION
It is incumbent on all owners of HDPE piping systems to insure that all persons responsible for installation are qualified to perform fusion. Inadequate fusions can compromise the expected high level of HDPE material performance.

Proper installation techniques, installer understanding of and training to these techniques, and effective examination before installation are key to a successful installation. This document provides detailed instructions for each key step to a successful installation, why each step is important, and the means of how to tell if the requirements of each step have been accomplished.

The inherent value of greater uniformity will provide all the incentive necessary for companies to evaluate the procedure as a first option for electrofusion joining of its large diameter PE piping products. MAB recommends the use of this procedure and every electrofusion fitting producer, equipment manufacturer, and pipeline operator retains the option of developing different procedures for its particular products and pipelines. However, MAB believes that its work in developing this procedure as a candidate for widespread acceptance throughout the industry will lead to greater efficiency, simplicity, and understanding, to promote the use of effective, qualified procedures for electrofusion joining of large diameter PE pipe.

Electrofusion joining of PE pressure pipe has been commonly used in North America for over 30 years. ASTM standard specifications for materials (ASTM D3350), performance (ASTM F1055), and installation practice (ASTM F1290) have been in publication for many years. All electrofusion fittings shall be marked to indicate that they meet the material and performance requirements of ASTM F1055 before being considered for use. Additional markings may be included to indicate that other performance and health effect requirements are satisfied, such as ANSI/AWWA C906 and NSF 61. Since each fitting manufacturer may have slightly varying geometrical designs, and each manufacturer is responsible for establishing safe installation temperature limits, it is also common that installation instructions can vary from one manufacturer to another. Although instructions can vary, all fittings share some common requirements for installation and all manufacturer's instructions include these same requirements. By successful completion, persons trained and qualified to these MAB documents have also demonstrated knowledge and understanding of the general procedures and techniques of ASTM F1290.

PRINCIPLES OF ELECTROFUSION

Polyethylene (PE) Electrofusion fittings are manufactured with a precision-designed resistance wire heating coil mechanism.

The electrofusion process works by introducing a controlled electrical voltage to the heating coil, which in turn generates heat to melt the fitting and pipe surfaces. As the polyethylene surfaces melt they also expand in volume to close allowable gaps between the pipe and fitting, then after the gaps are closed, the continuing melt expansion generates pressure within the heated zones. The expanding melt reaches "cold zones" within the fitting where the melt flow fronts cool and solidify, thereby blocking any further melt movement or material escape. The heating process continues for a predetermined time so that substantial pressure is reached through continued melt expansion in the contained melt pool of the pipe and fitting surfaces. Under pressure, the molten surfaces will join. Upon completion of the heating phase, the assembly is held stationary as the melted materials begin to immediately cool and co-crystallize into a single and solid monolithic structure between the pipe and fitting. (Figure a)

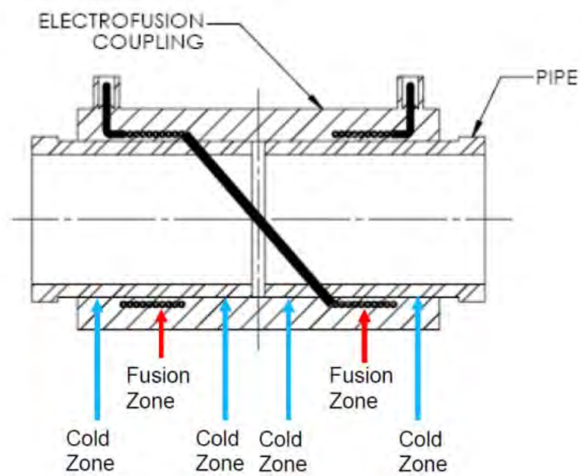


Figure a – Principals of Electrofusion

Equally as important as the heating phase of the fusion cycle, the cooling phase is a defined part of the electrofusion process. Because polyethylene is a thermoplastic, the material softens when heated and is therefore vulnerable to stresses from external forces such as the weight of the pipeline and bending forces from pipe curvature or misalignment while it is still hot. Fittings must be held stationary and in alignment during the fusion and cooling process by external clamps to protect against inadvertent disturbance of the molten PE until the assembly has cooled and regained its material strength. Once completely cooled, the surfaces are permanently joined together and cannot be separated.

Electrofusion manufacturers offer multiple cooling times. However, this generic electrofusion procedure only references one Cooling Time. Observe this Cooling Time prior to removal of clamps, movement, backfilling, pressure testing, tapping or placing the fitting in service. (See Table X-a and X-b for Cooling Time associated with these fittings).

I. **JOBSITE PREPARATION**

A. Safety: Fully understand and observe jobsite safety requirements. Electrofusion fittings and equipment are not intended to be, and are not "Explosion Proof". If used in a volatile environment, additional ignition concerns may be present and are not addressed in this document. When danger of electrical shock due to moisture at the fusion site is a concern, connect the leads to the fitting before the control unit is energized. Take safety precautions to prevent exposure to electrical shock hazards.

B. Control Flow: All heat fusion joining methods require that there is no water flowing or standing in the pipe that can reach the fusion surfaces. De-watering of the site may be required to prevent ground water from reaching the fusion and contaminating the surfaces to be joined. In moderate wet conditions, accomplish dewatering using portable submersible pumps (Fig. I-a). Saddle type fusions can be performed on mains under pressure.

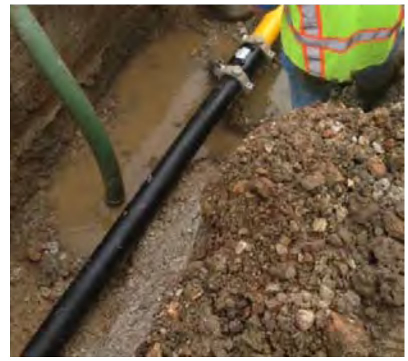


Figure I-a – Portable submersible pump (not visible)

In repair or cut-in situations, flowing water in the pipe may be present due to leakage of valves. Avoid flowing water in contact with the fusion surfaces during the assembly or fusion cycle as water will contaminate and hinder the fusion process and/or cause voids and pockets in the fusion surfaces as the moisture turns into expanding steam during the fusion process. Dry ice placed in the pipe upstream of the fusion location can temporarily freeze small amounts of flowing water until the fusion process is completed.

C. Ambient Temperature: Observe manufacturer's recommended minimum and maximum installation temperatures for electrofusion fittings.

1. Install electrofusion fittings in ambient temperatures as recommended by the manufacturer. A typical qualified temperature range for installation is 14°F minimum to 113°F maximum based on ISO standard 12176-2. Some manufacturers have lower and/or higher temperature limits and will state their qualified range in the technical specifications, contact the fitting manufacturer to verify.
2. The control box relies on the ambient temperature reading from sensors; it is important not to impact sensors with external heat sources such as generators emitting heat, or direct sun light that may affect the temperature of the processor.
3. Large diameter couplings may use a temperature specific fusion time or a pre-heat cycle prior to fusion.
4. Protect the fusion work site in case of inclement weather such as rain or snow. The use of a temperature controlled welding tent (or similar structure) may be required.

II. FITTING STORAGE AND HANDLING

Electrofusion fittings are packaged in sealed plastic bags as protection against accumulation of dust, dirt, and contamination. The bag should remain in place during normal handling and should only be removed at the time of installation. Fittings are also typically boxed to protect against other sources of degradation, such as oxidation due to UV exposure over long periods of storage. Always store fittings indoors in their original packaging until installation.

Black electrofusion fittings contain a 2% to 3% carbon black additive to protect against other UV effects and if stored indoors in their original packaging have potentially unlimited shelf life.

⚠ **Evaluate fittings with an unknown storage history or those exposed to questionable storage conditions through destructive testing of sample fusions. If fusion quality is shown to be affected, discard the fittings in question.**

Inspect fittings for damage before installing to ensure that connection points such as terminal pins have not been damaged by handling, that there is no visible damage to fusion surfaces or heating wires, and that no foreign materials are present on or near the fusion surfaces.

Clean fittings if incidental contact is made with the fusion surface. Use a suitable cleaning agent that contains no additives to hinder the fusion process. 96% (or greater) concentration of Isopropyl alcohol, with no additional additives except water, is recommended. . Other cleaning agents may be acceptable and the fitting manufacturer should be consulted. All surfaces must be dry before fusion; see Sec. X- A.5 to avoid contaminating the clean surfaces. Note: ASTM F2620 and F1290 allow 90% concentration or greater.

⊘ **Do not use denatured alcohol – Denatured alcohols may contain additives that can prevent fusion and shall not be used.**

III. REQUIRED TOOLS

Proper tools are essential to a successful electrofusion installation. Tools include devices for measuring, marking, cutting, scraping, cleaning, clamping (which includes aligning and securing), re-rounding, and power delivery. At minimum, the following items should be accessible during installation:

A. Measuring Tools: A tape measure (Figure III-a) or ruler for measurement of insertion (stab) depth of pipe ends inside a coupling. A circumferential wrap Pi tape for measurement of pipe diameter is also recommended. A caliper is used to determine the out-of-roundness of the pipe for side wall fittings. Use a Carpenter's Square to ensure square cut of pipe ends. A time measuring device must also be available to installers to monitor appropriate Cooling Times.

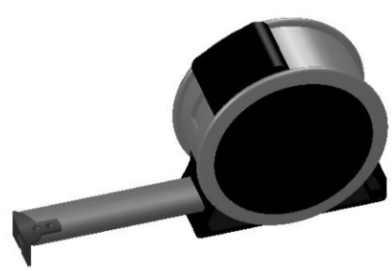


Figure III-a –Measuring Tape

B. Markers: The system owner is encouraged to specify / approve a permanent non-petroleum based visible marker to ensure consistency. Markers should be visible on the pipe color (Figure III-b) being used. For black pipe, a silver colored Sharpie®, or equivalent, permanent marker works well. The marker dries fast and contains no oils or other ingredients that could contaminate a prepared pipe surface. Use marks to locate insertion depths and as a guide for pipe scraping effectiveness. Also use markers to denote fusion Cooling Time.

Figure III-b -– Marking

⊘ **Do not use markers that are slow-drying or contain oils that could be spread onto fusion surfaces.**

C. Cutting Tools: Use a suitable saw (without lubricants, including oil or graphite based) and a guide or guide marks; reciprocating saws, circular saws with a coarse-tooth blade, hot saws, chop saws, and chain saws are commonly used for larger pipes with appropriate safety precautions and personal protective equipment. Make cutting marks around the pipe using a 4" or wider strap or encirclement clamp as a guide so that the pipe can then be cut along the line as shown in Figure III-c.

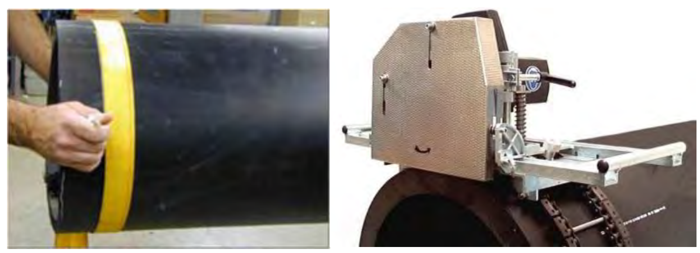


Figure III-c – Marking and cutting larger diameter pipes

D. Scraping Tools – Tools that are approved for scraping pipe for electrofusion joining are those that remove material uniformly and avoid contamination from surrounding area to expose a clean virgin surface. MAB recommends the use of "Peeler" type tools that remove a continuous and measureable ribbon of at least 0.007" in thickness from the pipe surface. The advantages of these tools are:

- The operator can measure the ribbon thickness to verify that the tool is performing as designed.
- A continuous ribbon ensures that the entire circumference of the pipe is being scraped.
- Any skipped or missed paths between peeler revolutions are easily identified using only lengthwise scribed witness marks.

NOTE: Avoid the use of hand tools when peelers are commercially available for the fitting being installed. Hand tools such as paint scrapers and scrapers with serrated blades have been used historically with good success. They can be used effectively especially in situations where confined working space or pipe scratches or gouges require a hand tool. It must be recognized by the user that they require more effort and diligence to ensure the entire area is being scraped adequately. Uniform scraping is more difficult to achieve with hand tools. Experience of the operator is required in order to know that adequate pipe surface material has been removed when using a hand scraper. The majority of failed fusions can be attributed to improper or inadequate pipe scraping.

E. Fitting and Alignment Clamps

- Alignment / Restraining Clamps - Electrofusion fittings generate significant pressure from thermal expansion during the melt phase of the fusion process. This melt pressure is an integral part of the fusion process and a designed function of the fitting and fusion parameter. Polyethylene is also a thermoplastic that softens when heated and the fusion assembly must be held stationary during both the melt and cool phases. As the materials cool and co-crystallize into a solid state again, the structures cannot be disturbed. Alignment and restraint clamps offer protection during both the melt and cooling cycles to prevent pipe and joint movement. Full encirclement type alignment clamps may provide the added benefit of re-rounding pipe ends, but chain or strap-type clamps will not provide re-rounding. The primary goal of clamping is to ensure that the pipe and fitting assembly are aligned, stable, free of external stresses, and immobile until the Cooling Time has been observed. **Always use** alignment / restraining clamps to install electrofusion couplings. Where alignment/restraining clamps are not commercially available, other means of joint stabilization may be utilized such as blocking and/or rigid timber and ratchet straps to prevent assembly movement.

- Saddle Clamps – **Always use** clamps when fusing saddles. The clamps provide the necessary attachment to the pipe and resist melt expansion forces to achieve the intended melt pressure on the pipe. Saddle clamps may be an external mechanical clamp that is re-usable or an integrated and permanent bolt-on clamp or strap. An underclamp (or strap) is a clamp that "pulls" the fitting base onto the pipe. A top loading clamp "pushes" the fitting downward onto the pipe. Each saddle fitting has a specific clamp(s) designed and qualified for its use. Substitutions are not acceptable and may result in fusion failures. Do not remove saddle clamps until Cooling Time has expired.

F. Blocking and Supports – If cribbing or pipe stands are needed to support the pipeline during the electrofusion process, ensure that the supports are placed on both sides of the fitting so that no weight is being supported by the electrofusion fitting and that no bending stresses are exerted on the joint area. See also the caution against attaching appurtenances (Section XIII, item H).

G. Coupling Puller – Due to the required tight diameter tolerance fit between the EF coupling and the pipe, mechanical pulling tools are available from several manufacturers to assist with coupling placement. (Figure III-d)

Figure III-d - Mechanical Pulling Tool

H. Full Encirclement Re-rounding Tools – These tools must always be used before and during installation to re-round the pipe. Several tools are available for both internal and external re-rounding.

IV. Pre-installation Requirements:

A. Pipe Diameter – Ensure that the pipe diameter is within the tolerances, at the specified temperature, of the applicable pipe standard (ASTM F714, AWWA C906, etc.) (see Table V-a). Standard tolerances are determined at 73°F. Measure pipe diameter with a Pi tape (Figure IV-a) at 2” and 6” from the pipe end to determine diameter. Pipe toe-in (See Appendix F for more info on Pi tape and toe-in) or reduction in diameter, is a condition that occurs at the pipe end and should be checked to ensure that the pipe diameter is within tolerance at 2” from the end. Severe toe-in (i.e. pipe diameter is less than the minimum pipe diameter), may require the removal of up to one pipe diameter from the pipe end.

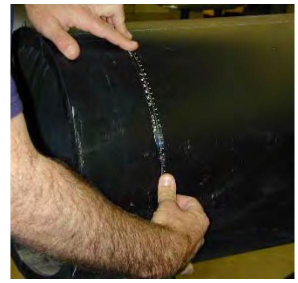


Figure IV-a - Measuring pipe diameter with Pi tape

B. Pipe Out-of-Roundness (OOR). Check if OOR condition exists even after use of re-rounding tools. Measure the pipe diameter (See Figure V-a in Section V) to determine the amount of OOR. Always use re-rounding tools.

C. Cut pipe ends squarely to 90° with a ½ inch maximum gap as measured from Carpenter’s Square (one inch maximum allowable gap between butted pipe ends; Figure IV-b). Use a 4” or wider sling or strap as a guide to mark the pipe for cutting (see Appendix G).

Figure IV-b - Measuring allowable gap with Carpenter's Square

D. Pipe alignment – Pipe alignment and clamping are required for proper fusion. Inspect alignment to ensure that no stresses are present in the assembly that might cause movement during fusion. Support pipe (See Figure VI-b).

E. Power Source – An adequate power source is required. Ensure that power source is capable of delivering power for entire coupling fusion time without interruption (check generator for full fuel supply). Ensure that all connections are tight and clean. Loose connections can result in arcing or blown fuses.

1. 110 Volt: A minimum 7000 watt **continuous** supply generator capable of delivering 115 volts to 135 volts at 55 Hz to 65 Hz to the control box. Minimum 30 amp breaker with “slow blow” or time delay fuse. .
2. 220 Volt: A minimum 7000 watt **continuous** supply generator capable of delivering 180 volts to 300 volts at 55 Hz to 65 Hz to the control box. Minimum 30 amp breaker with “slow blow” or time delay fuse.
3. Do not connect other electrical devices to the generator during fusion.
4. Insure that the generator is fully warmed up prior to attempting electrofusion procedure.

F. Extension Cords – Typically, a single extension of up to 25 ft. is permitted between the generator and the control box. The minimum wire gauge is #8/3 AWG for extension lengths up to 25 ft.; consult the fitting and equipment manufacturer for specific recommendations on the use of longer length cords.

G. Control Box – Use a 24 digit barcode compatible control box conforming to ISO 12176-2 to deliver the required energy to the coupling.
   1. The control box must be capable of delivering 80 amperes average (up to 105 amps peak) at 8 to 48 volts output.
   2. The control box must be capable of reading the coupling barcode and applying the correct fusion parameters, including automatic temperature compensation, to the fitting without operator intervention.
   3. The control box must be capable of reading ambient temperatures at the fusion site.
   4. The control box must include fusion data recording capabilities for installed fittings.

H. Scraping Tools – PIPE PREPARATION IS VERY CRITICAL TO THE ELECTROFUSION PROCESS. GIVE CAREFUL ATTENTION TO CLEANING AND SCRAPING PROCEDURES TO REMOVE CONTAMINATION AND SURFACE OXIDATION FROM THE PIPE SURFACE.
   1. Only use mechanical type scraping tools designed specifically for electrofusion preparation to prepare the pipe surface. Alcohol will not remove oxidation.
   2. Do not use abrasives such as grinders, emery cloth, or sandpaper.
   3. Exercise care in the maintenance and storage of scraping tools to ensure proper operation. Verify before each use that the scraping tool is operating properly.

I. Markers – Ensure that insertion depth and pipe scrape area markings are made with a non-greasy, non-petroleum based, fast-drying, permanent marker or paint pen.

J. Cleaning agent / wiping cloth – Commercially available pre-packaged 96% (or greater) isopropyl alcohol impregnated disposable wipes without additives are recommended to clean pipe surfaces. **Denatured alcohol may contain other impurities and is NOT suitable.** . Under no circumstances should a coupling fusion be made with any liquid (water, oil, sewage, etc.) flowing through the fusion area. The fusion zone must be clean and dry before and during fusion.

K. Weather Conditions – Observe manufacturer's recommended minimum and maximum installation temperatures for electrofusion fittings.
   1. The typical ambient installation temperature range is 14°F to 113°F maximum based on ISO standard 12176-2 but can vary above and below that range depending on the manufacturer. If ambient temperatures are outside this range, consult the equipment and fitting manufacturer for a specific recommendation.
   2. The fusion processor relies on ambient temperature reading from sensors; it is important not to impact sensors with external heat sources (such as generators emitting heat, or direct sun light) that may affect the temperature of the processor.
   3. Large diameter couplings may use a temperature specific fusion time or a pre-heat cycle prior to fusion.
   4. Protect the fusion work site in case of inclement weather such as rain or snow.
   5. Pipe and fittings surfaces must be dry.

V. PIPE PREPARATION

A. Measuring pipe:
   1. Diameter**:** Electrofusion fittings are designed for use on pipe made to standard diameters in dimensions for Iron Pipe Size (IPS) and Ductile Iron Pipe Size (DIPS). Do not use pipe that is outside of the diameter tolerance band of the appropriate pipe standard. Use the following table (Table V-a) for reference when measuring pipe diameter to ensure that the pipe is within tolerance.

      Standard tolerances are determined at 73°F. Measure pipe diameter with a Pi tape (see Appendix F) at 2" and 6" from the pipe end to determine diameter. Pipe toe-in or reduction in diameter, is a condition that occurs at the pipe end and should be checked to ensure that the pipe diameter is within tolerance (Table V-a) at 2” from the end. Severe toe-in (i.e. pipe diameter is less than the min. pipe diameter) may require the removal of minimum of 12” from the pipe end.

Table V-a – Standard PE 4710 IPS and DIPS Pipe Dimensions (AWWA C906/ASTM F714)
(Dimensions apply to pipe at 69.8–77.0ºF (21-25ºC))

PE 4710 OUTSIDE DIAMETERS (OD) AND TOLERANCES FOR IPS SIZES		
PIPE SIZE	AVERAGE OD	TOLERANCE
14" IPS	14.000"	±0.063
16" IPS	16.000"	±0.072
18" IPS	18.000"	±0.081
20" IPS	20.000"	±0.090
22" IPS	22.000"	±0.099
24" IPS	24.000"	±0.108
26" IPS	26.000"	±0.117
28" IPS	28.000"	±0.126
30" IPS	30.000"	±0.135

PE 4710 OUTSIDE DIAMETERS (OD) AND TOLERANCES FOR DIPS SIZES		
PIPE SIZE	AVERAGE OD	TOLERANCE
14" DIPS	15.300"	±0.069
16" DIPS	17.400"	±0.078
18" DIPS	19.500"	±0.088
20" DIPS	21.600"	±0.097
24" DIPS	25.800"	±0.116
30" DIPS	32.000"	±0.144

(NOTE: For sizes 12 inch and smaller, See MAB-1-2015)

2. Roundness: Polyethylene is a flexible material. A number of conditions can affect pipe roundness; these conditions include manufacturing process, storage/stacking, and soil load for buried installations (Figure V-a).

   - Out-of-roundness is the difference in the maximum measured diameter minus the minimum measured diameter. Measure the pipe with a tape measure or calipers to find the maximum (d1) and minimum (d2) diameter points. Calculate the out-of-roundness as d1-d2 as measured in the field. Use calipers to measure out-of-roundness for side wall fitting installations. If calipers (or other OOR measurement devices) are not available, installers shall use cold ring clamps to re-round the pipe.

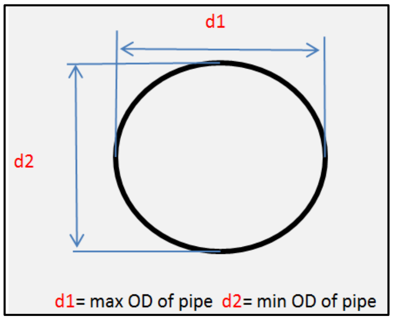


Figure V-a - Roundness Measurement

   If severe enough (>1/4”), pipe out-of-roundness can have a negative effect on electrofusion joint quality. If the pipe is out-of-round, and is not corrected by full encirclement clamp, the amount of gap between the pipe and fitting can be too large for the melt expansion to close. Pipe out-of-roundness may also increase the difficulty of sliding the fitting onto the pipe.

   For sizes equal to or larger than 14 inch IPS / DIPS, always use re-rounding tools on either side of an electrofusion saddle or coupling.

B. Pre-Cleaning: Clean the inside and outside of both pipe ends by removing dirt, mud and other debris. USE clean water for initial cleaning of pipe surfaces prior to scraping.

C. Cleaning: It is important to clean the fusion area with 96% disposable isopropyl wipes and avoid recontamination of these areas prior to scraping.

⚠ **Pipe that has been installed by directional boring where drilling lubricants such as bentonite have been used require particular attention to pre-cleaning before scraping as well as any cleaning after scraping. Drilling lubricants, even when dried, can be difficult to see and are easily spread by wiping. Use extra caution to only wipe over areas that were previously cleaned with isopropyl alcohol to prevent spreading onto prepared surfaces.**

D. Scraping: Pipe preparation is perhaps the most important and least understood aspect of making a sound electrofusion joint. Improper pipe preparation is overwhelmingly the leading cause of unsuccessful electrofusion joint attempts; in these cases, the installer may not completely understand the goal of pipe scraping, which is to remove a thin layer of the outer pipe surface (see FAQ section and Appendix H for more details) to expose clean virgin material beneath.

Pipe surfaces exhibit surface oxidation from the extrusion process, transportation, and outdoor exposure. Surface oxidation is a normal chemical reaction that results in a physical change to the molecular structure of the polymer chains on the pipe surface. Oxidation acts as a physical barrier and therefore those surfaces cannot be heat fused effectively. Simply roughing the pipe surface is not sufficient. To achieve fusion, remove this layer. Even new pipe must be scraped before a fusion will be successful.

The outer oxidation layer on a pipe surface is very thin. It does not increase in depth of more than a few thousandths of an inch even over long periods of exposure, so regardless of the amount of time the pipe has been stored before scraping, the scraping depth requirement is the same. An adequate minimum amount of material that must be removed (Figure V-b) is just seven thousandths of an inch (0.007"). That thickness is approximately the same as two sheets of ordinary paper. The maximum amount of removed material shall not exceed forty thousandths of an inch (0.040"). Care shall be taken to avoid compromising the minimum wall requirement of the pipe when scraping.

Figure V-b - Scraping Measurement

⊘ **Never use sand paper, emery cloth, or other abrasives to prepare a pipe surface for electrofusion. Abrasives have been proven to be ineffective for electrofusion because they do not adequately remove material, they can redistribute contaminates on the surfaces, and because they can leave behind a grit residue that forms another barrier that prevents fusion.**

✔ There are many tools used for pipe scraping, however they are not all the same and care must be used depending on the type of tool selected. The only tools that should be used for surface preparation are those that are specifically designed for electrofusion scraping and peeling:

Examples of acceptable tools that "peel" the pipe surface to a controlled depth are most commonly referred to as "peelers" (Figure V-c).

Figure V-c – Acceptable "Peelers"

- No matter what type of tool is used, make witness marks on the pipe surface with a permanent marker prior to scraping so that any marking that remains after scraping is evidence that areas were missed and that more scraping is required. (Figure V-d)

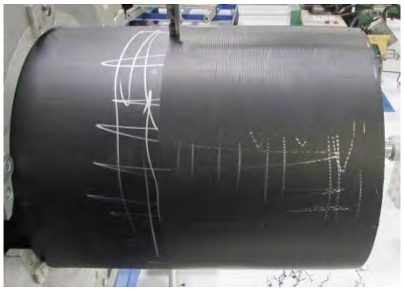


Figure V-d – Inadequate Removal of Witness Marks

- Another type of tool is referred to as a "hand scraper". Except as noted below (see <u>hand tool</u>), avoid the use of these hand scrapers due to inconsistent surface preparation and difficulty in mastering skills required for uniform surface preparation. (Figure V-e).

Figure V-e – Not Recommended "Hand Scrapers"

⚠ **Gouges that are deeper than the scrape depth may also require extra attention when scraping the pipe to ensure the removal of any debris or contaminates embedded in the gouges; use of a <u>hand tool</u> to scrape the gouge may be necessary. If the gouge exceeds 10% of the pipe wall thickness, cut out and replace that pipe section to maintain the maximum pressure rating of the pipe.**

⚠ **Pipe scratches and/or gouges: Installation of pipe can cause surface scratches or gouges. Smaller scratches from dragging or normal handling are not problematic and will normally be removed during the pipe preparation process by scraping. Avoid surface damage when installing pipe with use of rollers or other devices that separate the pipe from sharp surfaces. If surface damage is questionable and cannot be removed by scraping, contact the fitting manufacturer.**

⚠ **Wood rasps and metal files are not acceptable scraping tools.**

VI. FITTING CLAMPING AND ALIGNMENT

Electrofusion fittings generate significant pressure from thermal expansion during the melt phase of the fusion process. This melt pressure is an integral part of the fusion process and a designed function of the fitting and fusion parameter. Polyethylene is a thermoplastic that softens when heated. As a result, install all electrofusion fittings with the use of alignment and restraining clamps (Figure VI-a).

Figure VI-a - Fitting Clamps

Use clamps on all coupling installations to restrain the pipe ends from moving and keep the pipes in alignment.

⚠ **Check pipe end alignment to ensure that there is no bind or stress exerted on the coupling during fusion and until Cooling Time is complete. Support for the pipe is necessary to prevent stresses or sagging that may develop as heat is applied during fusion.**

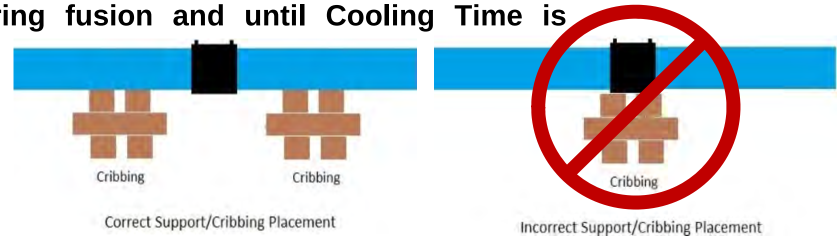


Figure VI-b - Cribbing placement

Saddles require clamping to secure the fitting to the main to prevent movement, restrain against generated melt pressure, and in some cases to form the fitting to the contour of the main. Saddles are designed to be used with a particular clamping device. Clamping devices are typically not interchangeable from one fitting design or main size to another. Other designs include a clamp that is re-usable (Figure VI-c along with top loading tools that cannot be removed until observance of the Cooling Time). Some manufacturers specify allowable gaps between the underside of saddles and pipe OD. Consult saddle manufacturer for allowable gap dimension.

Figure VI-c - Reusable saddle clamps

Note: Consult manufacturer for nylon type strap tools that are intended for multiple use regarding frequency of strap replacement interval.

VII. CONTROL BOX

Electrofusion control boxes, sometimes referred to as processors, perform vital functions during the fusion process. The control box provides carefully regulated voltage for the required fusion cycle time resulting in the designed energy required for fusion. During the fusion process, the control box also monitors the power being supplied to the fitting and can detect certain assembly or fitting errors such as shorted heating coils or short-stabbed pipe ends.

When using the fitting barcode, the control box confirms the dimensions of the fitting to be installed and automatically adjusts the fusion parameters for that particular fitting based on the manufacturer's requirements and field ambient temperature.

- Adjustment of the fusion time for higher or lower ambient temperature is referred to as "temperature compensation". Not all fittings require temperature compensation, but all barcodes contain two characters that define whether the feature is used or not.

- Let the control box acclimate to the jobsite weather conditions for minimum period of 15 minutes to ensure that it accurately measures ambient temperatures before beginning the fusion process.

The control box will terminate a fusion process when any defined protocol is out of range and will display an error message. Control boxes have a list of error message definitions affixed to the unit or available in the associated operator's manual for reference if an error occurs. A record of each fusion, as well as the result of the fusion cycle, is stored and is downloadable via a USB, Bluetooth or other wireless connection. Displayed error codes are unique to each manufacturer - refer to manufacturer's user manual for interpretation. System operators should retain these down-loaded fusion records and associate them with installed fittings in the project records.

Change or adapt control box fusion cable tips to fit the size of the connecting pins on the electrofusion fitting. There are two sizes of fitting connecting pins, 4.7mm and 4.0mm.

The control box manufacturer recommends regular calibration intervals, typically every 1 to 3 years, to ensure that all monitored parameters are measured accurately and the control box is functioning normally. Units that are past their calibration interval will normally alert the installer at power-up, but will continue to function when acknowledged.

Minimum Requirements for Control Box

- Use a 24 digit barcode compatible control box conforming to ISO 12176-2 to deliver the required energy to the coupling.
- The control box must be capable of delivering 80 amperes average (up to 105 amp peak) at 8 to 48 volts output.
- The control box must be capable of reading the coupling barcode and applying the correct fusion parameters, including automatic temperature compensation, to the fitting without operator intervention.
- The control box must be capable of reading ambient temperatures at the fusion site.

Additional Control Box Data: Some control boxes also include GPS (Global Positioning System) positional location data associated with the location of the installed fitting. This information can also be retained, along with the fusion record, as an attribute for the installed fitting in the Owner's GIS (Geographic Information System) system.

VIII. POWER REQUIREMENTS

Control boxes are typically available in 120v or 240v versions. The control box monitors the energy input from the power source to ensure that fluctuations from the generator are within designed tolerances and alerts the installer when parameters fall out of range. Control boxes are typically tolerant to small fluctuations in input voltage or frequency, however not all generators or inverters are equal. When an assembly is known to have been completed correctly, and there is an error code or failure, the cause can usually be traced to the power supply. It is important to ensure that the power supply is in good working order and capable of supplying the required energy for the fusion process.

Each electrofusion fitting has an integral heating coil that requires a defined amount of energy input to achieve the designed results. Heating coils are engineered specifically for a fitting size or configuration and power requirements will vary from one manufacturer to another for the same size fitting. A minimum 7000 watt continuous output generator is recommended.

Job site conditions may dictate placement of the generator at a distance further than the length of the provided power supply cord; in this instance an extension cord may be needed. Avoid the use of Extension cords; however, if necessary, the wire gauge should not be less than #8/3 AWG for the maximum length of 25 feet.

An adequate power source is required. Ensure that power source is capable of delivering power for entire coupling fusion time without interruption (check generator for full fuel supply). Ensure that all connections are tight and clean. Loose connections can result in arcing or blown fuses.

- 120 Volt: A minimum 7000 watt **continuous** supply generator capable of delivering 115 volts to 135 volts at 60 Hz to the control box. Minimum 30 amp breaker with "slow blow" or time delay fuse.
- 240 Volt: A minimum 7000 watt **continuous** supply generator capable of delivering 180 volts to 300 volts at 60 Hz to the control box. Minimum 30 amp breaker with "slow blow" or time delay fuse.
- Do not connect other electrical devices to the generator during fusion

Consult the control box manufacturer for further details on recommended generator requirements.

⊘ **Do not use welding generators.**

⚠ **CAUTION: The rated capacity of a generator is less than the peak generator capacity; use the lower of the two stated capacities. The age of the generator further reduces its capacity. The generator governor control (economy switch) must be turned off and the warmed up generator running at full speed before fusion begins to provide constant generator electrical output. Users must verify/qualify the output of generator on a minimum annual basis, or at the start of each contractor's project and approved/tagged accordingly. Generators are a potential source of inadequate fusion due to inadequate power supply. Verify the performance of generators by test sets such as** http://www.sotcher.com/Load_Bank_Generator_Test_Sets**. Generator maintenance must be performed on defined schedule; examples include** https://www.briggsandstratton.com/na/en_us/buying-guides/portable-generators/portable-generators-101/storage-and-maintenance.html

IX. FUSION PARAMETERS

Enter fusion parameters including but not limited to: fitting manufacturer, fitting size, fusion time, voltage, and cooling time, into the control box by scanning the bar code.

All electrofusion fittings have a barcode attached that contains all of the information needed by the control box to perform the fusion process. Barcodes contain additional information about the fitting manufacturer, fitting size, fitting resistance, and temperature correction values if required by the fitting manufacturer.

A. Codes are displayed on the fitting label in an interleaved barcode format that can be read by a barcode wand or hand-held scanner. Keep bar code scanners clean to insure proper working order.

B. Because of limitations in the number of characters allowed by the barcode standard, DIPS fittings will not display accurately. DIPS sizes will display as the metric (mm) equivalent, or as non-standard IPS sizes. For DIPS sizes, consult EF processor or fitting manufacturer for further information.

C. The 24-digit numerical value is also printed on the label, either directly above or below the barcode (Fig. IX-a) that can be entered into the control box in the event that the code cannot be scanned.

EF COUPLING 1 CTS FT30sCT5M 12062462

951320308152401207030114

Figure IX-a – Barcode with Numerical Value

X. ELECTROFUSION INSTALLATION TRAINING PROCEDURES

A. COUPLING INSTALLATION:

1. Cut the pipe ends (Figure X-a) squarely and evenly.

Figure X-a – Cut Pipe Ends

2. Clean inside and outside of both pipe ends (Figure X-b) by removing dirt, mud, and other debris. USE clean water for initial cleaning of pipe surfaces prior to scraping. Clean the pipe for a length far enough beyond the fusion area to ensure that remaining debris on the pipe surfaces will not be transferred to the area to be prepared during handling. Dry with a clean lint free towel.

Figure X-b – Clean Pipe Ends

3. Measure and mark the stab depth on the pipe ends (Figure X-c). If stab depth marks are not indicated on the outside of the coupling, measure the total length of the coupling to be installed and make a mark on both pipe ends equal to ½ the length of the coupling. This mark is used as visual indication by the installer that the pipe ends are correctly inserted to the center of the coupler. Check the pipe surface for any embedded debris that may cause damage to scraping tools, and once more make sure that the outer pipe surface is clean and free of any dirt or mud that could re-contaminate the scraped pipe surfaces. Mark the entire pipe surface (witness lines) to be scraped with longitudinal and/or circumferential lines.

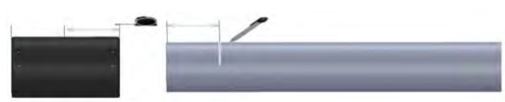


Figure X-c- Measure and mark Stab Depth

Clean surface of EF fitting and fusion area of the pipe with approved alcohol, do not scrape EF Fitting.

When one of the pipes to be joined has limited movement capability, it may be necessary to slide the coupling onto the pipe for its full depth before placing the other pipe in place (Figure X-d). If the full coupling must be placed on one pipe end, clean and scrape that pipe end for a minimum of the full depth of the coupling to avoid contamination. Use the depth mark on the opposite pipe for centering the coupling assuming that the two pipe ends are butted/in contact (Figure X-e).

Figure X-d – Limited Movement Example **Figure X-e – Center Couplings Between Depth Marks**

4. Scrape the outside of the pipe surface to remove oxidation and other contaminates (Figure. X-f). Use an appropriate scraping tool as described in the PIPE PREPARATION section of this guide. Scrape the pipe surface until the outer layer or "skin", at least .007" thick, of the pipe has been removed to expose a clean, virgin pipe material. Remove longitudinal or circumferential markings made in Step 3. Inspect the entire scraped area to ensure total scraping coverage.

Figure X-f – Pipe Scraping

Re-mark pipe to replace original stab depth marking removed by scraping. Use this mark as visual indication by the installer that the pipe ends are correctly inserted to the center of the coupler. Apply re-rounding tools if alignment clamp does not act as re-rounding tool. (Note: there are large diameter alignment tools that act as re-rounding tools).

While not common, it is possible to remove too much surface material by repeated scraping. Removal of 0.040" is the maximum recommended. Use caution if scraping multiple times to ensure that the pipe OD is not reduced (by more than the allowable minimum diameter) to the point that the gap between the pipe and fitting is too large.

5. Do not touch the scraped pipe surface or the inside of the coupling as body oils and other contaminates can adversely affect fusion joint quality. Commercially available pre-packaged 96% (or greater) isopropyl alcohol impregnated disposable wipes without additives are recommended to clean pipe surfaces. Do not use alcohol with any additives other than water. Installer should have a handy source of clean disposable wipes available to avoid reuse/contamination issues. Note: ASTM F2620 and F1290 allow 90% concentration or greater.

Do not use Denatured Alcohol.

6. Install coupler onto the pipe ends so that the stab depth marks are aligned at the outer edges of the coupler. Chamfer or bevel the pipe ends (if required by manufacturer) to allow for easier insertion into the coupling. Use re-round clamps or other available fittings as anchors for pulling couplers onto pipe with mechanical assist devices such as a hand winch. **Use care not to damage internal wire or terminal pins.** Leave plastic bag over one end of coupler to prevent contamination, and debris from entering the open end. If necessary, use a rubber mallet (or metal hammer and wood blocks) to move coupler onto pipe. (Figure X-g).

Figure X-g – Avoid Contamination During Installation

⚠ **CAUTION: AVOID ALL POSSIBLE RECONTAMINATION OF THE PREPARED SURFACE. Keep one end of the coupling bagged during this process.**

⚠ **Note: Chamfer or bevel pipe ends (if required by manufacturer) on the outer edges when installing couplings that incorporate bare exposed heating wires to prevent snagging of wires on pipe edge.**

When making a repair, or in situations where the coupling must slide completely over one of the pipe ends, scrape that pipe end for a minimum of the entire length of the coupling (Figure X-h).

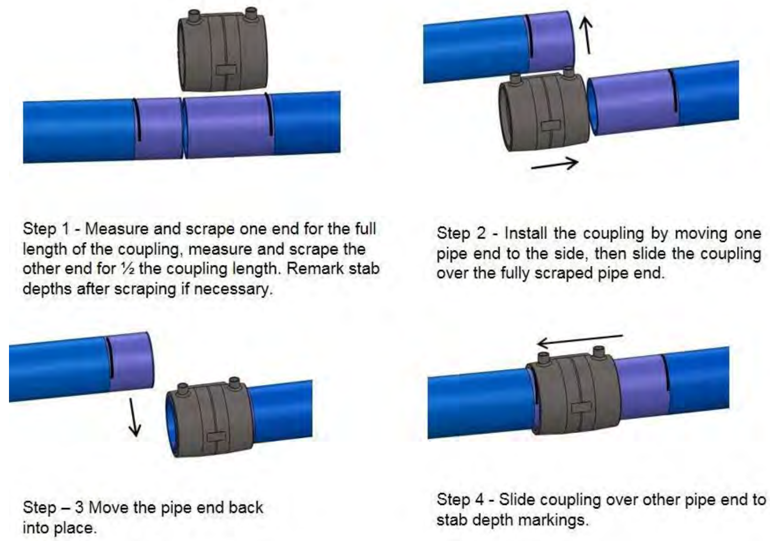


Figure X-h – Repair - Coupling Over Entire Pipe End

7. Clamp the pipe ends to align and secure the assembly (Figure X-i). Coupling and pipe assembly must be immobile during the fusion and cooling cycles.

Figure X-i – Clamp and Secure

8. Connect the fitting to the control box (Figure X-j), enter the fusion parameters (bar code scan the fitting), and fuse the joint. See "Fusion Parameter" section for details.

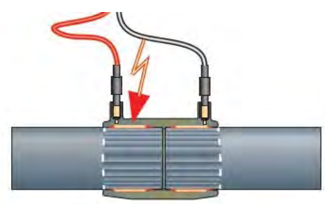


Figure X-j – Connect Fitting to Control Box

9. Mark the time of day on the fitting (or pipe) when the fusion cycle ends. If required by the pipeline owner, note additional information such as: date, fusion record number, installer name and identification number, fusion ID card number, contractor name, fusion machine identification number, time of day when Cooling Time will elapse, etc.

10. Allow the fused fitting and pipe assembly to remain clamped (alignment clamp and rounding clamp) and undisturbed for the Cooling Time (Tables X-a and X-b).

⊘ **Cooling is a vital part of the fusion process. Observe Cooling Time and do not disturb fused joints until the Cooling Time has elapsed.**

Table X-a: Cooling Time Guidelines for Couplings*

Coupling Sizes and (Pressure Class, psi)	IPS Cooling Time	DIPS Cooling Time
14" - 30" (PC 200)	3 hrs.	3 hrs.

*The Cooling Time must be observed prior to removal of clamps, movement, backfilling, pressure testing, tapping or placing the fitting in service. Consult manufacturer for other Pressure Classes.

B. SADDLE INSTALLATION:

1. Clean the pipe (Figure X-k) by removing dirt, mud, and other debris. Clean the pipe for a length far enough beyond the fusion area. Use clean water for initial cleaning of pipe surfaces prior to scraping to ensure that remaining debris on the pipe surface will not be transferred to the area to be prepared during handling.

Figure X-k – Clean Pipe

2. Re-rounding Clamps: Installer shall always use 2 re-rounding clamps to re-round the saddle installation location regardless of OOR.

3. Mark the saddle installation area on the pipe (Figure X-l). Use the bagged fitting as a template for marking. The installer may use these marks to indicate the approximate size of the preparation area. Check the pipe surface for any embedded debris that may cause damage to scraping tools, and to make sure that the outer pipe surface is clean and free of any dirt or mud that could re-contaminate the scraped pipe surface. Mark the entire pipe surface (witness marks) to be scraped with longitudinal and/or circumferential lines.

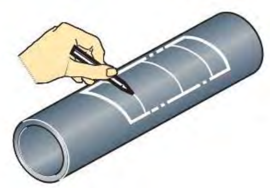


Figure X-l – Mark Installation Area

4. Scrape the outside of the pipe surface (Figure X-m) to remove oxidation and other contaminates. Use an appropriate scraping tool as described in the PIPE PREPARATION section of this guide. Scrape the pipe surface until the outer layer or "skin", at least .007" thick, of the pipe has been removed to expose a clean, virgin pipe material. Remove longitudinal or circumferential markings made in step 2. Inspect the entire scraped area to ensure total scraping coverage and removal of witness marks.

Figure X-m – Scrape Pipe

5. Do not touch the scraped pipe surface or the inside of the saddle fitting as body oils and other contaminates can adversely affect fusion. Commercially available pre-packaged 96% (or greater) isopropyl alcohol impregnated disposable wipes without additives are recommended to clean pipe surfaces. Do not use alcohol with any additives other than water. Discard the wipes after each use. Installer should have a readily available source of clean disposable wipes. Do not scrape EF Fitting. Note: ASTM F2620 and F1290 allow 90% concentration or greater.

⊘ **Avoid all possible recontamination of the prepared surface**

⊘ **Do not use Denatured Alcohol.**

6. Place the saddle over the scraped pipe surface (Figure X-n). Ensure that the fitting fusion surface is only in contact with the scraped pipe surface.

Figure X-n – Place Saddle Over Scraped Surface

7. Secure the saddle-to-pipe assembly with the appropriate clamping mechanism required by the fitting manufacturer. If bolts are used in the clamping device (note not all clamps are associated with bolts-see Figure X-t) make sure they are tightened in the proper sequence and the required amount of torque /engagement per the manufacturers' instructions. See "clamping" section of this guide for further details. Some manufacturers specify allowable gaps between the underside of saddles and pipe OD. Consult saddle manufacturer for allowable gap dimension.

⚠ **Use only the clamps provided or required by the fitting manufacturer. Clamps from one manufacturer's fitting are not interchangeable with another's.**

8. Connect the fitting to the control box (Figure X-o), enter the fusion parameters, and fuse the saddle. See "Fusion Parameter" section for details.

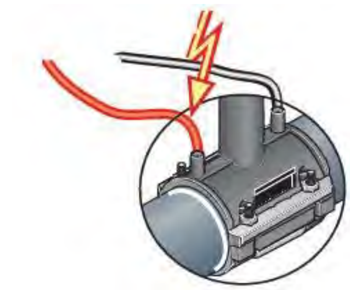


Figure X-o – Connect Fitting to Control Box

9. Allow the fused fitting and pipe assembly to remain clamped and undisturbed for the Cooling Time.

⊘ **Do not tap saddle fittings until after observance of Cooling Time**

10. Mark the date, time and fusion record number on the fitting when the fusion cycle ends. If required by the pipeline owner, include installer and installation information such as the date, installer identification number, fusion ID card number, contractor name, fusion machine identification number, time of day when Cooling Time will elapse, etc.

⊘ **Cooling is a vital part of the fusion process. Observe Cooling Times and do not disturb fused joints until the Cooling Time elapses.**

11. After the Cooling Time elapses, conduct pressure leakage testing per ASTM standards. Limit the test pressure to a minimum of 1.5 x working pressure (and a maximum of 1.5 x PC). If leakage is observed at a fusion joint, the fitting shall be depressurized and abandoned in place and a new fitting installed. **Do not use end closures or mechanical end caps that are defective or that cannot be fully restrained.** (Figure X-p).

Figure X-p – Pressure Testing

⚠ **Pressure testing (Hydrostatic or pneumatic) can be dangerous. Per ASTM F2164/F2786, take measures to structurally restrain all parts of the section under test against movement if failure occurs. Observe manufacturer's precautions for securing and restraining mechanical end (test) caps.**

Table X-b: Cooling Time Guidelines for Saddle Type Fittings

Branch Saddles	Cooling Times
14" to 30"	1 hr. 12 min.

C. **INSTALLATION INSPECTION CHECKLIST:**

1. SQUARE CUT: Cut pipe ends squarely to 90° with a ½ inch maximum gap as measured from Carpenter's Square. Find the largest gap by rotating the Carpenter's Square. To obtain minimal gap between the pipe ends the installer may have to use additional tooling to remove high spots (planer).

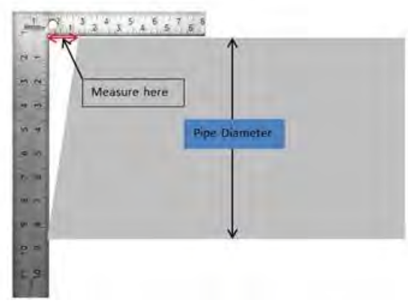


Figure X-q – Check for Square-ness

2. Re-rounding Clamps: Installer shall use re-rounding clamps to re-round the pipe regardless of OOR.

3. SCRAPING: A properly scraped pipe has a thin outer layer of the pipe surface removed to expose clean virgin PE material for fusion. Witness marks can be very helpful and shall be used in all cases to ensure that the entire surface has been scraped, and that an adequate amount of material has been removed. Marking the pipe surface with a permanent marker is a simple and effective step. Removal of the pipe print line as a depth indicator is also useful, but should not be used as the only means to determine that proper scraping has been accomplished. (Refer to Figure X-r and Figure X-s for correct and incorrect scraping.)

Figure X-r - Correct Scraping

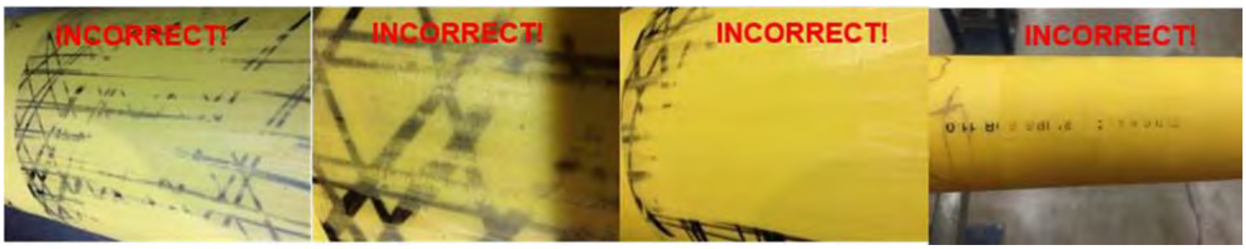


Figure X-s - Incorrect Scraping! Improper surface preparation / Not enough material removed, marks still visible.

4. CLAMPING/ASSEMBLY/ALIGNMENT: Clamps are necessary to ensure:
   a) pipe is properly aligned and re-rounded
   b) no external stresses are exerted on the fitting or assembly
   c) blocking to support both the pipe and fitting
   d) no movement occurs during the melt and cooling phases
   e) saddle fittings are securely clamped to the main. (Figure X-t)

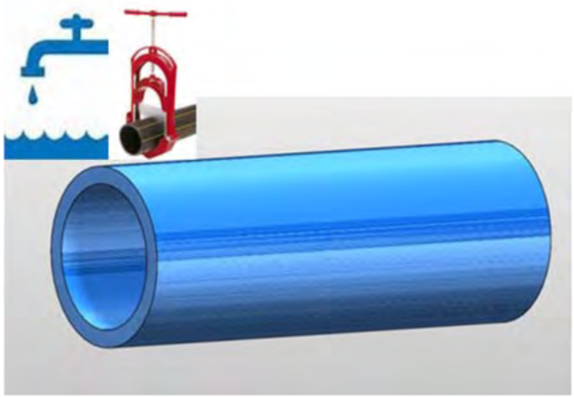
Figure X-t – Saddle Clamp

5. FUSION
   a) Ensure that the generator or power source is adequately sized for the fitting being fused.
   b) Ensure the generator fuel tank is full.

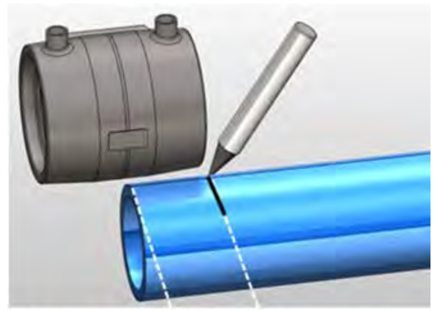
6. COOLING: Allow the fused fitting and pipe assembly to remain clamped and undisturbed for the Cooling Time. The Installer shall add the Cooling Time to the time observed at the end of the fusion heating cycle and mark it on the pipe to provide a reference for time of day when the Cooling Time will elapse. Observe the Cooling Time prior to removal of clamps, movement, backfilling, pressure testing, tapping or placing the fitting in service.

⊘ **Do not move or expose pipe and fitting to stress before the Cooling Time elapses!**

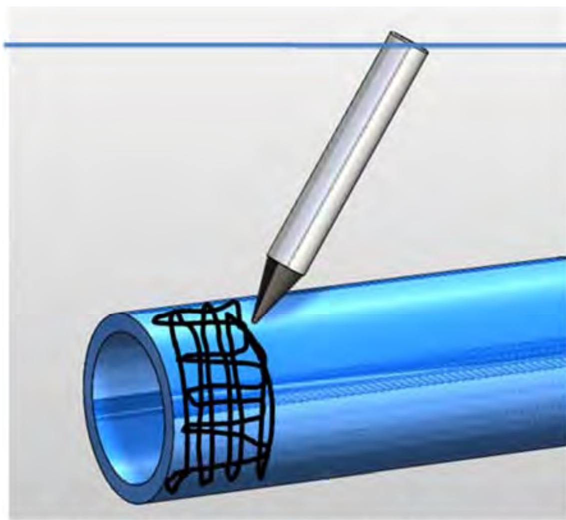
XI. FIELD GUIDE FOR ELECTROFUSION COUPLING INSTALLATION



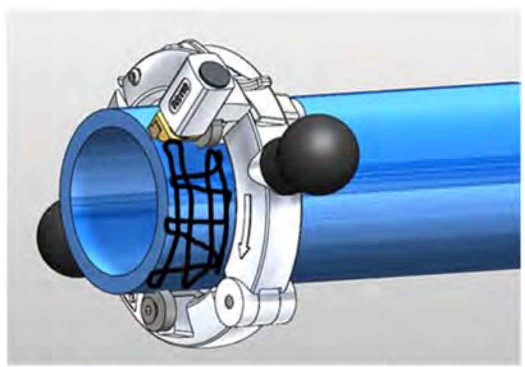
1. Clean pipe ends with clean water and cut as squarely (≤ ½ inch) as possible. See Sections V (B/C) and X-A.2.



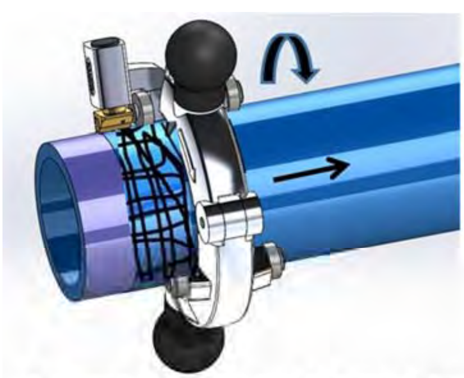
2. Measure and mark the stab depth on both pipe ends



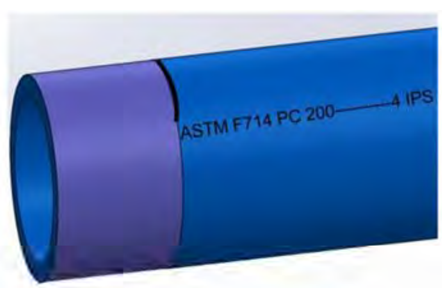
3. Mark the pipe surface to be scraped in a criss-cross pattern.



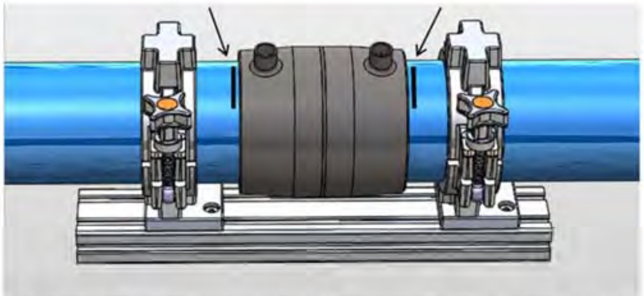
4. Mount the scraper over the area to be scraped.



5. Scrape or peel the pipe to remove the surface layer and expose clean virgin pipe beneath.

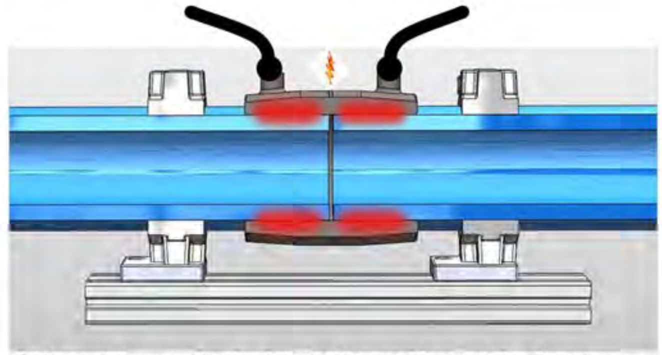


6. Inspect the scraped pipe surface thoroughly to ensure that all marks are removed and that only virgin pipe surface is exposed.



7. Clean surfaces with Isopropyl alcohol if necessary, avoid touching cleaned surfaces.

8. Insert the pipe ends to the stab depth marks made in step one.
Secure in alignment clamp with coupling centered between stab depth marks.



9. Connect the control box leads to the fitting and fuse the joint. Do not move or disturb joint for the recommended cooling time. Mark time of day on fitting when fusion cycle ends.

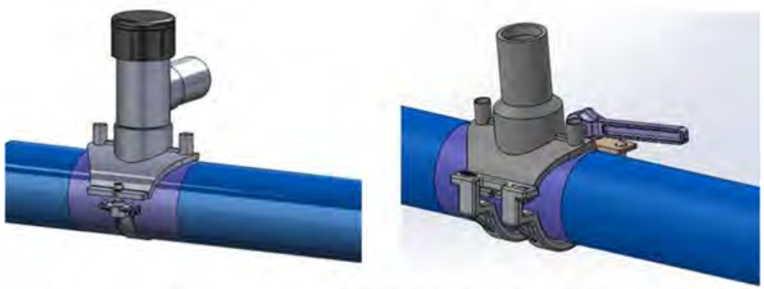
XII. FIELD GUIDE FOR ELECTROFUSION SADDLE INSTALLATION

1. Mark position of saddle on pipe.

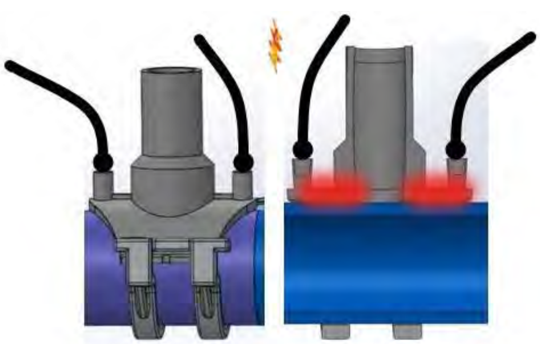
2. Mark pipe surface in area to be scraped.

3. Scrape or peel the pipe to remove the surface layer and expose clean virgin pipe beneath.

4. Inspect the scraped pipe surface thoroughly to ensure that all marks are removed and that only virgin pipe surface is exposed.



5. Clean surfaces with Isopropyl alcohol, avoid touching cleaned surfaces. Clamp saddle to the scraped pipe using only the clamp provided or recommended by the fitting manufacturer.



6. Connect the control box leads to the fitting and fuse the joint. Do not move or disturb the joint for the recommended cooling time. Mark the time of day on fitting when fusion cycle ends. Picture to left shows clamps to pipe and picture to right shows EF.

7. After observance of cooling time and prior to tapping main, saddle should be pressure leak tested. It is recommended to use hydrostatic testing whenever possible. Care must be exercised during pressure testing of saddles due to the stored energy of the test fluid. Pipe plugs or other sealing mechanisms should be restrained to avoid expulsion and possible safety related issues associated with this procedure. Refer to ASTM F2786 when performing pneumatic tests.

XIII. FREQUENTLY ASKED QUESTIONS

A. What pipes can be fused with electrofusion fittings?
   1. Electrofusion fittings are compatible with pipe dimensions conforming to AWWA C906, ASTM D2513, F714 and D3035.
   2. Fittings are typically compatible with pipes with a SDR or DR range of 9 to 17. Other wall thickness ranges and pressure ratings may also apply. Consult the specific fitting manufacturer for details.
   3. Electrofusion fittings are compatible with PE 2406/2708 and PE3408/3608/3708/3710/4710 pipes.

B. What are the power requirements?
   A reliable source of AC power is necessary for a successful fusion.
   1. Generator – well maintained generator providing a minimum of 7000 watts continuous output.
      b. Prior to the electrofusion cycle fill generator with fuel.
      c. The governor/economy switch should be off so that the throttle is opened all the way in anticipation of the power draw at the start of the fusion cycle.
      d. Insure that the generator is fully warmed up prior to attempting electrofusion procedure.
   1. Provide output voltage in the range that meets the specifications of the applicable processor model.
   2. Rated for 60 Hertz.
   3. A matching outlet is needed to mate with the plug equipped on the electrofusion processor.

C. Can I use an extension cord with my processor?
   Avoid the use of extension cords; in the event an extension cord must be used, a 25 foot cord shall have a minimum wire gauge of #8/3 AWG.

D. Can I use a pigtail or electrical adaptor with my electrofusion processor? **No**, connect the power cord directly from the processor to generator.

E. What are the most common electrofusion failures? Electrofusion has proven to be an extremely reliable joining system. The most common reasons for failure account for more than 95% of all fusion failures:
   1. Contamination – inadequate pipe preparation
      a. Inadequate scraping
      b. Dirt, mud, dust
      c. Grease, oils
      d. Moisture
      e. Hands (body oil, sunscreen, etc.)
      f. Solvents, unsuitable wiping fluids
      g. Unclean or unsuitable wiping rags

   2. Geometry – pipe out of round or not cut square
      a. Alignment Errors
         i. Pipe Mis-Stab: pipe not cut square and pipe ends not being centered in the fitting.

ii. Short Stab: can result from improper insertion of the pipe or movement during weld due to incorrect restraint
iii. Mis-alignment of pipes and fitting
iv. Flat spots on pipe
v. Excessive Gap
   - excessive gap between pipe and fitting due to pipe out of roundness, undersized pipe or over scraping of pipe surface.
   - Pipe ends not butted together
   - Pipe ends are not cut square.
vi. Pipe Movement during Fusion Cycle – due to external forces or forces induced by the welding process, when the pipes are not clamped properly.
vii. Movement – pipe not properly restrained during fusion process
viii. Unusual conditions - Contact EF manufacturers if you observe smoke or melt flow outside the fitting.
ix. Over Scraping (never exceed 0.040 inches)

3. Removal of clamping equipment before observance of minimum Cooling Time.

F. Can I use sandpaper, dragon skin, emery cloth or wipes to scrape the PE pipe?
No, it is very important to never use abrasive materials such as sand paper, dragon skin or emery cloth and wipes in place of an approved scraping tool. Abrasive materials have been proven to be ineffective in the removal of sufficient amounts to surface material needed to achieve an electrofusion bond and in fact have been shown to impede the electrofusion process. See "SCRAPER" section of this document.

⚠ **Wood rasps and metal files are not acceptable for scraping PE pipe.**

G. Why does the fitting need to observe the Cooling Time prior to removal of re-rounding and alignment clamps, movement, backfilling, pressure testing, tapping or placing the fitting in service?
1. It is often assumed that if the fitting is cool enough to touch it must be cool enough to remove the restraint device, pressure test, movement, backfill, tap or return to service. The cooling phase is critical to the success of the electrofusion process. Careful attention shall be given to insure the observance of the stated Cooling Time.
2. When current is applied to the fitting the plastic in the fitting and on the pipe surface begins to melt and form a melt pool. With continued application of current the melt pool deepens at the pipe and fitting interface which in turn forces internal pressure to build up. After the heating phase, the melt pool re-solidifies. This process is known as co-crystallization between the melted pipe and fitting material. The cooling phase provides a controlled environment between the pipe and fitting where solidification can effectively take place. This cooling phase begins immediately following the termination of current being supplied to the fitting and continues for a period of time beyond the point where the PE polymer re-solidifies. This allows ample time for the fusion area to regain the strength and flexibility it exhibited prior to fusion. Any movement or external stresses applied to the fused area during this cooling phase may result in a compromised fusion joint.

H. Do I need to use clamps?
1. Electrofusion couplings:
   a. All electrofusion couplings require the pipe to be restrained and sufficiently supported on each side of the pipe to restrict movement during the fusion and cooling processes and alleviate or eliminate sources of stress and/or strain until both the fusion heating and cooling cycles are complete.
   b. To achieve immobility, use of some form of pipe restraint and support for the primary purpose of controlling and eliminating any movement of the fitting due to fusion pressures generated during the fusion processes or any external forces exerted on the pipe or fitting. The basis for using a pipe restraint system and support when joining two pieces of PE pipe with an electrofusion coupling is to:
      - Minimize potential short stab, mis-stab or binding situations
      - Ensure proper cold zone contact with the prepared fusion area so that sufficient interfacial pressure is built up
      - Eliminate unwanted loss of molten material from the fusion zone
      - Re-round the pipe

2. Electrofusion saddles
   Electrofusion saddle fittings include tapping tees, branch saddles, corporation/transition saddles and others. Installation of an electrofusion saddle requires the use of recommended re-rounding clamps and restraint systems for the purpose of:
   a. Holding the fitting in place during the fusion process
   b. Eliminating fitting movement due to material expansion
   c. Ensuring proper cold zone contact with the prepared fusion area so that sufficient interfacial pressure is built up

⚠ **To ensure good joint integrity during the fusion process and Cooling Time, the joint must remain stationary and free from stress.**

⚠ **The installer is cautioned against attaching appurtenances to the outlet of saddle-type fittings before fusion. All appurtenances to the saddle outlet shall be self-supported and only installed after observance of Cooling Time.**

⚠ **All appurtenances (tees, elbows, services, valves, air relief valves, fire hydrants, etc.), must be independently supported and <u>shall not</u> rely on the pipeline and its connections for this support. Excessive stresses may be encountered when appurtenances are inadequately supported.**

I. Can electrofusion couplings be re-fused if I have a power related failure?
1. Electrofusion couplings can be re-fused only in the event of an input power interruption.
   a. Fusion leads were detached during fusion
   b. Generator runs out of gas
   c. Other circumstances that results in processor input power interruption

2. Recommended procedure for re-fusing couplings:
   a. Keep coupling in restrained position.
   b. Allow coupling to cool completely to ambient temperature. Installers shall follow

the instructions of the manufacturer. Additional instrumentation (pyro meter) is required to determine when the assembly reaches ambient temperature.

c. Reconnect coupling to the processor.
d. Refuse coupling completely for the entire fusion cycle.

⚠ **Only use this re-fusion procedure for fusions that terminated due to input power reasons. Remove and discard couplings that fault for any other reason.**

XIV. INSTALLER TRAINING AND QUALIFICATION GUIDELINES

Installer Experience: Only properly trained persons, that have a strong working knowledge of polyethylene and heat fusion, and have qualified 14 inch and larger electrofusion joints through destructive testing shall install electrofusion fittings. This document is a guide only, and should not be used in place of training and qualification. Failure to follow all preparation steps can result in joint failure or leakage due to contamination or improper installation resulting in significant financial impact.

Destructive tests are described in ASTM F1055 (latest edition) and can be in the form of burst tests, bend tests, peel tests and other methods useful in determining the quality of a fusion joint. See Section D in XIV for additional information on destructive testing.

⚠ **It is the owner's responsibility to specify EF procedures and qualify installers.**

A. Scope

This section applies to the Generic Electrofusion Procedure for Field Joining of Polyethylene (PE) Pipe and specifies the method of testing the knowledge and skill of an installer who is authorized to perform electrofusion joining to polyethylene pipe ≥14 inch in diameter. The examination of an installer is essential for the assurance of the installer's skills and quality of electrofusion work. The application of this section is intended to ensure that the examination is carried out according to a uniform and standard test method.

B. Training and Qualification

1. Any installer that performs or inspects electrofusion joints on polyethylene (PE) pipe shall successfully complete an annual electrofusion training program or more frequently if required.
2. During the qualification test, the installer shall demonstrate practical skill and knowledge of electrofusion joining methods on PE pipe.
3. The qualification test will be carried out in two parts under the direction of the utility.
   a. The installer will answer questions relevant to electrofusion qualification testing. The questions will be presented to the installer in written form. The written test will be a True/False and/or multiple choice questionnaire. The installer must answer all questions correctly! 100% is the only passing grade.
   b. The installer will perform a minimum of two electrofusion joints (one coupler and one saddle) adhering to this Generic Electrofusion Procedure. Use a 14 inch or larger coupling and a 14 inch or larger main size saddle fitting as test specimens. This will qualify the installer for electrofusion joining 14 to 30 inch.
      i. The utility shall require all tooling to be used in the field for qualification testing of the installer. Installers will supply all tooling, power supplies, fittings and pipe similar to actual field conditions so the utility can inventory tooling, verify quality of tooling and generator performance including any extension cords intended for work. A controlled environment does not represent field conditions.

ii. The utility shall witness the entire fusion procedure and all required steps to perform fusion. If anything is skipped or inadequately performed, including observing Cooling Time, rejection of the installer is required and the prepared fitting will not be tested. If and only if, all of the required steps are conducted, all of the required tooling is used and is in good working order and the Cooling Time is observed, the fitting is destructively tested per ASTM F1055.

iii. The installer will make and submit electrofusion joints for approval via the attached destructive testing procedures in Section D. Individuals who successfully complete both sections of the testing will be qualified to perform electrofusion joints on polyethylene piping ≥ 14 inch.

iv. All installers must requalify annually. If any failures associated with their work are encountered, the installer must be requalified. Fusion failures are defined as leaking connections allowed to be placed into service. If a fitting fails during fusion or by observance after installation but before being placed into service it does not count as a joint failure (it is critical for the fuser to identify and cut out bad joints without penalty).

C. Electrofusion Joint Failures
Electrofusion joint failures that are detected during pressure tests are subject to the provision set forth in Section E.

D. Destructive Testing Procedures for Electrofusion Fitting Qualification
The following test methods are useful as an evaluation of fusion quality between the pipe and fitting. These procedures are based on requirements from current version of ASTM F1055 Standard *Specification for Electrofusion Type Polyethylene Fittings for Outside Diameter Controlled Polyethylene Pipe and Tubing* Fusion Evaluation Test section. Refer to ASTM F1055 for more detailed test requirements. These tests can be used as user qualification criteria. As these methods are destructive, they are only useful in determining joint quality of a fitting that was fused for the purpose of testing, and cannot be used for testing of fusions intended for service. One of the following methods should be utilized for destructive testing as outlined in ASTM F1055 (latest edition).

1. **Couplings:**
Bend tests, peel tests, and crush tests are helpful in locating fusion weaknesses. It is desirable to obtain x-ray photographs of the fitting before dissection to locate any possible contact points of the fusion coil.
When large diameter crush tests are impractical, the strip bend back test or other methods (see ASTM F1055) may be utilized.
To prepare a specimen for crush testing, it is necessary to cut the pipe and coupling longitudinally in half as near to the centerline of the pipe and coupling as possible. It is desirable to leave at least 12" (300mm) of pipe length at each end of the coupler.

Place a specimen half in a vise so that the outermost wire of the fusion zone is approximately 1 1/4" (32mm) from the vise jaws. (Figure XIV-a)

Close the vise jaws until the pipe walls meet. (Figure XIV-b)

Repeat this process for each end of both halves of the coupling.

Inspect the crushed specimens for separation of the pipe and fitting in the fusion zone. Some minor separation (up to 15% measured as shown in the following examples) may be seen at the outermost region of the fusion zone, this does not constitute failure. Ductile failure of the pipe, fitting, or PE insulation around the wires is acceptable. There should be no separation at the fusion interface of the pipe and fitting. Passing (Figure XIV-c) and failing (Figure XIV-d) results are shown in the photographs.

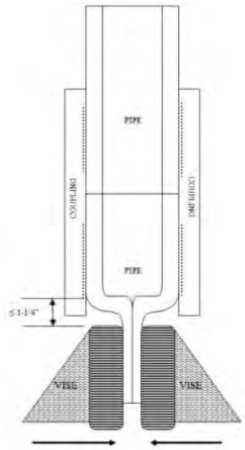


Figure XIV-a

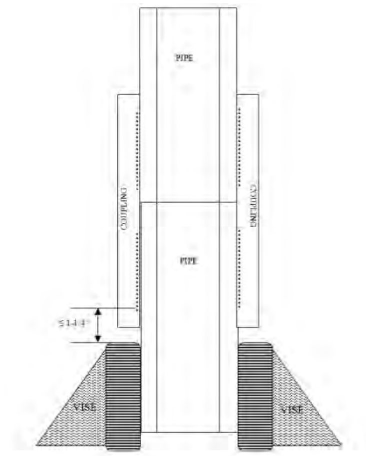


Figure XIV-b

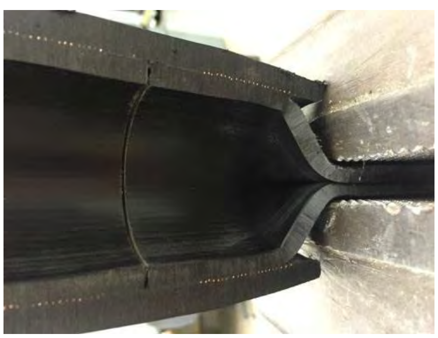


Figure XIV-c - Pass

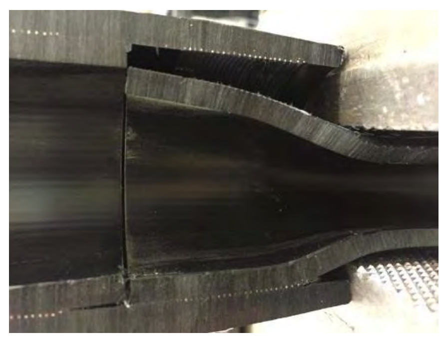


Figure XIV-d- Fail

2. **Saddles/Tapping Tees**

Leave tapping tees intact for crush testing. Pipe lengths can be cut to the edges of the fitting base.

Place the pipe and fitting into a vise (or suitable press) so that the jaws are within 1/2" (13mm) of the bottom of the saddle (Figure XIV-e). Close the vise until the pipe walls meet **(**Fig**.** XIV-f).

Inspect the crushed specimens for separation of the pipe and fitting in the fusion zone. Some minor separation (up to 15%) may be seen at the outermost region of the fusion zone, this does not constitute failure. Ductile failure of the pipe, fitting, or PE insulation around the wires is acceptable. There should be no separation at the fusion interface of the pipe and fitting. Passing (Figure XIV-g) and failing (Figure XIV-h) results are shown in the photographs.

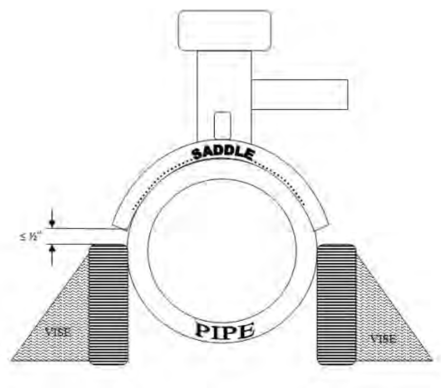


Figure XIV-e

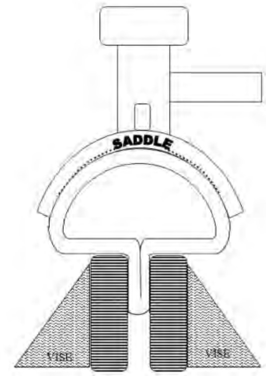


Figure XIV-f

Figure XIV-g - PASS

Figure XIV-h – FAIL

Further evaluations are possible by cutting the fusion area and surrounding pipe and fitting materials in thin longitudinal /cross sectional strips for bend tests. Place the strips into a vise and bend 90 degrees in both directions directly at the fusion interface and evaluate for separation. Use the same visual criteria for fusion evaluation tests and crush tests. (Figure XIV-i)

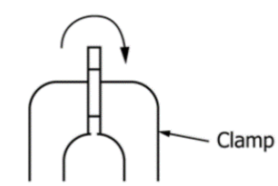
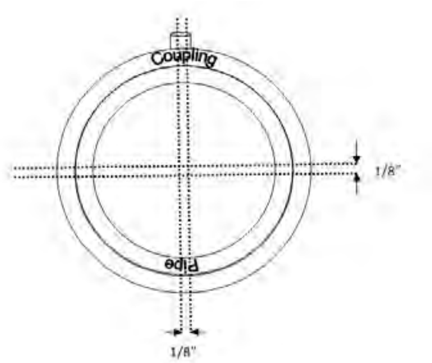


Figure XIV-i

Couplings should have four longitudinal strips cut from the fusion interface at 90 degree intervals as shown (Figure XIV-j). The strips should be approximately 1/8"(3mm) in thickness. Place the strips into a vise and bend 90 degrees in both directions directly at the fusion interface and evaluate for separation.



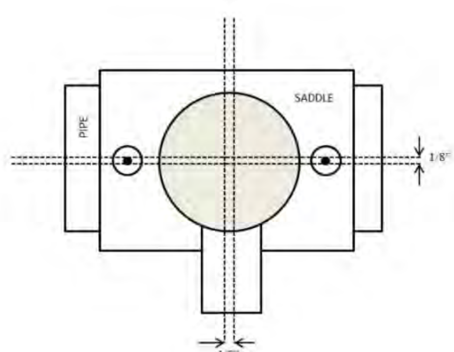


Figure XIV-j

Tapping Tees should have strips cut along the center line of the pipe through the fitting fusion surface and a strip cut from the radial side of each half of the fitting, totaling 4 strips for each sample fusion made. Place the strips into a vise and bend 90 degrees in both directions directly at the fusion interface and evaluated for separation.

E. Required Re-Qualification and Retraining

Failed electrofusion joints determined to be caused by improper installation procedures warrant retraining and/or qualification of the installer. If an installer has failed electrofusion joint(s) under the provision previously listed or is observed using non specified or faulty equipment or not strictly adhering to all fusion procedures that installer will be disqualified from making additional electrofusion joints, their qualification revoked, and will require additional training and requalification before performing any additional fusion joining.

F. Test Result and qualification test certificate

1. Issue the installer a certificate (Qualification Card) upon successful completion of the Generic MAB Electrofusion Installer Qualification Test (See Appendices B and C); the Qualification Card is valid for one year from date of issuance.

2. Successful Completion: Installer cannot miss any questions on the written test.
   a) Installer who misses two (2) questions or less can re-address the specific questions with the trainer and re-take written test in its entirety.
   b) In event of fitting failure from destructive testing, the Installer shall prepare an additional specimen (of the same fitting type) for destructive testing.

3. Qualification Test Certificate

   Certificate shall contain the following:
   a) Installers Full Name
   b) Date, Place of training
   c) Date of Issue
   d) Expiration Date of Certificate
   e) Signature of Authorized Trainer
   f) Indication of qualified type of fitting(s)
   g) Owner card number
   h) Photograph of installer
   i) Name of utility owner

Appendix A – List of Electrofusion Manufacturing Companies

The following Electrofusion companies (listed alphabetically) endorse this generic electrofusion procedure for use with their Fittings. This list will be updated as needed.

1. Agru America (800) 373-2478 http://agruamerica.com
2. Georg Fischer Central Plastics (800) 654-3872 www.gfcp.com
3. Integrity Fusion Products (770) 632-7530 http://integrityfusion.com
4. IPEX Inc. (866) 473-9462 http://www.ipexinc.com/
5. Plasson USA (800) 241-4175 www.plassonusa.com
6. Strongbridge-Tega (904) 278-7499 http://strongbridge.us/

Appendix B – Generic Electrofusion Installer Qualification Test

DESTRUCTIVE TESTING

Installer Name:___________________Date:____________________Location:________________

Electrofusion Coupling 14 inch to 30 inch

Fitting Size:
Fitting Manufacturer:
Fitting Fusion Time:
Fitting Cooling Time:

PASS/FAIL:______________________________

Electrofusion Saddle Fitting 14 inch to 30 inch

Fitting Size:
Fitting Manufacturer:
Fitting Fusion Time:
Fitting Cooling Time:

PASS/FAIL:______________________________

Authorized Trainer:_______________________Date:________________

Qualification Test Certificate **Qualification Card No: ####**

Insert Photo

(Installer Name)____
has successfully completed the training requirements for qualifications
to **install 14 – 30 inch Electrofusion Fittings** according to **(Utility Name)**
____________________________________ Department Standards

- ☐ **Couplings**
- ☐ **Saddles**

I have instructed and tested the above in all requirements and procedures related to installation of Electrofusion Fittings according to **(Utility Name)** Department Standards.

Authorized Instructor **Date Issued** **Expiration Date**

Appendix C – Sample Test

The following is a sample written qualification test.

Users should modify this test to address their unique operating environment.

Generic Electrofusion Installer Training & Qualification Section

Installer Name: ______________________________ **Date:** ___________________

Location: ______________________________

Answer all Questions with either T for True or F for False. The installer must answer all questions correctly! 100% is the only passing grade.

1. The purpose of scraping is to remove the oxidized layer of PE pipe from the pipe surface prior to electrofusion.
   a. True
   b. False
2. For out of round pipe it is acceptable to scrape the high points until the pipe fits into the electrofusion coupling.
   a. True
   b. False
3. Sand paper, dragon skin, emery cloth, and other abrasives are acceptable for scraping.
   a. True
   b. False
4. If the pipe becomes re-contaminated with dirt after scraping it is acceptable to use Isopropyl Alcohol for cleaning purposes.
   a. True
   b. False
5. It is acceptable to perform an electrofusion with a slight trickle of water running across the fusion area.
   a. True
   b. False
6. The Cooling Time for 14” to 30” couplings is 3 hrs.
   a. True
   b. False
7. Perform pressure testing, movement, backfill, tapping and return to service immediately after the electrofusion power cycle is complete
   a. True
   b. False
8. Cut pipe ends square within ± 1/2” for coupling installation
   a. True
   b. False

9. A 2500 watt continuous output generator is recommended for fusing electrofusion couplings (14 inch to 30 inch).
   a. True
   b. False
10. Do not use slow drying markers that contain oils when marking the pipe for scraping.
    a. True
    b. False
11. If the electrofusion coupling is to be pushed completely over one pipe, it is necessary to scrape the entire length of the coupling onto one of the pipes.
    a. True
    b. False
12. A standard metal file is acceptable for scraping the pipe surface.
    a. True
    b. False
13. There is no need to support hanging pipe ends during fusion.
    a. True
    b. False
14. Installers must re-qualify annually or if they make any bad joint.
    a. True
    b. False
15. Observance of pipe print line under saddle fitting fusion area after scraping is acceptable.
    a. True
    b. False
16. A gouge or scratch in the pipe of more than 10% of the wall thickness is acceptable.
    a. True
    b. False
17. It is acceptable to pressure test a saddle fitting prior to tapping.
    a. True
    b. False
18. Always use alignment clamps with electrofusion couplings.
    a. True
    b. False
19. Check the generator prior to electrofusion to make sure it is full of gas.
    a. True
    b. False
20. Keep electrofusion fittings in original packaging until installed.
    a. True
    b. False

Number Correct: _______

Authorized Trainer: __________________________ **Date:**________________

APPENDIX D – ELECTROFUSION COUPLING INSTALLATION INSPECTION CHECKLIST

Location / Job # ______________________ Station # ____________________ Date/Time_________________

Fusion Technician ______________________ Company ______________________ Certificate Card #__________

Installer Credential Issue Date __________ Credential issued by ____________

Pipe Manufacturer ____________________ Material Type __________________

Pipe Size _____________________________ DR ____________________________

EF Coupling Manufacturer _______________ Part #________________________ Description __________

EF Processor Model ___________________ Serial Number _________________

Generator Make & Model _______________ Serial Number _________________

Temperature / Weather ________________ Trench Conditions ______________

General:		
Inspect the equipment for cleanliness and proper operation.		
Verify that the generator / power source is adequately sized.		
Check that the generator is full of gas.		
Verify that the generator eco throttle / economy setting is turned off.		
Verify that the extension cord is adequately rated for the fusion machine and coupling	25' cord: #8/3 AWG	
Is EF fitting still in original packaging? If so, inspect the coupling for damage. If not, discard fitting.		
Let the EF processor acclimate to the jobsite weather conditions for a minimum period of 15 minutes before beginning the fusion process.		
Couplings:		
Cut pipe ends squarely and evenly (+/- ½ inch). Check the squareness of the cut by placing a square at the end of the pipe at its longest point and measuring the resulting gap between the Carpenter's Square and shortest point of the cut. Maximum measured gap is less than ½ inch as measured from Carpenter's Square:		
Clean pipe ends of dirt and debris prior to scraping with clean water and lint-free rag		
Measure and mark one of the pipe ends for the full length of the coupling. Measure and mark the other pipe end for half the coupling length. Mark the entire pipe area to be scraped with an approved marker.		
Verify that the pipeline out-of-roundness is within tolerance. Maximum Out-of-Roundness is ¼" for all sizes 14 inchto 30 inch.		
Mount the scraper over the area to be scraped. Scrape the outside of the pipe to remove the surface layer and expose clean virgin material beneath. Remark stab depths after scraping if necessary. This should remove at least 0.007" of the pipe surface material. **Do not remove more than 0.040" on 14 inch to 30 inch pipe sizes.**		
Bevel the pipe ends if required by fitting manufacturer.		
Inspect the scraped pipe surface thoroughly to ensure that all witness marks are removed and only virgin surface material is exposed. Do not touch the scraped pipe surface or the inside of the coupling to avoid contamination.		
Clean surfaces with approved pre-impregnated disposable wipes.		
Insert the pipe ends to the stab depth marks. Leave plastic bag over coupler to prevent contamination and debris from entering the open end. Use caution not to damage internal wire or terminal pins. Mechanical assist tools are also available for moving couplings on large diameter piping systems. If necessary, place a block of wood over the coupling end and use a hammer to drive the coupling onto the pipe.		
Secure assembly with an alignment clamp, with coupling centered between stab depth marks.		
Provide adequate support/blocking of pipe on either side of coupling.		
Connect the control box leads to the fitting. Scan the numerical barcode on the fitting.		
Verify that the fitting was read correctly and initiate the fusion cycle.		
Verify that the EF processor indicated a complete fusion cycle.		
Did the EF processor indicate a cycle failure? If yes, see * below. If no, see * below.	Yes	No

* Was the failure due to an input power interruption? If yes, see (A) below. If no, see (B) below. Examples of input power interruption include the following: (i) fusion leads were detached during fusion, (ii) generator ran out of gas, or (iii) other circumstances that resulted in processor input power interruption.	Yes	No
(A) If failure was due to an input power interruption, the coupling must be re-fused. 1. Coupling should remain in restrained position. 2. Allow the coupling to completely cool to ambient temperature. 3. Reconnect coupling to the processor. 4. Completely refuse coupling for the entire fusion time.		
(B) Remove and discard coupling that faults for any other reason and install new coupling.		

Fusion cycle	Time of day:	Time of day when Cooling Time will elapse:
Mark end of cooling time. Add cooling time to Time of day and mark result on pipe or fitting. Do not remove clamps, move assembly, pressure test, backfill, or return to service until completion of Cooling Time. Mark name and installer's certificate card ID number.		
Was this coupling accepted?	**Yes**	**No**

Comments ____
____

Inspector ____________________ Company ____________________ Employee # __________
Inspector Credential Issue Date __________ Credential Issued by ______________ Date ______________

Note: At the end of the project, download and review the EF data. Provide EF Data Report for review and filing.

Refer to Table X-a for Cooling Time Guidelines for Couplings

APPENDIX E – ELECTROFUSION SERVICE SADDLE INSTALLATION INSPECTION CHECKLIST

Location / Job # ______________________ Address / Tap # ________________ Date/Time____________
Fusion Technician ____________________ Company ______________________Certificate Card #__________
Installer Credential Issue Date _________ Credential issued by _____________
Pipe Manufacturer ____________________ Material Type ___________________
Pipe Size ____________________________ DR ____________________________
EF Saddle Manufacturer ________________ Part #_________________________ Description __________
EF Processor Model ___________________ Serial Number __________________
Generator Make & Model _______________ Serial Number __________________
Temperature / Weather ________________ Trench Conditions _______________

General:		
Inspect the equipment for cleanliness and proper operation.		
Verify that the generator / power source is adequately sized		
Check that the generator is full of gas.		
Verify that the generator eco throttle / economy setting is turned off.		
Verify that the extension cord is adequately rated for the fusion machine and saddle.	25' cord: #8/3 AWG	
Is EF fitting still in original packaging? Is so, inspect the service saddle for damage.		
Let the EF processor acclimate to the jobsite weather conditions for a minimum period of 15 minutes before beginning the fusion process.		
Service saddles:		
Install re-rounding clamps on both sides of location where saddle will be installed.		
Clean the pipe of dirt and debris prior to scraping with clean water and lint-free rag.		
Mark the area to be fused with an approved marker.		
Scrape the area to be fused with an approved scraping tool.		
Remark the saddle location to be fused with an approved marker.		
Clean the pipe area to be fused with approved pre-impgregnated disposable wipes		
Clean the fitting to be fused with with approved pre-impgregnated disposable wipes		
Secure the saddle to the pipe with the manufacturer recommended clamping mechanism.		
Scan the numerical barcode on the fitting		
Verify that the fitting was read correctly.		
Verify that the EF processor indicated a complete fusion cycle.		
Did the EF processor indicate a cycle failure? Abandon saddle and install new saddle.		
Fusion cycle	Time of day:	Time of day when Cooling Time will elapse:
Mark end of cooling time Add cooling time to Time of day and mark result on pipe or fitting. Do not pressure test, backfill, tap or return to service until completion of Cooling Time Mark name and installer's certificate card ID number Mark the pipe with the house # / tap # (if required)		
Perform hydrostatic test after Cooling Time elapses. Test saddle at 1.5 times working pressure or a maximum of 1.5 times PC for 5 minutes. - If saddle leaks during pressure test, remove outlet /abandon saddle and install new saddle next to failed saddle. Once saddle passes test, the saddle is acceptable for tapping.		
Was this saddle accepted?	**Yes**	**No**

Comments ____
____

Inspector ____________________________ Company _________________________ Employee # __________
Inspector Credential Issue Date __________ Credential Issued by _______________ Date ________________

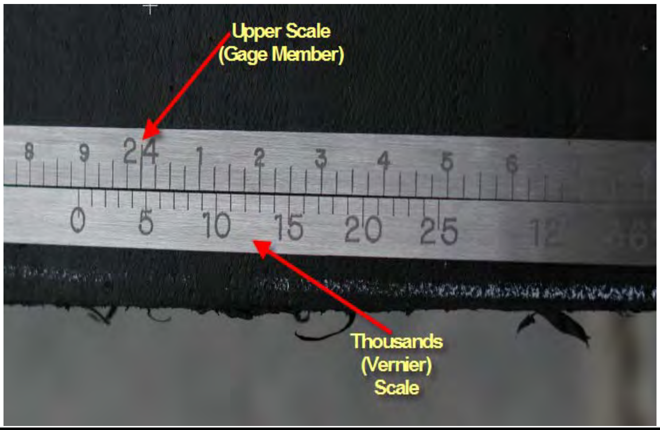
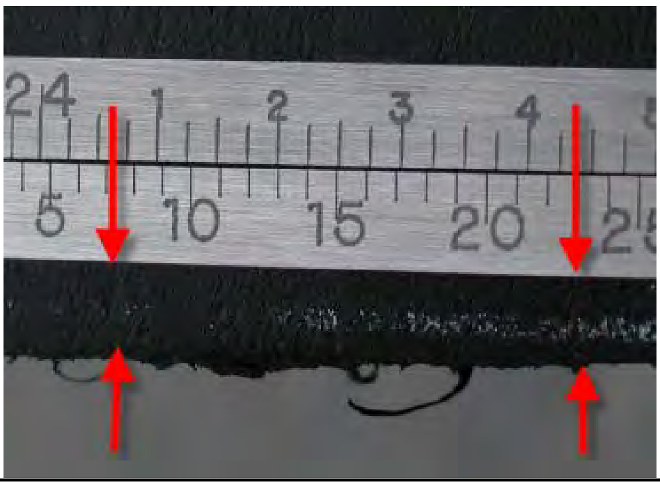
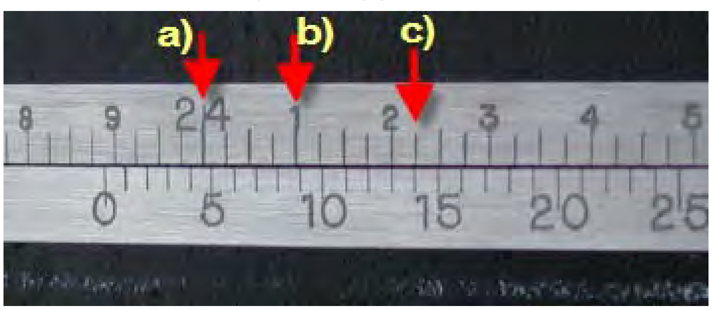
Note: At the end of the project, download and review the EF data. Provide EF Data Report for review and filing.

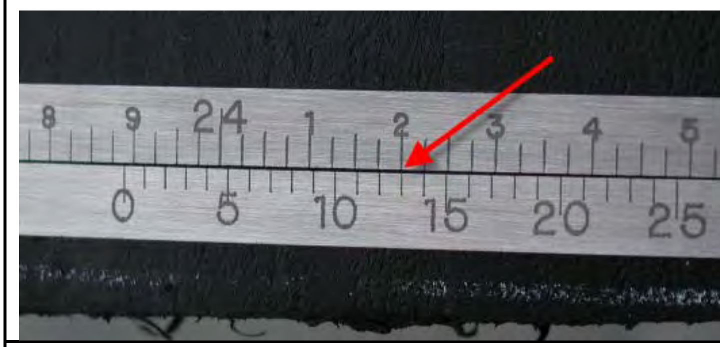
Refer to Table X-b for Cooling Time Guidelines for Saddle Type Fittings

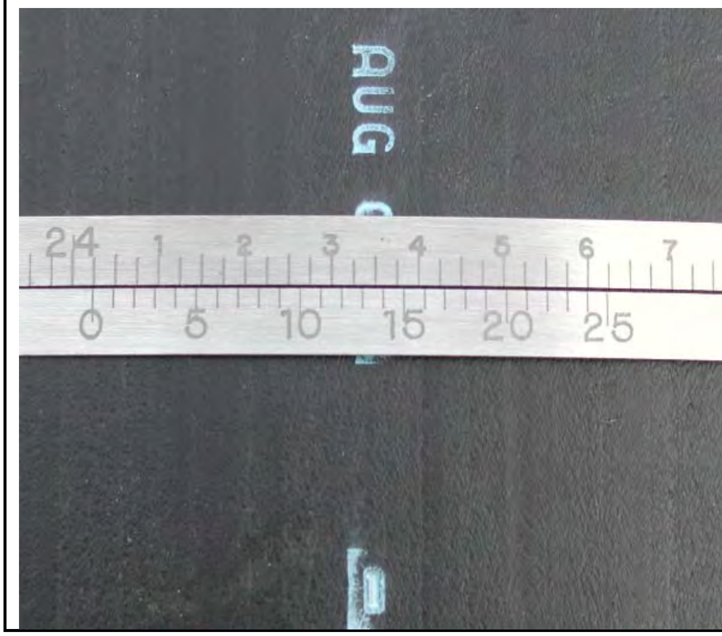
APPENDIX F – How to Measure Diameter using a Pi Tape

Purpose	To accurately measure the true diameter of pipe &/or fittings
Start	To determine if material is made to ASTM F-714 or AWWA C906 specifications, or to qualify pipe or fitting for Electrofusion Coupling use
Materials	Correct sized Decimal Pi Tape, Pipe &/or Fitting to be measured, paper & pencil or calculator.

Actions:	**Do this:**
1. Determine correct Pi Tape 	**a.** Locate the properly sized Pi Tape, based upon the size pipe or fitting to be measured **b.** A decimal tape is required instead of a fractional tape, as it gives greater accuracy
2. Identify the area of toe-in (see gap at arrow) 	**a.** Toe-in (Tapered end) usually takes place within the first 2”-3” from end of large diameter HDPE pipe & fittings **b.** The diameter may be smaller at this location than at any other point along the pipe or fitting

Actions:	Do this:
3. Place Pi Tape around pipe or fitting 	**a.** The Upper Scale (Gage Member) is placed above the Thousands (Vernier) Scale Identify typical distance to measure from end of pipe
4. Correctly locate Pi Tape around pipe or fitting 	**a.** To make an accurate measurement, make sure the Pi Tape is evenly placed around the circumference **Note:** When measuring away from the end, make sure to mark the distance at (4) locations around the circumference
5. What markings on Upper Scale mean 	View upper part of scale **a.** 24 represents the closest diameter in inches **Example a) = 24.000"** **b.** The 1, 2, 3, 4, 5, etc. represent the .100" decimal, or 1/10th inch increments. **Example b) = 24.100"** **c.** Broken into (4) graduations, each mark represents .025" **Example c)= 24.225"**

Actions:	Do this:
6. Measure diameter – Part 1  	View lower part of scale **a.** Using the "0" on the Thousands (Vernier) Scale, write down the measurement on the Upper Scale to the left of the "0" **Example: arrow measure 23.875"**
7. Measure diameter – Part 2  	**a.** On the Thousands Scale, each indentation represents 0.001". The range is from .001" to .025" **b.** Visually locate where the marks on the Upper Scale match up with the marks on the Thousands Scale **c.** Reading the Thousands Scale, write down the number of thousands where the lines match **Example: .013"**
8. Determine the actual diameter	Add the (2) measurements together **Example: 23.875"** **.013"** **Actual Diameter 23.888"**

Actions:	Do this:
9. For Reference only. **Same Pipe** as above, but measured 11.8" from pipe end  	**a.** Since "0" on the Thousands Scale does not perfectly line up with the line above it: 1st Measurement = **24.000"** **b.** An indentation on both scales match up on the Thousands Scale at **.024"** **c.** Adding **24.000" + 0.024" = 24.024"** actual OD

Result True diameter accurately measured

Task standards

- Tape measurement is read correctly
- Tape is placed on material at proper location

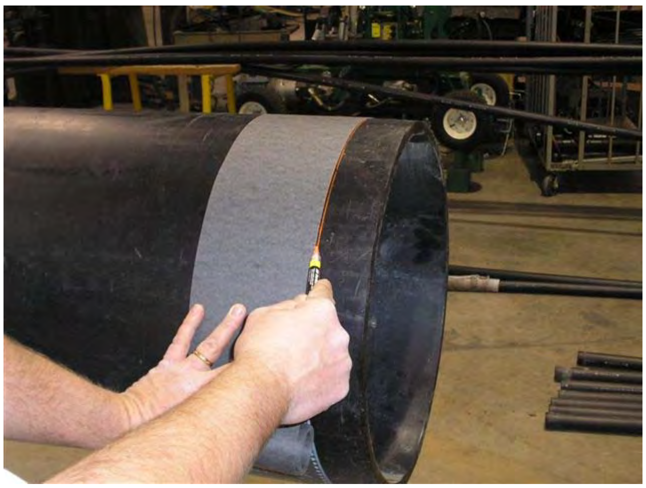
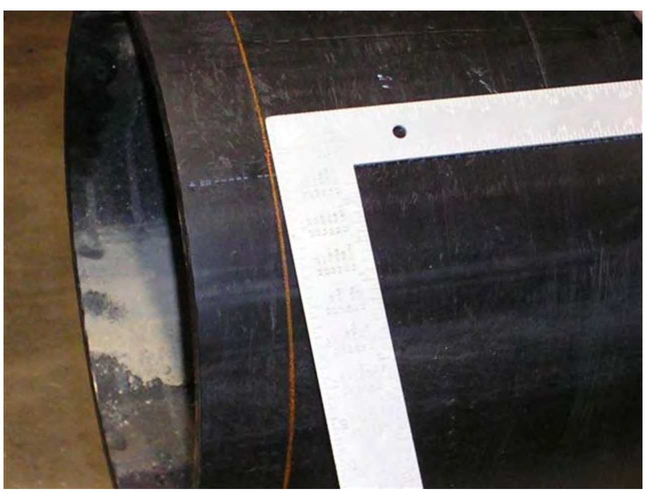
APPENDIX G – Make a Square Cut with a Pipe Wrap

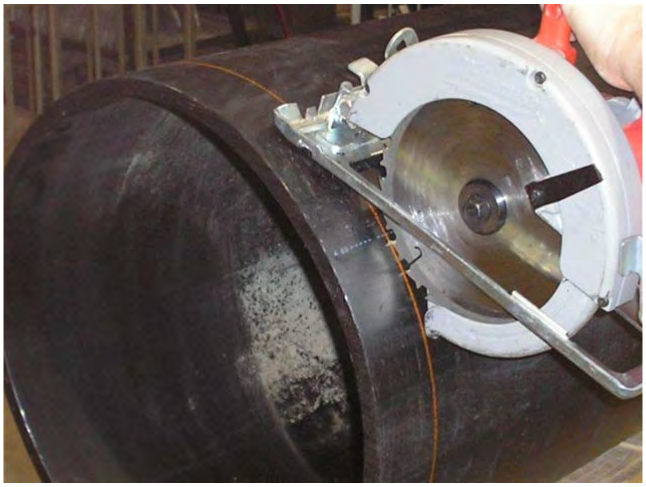
Purpose Make a square on HDPE Pipe by using a 4” wide pipe wrap for marking.

Start Use when square cut on pipe is required: Electrofusion coupling installation requires a square cut, use the pipe wrap to mark pipe for installation of a coupling

Materials Pipe to be cut, pipe wrap for pipe size, pi tape and non-greasy marker

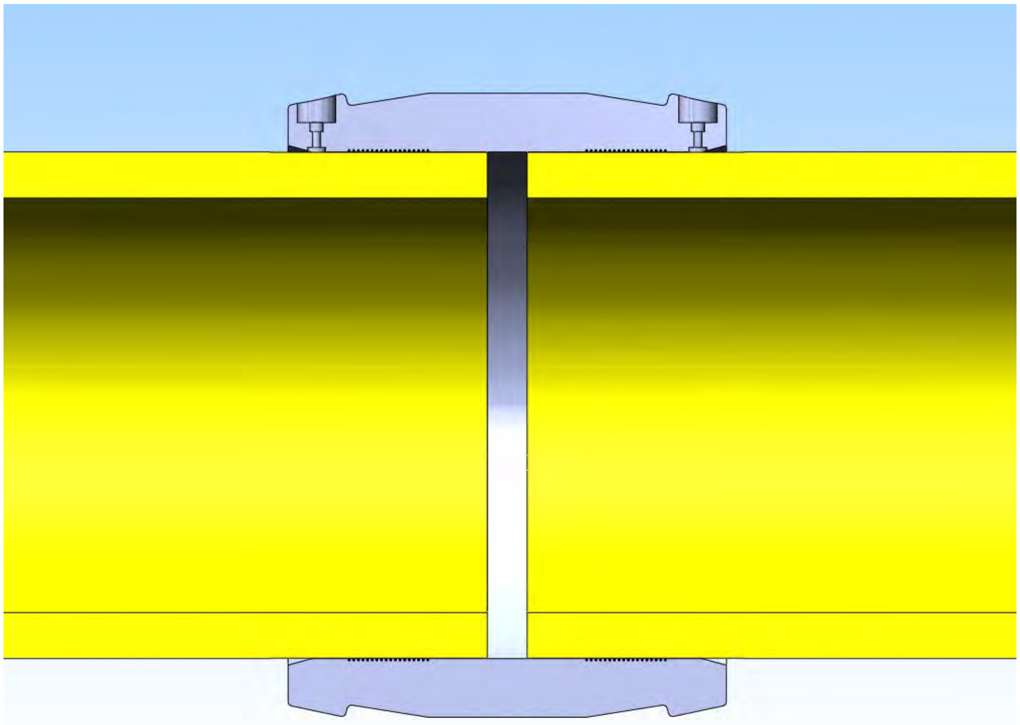
Actions:	Do this:
1.Determine diameter of pipe  	• Check print line on pipe and verify with pi tape • If you cannot read print line, use pi tape to determine diameter of pipe
2. Based on diameter of pipe, select pipe wrap of correct length	Place pipe wrap around pipe. Pipe wrap must be long enough to reach around the pipe more than the circumference. Pipe wraps are usually 1.25 to 1.5 times the circumference of the pipe.

Actions:	**Do this:**
3. Place pipe wrap around pipe	• When pipe wrap is pulled tightly around pipe, it will be perpendicular to the end of the pipe. • Visually check alignment of wrap. Adjust until there is no slack and wrap appears to be square.
4. When pipe wrap appears to be tight and square, make line around pipe with non-greasy marker. 	Carefully mark a line around pipe with marker.
5. Use square or tee to check that line is perpendicular 	**Check line. Is line square? Is line completely around pipe?**

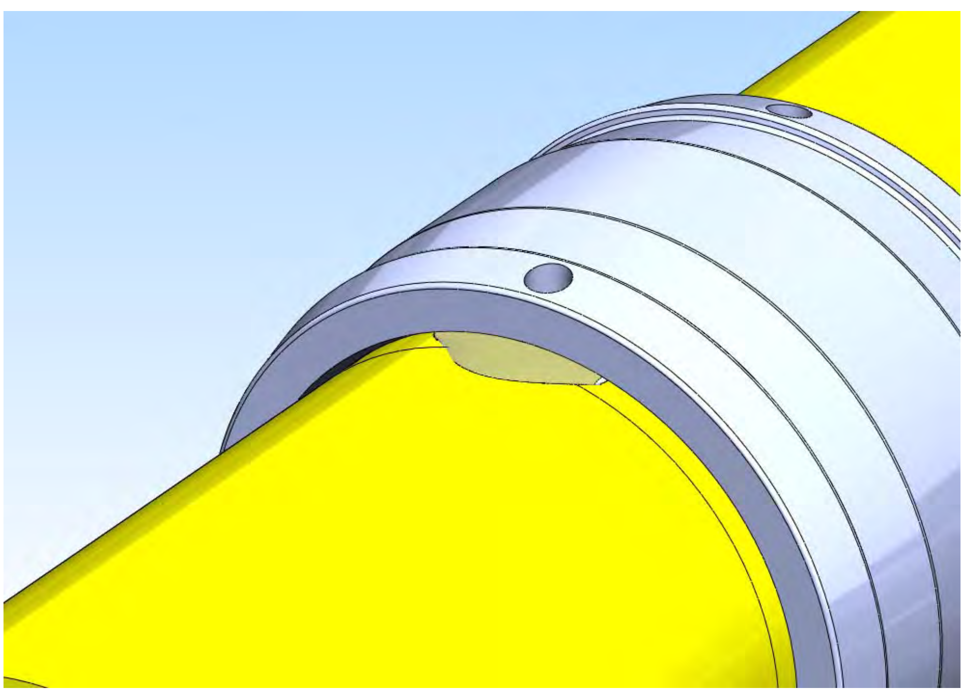
6. Cut pipe to provide square cut using circular saw with wood cutting blade. 	Follow line around pipe with saw.
7. Check cut for square cut. 	Check line. Is line square with ≤ ½" gap?
8. Surface Planer 	Resurface with a surface planer until an acceptable square cut is achieved.

APPENDIX H – Acceptable and Unacceptable EF Joints

The following are illustrations of acceptable and unacceptable electrofusion joints (Refer to Manufacturer when in doubt)

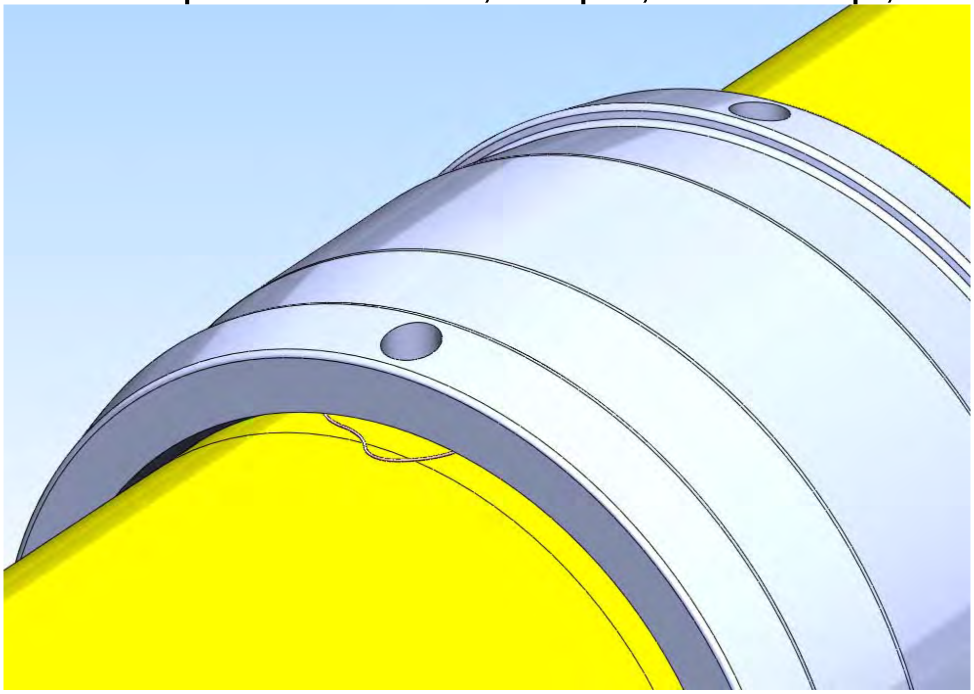


Good Fusion Acceptable- However, Installer Must Butt Pipe Ends Together

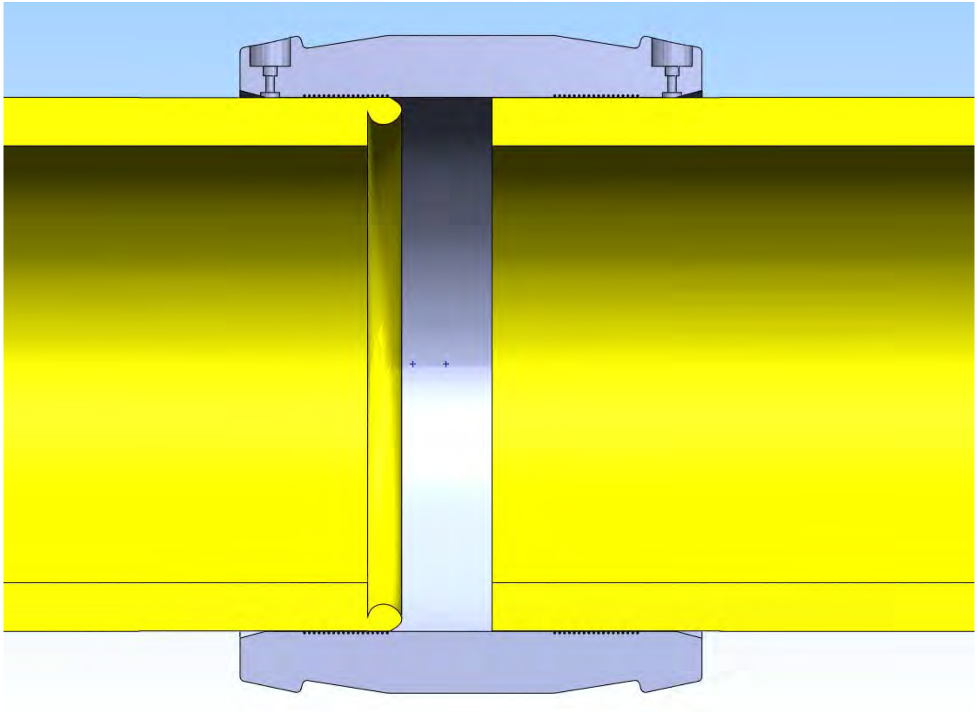


Melt Out Unacceptable:

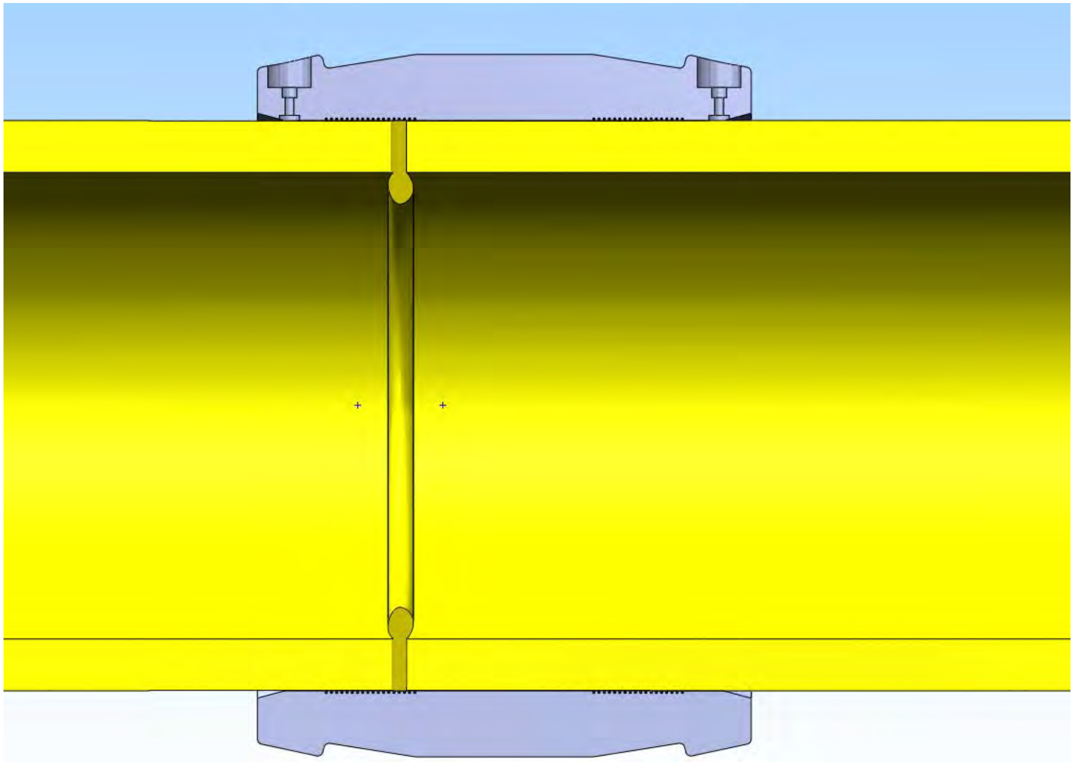
Possible Causes: Pipe Out-of-Roundness, Flat Spots, Undersized Pipe, and Binding



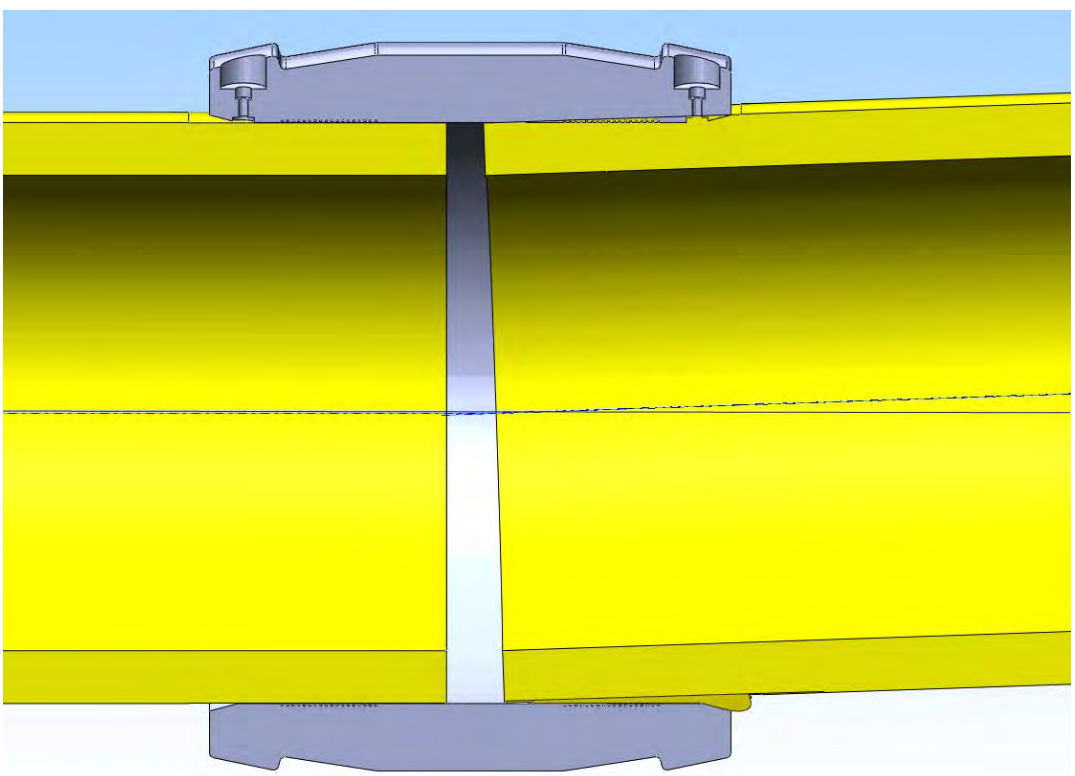
Exposed Wire Unacceptable
Possible Causes: Pipe OOR, Flat Spots, Undersized Pipe or Binding



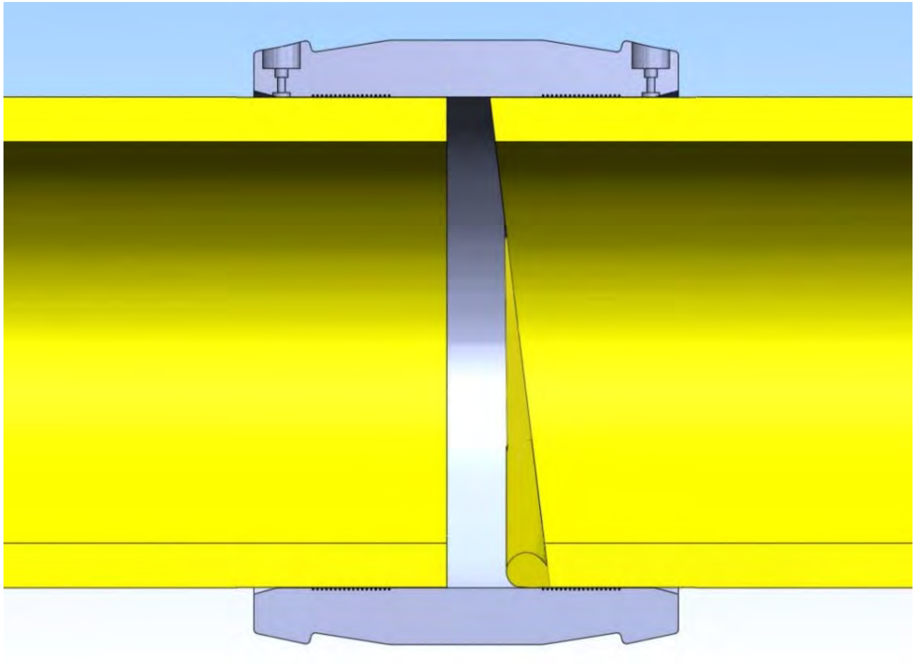
Short Stab Unacceptable
Possible Cause: Failure to Mark or Monitor Stab Depth



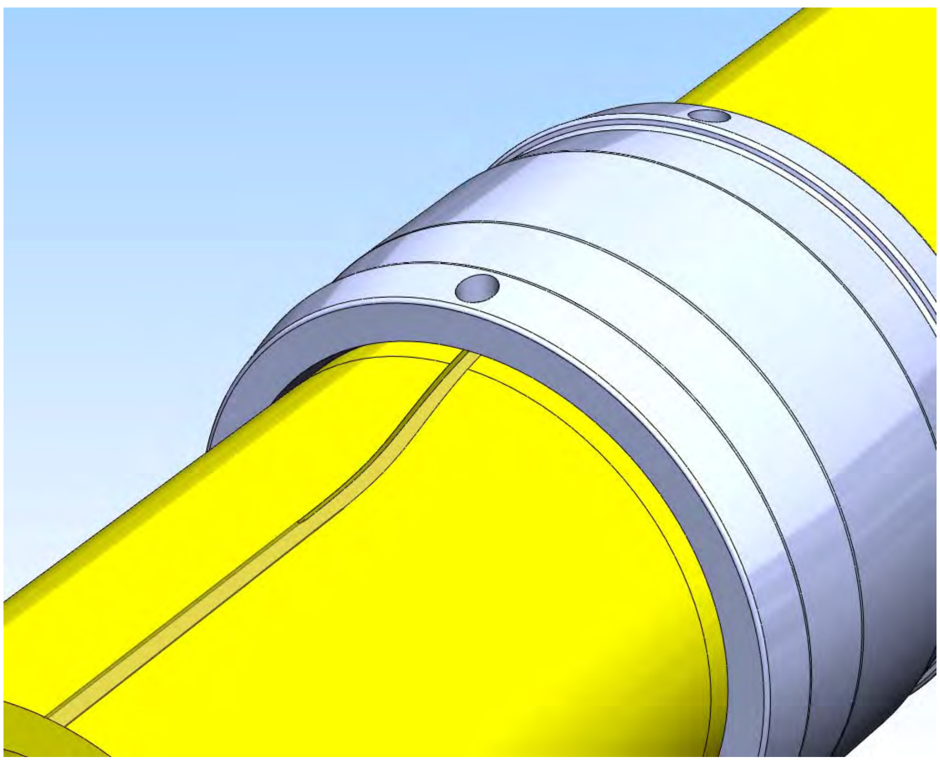
Mis-Stab Unacceptable
Possible Cause: Failure to Mark or Monitor Stab Depth



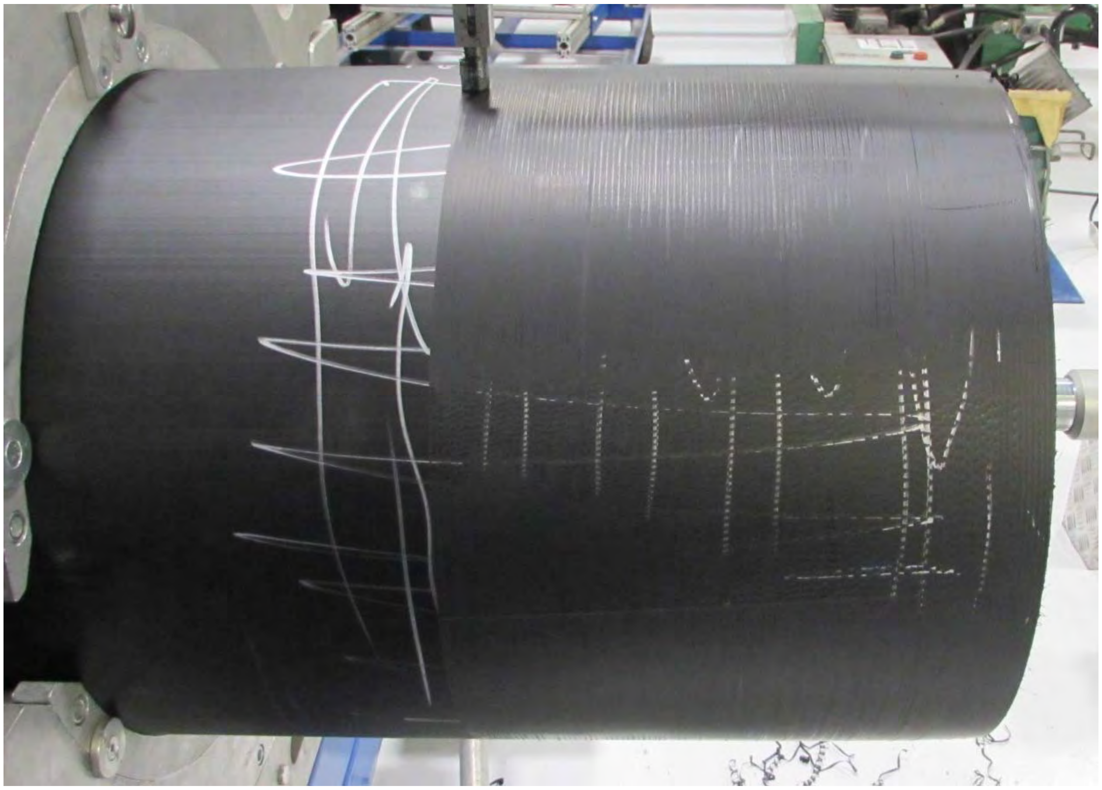
Misalignment Unacceptable
Possible Cause: Inadequate Clamping or Restraint During Fusion



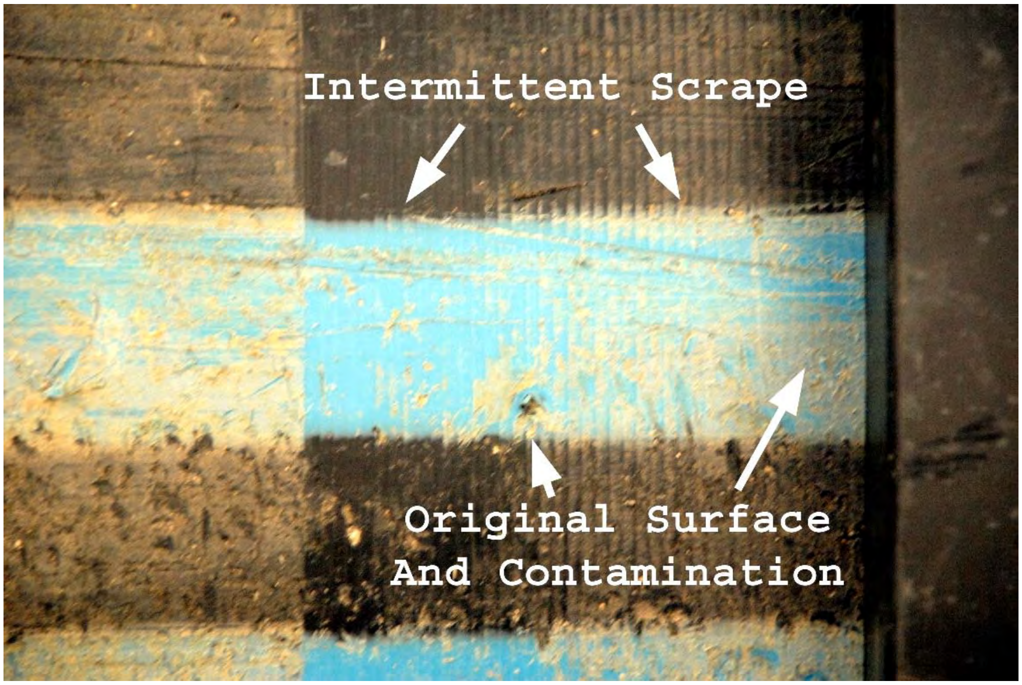
Mis-cut Unacceptable
Possible Cause: Failure to cut Pipe End Perpendicular to The Axis of The Pipe



Gouges and Scratched (that exceed 10% wall) Unacceptable
Possible Cause: Damage During Transportation or Handling of The Pipe

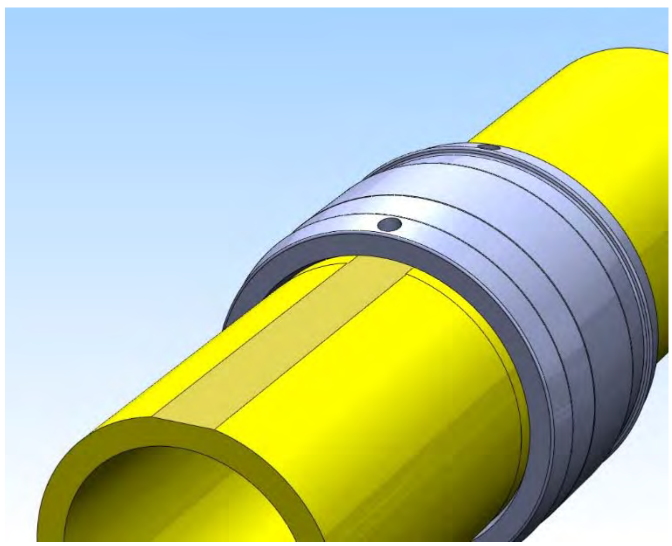


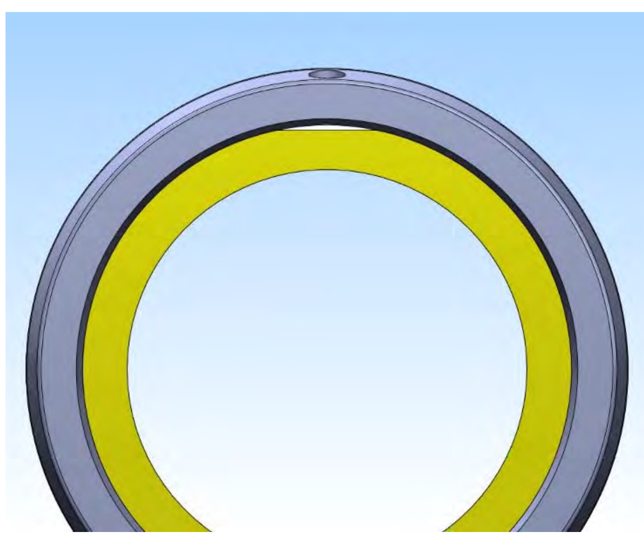
Poor Scrape Unacceptable



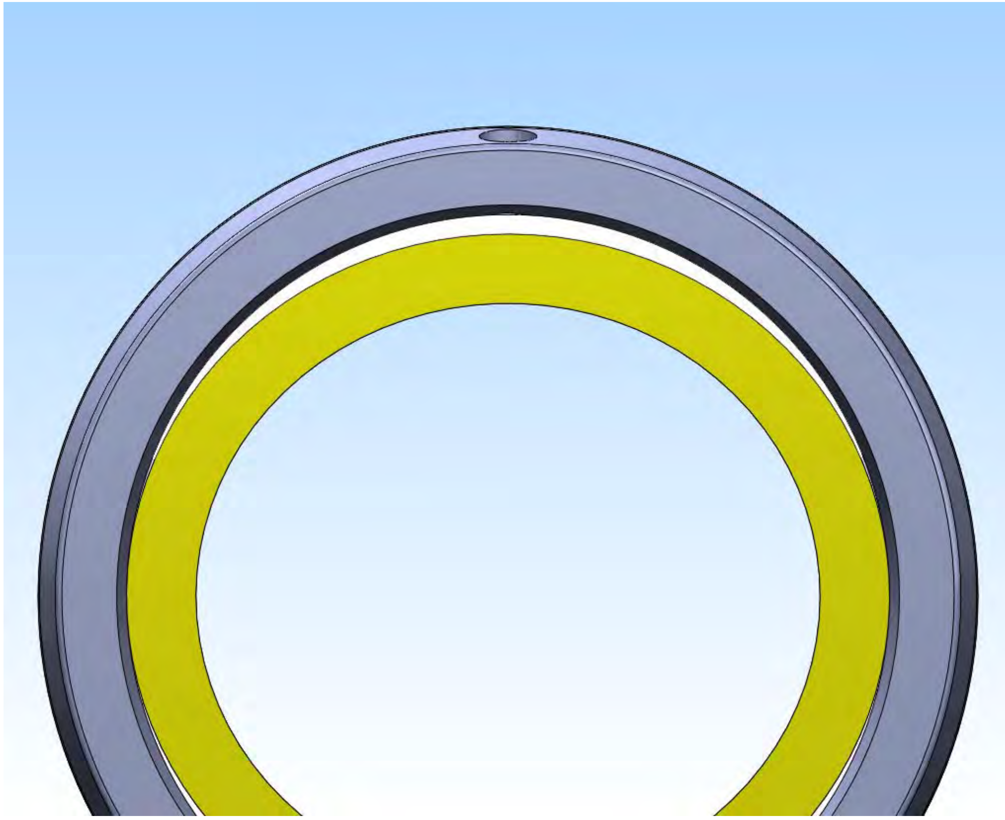
Poor Scrape Unacceptable
Possible Causes: Incorrect Scraper, Poorly Maintained Scraper, Inadequate Number of Passes With Scraper, or Ineffective Evaluation of Scraping

Over Scrape Unacceptable
Possible Causes: Incorrect Scraper, Poorly Maintained Scraper, Excessive Number of Passes With Scraper, or Ineffective Evaluation of Scraping





Pipe Flat Spots Unacceptable (>10% wall thickness)
Cause: Damage During Transportation or Handling of The Pipe



Pipe Out of Round Unacceptable
Possible Causes: Manufacturing Defect, or Transportation or Storage Damage or Non-Use of Full Encirclement Rounding Clamps

Municipal Advisory Board

Established May 1, 2008 at the University of Texas, Arlington

MAB Basic HDPE Repair Options

(MAB-4-2018)

First edition approved at MAB 22 hosted by San Antonio Water System, TX
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FOREWORD

The MAB-4 Basic HDPE Repair Options document was developed by the Municipal Advisory Board (MAB) and published with the help of the members of the Plastics Pipe Institute, Inc. (PPI).

The MAB-4 Basic HDPE Repair Options is intended as a guide for engineers, users, contractors, code officials, and other interested parties for use in the repair of high density polyethylene (HDPE) pressure water piping systems. The local utility or engineer may need to modify these guidelines to adapt the document to local conditions, operations, and practices.

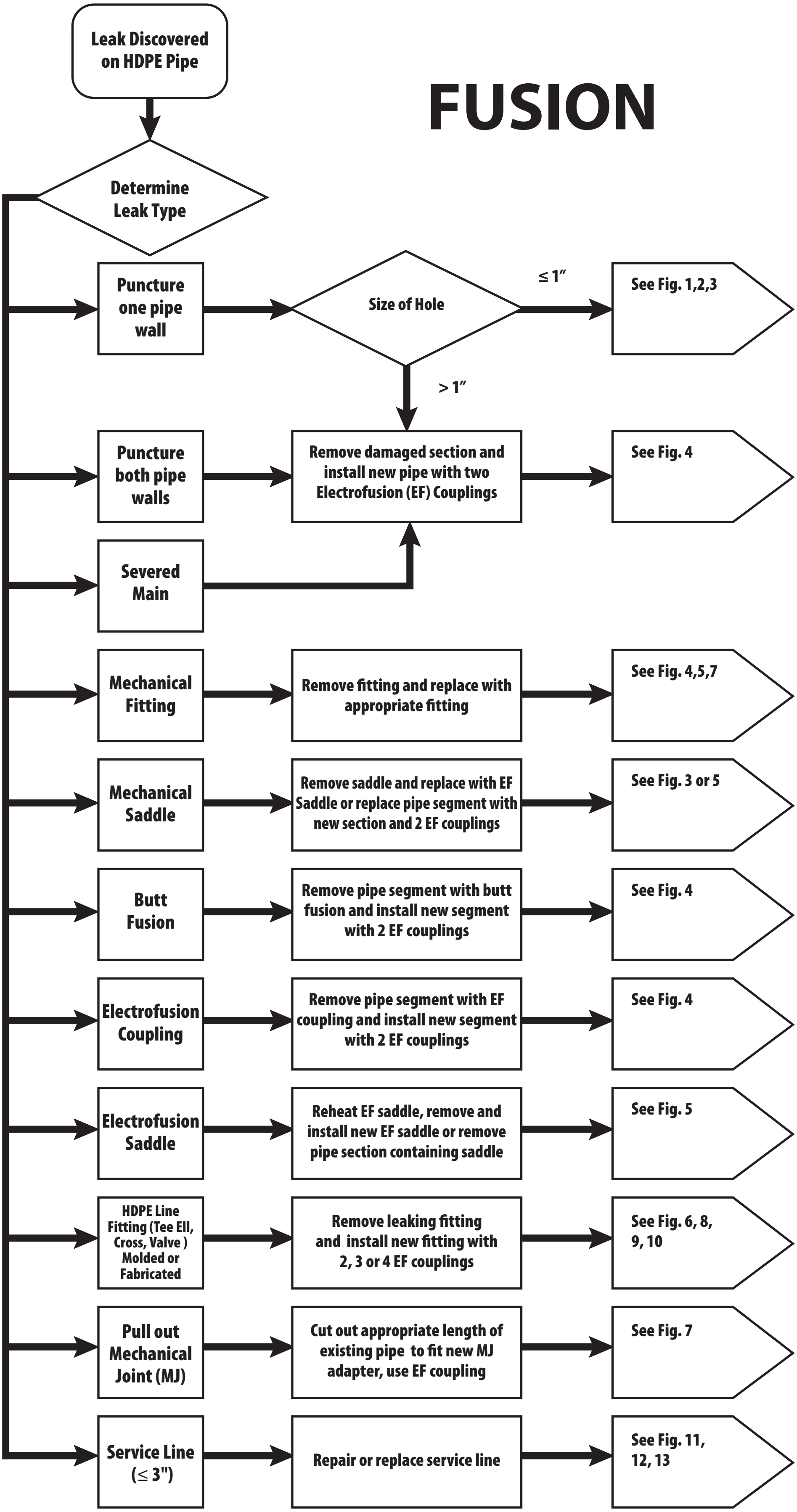
The MAB-4 Basic HDPE Repair Options were prepared by MAB members and associates as a service to the water industry. The information in this document is offered in good faith and believed to be accurate at the time of its preparation, but is offered "as is" without express or implied warranties, including WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. Any reference to a specific manufacturer's product is merely illustrative, and not intended as an endorsement of that product. Reference to or testing of a proprietary product should not be construed as an endorsement by the MAB or PPI, which do not endorse the proprietary products or processes of any manufacturer. Users are advised to consult the manufacturer for more detailed information about the specific manufacturer's products. The information in this document is offered for consideration by industry members in fulfilling their own compliance responsibilities. MAB and the PPI assume no responsibility for compliance with applicable laws and regulations.

The MAB serves as an independent, non-commercial adviser to the Municipal & Industrial (M & I) Division of the PPI. Once adopted, MAB will consider revising this document from time to time, in response to comments and suggestions from users of the model specification. Please send suggestions of improvements to Camille George Rubeiz, PE, F.ASCE, at ***crubeiz@plasticpipe.org***.

RECOMMENDATIONS

1. If you are able to eliminate water through the pipe, then fusion should be the first choice of repair.
2. Squeeze off tools can create dry conditions for fusion.
3. All mechanical couplings should include pull out resistance/restraint or be used with external restraint clamps when using non-restraint mechanical couplings.
4. Internal stiffeners should be used for all mechanical couplings.
5. Corrosion protection should be provided for all underground metallic fittings.
6. Fabricated fittings should always be at least one SDR thicker than pipe and have the same Pressure Rating as the pipeline.
7. Illustrations for repair with fabricated fittings are appropriate for molded fittings.
8. For mechanical connections, contact the fitting manufacturer to verify that these connections are designed to work specifically with HDPE.

FUSION



Leak Discovered on HDPE Pipe
Determine Leak Type
Puncture one pipe wall
Size of Hole
≤ 1"
See Fig. 1,2,3
> 1"
Puncture both pipe walls
Remove damaged section and install new pipe with two Electrofusion (EF) Couplings
See Fig. 4
Severed Main
Mechanical Fitting
Remove fitting and replace with appropriate fitting
See Fig. 4,5,7
Mechanical Saddle
Remove saddle and replace with EF Saddle or replace pipe segment with new section and 2 EF couplings
See Fig. 3 or 5
Butt Fusion
Remove pipe segment with butt fusion and install new segment with 2 EF couplings
See Fig. 4
Electrofusion Coupling
Remove pipe segment with EF coupling and install new segment with 2 EF couplings
See Fig. 4
Electrofusion Saddle
Reheat EF saddle, remove and install new EF saddle or remove pipe section containing saddle
See Fig. 5
HDPE Line Fitting (Tee Ell, Cross, Valve) Molded or Fabricated
Remove leaking fitting and install new fitting with 2, 3 or 4 EF couplings
See Fig. 6, 8, 9, 10
Pull out Mechanical Joint (MJ)
Cut out appropriate length of existing pipe to fit new MJ adapter, use EF coupling
See Fig. 7
Service Line (≤ 3")
Repair or replace service line
See Fig. 11, 12, 13

FUSION

Fig. 1 Repair Patch

Fig. 2 Branch Saddle w/cap

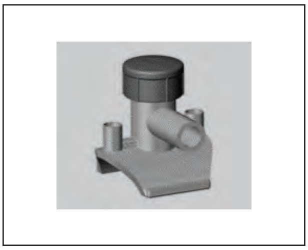


Fig. 3 Tapping Tee (requires outlet cap)

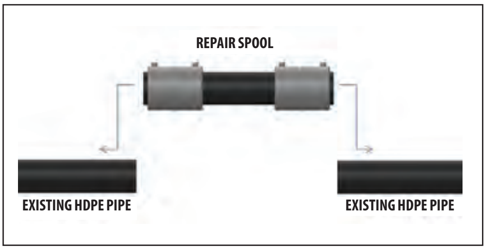


Fig. 4 Pipe Section Replacement with Two Electrofusion Couplings

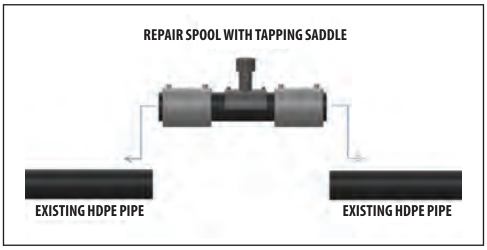


Fig. 5 Pipe Section Replacement with Tapping Tee

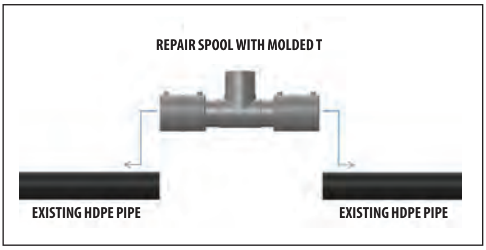


Fig. 6 Section Replacement with Molded Tee

Fig. 7 Mechanical Joint (MJ) Adapter w Install Kit

Fig. 8 Fabricated Elbow with Two EF Couplings

Fig. 9 Fabricated Tee with Three EF Couplings

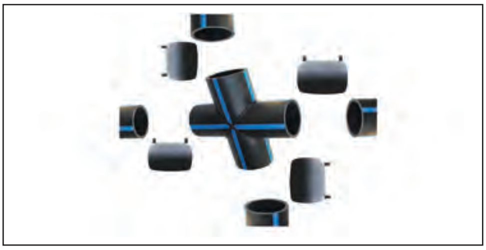


Fig. 10 Fabricated Cross with 4 EF Couplings

Fig. 11 Service line EF Coupling

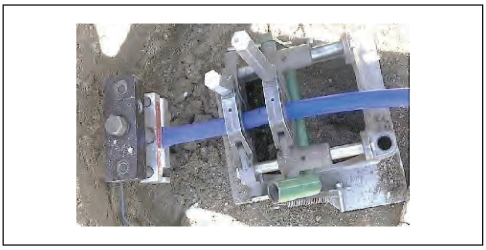


Fig. 12 Service Butt Fusion

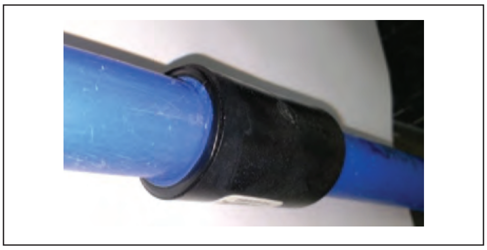


Fig. 13 Service Line Socket Fusion

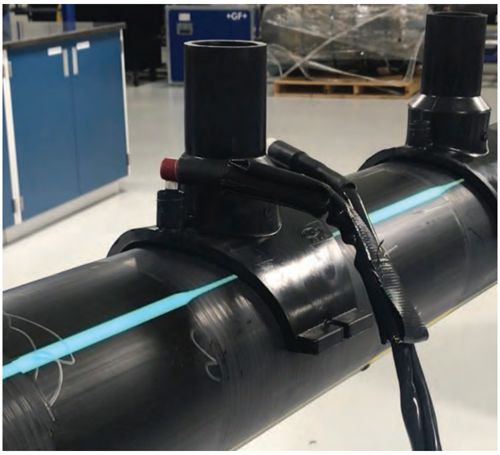
ELECTROFUSION REPAIR OF LEAKING SADDLE FUSIONS:

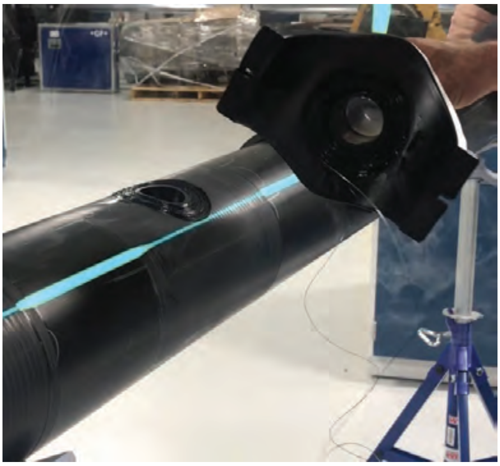
Leaks due to suspect electrofusion saddle joints can be repaired by removing the leaking connection and replacing the saddle. A weak or leaking fusion is likely due to contamination in the fusion zone or the lack of pipe preparation at the time of initial installation. In such cases, the saddle can be removed by re-energizing the heating coil to the point that the PE material becomes melted and softened. Once re-melted, the old saddle can be pulled from the pipe and a new saddle can be installed in the same location.

PROCEDURE:

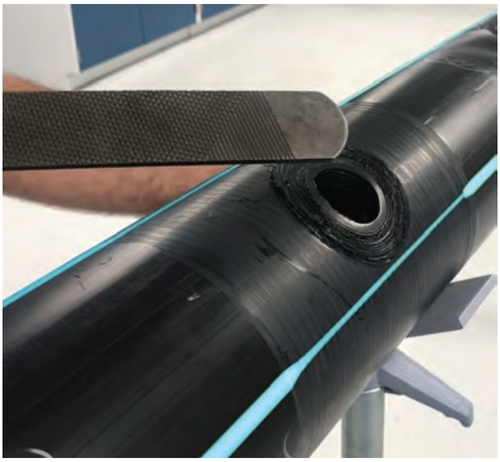
Excavate to expose the suspect saddle and depressurize the system. Disconnect the service line and clean the pipe surfaces immediately surrounding the suspect saddle.

If the saddle has a “permanent" clamping device, such as a bolt-on strap or plastic underpart, the clamp must be removed. Connect the electrofusion control box to the suspect saddle and start the fusion cycle.

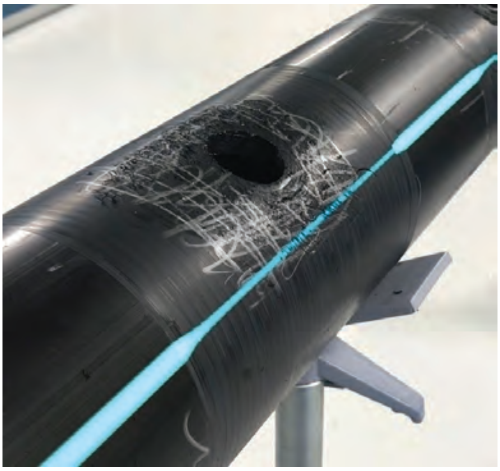




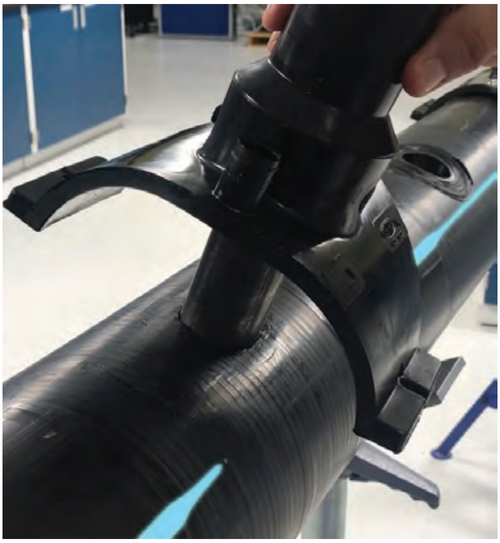
When the fusion cycle is complete, immediately pull the saddle from the pipe. Wear gloves and use caution to avoid burns from hot plastic or wires. Small tapping saddles can normally be removed by hand, but if necessary a suitable rubber mallet may be used to strike the fitting.



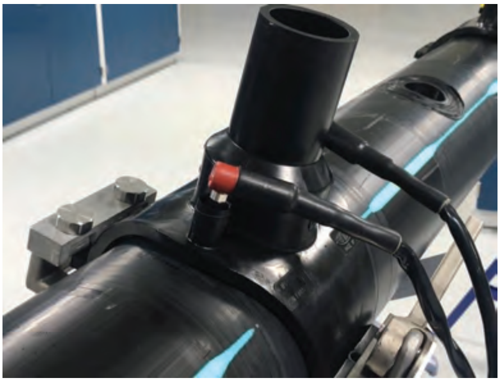
Inspect the pipe surface for damage. Remnants of PE material from the saddle will likely remain on the pipe surface and can be removed with a rasp to re-shape the pipe curvature. Once the remnants are removed, the pipe can be prepared for fusion by peeling/scraping using approved procedures. The tap hole may require that the peeler blade be manipulated to allow it to pass over the hole in the pipe as it revolves over that area.



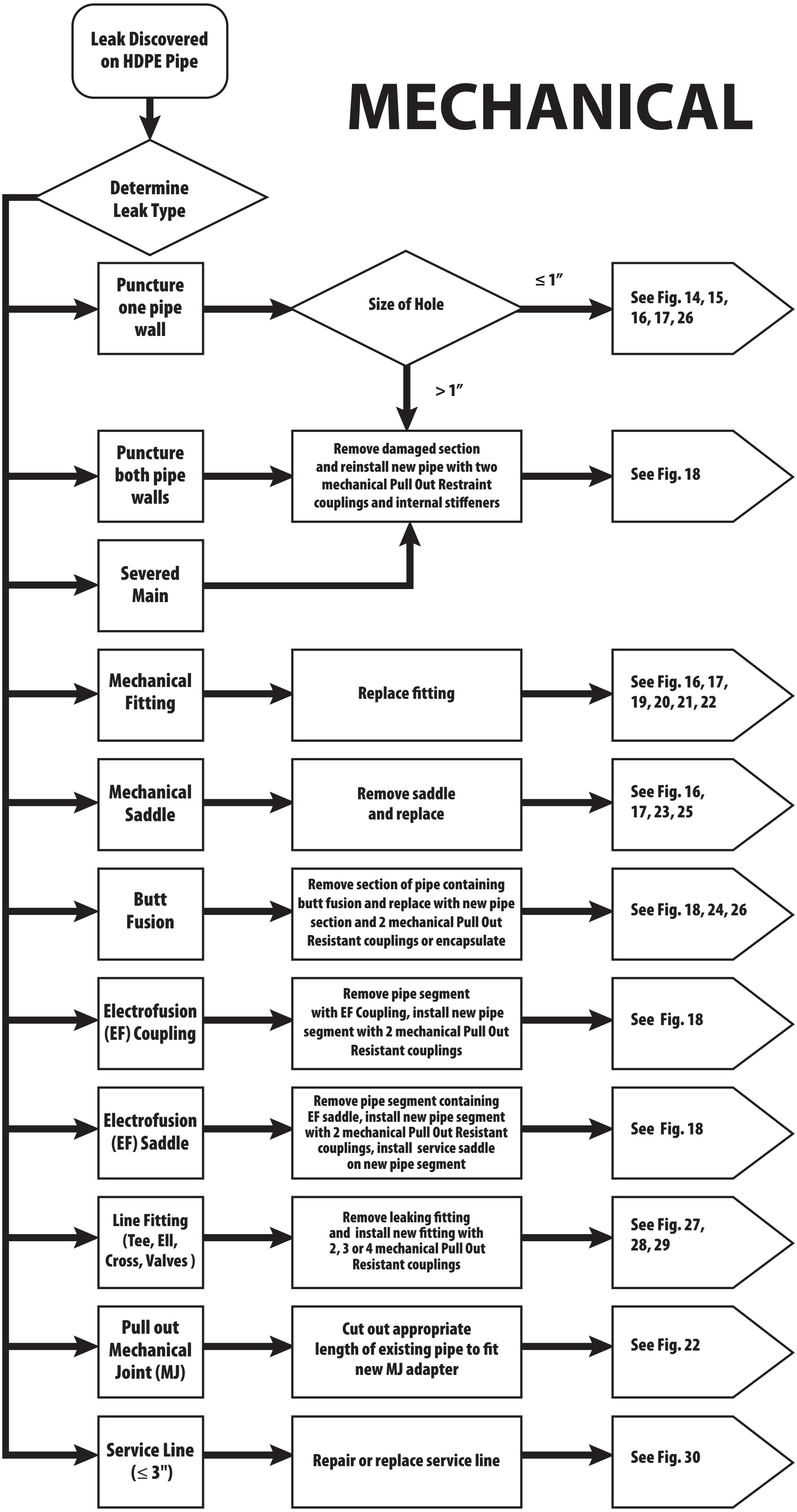
Place the new fitting over the tap hole carefully to ensure that the hole is inside of the fusion zone boundary. A mandrel or guide may be inserted into the tap hole to aid in aligning the replacement fitting over the hole. Clamp the fitting in place and fuse per normal procedures.



Allow the fitting to cool per normal procedures prior to removing the clamp, reconnecting the service line, and returning to service.



MECHANICAL


Leak Discovered on HDPE Pipe
Determine Leak Type
Puncture one pipe wall
Size of Hole
≤ 1”
See Fig. 14, 15, 16, 17, 26
> 1”
Puncture both pipe walls
Remove damaged section and reinstall new pipe with two mechanical Pull Out Restraint couplings and internal stiffeners
See Fig. 18
Severed Main
Mechanical Fitting
Replace fitting
See Fig. 16, 17, 19, 20, 21, 22
Mechanical Saddle
Remove saddle and replace
See Fig. 16, 17, 23, 25
Butt Fusion
Remove section of pipe containing butt fusion and replace with new pipe section and 2 mechanical Pull Out Resistant couplings or encapsulate
See Fig. 18, 24, 26
Electrofusion (EF) Coupling
Remove pipe segment with EF Coupling, install new pipe segment with 2 mechanical Pull Out Resistant couplings
See Fig. 18
Electrofusion (EF) Saddle
Remove pipe segment containing EF saddle, install new pipe segment with 2 mechanical Pull Out Resistant couplings, install service saddle on new pipe segment
See Fig. 18
Line Fitting (Tee, Ell, Cross, Valves)
Remove leaking fitting and install new fitting with 2, 3 or 4 mechanical Pull Out Resistant couplings
See Fig. 27, 28, 29
Pull out Mechanical Joint (MJ)
Cut out appropriate length of existing pipe to fit new MJ adapter
See Fig. 22
Service Line (≤ 3")
Repair or replace service line
See Fig. 30

MECHANICAL

Fig. 14 Band Clamp

Fig. 15 Band Clamp w Pull Out Restraint

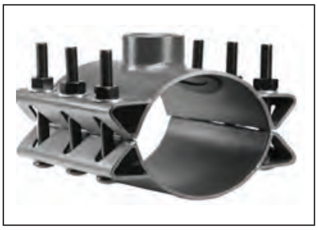


Fig. 16 Repair Sleeve requires outlet plug

Fig. 17 Repair Sleeve Flanged Outlet

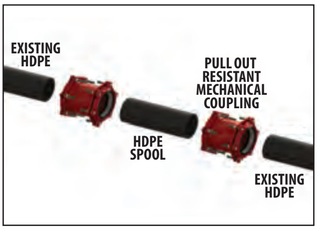


Fig. 18 HDPE Pipe Spool Replacement
w Mechanical Couplings

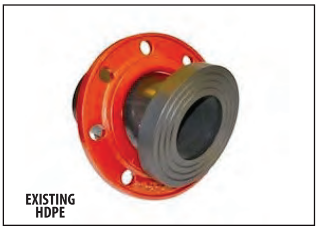


Fig. 19 HDPE Flange

Fig. 20 Pull Out Resistant Coupling by Flange

Fig 21 Fabricated Ell w Flanges

Fig. 22 Restrained Mechanical Joint

Fig. 23 "Mega-Lug" DIP Spool

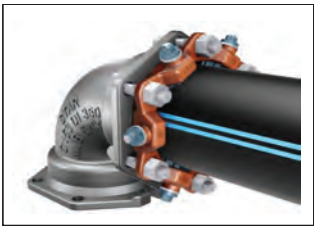


Fig. 24 "Mega-Lug" Connection to DIP Ell

Fig. 25 Service Saddle

Fig. 26 Band Clamp capable of
Encapsulating Butt Fusion

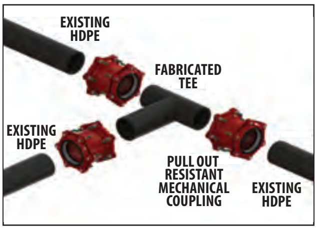


Fig. 27 Fabricated Tee

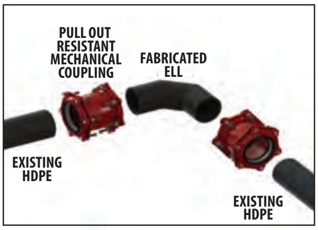


Fig. 28 Fabricated Ell

Fig. 29 Fabricated Cross

Fig. 30 Service Leak - Stab Type Coupling

FOR ADDITIONAL INFORMATION

- **ASTM F1041:** Standard Guide for Squeeze-Off of Polyolefin Gas Pressure Pipe and Tubing
- **ASTM F1055:** Standard Specification for Electrofusion Type Polyethylene Fittings for Outside Diameter Controlled Polyethylene and Crosslinked Polyethylene (PEX) Pipe and Tubing
- **ASTM F1563:** Standard Specification for Tools to Squeeze-off Polyethylene (PE) Gas Pipe or Tubing
- **ASTM F2620:** Standard Practice for Heat Fusion Joining of Polyethylene Pipe and Fittings
- **ASTM F3190:** Standard Practice for Heat Fusion Equipment (HFE) Operator Qualification on Polyethylene (PE) and Polyamide (PA) Pipe and Fittings

- **MAB-1:** MAB Generic Electrofusion Procedure for Field Joining of 12 Inch and Smaller Polyethylene (PE) Pipe
https://plasticpipe.org/pdf/mab-generic-ef-110515.pdf
- **MAB-2:** MAB Generic Electrofusion Procedure for Field Joining of 14 Inch to 30 Inch Polyethylene (PE) Pipe
https://plasticpipe.org/pdf/mab-02-generic-electrofusionn.pdf
- **MAB-3:** MAB Model Specifications for PE 4710 Buried Potable Water Service, Distribution and Transmission Pipes and Fittings
https://plasticpipe.org/pdf/mab3.pdf
- **MAB-4:** MAB Basic HDPE Repair Options
https://plasticpipe.org/municipal_pipe/advisory/repairs/mab4.html

Alliance Case Study Data Sheet

Case ID ____

Fill in as much as you can, through personal knowledge or research….use separate sheet if you prefer. Try to fill in at least 10 rows!! Thank you. We will write up the case study and share it with you. Please email to me at pdyke@pepipe.org.

PROJECT NAME
Project Location
Construction Method
Contractor Name and contact info
Has anything been written up yet? *(Pls share)*
Diameter, IPS or DIPS
DR (dimension ratio)
Engineering Firm
Engineer and contact info
Equipment – (McElroy, EF processor etc.)
Image *(we need at least one image!)*
Old Pipe Diameter and Type
Owner
HDPE Distributor
Pipe Manufacturer
Project Date
Project Length
Region of country
Type – Water, WW, storm, industrial etc.
What is Unique about this project? (*VERY IMPORTANT)*
Who was fusion operator?
____
____ ____

HDPE Municipal Contacts

Name	Title	Company	Location	Phone	Email	Comment
Jessie Allen, PE	Senior Engineer, Ops	Arlington Water Utilites	Arlington, TX	817-459-6610	Jessie.Allen@arlingtontx.gov	HDPE adopter following pilots and research
Dr. Alan Atalah, PE	Associate Dean for Graduate Affairs	Bowling Green State Univ	Bowling Green, OH	419-372-8354	aatalah@bgnet.bgsu.edu	PPI Municipal Advisory Bd
E. Alan Ambler, PE	Water Resources Mgr	Casselberry FL (former)	Casselberry, FL	407-446-4645	alanambler@amtrenchless.com	largest user of HDPE for AC pipe bursting in the US
Matthew T. Klein	Dir of Resource Planning	Citizens Energy Group	Indianapolis, IN	317-607-0136	mklein@oucc.in.gov	Early adopter only using HDPE has significant cost data avail
Eric Shaffer, PE	Chief Engineer for Utilities	City of Duluth	Duluth, MN	218-730-5072	eshaffer@DuluthMN.gov	systemwide acceptance following years of research
Matthew A. Wirtz, PE	Deputy Dir of City Utilities	City of Ft. Wayne	Ft. Wayne, IN	519-888-4567	Matthew.wirtz@cityoffortwayne.org	HDPE adopter following pilots and research
Dave Stewart	Assistant PW Dir	City of Lago Vista	Lago Vista, TX	512-267-1155	dave.stewart@stewartenv.com	using HDPE for all water and WW replacements
Chad E. Owens, PE	Assistant Mgr Natural Gas and Water - Engineer	City of Springfield	Springfield, MO	417-831-8993	chad.owens@cityutilities.net	Early adopter and user of HDPE pipe
Holly Link	Engineering Support	Colorado Springs Utilities	Colorado Springs	719-668-4733	hlink@csu.org	System wide acceptance following years of research
Collins K. Orton	Consultant	Consultant	Redwood City, CA	800-533-2078	pipedr96@aol.com	30-year career installing HDPE via trenchless
Greg Scoby, PE	President	Crossbore Consultants former Palo Alto, CA (Ret.)	Los Gatos, CA	408-201-3204	GregS@CrossboreConsultants.com	HDPE only system following gas use, years of research
Marisa Boyce, PE	Large Dia Pipeline & Aqueduct Section	East Bay Muni Util Dist	Oakland, CA	510-287-0987	mboyce@ebmud.com	systemwide acceptance following years of research
Richard Brand	Executive Director	East Windsor MUA	East Windsor, NJ	609-443-6000	Rbrand@Eastwindsormua.com	only permits HDPE in their system to replace DIP
Serge Terentieff, PE	Dist Systems Engineer	EBMUD	Oakland, CA	866-403-2683	sterenti@ebmud.com	MAB, expert in AC pipe replacement strategies
Mike Heitmann	President	Garney Construction	Kansas City, MO	816-746-7250	mheitmann@garney.com	Conducted numerous HDPE studies

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Kevin Miller	President	Miller Pipeline Corp	Indianapolis, IN	317-293-0278	Kevin.Miller@millerpipeline.com	HDPE contractor, significant PE installation experience
Todd Grafenauer	Educational Dir	Murphy Pipeline Contractors	Milwaukee, WI	414-321-2247	toddg@murpheypipelines.com	country's most prolific speaker and educator on HDPE trenchless
Jimmy Dang	Chief Engineer	Oro Loma Sanitary District	Oakland, CA	510-755-7956	eshaffer@DuluthMN.gov	Capital program that only uses HDPE for replacement of metal pipes
Romel Antonio	Senior Project Engineer, Chief of CIP	Palo Alto	Palo Alto, CA	650-566-4518	romel.antonio@cityofpaloalto.org	"PE has made my job worry free"
Stephen Boros	VP Engineering	Pipeline Plastics	Decatur, TX	940-765-9645	sboros@pipe.us	Knowledgeable expert working at the national level
Heath Casteel	Technical Director	Performance Pipe	Plano, TX	972-599-7440	castehw@cpchem.com	Knowledgeable expert working at the national level
Camille Rubeiz, PE	Director of Engineering	PPI	Fairfax, VA	469-499-1050	crubeize@plasticpipe.org	nation's authority on technical HDPE issues
John Fishburne, PE	Principal	Toughwater Fishburne Pipeline Mgt & Eng	Charlotte, NC	704-620-3516	john@fishburnepipeline.com	Led AWWA C906 effort, now an industry consultant
Dr. Mark Knight, PE	Executive Dir CATT Center	University of Waterloo	Waterloo, ON	317-278-4970	maknight@uwaterloo.ca	PPI Municipal Advisory Bd
Richard Kolasa	Technical Sales Manager	WL Plastics	Crossfield, AB	403-818-1320	rkolasa@wlplastics.com	Knowledgeable expert working at the national level

The purpose of this contact list is to provide a line of communication between advisors, who have knowledge of HDPE and trenchless applications, and the municipal industry. The goal is to clarify issues and concerns regarding HDPE and trenchless installations and spread knowledge of these applications.

ALLIANCE FOR pe pipe

PE 4710 Standard Pressure Rating Chart

rev. 4/17

Table 1: PE 4710 IPS

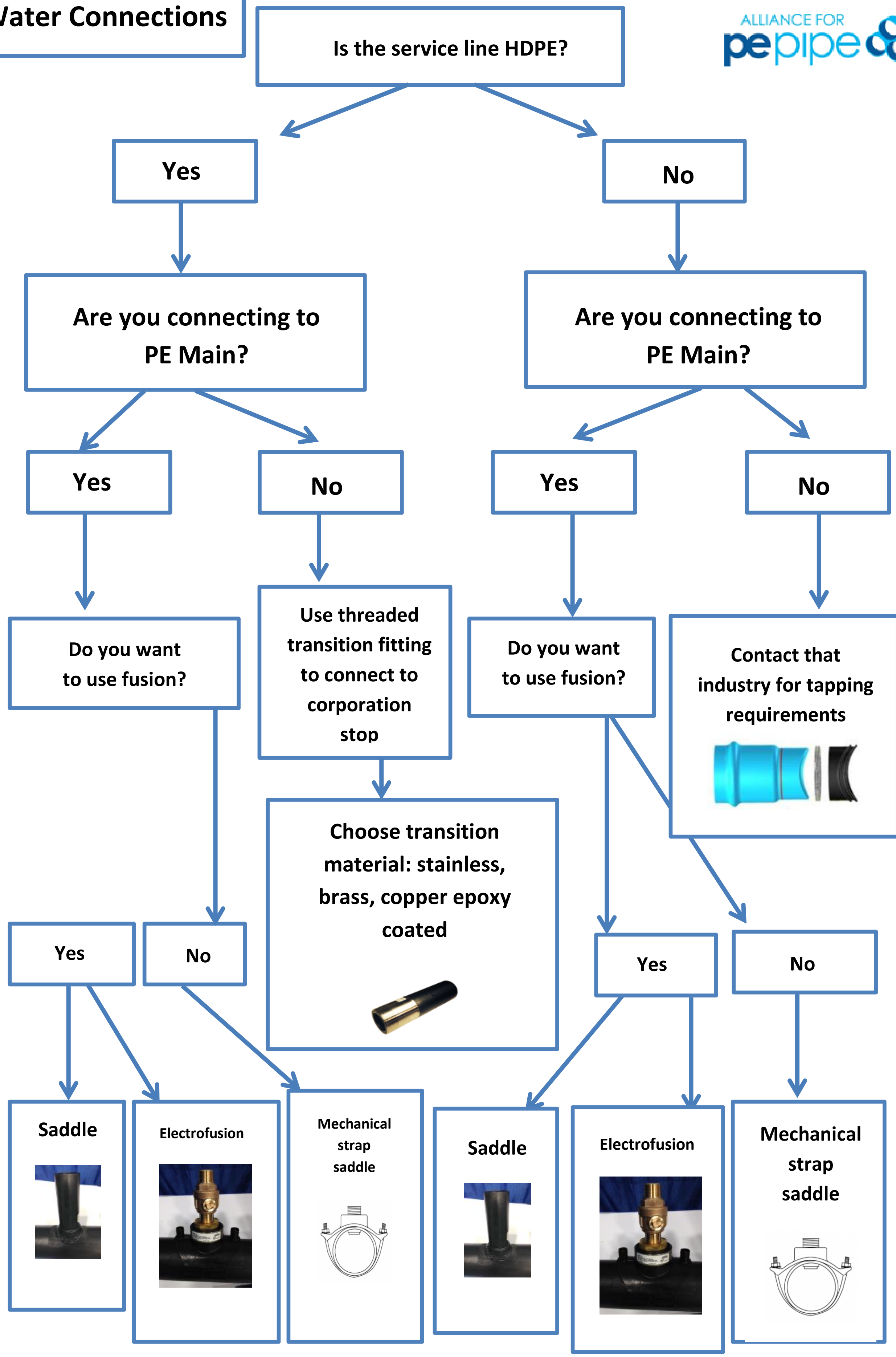
Working Pressure Rating[2] (psi) or Pressure Class[3]		125		160		200		250	
Pipe Dimension Ratio		DR 17		DR 13.5		DR 11		DR 9	
Nominal Pipe Size	IPS OD (in)	Average ID (in)	Weight (lbs/ft)	Average ID (in)	Weight (lbs/ft)	Average ID (in)	Weight (lbs/ft)	Average ID (in)	Weight (lbs/ft)
4"	4.50	3.94	1.54	3.79	1.09	3.63	2.29	3.44	2.73
6"	6.63	5.80	3.33	5.59	4.12	5.35	4.97	5.07	5.93
8"	8.63	7.55	5.64	7.27	6.99	6.96	8.43	6.59	10.05
10"	10.75	9.41	8.76	9.06	10.85	8.68	13.07	8.22	15.61
12"	12.75	11.16	12.33	10.75	15.27	10.29	18.39	9.75	21.96
Allowable Total Pressure[4] During Recurring Surge[5] (psi)		187.5		240		300		375	
Allowable Total Pressure During Occasional Surge[6] (psi)		250		320		400		500	

Table 2: PE 4710 DIPS

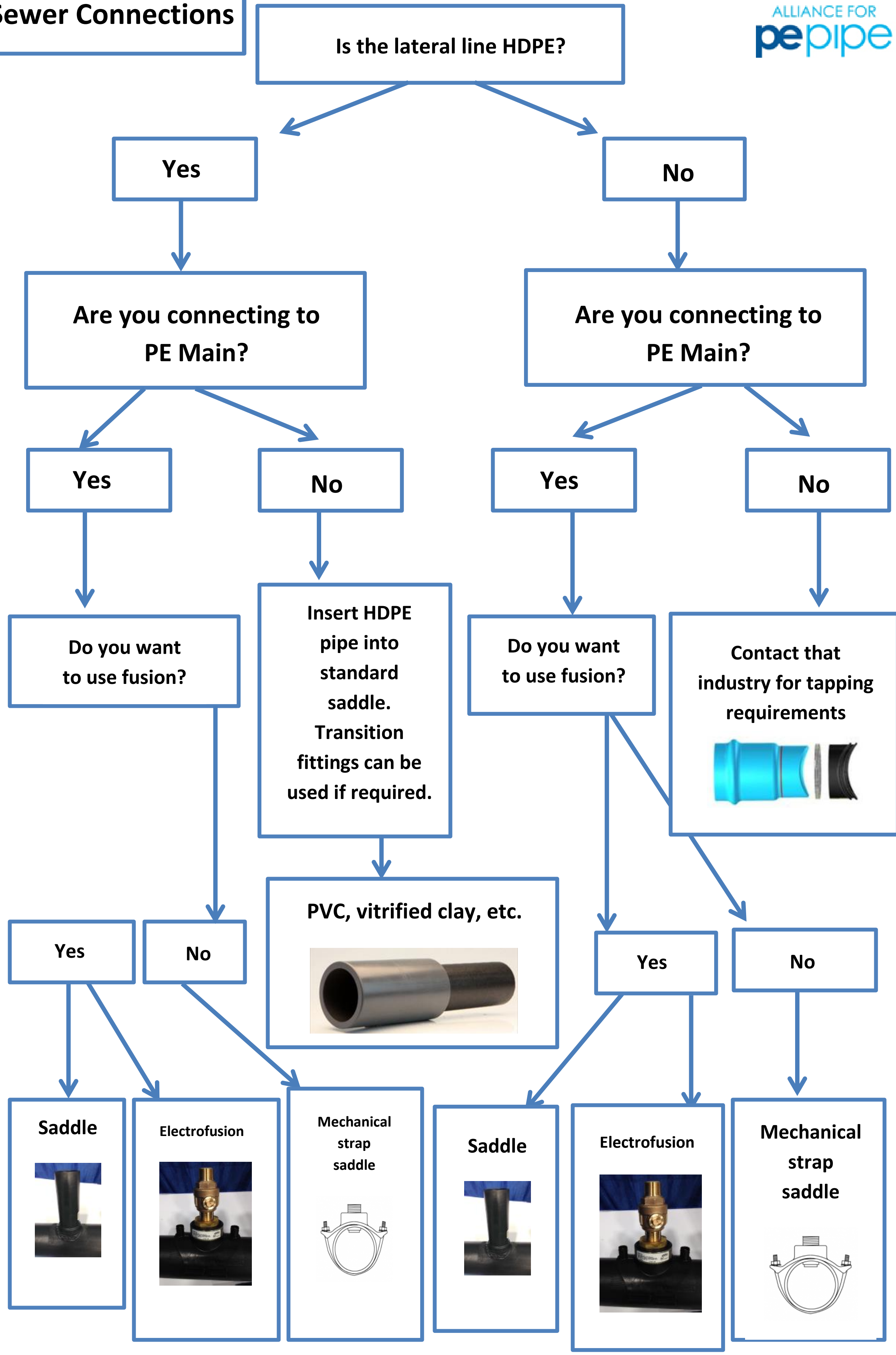
Working Pressure Rating[2] (psi) or Pressure Class[3]		125		160		200		250	
Pipe Dimension Ratio		DR 17		DR 13.5		DR 11		DR 9	
Nominal Pipe Size	DIPS OD (in)	Average ID (in)	Weight (lbs/ft)	Average ID (in)	Weight (lbs/ft)	Average ID (in)	Weight (lbs/ft)	Average ID (in)	Weight (lbs/ft)
4"	4.8	4.20	1.75	4.05	2.17	3.88	2.60	3.67	3.11
6"	6.9	6.04	3.61	5.82	4.47	5.57	5.38	5.27	6.43
8"	9.05	7.92	6.21	7.63	7.69	7.31	9.26	6.92	11.07
10"	11.1	9.72	9.35	9.36	11.57	8.96	13.94	8.49	16.64
12"	13.2	11.56	13.21	11.13	16.37	10.66	19.71	10.09	23.54
Allowable Total Pressure[4] During Recurring Surge[5] (psi)		187.5		240		300		375	
Allowable Total Pressure During Occasional Surge[6] (psi)		250		320		400		500	

1 PE4710 pipe materials and Pressure Ratings are described in ASTM F714, ASTM D3035, and AWWA C901.
2 Working Pressure Rating is the Maximum Continuous Pressure Allowed assuming Recurring and Occasional Surge Allowances above are not exceeded per AWWA C906 and AWWA M55.
3 Pressure Class (PC) is the design capacity to resist working pressure up to 80F maximum service temperature including specified maximum allowances for recurring positive pressure surges above working pressure. NOTE: AWWA defines Pressure Class differently for different materials
4 Total Pressure = sum of Pumping Pressure and the Repetitive Transient Surge Pressure. PE Pipes have built-in Surge Allowance to Repetitive Transient Surge due to excellent fatigue resistance.
5 Recurring surge pressures (PRS) occur frequently and are inherent in the design and operation of the system (such as normal pump startup or shutdown, and normal valve opening or closure). WPR = 1.5 x PC x FT - PRS. Note that 1.5xPC is also the maximum test pressure per ASTM F2164.
6 Occasional surge pressures (POS) caused by emergency operations, usually the result of a malfunction (e.g. power failure, sudden valve closure, system component failure). WPR = 2 x PC x FT - POS
7 Data obtained from PE Alliance membership. Please consult pipe manufacturers for data specific to your project. Greater pipe sizes and DRs are also available.
Sources: http://www.performancepipe.com/en-us/Documents/PP%20401%20Pressure%20Rating_PE4710.pdf and http://www.wlplastics.com/pdf/WL118%200712%20Pressure%20Rating.pdf

Water Connections



Sewer Connections



List of Standards Applicable to PE Pipe

The PE Pipe Industry has developed a vast list of standards applicable to working with every aspect of PE pipe. The list compiled below has been developed to provide engineers designing with PE pipe the resources necessary to validate every aspect of PE pipe design.

These applicable standards are issued by widely respected agencies within the municipal pipe industry including the American Water Works Association, the American Society for Civil Engineers, the American Society for Testing and Materials, the Occupational Safety and Health Administration, the North American Society for Trenchless Technology, the Plastics Pipe Institute, the Plastics Pipe Institute Municipal Advisory Board, These robust standards include the following topics: product material design for pipe and fittings, manufacturing quality standards, product testing methods, product labelling standards, standards for the process of butt fusion, socket fusion, saddle fusion, and electrofusion, installation methods, field testing methods and many more.

A. American Water Works Association (AWWA) latest edition:

1. AWWA C622 – Pipe Bursting of Potable Water Mains 4 In. (100 mm) to 36 In. (900 mm)
2. AWWA C651 – Disinfecting Water Mains
3. AWWA C901 - Polyethylene Pressure Pipe and Tubing, ½ Inch Through 3 Inch for Water Service
4. AWWA C906 - Polyethylene Pressure Pipe and Fittings, 4 Inch Through 65 Inch for Water Distribution and Transmission

B. American Society for Civil Engineer's (ASCE) latest edition:

1. ASCE Manual of Practice 108 – Pipeline Design for Installation by Horizontal Directional Drilling (Second Edition)
2. ASCE Manual of Practice 112 – Pipe Bursting Projects
3. ASCE Manual of Practice 125 – Pipelines for Water Conveyance and Drainage
4. ASCE Manual of Practice 132 – Renewal of Potable Water Pipes

C. American Society for Testing and Materials (ASTM) latest edition:

1. ASTM C136 – Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates
2. ASTM D422 – Standard Test Method for Particle-Size Analysis of Soils
3. ASTM D1556 – Standard Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method
4. ASTM D638 – Tensile Method for Tensile Properties of Plastics
5. ASTM D790 – Test Materials for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
6. ASTM D2122 – Standard Method of Determining Dimensions of Thermoplastics Pipe and Fittings
7. ASTM D2167 – Standard Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method

8. ASTM D2239 – Standard Specification for Polyethylene (PE) Plastic Pipe (SIDR-PR) Based on Controlled Inside Diameter
9. ASTM D2657 – Practice for Heat-Joining of Polyolefin Pipe and Fittings
10. ASTM D2683 – Standard Specification for Socket Type Polyethylene Fittings for Outside Diameter-Controlled Polyethylene Pipe and Tubing
11. ASTM D2774 – Standard Practice for Underground Installation of Thermoplastic Pressure Piping
12. ASTM D2837 – Standard Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products
13. ASTM D2937 – Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method
14. ASTM D3035 – Polyethylene (PE) Plastic Pipe (DR-PE) Based on Controlled Outside Diameter
15. ASTM D3261 – Butt Heat Fusion Polyethylene (PE) Plastic Fittings for Polyethylene (PE) Plastic Pipe and Tubing
16. ASTM D3350 – Polyethylene Plastic Pipe and Fittings Material
17. ASTM D3740 – Standard Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
18. ASTM D4253 – Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table
19. ASTM D4254 – Standard Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density
20. ASTM D4318 – Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
21. ASTM D6938 – Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)
22. ASTM F412 – Standard Terminology Relating to Plastic Piping Systems
23. ASTM F714 – Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter
24. ASTM F905 – Standard Practice for Qualification of Polyethylene Saddle-Fused Joints
25. ASTM F1055 – Standard Specification for Electrofusion Type Polyethylene Fittings for Outside Diameter Controlled Polyethylene Pipe and Tubing
26. ASTM F1056 – Standard Specification for Socket Fusion Tools for Use in Socket Fusion Joining Polyethylene Pipe or Tubing and Fittings
27. ASTM F1290 – Standard Practice for Electrofusion Joining Polyolefin Pipe and Fittings
28. ASTM F1962-11 – Standard Guide for Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossings
29. ASTM F2164 – Field Leak Testing of Polyethylene (PE) Pressure Piping Systems Using Hydrostatic Pressure
30. ASTM F2206 – Fabricated Fittings for Butt-Fused Polyethylene Plastic Pipe

31. ASTM F2620 – Standard Practice for Heat Fusion Joining of Polyethylene Pipe and Fittings
32. ASTM F2786 – Standard Practice for Field Leak Testing of Polyethylene (PE) Pressure Piping Systems Using Gaseous Testing Media Under Pressure (Pneumatic Leak Testing)
33. ASTM F3124 – Standard Practice for Data Recording the Procedure used to Produce Heat Butt Fusion Joints
34. ASTM F3190 – Standard Practice for Heat Fusion Equipment (HFE) Operator Qualifications on Polyethylene (PE) and Polyamide (PA) Pipe and Fittings

D. North American Society for Trenchless Technology (NASTT) latest edition:

1. NASTT's Horizontal Direction Drilling (HDD) Good Practices Guidelines – 4th Edition
2. NASTT's Pipe Bursting Good Practices Guidelines – 3rd Edition

E. Occupational Safety and Health Administration's (OSHA) Trench Excavation Standard – 29 C.F.R, s.1926.650, Subpart P latest edition

F. Plastics Pipe Institute (PPI) latest edition:

1. The Plastics Pipe Institute Handbook of Polyethylene Pipe
2. PPI – TN-36 – General Guidelines for Connecting HDPE Potable Water Pressure Pipes to DI and PVC Piping Systems
3. PPI – TN-38 – Bolt Torque for Polyethylene Flanged Joints
4. PPI – TN-44 – Long Term Resistance of AWWA C906 Polyethylene (PE) Pipe to Potable Water Disinfectants
5. PPI – TN-45 – Mechanical Couplings for Joining Polyethylene Pipe
6. PPI – TN-46 – Guidance for Field Hydrostatic Testing of High Density Polyethylene Pressure Pipelines: Owner's Considerations, Planning, Procedures, and Checklists
7. PPI – TN-49 – Recommendations for AWWA C901 Service Tubes in Potable Water Applications
8. PPI – TN-54 – General Guidelines for Squeezing Off Polyethylene Pipe in Water, Oil and Gas Applications
9. PPI – TR-46 – Guidelines for Use of Mini-Horizontal Directional Drilling for Placement of High Density Polyethylene Pipe

G. Plastics Pipe Institute Municipal Advisory Board (MAB) latest edition:

1. MAB Generic Electrofusion Procedure for Field Joining of 12 Inch and Smaller Polyethylene Pipe
2. MAB Generic Electrofusion Procedure for Field Joining of 14 Inch to 30 Inch Polyethylene Pipe
3. MAB Model Specifications for PE 4710 Buried Potable Water Service, Distribution and Transmission Pipes and Fittings
4. MAB Guidelines for PE 4710 Pipe Bursting of Potable Water Mains

Thrust Block Design

1. Poisson's Ratio – Negative Ratio of Transverse to Axial Strain
2. Pull Out Prevention Required for In-Line Non-Restrained Joints – Sleeve, Bell
3. Fully Restrained Joints Do Not Require Thrust Blocks – Fusion, MJ, Flange Adapter

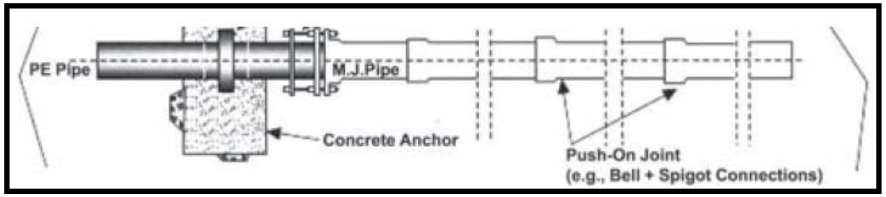
Pull Out Force? PPI Handbook Chap. 7

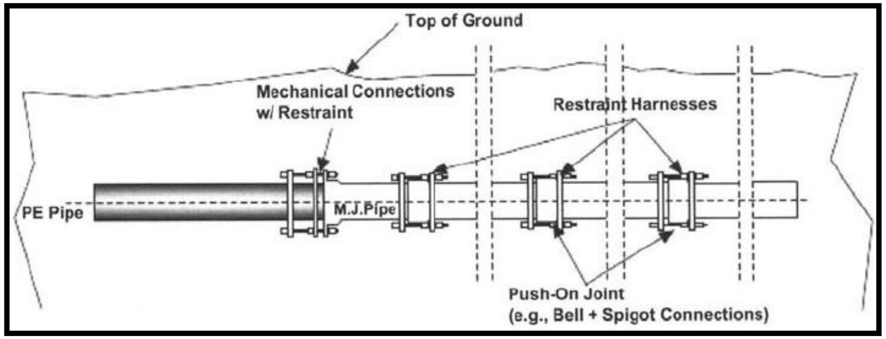
$$F_p = \frac{P(DR-1)}{2}\mu\pi D_M{}^2\left[\frac{1}{DR}-\frac{1}{DR^2}\right]$$

P= internal pressure, lb/in²

μ= Poisson ratio (0.45 long, 0.35 short)

D_M= pipe mean diameter, in





Thrust Block Sizing? PPI Field Manual

$$A = 1.5\times\frac{F_p}{q}$$

FS = 1.5 = Factor of Safety

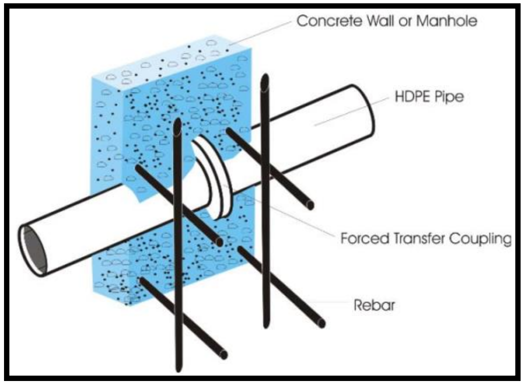
q= soil bearing capacity, lb/ft²

<u>Example: 20" DR11 at 200psi, 1500 lb/ft² sand soil</u>

$$F_p = \frac{200(11-1)}{2}0.35\pi(20-1.818)^2\left[\frac{1}{11}-\frac{1}{11^2}\right] = 30{,}041\ lbs$$

$$A = 1.5\times\frac{30{,}041}{1500} = 30.04\ ft^2$$

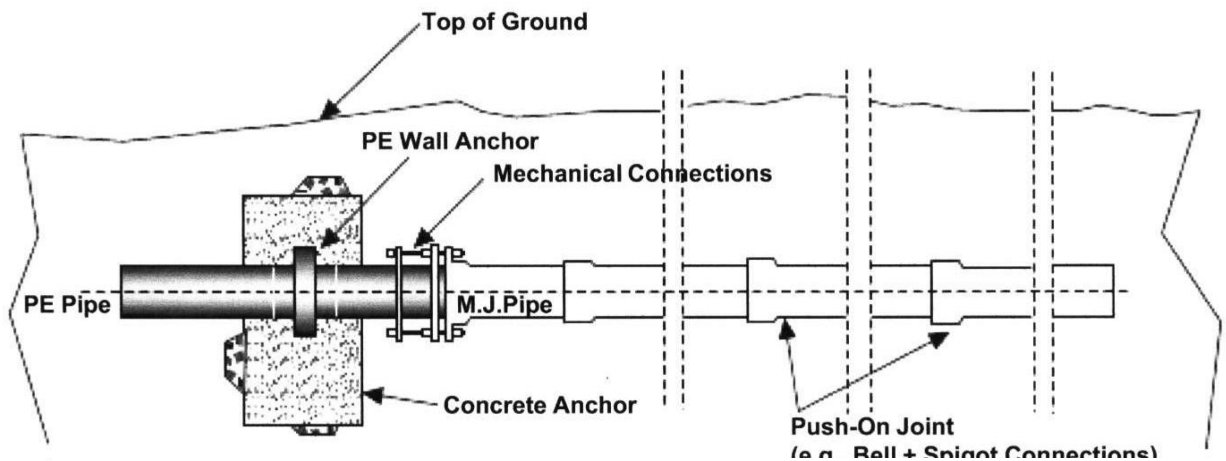
area of concrete in contact with soil

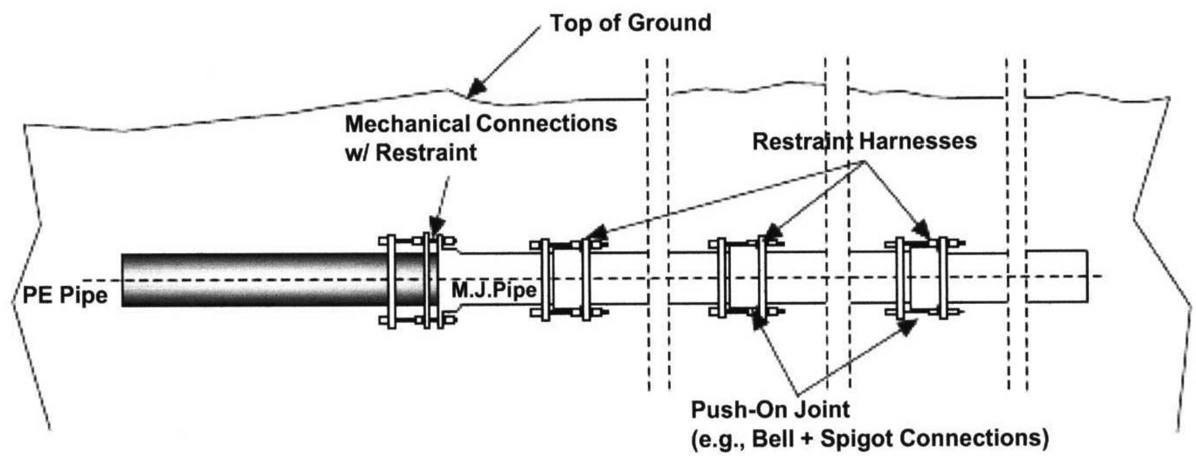


Transitions to Traditional Bell and Spigot Pipe

Poisson's Effect

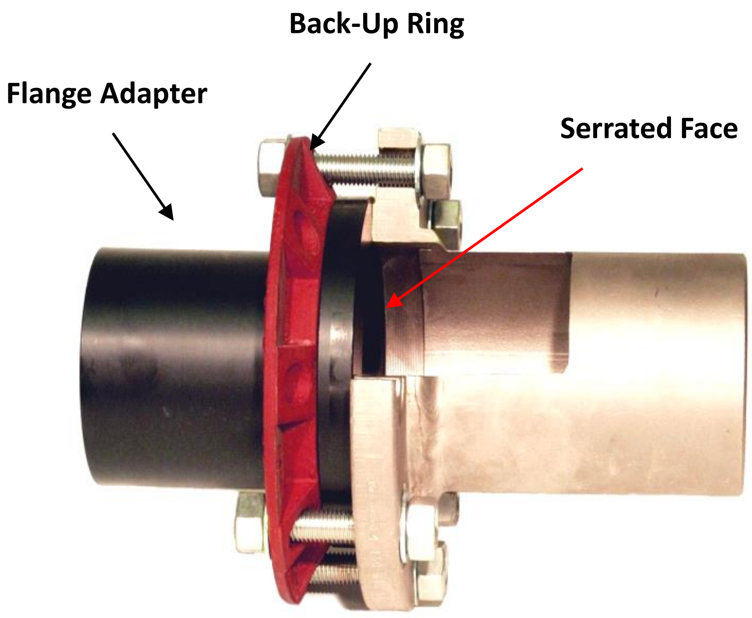
- Pipe shortens when pressurized
- Protect slip joint pipe against pull out
- ***Option 1:*** PE Concrete Wall Anchor
- ***Option 2:*** Bell restraint as required by manufacturer

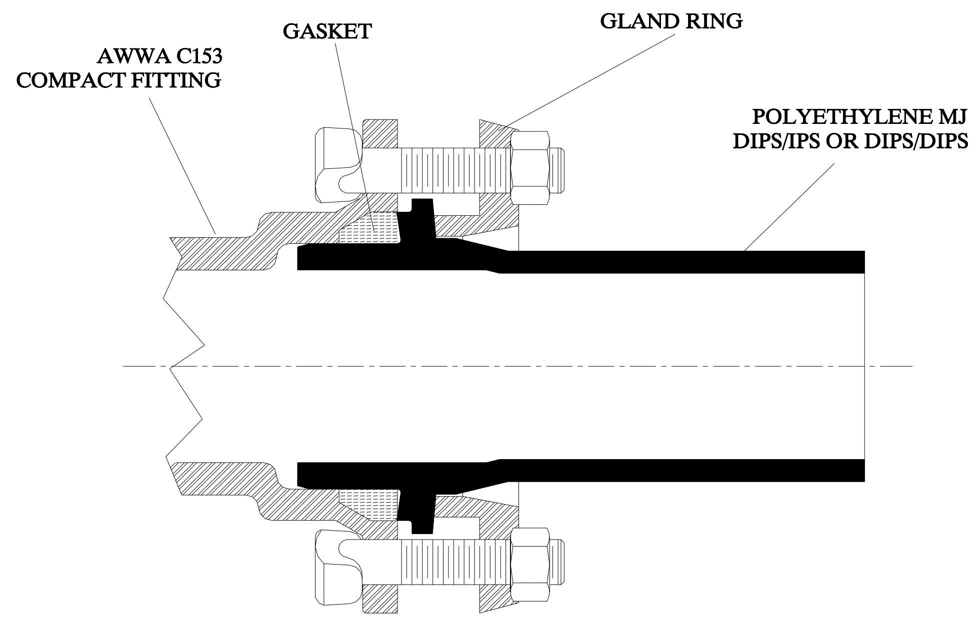




Transitions to Traditional Bell and Spigot Pipe

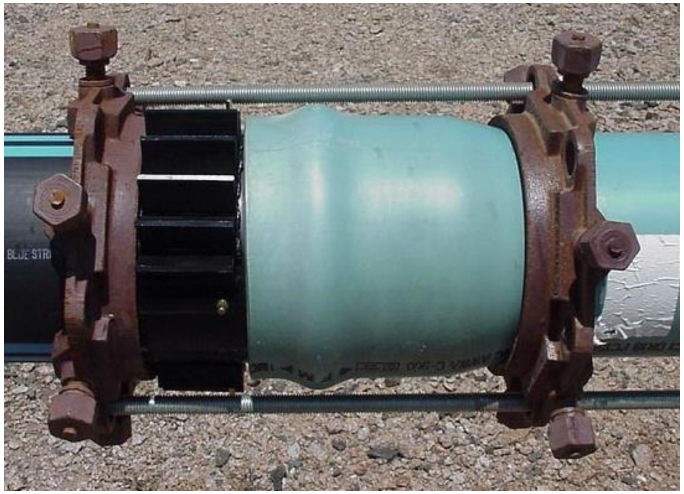
- ***Option 3:*** Mechanical joint (MJ) Adapter
- ***Option 4:*** Flange (gasket optional)

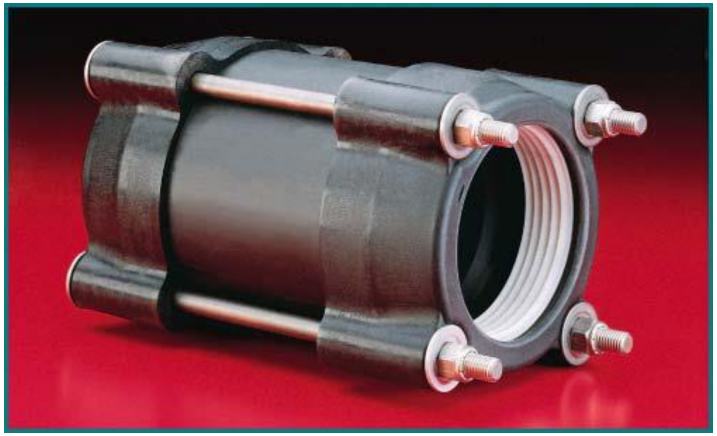


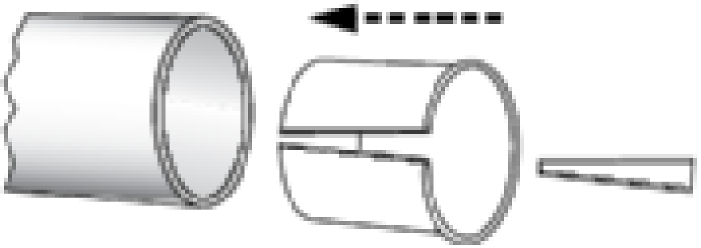


Transitions to Traditional Bell and Spigot Pipe

- ***Option 5:*** Restrained bell
- ***Option 6:*** Mechanical coupling with ID stiffener







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E. Alan Ambler, PE	Water Resources Mgr	Casselberry FL (former)	Casselberry, FL	407-446-4645	alanambler@amtrenchless.com	largest user of HDPE for AC pipe bursting in the US
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John Fishburne, PE	Principal	Toughwater Fishburne Pipeline Mgt & Eng	Charlotte, NC	704-620-3516	john@fishburnepipeline.com	Led AWWA C906 effort, now an industry consultant
Dr. Mark Knight, PE	Executive Dir CATT Center	University of Waterloo	Waterloo, ON	317-278-4970	maknight@uwaterloo.ca	PPI Municipal Advisory Bd
Richard Kolasa	Technical Sales Manager	WL Plastics	Crossfield, AB	403-818-1320	rkolasa@wlplastics.com	Knowledgeable expert working at the national level

The purpose of this contact list is to provide a line of communication between advisors, who have knowledge of HDPE and trenchless applications, and the municipal industry. The goal is to clarify issues and concerns regarding HDPE and trenchless installations and spread knowledge of these applications.

General Guidelines for Connecting HDPE Potable Water Pressure Pipes to DI and PVC Piping Systems

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Foreword

This technical note (TN) was developed and published with the technical help and financial support of the members of the Plastics Pipe Institute (PPI). The members have shown their interest in quality products by assisting independent standard making and user organizations in the development of standards, and also by developing reports on an industry-wide basis to help engineers, code officials, specifying groups, and users.

The TN has been prepared to provide those responsible for specifying, installing and connecting High Density Polyethylene (HDPE) solid wall piping systems to other Potable Water piping systems. These guidelines constitute a set of basic operations that has been demonstrated by test and experience to produce satisfactory connections with commercially available materials. Each specific procedure must be acceptable to, and qualified by, the operator having legal responsibility for the performance of the piping system.

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General Guidelines for Connecting HDPE Potable Water Pressure Pipes to DI and PVC Piping Systems

1.0 Introduction

High Density Polyethylene (HDPE) pipe is normally connected by heat fusion which creates a leak-free bond as strong, if not stronger, than the pipe itself in tensile and pressure applications. These heat fused joints are also self restrained and require no external restraining method to prevent the joint from pulling apart.

In this document, we will cover the various ways to connect HDPE pipe to existing Ductile Iron (DI) and PVC piping systems. In most cases, HDPE pipe can be easily connected to standard Ductile Iron fittings. Because Ductile Iron and PVC pipe are normally joined with bell and spigot joints, the connection to these systems generally requires some sort of restraint to prevent the expansion/contraction of HDPE pipe from pulling the existing systems joints apart. Several different restraining methods will be discussed. Before using any mechanical fitting, contact the manufacturer to verify the fitting is designed for HDPE pipe.

2.0 Connections to Ductile Iron Pipe / Fittings and PVC Pipe / Fittings

2.1 MJ Adapter Connections to DI Fittings

MJ (mechanical joint) Adapters are manufactured in standard IPS and DIPS sizes for connecting IPS sized or DIPS sized polyethylene pipe to mechanical joint fittings and appurtenances that meet AWWA C111/ANSI A21.11. When connected, they seal against leakage and restrain against pullout. No additional external clamps or tie rod devices are required unless connected to an existing piping system. In that case, refer to Section 4 on restraint recommendations.

In water systems that use ductile iron pipe (DIP), many valves are connected to pipe using MJ Adapters. A typical MJ Adapter Kit is shown below in Figure 1. Refer to the fitting manufacturer's installation instructions for joining a MJ Adapter to a DI Fitting. In general, the procedure is to first attach the HDPE MJ Adapter to the HDPE pipe line. Slip the Gland Ring over the pipe end and then butt fuse the HDPE MJ Adapter to the end of the pipe using the *PPI Generic Butt Fusion Joining Procedure TR-33*. Install the Gasket over the MJ Adapter and align the fitting with

the socket hub of the ductile iron fitting. Lubricate the gasket, the end of the MJ adapter, and the inside of the socket hub with an approved pipe lubricant meeting AWWA C111. Do not use soapy water.

Insert the MJ Adapter into the socket hub. Make sure it is evenly and completely seated in the socket hub. The MJ Adapter and the socket hub must be aligned straight into each other. Insert the gland bolts, and run the nuts up finger-tight. Tighten the gland bolts evenly to the fitting manufacturer's recommended procedures. This connection is used with a large number of DI fittings, some of which are shown in Figure 4.

When connecting to a valve with an MJ connection, longer T-Bolts may be required. If the T-Bolts that come with the kit are not long enough for the assembly, use a coupling nut and Grade 5 all thread to make up the length required (Figure 5).

Figure 1 HDPE MJ Adapter Kit

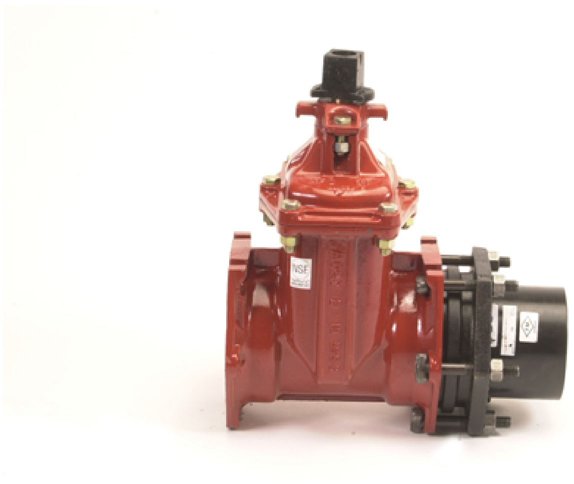


Figure 2 MJ connection to typical gate valve with MJ ends

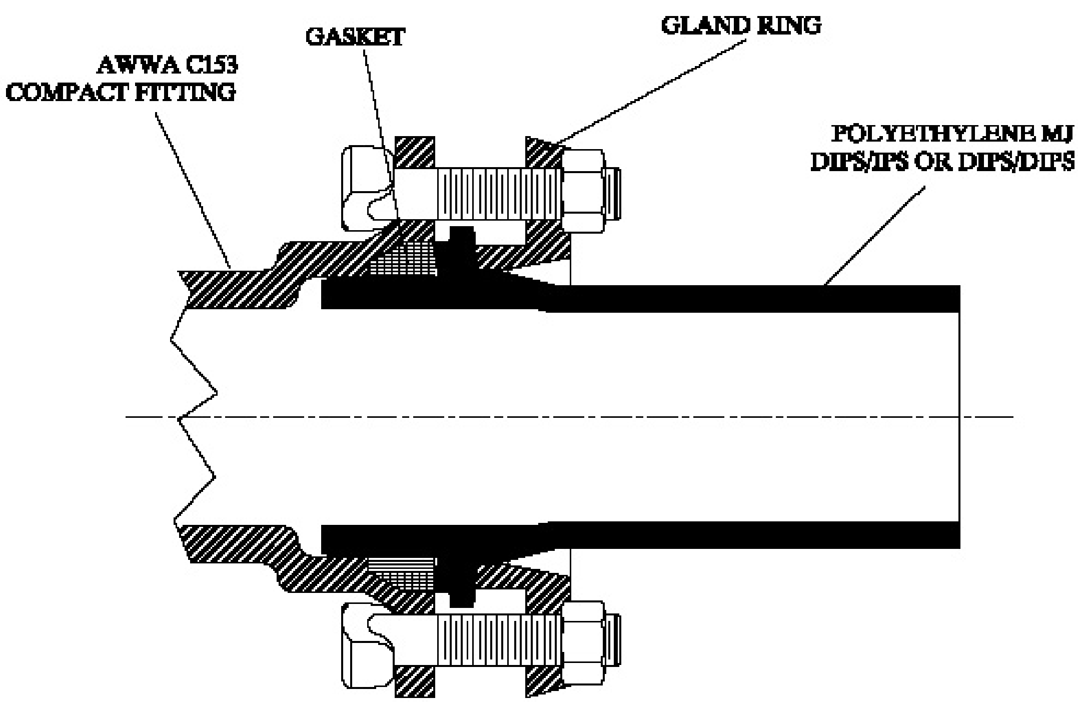


Figure 3 MJ Connection to DI fitting

Figure 4 Ductile Iron Fittings **MJ Connection**

Figure 5 T-Bolt Extension

2.2 Flanged Connection to DI Fittings

It is common to use a flanged connection to join HDPE pipe to HDPE pipe in a close quarter tie-in or when a piping section will require removal in the future. Flanged joints are also used to attach HDPE pipe to valves or DI fittings. The parts for a flange connection are the HDPE Flange Adapter, Back-Up Ring, Gaskets and Bolts, Nuts and Washers.

This connection is made by first sliding the Back-Up Ring over the pipe end and then butt fusing the HDPE Flange Adapter to the end of the pipe using the *PPI Generic Butt Fusion Joining Procedure TR-33*. Then align the flanges and back-up rings and follow the fitting manufacturer's recommended procedures for bolting the flanges together. The service pressure rating for the back-up ring should meet or exceed the service pressure in the pipe.

Gaskets may not be required, depending on the pressure in the pipeline. Gaskets are usually used for higher pressure application (over 100 psi) and <u>must</u> be used for connections between polyethylene and non-polyethylene flanges. If gaskets are used, the gasket manufacturer should recommend the gasket to use with polyethylene pipe.

This is considered a "fully restrained joint" and should not need external restraint devices.

Figure 6 Flange Adapter Assembly

Figure 7 Fused Manifold Assembly with Flange Adapters And Back Up Rings

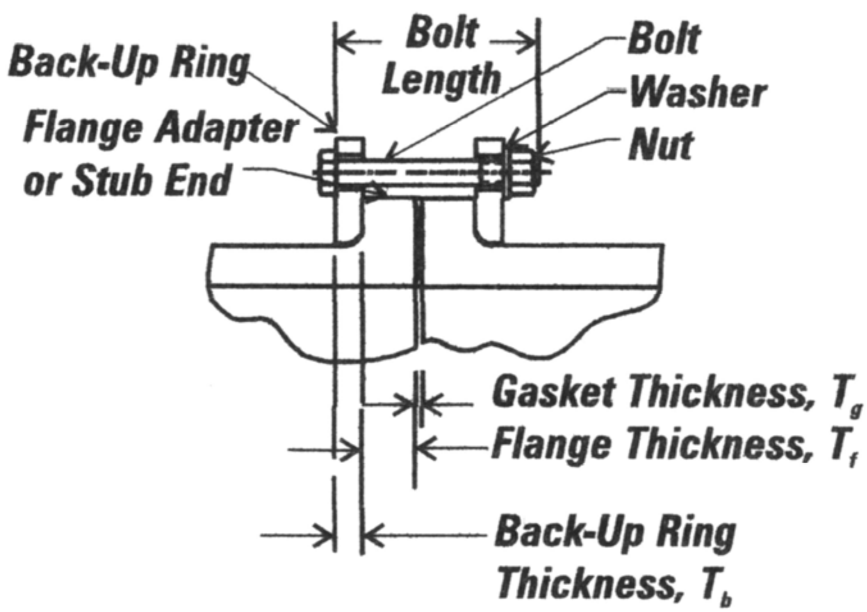
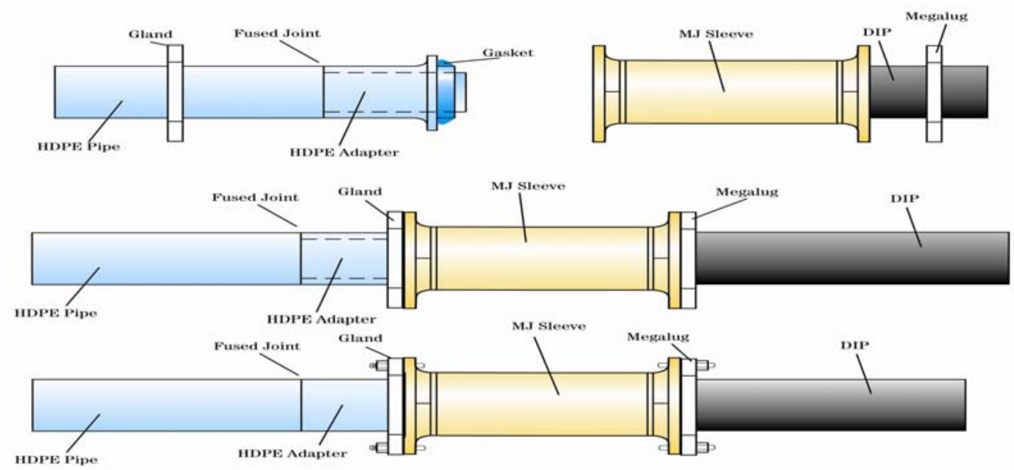


Figure 8 Flange Adapter Bolted Assembly Cross Section

Figure 9 Ductile Iron Tee with Flanged Outlet

2.3 Solid DI Sleeve Connections to HDPE pipe

Solid Sleeves are ductile iron fittings designed to connect DI / PVC pipe to other piping materials including HDPE pipe. They come in a variety of configurations depending on the application. Most solid sleeves have a flange or MJ hub to attach to the HDPE pipe. On the ductile iron pipe side, a Megalug flange is attached to the pipe and a gasket is installed over the pipe and into the sleeve before bolting the Megalug to the Sleeve flange. A standard HDPE MJ Adapter kit is used on the HDPE pipe side to complete the assembly. Be sure to use the manufacturer's recommended bolting procedures for this assembly. (see Figure 10)



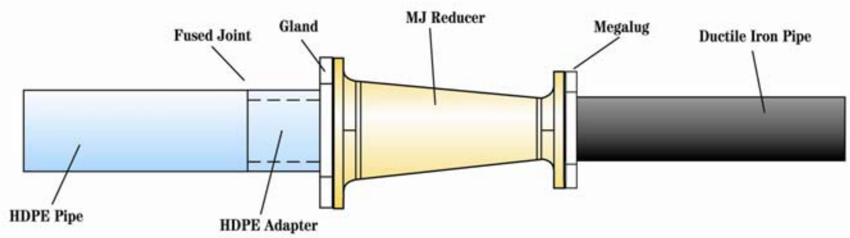


Figure 10 Solid DI Sleeve Connections to HDPE pipe

Another solid sleeve design is called a "One Bolt" Solid Sleeve and can be used to connect HDPE pipe to PVC or DI pipe. This is similar to a standard HDPE mechanical connector but has a special locking ring that grips the HDPE pipe to prevent pullout. It is recommended to use a stiffener inside the HDPE pipe, especially if the DR is more than 11. This connection can be installed very quickly in the field and may also be used for repair. Consult with the sleeve manufacturer for application and restraint advice.

Figure 11 One Bolt Solid Sleeve Connection

2.4 <u>HDPE Pipe Connection to DI or PVC Bell End</u>

Another method of restraining the above mentioned connection would be the use of a restraint harness and the attachment of flex restraint sections to the HDPE pipe. These flex restraint pieces are electro-fused to the HDPE pipe to achieve the proper stab depth in the PVC or DI bell and the restraint harness plate is attached behind them. The opposite end of the restraint harness is attached behind the DI /PVC hub. Install the HDPE pipe in the PVC/DI bell until it bottoms out on the flex restraints

and tighten the tie rods to prevent the assembly from pulling apart. As discussed above: to maintain proper contact with the seal in the DI /PVC fitting, it is recommended that a stiffener be installed in the HDPE pipe end.

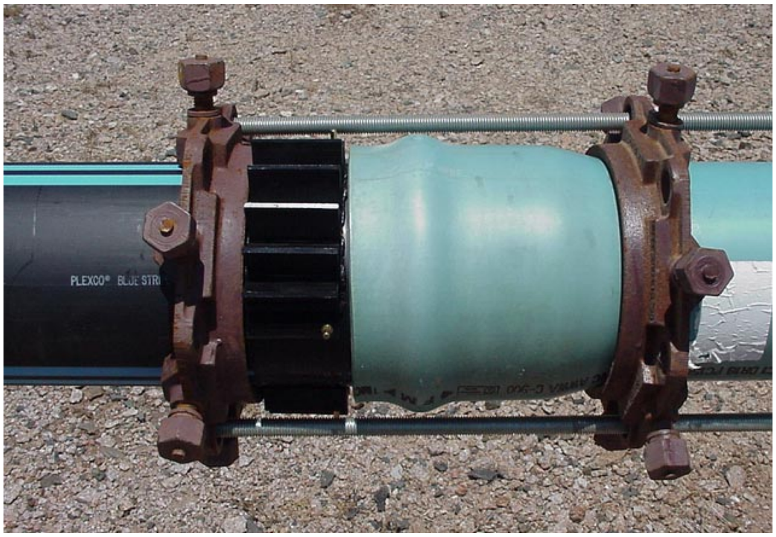


Figure 12 HDPE pipe connection to DI / PVC bell end using Flex Restraints on the HDPE pipe

2.5 <u>HDPE Bell Adapters to DI or PVC Pipe End</u>

There are HDPE Bell Adapters available, up to 24" IPS, that are machined to the standard MJ Adapter internal configurations and have an external stainless steel backup ring installed to ensure positive seal contact. This connection incorporates a back-up flange behind the HDPE Adapter and a Mega-Lug flange on the PVC or DI pipe. Standard MJ seals and bolts are used to connect the assembly.

Figure 13 HDPE Bell Adapter to DI or PVC Pipe End

2.6 <u>DI Valve with HDPE Ends</u>

In most potable water systems, a valve is installed between the main and the hydrant. This can be fused in line using this special valve assembly with HDPE pipe installed on each side and available up to 12" pipe size. It has an HDPE ends installed on each side of the valve.

Figure 14 Ductile Iron Gate Valve with HDPE Ends

2.7 Dismantling Joint

Dismantling joints simplify installations and replacement of flanged fittings in retrofitting applications. Dismantling Joints provide the solution for adding, repairing or replacing flanged fittings within a flanged pipe system. In all applications, a restrained dismantling joint is required unless otherwise specified. (see Section 4).

Adjustable, slip joint design accommodates either wide gaps or close quarter installations and eliminates the need for precise measurements between flange connections. Available in sizes 2" and larger, for ductile iron or flanged HDPE piping systems. Standard flanges AWWA C207 Class D Flange. Other flanges are available upon request.

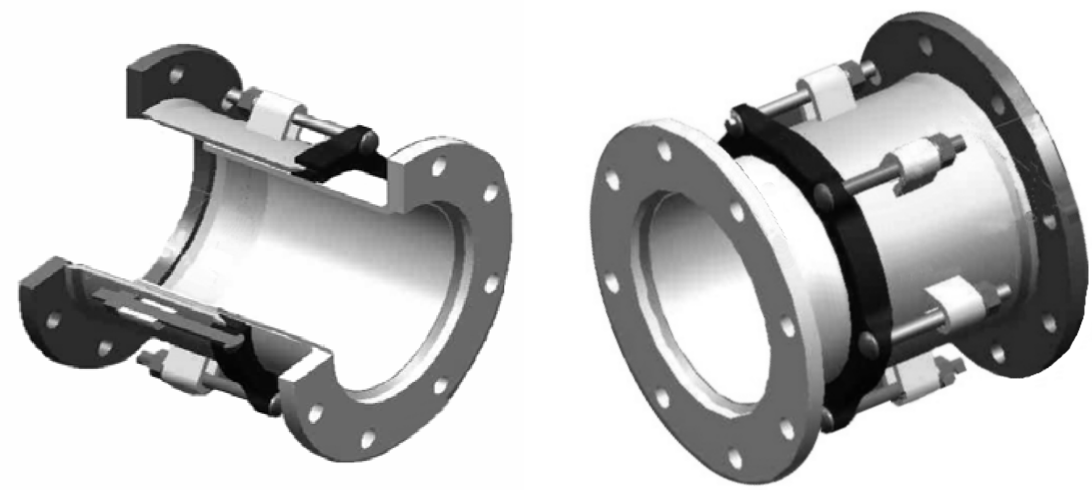


Figure 15 Dismantling Joint

2.8 Transition Fitting – HDPE pipe to DI / PVC pipe

A transition fitting is a mechanical assembly of HDPE and PVC or DI pipe. The resulting product will allow a butt fusion joint on the HDPE end and standard PVC

or DI mechanical connection on the other end. (See Figures 17, 18 & 19 for different configurations.)

Figure 16 Transition Fitting – HDPE to PVC

Figure 17 Transition Fitting – HDPE to DI with MJ Adapter

Figure 18 Hydrant Swivel Transition Fitting – HDPE to DI

2.9 Mechanical Connection – HPDE to PVC

This coupling provides the convenience of bolted mechanical assembly of plain-end PVC pipe to plain-end high density polyethylene (HDPE) pipe without special adapters. Integral rows of teeth on the HDPE side grip the pipe and diamond-shaped teeth safely grip the PVC pipe as you tighten the bolts to achieve metal-to-metal contact at the pads. This coupling is available in IPS pipe sizes up to 8" IPS. When connecting HDPE pipe to a mechanical coupling, restrain the fitting unless otherwise stated by the coupling manufacturer.

Figure 19   Mechanical Connection – HPDE to PVC

Figure 20   Mechanical Connection – HPDE to PVC

3.0 Stiffener Installation Guidelines

When connecting HDPE pipe to the bell end of a ductile iron or PVC pipe, it is recommended that a stiffener be added to the ID of the pipe to insure a good connection between the seal in the bell and the pipe. Check the pipe for toe in. If it is severe, cut the pipe back to remove it. If possible, have some means to press the stiffener into place. Lubricant will minimize the insertion effort required. A detergent or silicone grease is recommended.

There are two types of stiffeners available on the market. One type is a fixed diameter stiffener that matches the ID of the pipe being repaired (see Figure 21). Caution should be used when using fixed diameter stiffeners to be sure they are sized properly to obtain the proper press fit in the HDPE pipe. These are mainly used with smaller diameter service lines.

Figure 21 Fixed Diameter Stiffener for HDPE pipe

The other type of stiffener is a split ring stiffener (see Figure 22a). These are normally made of stainless steel and provide a thin yet strong pipe wall reinforcement without disturbing the flow characteristic of the pipe. The easy installation instructions are shown in Figure 22b.

Figure 22a **Split Ring Stiffener for HDPE pipe**

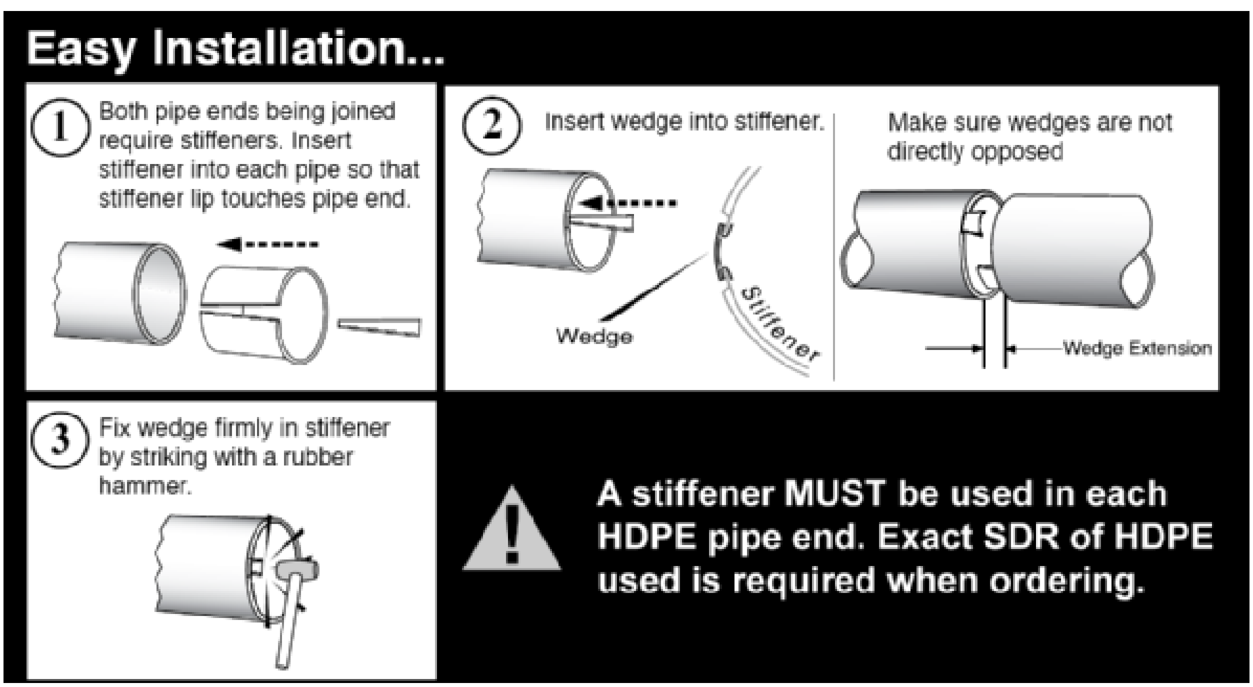


Figure 22b **Easy installation instructions**

Figure 23 Install Split Ring Stiffener in HDPE pipe

4.0 Restraint Methods

A pipe section with fully restrained joints such as a long string of butt fused HDPE pipe will transmit Poisson effect pipe shortening from length to length through the restrained joints along the pipe string. Restrained joints include butt fusions, electro-fusions, socket fusions, bolted flange connections, MJ Adapter connections or other restrained mechanical connections. If an unrestrained bell and spigot or mechanical sleeve joint is in-line with the restrained section, the cumulative Poisson effect shortening and possible thermal expansion / contraction effect may cause in-line unrestrained joints or connections to be pulled apart. Therefore, unrestrained joints or mechanical connections that are in-line with fully restrained HDPE pipe must be either restrained or otherwise protected against pullout disjoining.

4.1 Wall Anchor

A typical pullout prevention technique is to restrain the transition connection by butt fusing a Wall Anchor in the HDPE pipeline close to the connection and pouring a concrete anchor around it as shown in Figure 24. Refer to the pipe manufacturer's recommendations on anchor size and pull out loads.

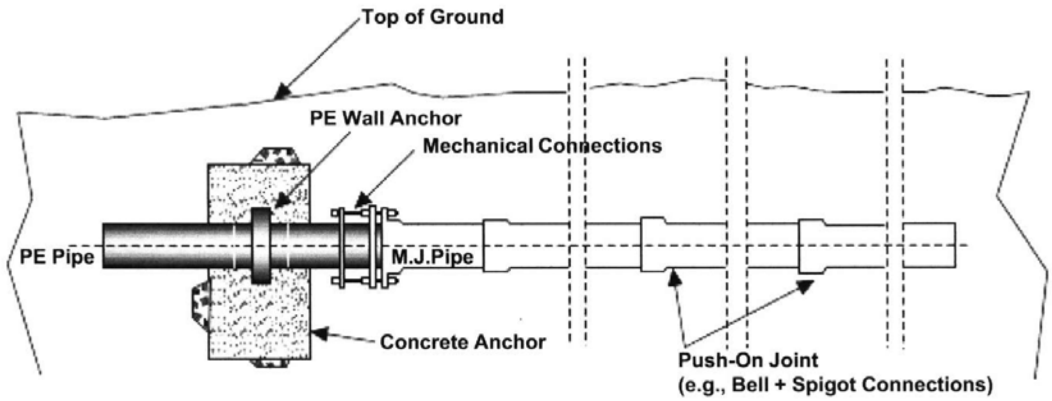


Figure 24 Wall Anchor Diagram

Another method of anchoring this connection is to electro-fuse several Flex Restraints to the HDPE pipe instead of butt fusing a wall anchor to the line as shown in Figure 25.

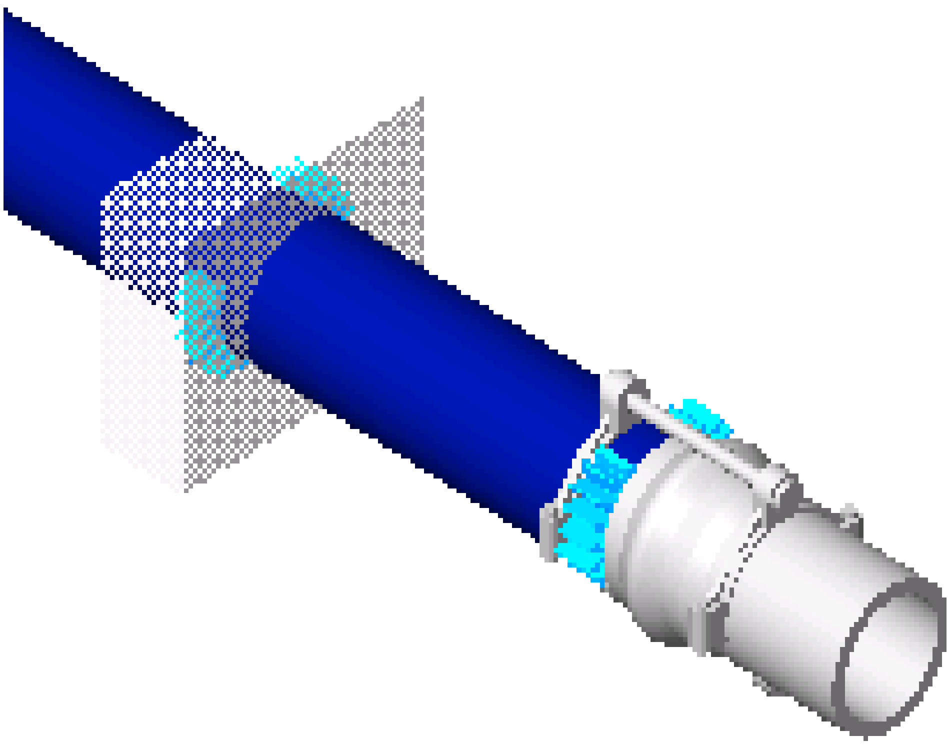


Figure 25 Flex Restraint Anchor

4.2 <u>Mechanical Restraint Anchor</u>

A typical pullout prevention technique is to restrain the transition connection and several non-PE bell and spigot joints down line from the transition connection as shown in Figure 26.

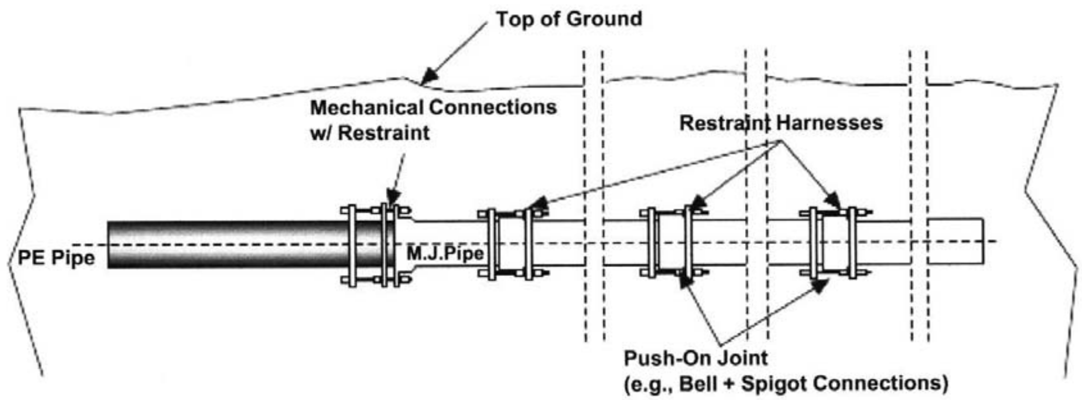


Figure 26 Mechanical Restraint of existing pipeline when attaching to HDPE pipe

4.3 <u>Buried Poly Anchor</u>

This product is designed to be buried in the soil and resist any linear movement that might occur with polyethylene pipe without pouring a concrete anchor around it. In order to mobilize its buried anchoring restraint action, the Poly-Anchor simply requires at least 85% standard Proctor Density soil compaction in-situ to the top of the plate. Consult with the fitting manufacturer to ensure that the anchor size is adequate for the bearing capacity of the soil.

Figure 27 Buried Poly Anchor

4.4 <u>Above Ground Pipeline Anchor</u>

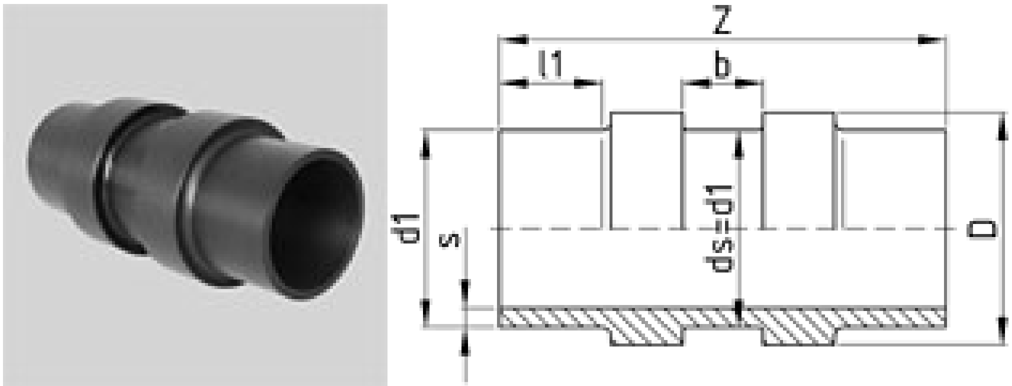


Figure 28 Above Ground Pipeline Anchor

The above ground anchor fitting is commonly used to manage HDPE pipe from thermal expansion and contraction. The fitting is fused into the pipe-line, and a metal band (C-Clamp) is secured over the anchor fitting in the middle, and securely bolted to an I-beam, support bracket, or embedded into a concrete block up-to the spring-line with C-clamp over the pipe crown and bolted to the block . The metal band attaches the pipeline to the anchoring point; the OD rings prevent the pipeline from moving in expansion or contraction in either direction. The width of the center groove can be made as wide as required so as to get sufficient grip on the HDPE pipe for the thermal excursions expected.

4.5 HDPE to PVC Slip-Joint Anchor Fitting

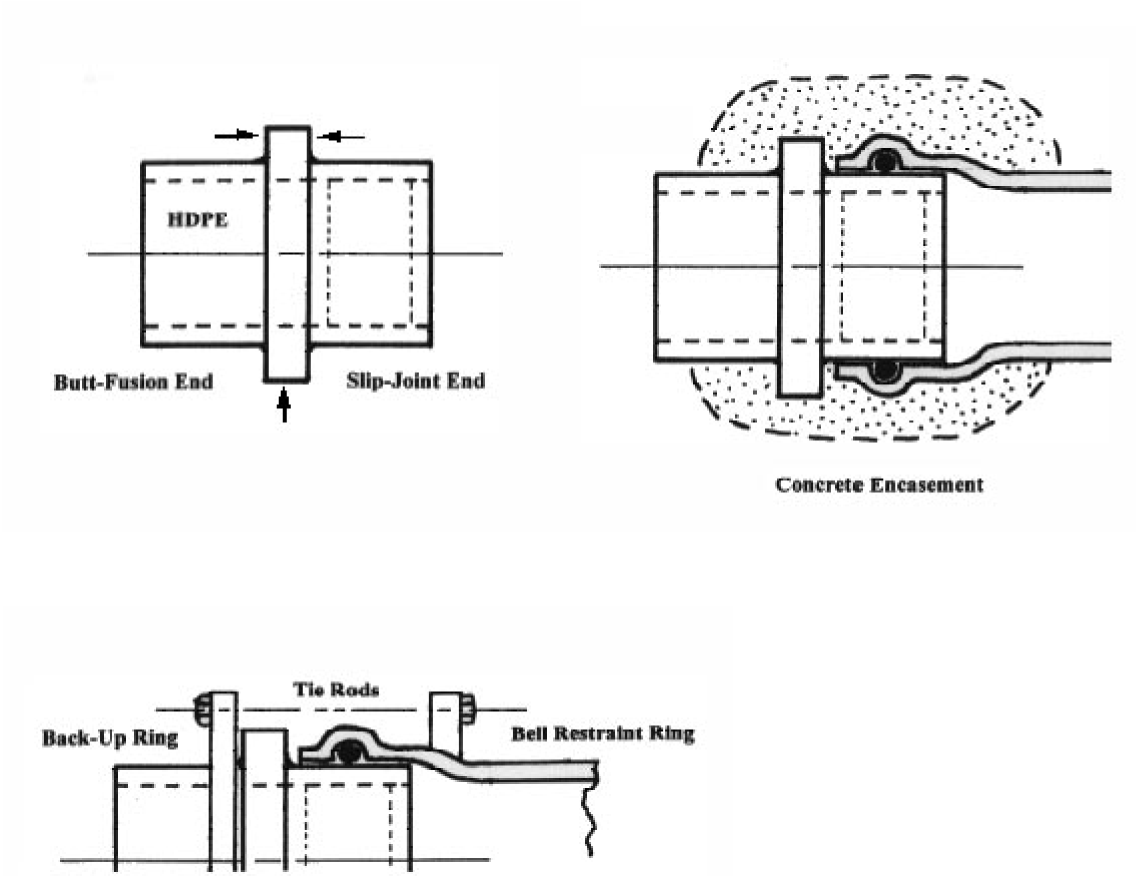


Figure 29 HDPE to PVC Slip-Joint Anchor Configurations

A gasketed PVC pipe bell to plain end HDPE pipe should be restrained against HDPE thermal contraction and pressure thrust, to avoid possible long-term joint separation. The PVC-Bell slip-Joint Anchor Fitting (PVC-SJA Fitting) with internal stiffener to support gasket load, provides the restrained connection from HDPE pipe to bell-end PVC pipe. (For plain-end PVC, refer to Section 2.5: the HDPE Bell-Adapter Fitting). When the restraint rings with tie-rod option is specified, the rods and rings are supplied separately from the SJA fitting.

5.0 References:

Plastics Pipe Institute -- www.plasticpipe.org
PPI Polyethylene Pipe Handbook
Technical Report TR-33 "Generic Butt Fusion Procedure"
Technical Report TR-41 "Generic Saddle Fusion Procedure"
Technical Note TN-34 "Installation Guidelines for Electrofusion Couplings 14" and Larger (2004)"
Technical Note TN-35 "General Guidelines Repairing Buried HDPE potable Water Pressure Pipes"

AWWA -- PE Pipe- Design and installation, M55, www.awwa.org

ASTM -- F1025 "Selection and Use of Full-Encirclement-Type Band Clamps for Reinforcement or Repair of Punctures or Holes in Polyethylene Gas Pressure Pipe"

Fusion Equipment Manufacturers

Connectra Fusion	www.connectrafusion.com
Fast Fusion	www.fastfusion.com
McElroy Manufacturing, Inc.	www.mcelroy.com
Ritmo America	www.ritmoamerica.com

Electro-Fusion Fitting and Equipment Manufacturers

Central Plastics Co.	www.centralplastics.com
Friatec	www.friatecusa.com
Kerotest-Innogaz	www.kerotest.com

Polyethylene Fitting Manufacturers

Central Plastics	www.centralplastics.com
Independent Pipe Products, Inc.	www.indpipe.net
ISCO Industries	www.isco-pipe.com
Industrial Pipe Fittings	www.hdpefittings.com
KWH Pipe	www.kwhpipe.ca
Performance Pipe	http://www.cpchem.com/enu/performance_pipe.asp
Poly-Cam	www.polycam.com

Pipe Manufacturers

ARNCO	www.arncocorp.com
Charter Plastics	www.charterplastics.com
Endot Industries	www.endot.com
Independent Pipe Products, Inc.	www.indpipe.net
J-M Manufacturing	www.jmpipe.com
KWH Pipe	www.kwhpipe.ca
Lamson and Sessions	www.vylonpipe.com
Performance Pipe	http://www.cpchem.com/enu/performance_pipe.asp
PolyPipe, Inc.	www.rinker.com/polypipe
Silverline	www.slpipe.com
US Poly	www.uspolycompany.com
WL Plastics	www.wlplastics.com

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Mechanical Fitting Manufacturers (Partial Listing)

Dresser	www.dressercouplings.com
Ebba Iron	www.ebba.com
Ford	www.fordmeterbox.com
JCM	www.jcmindustries.com
Mueller	www.muellercompany.com
One Bolt	www.onebolt.com
Romac	www.romacindustries.com
Smith-Blair	www.smith-blair.com
Tyler Union	www.tylerpipe.com
Union Foundry	www.ufco.com
Victaulic	www.victaulic.com

BOLT TORQUE FOR POLYETHYLENE FLANGED JOINTS

TN-38

2019

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Foreword

This technical note was developed and published with the technical help and financial support of the members of the Plastics Pipe Institute. The members have shown their interest in quality products by assisting independent standard-making and user organizations in the development of standards, and also by developing reports on an industry-wide basis to help engineers, code officials, specifying groups, and users.

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CAUTION

FLANGES IN NATURAL GAS PIPELINES

Note: In jurisdictional installations any metallic pipeline components must be protected from corrosion as prescribed in US CFR Title 49, Part 192, Subpart I, sections 451-491. Furthermore, Part 195 Subpart H, sections 551-589 applies to steel pipelines used in the transport of Hazardous Liquids.

Index

Preface:

Based on ASME B16.5 flange styles, the polyethylene **Lap-Joint Flange Assembly** is a three-component device consisting of:

1. Polyethylene flange adapter (FA) or stub-end.
2. A loose, metal, Lap-Joint Flange (**LJF**).
3. The bolt set.

The metal **Lap-Joint Flange** (LJF) cross-section geometry may be a rectangular solid or a contoured cross-section. The rectangular cross-section typically is machined from metal plate; the contoured cross-section is typically cast using molten ductile-iron or stainless-steel.

The LJF is typically in flat-face contact with the polyethylene flange adapter hub, and has a radius on the contact side of the LJF ID which mates with the fillet radius of the matching polyethylene flange-adapter (stub-end). The LJF slips over the pipe; is not welded to the pipe; is loose until bolted; and is free to rotate into bolt-hole alignment with another flange. The bolt-load is transferred to the sealing face by the pressure of the LJF against the back-face of the HDPE Flange Adapter's hub.
PPI strongly recommends that each flanged joint be independently analyzed by the project engineer for sealing capacity when subjected to all expected operating and installation loads.

Two methods are commonly used to seal polyethylene Lap Joint Flange assemblies between various combinations of pipe materials such as HDPE to HDPE; HDPE to Steel; HDPE to Ductile-Iron; HDPE to PVC; HDPE to Fiberglass.

1. The first method, (non-gasketed), uses the specified HDPE seating torque initially applied to the HDPE flange adapters, followed by a mandatory re-torque applied 4-hours to 24-hours after completion of the initial torque application
2. The second method, (gasketed), uses a low gasket seating bolt torque, applied to a soft elastomeric gasket, for lower pressure applications (like landfill gas collection or use with torque-limited PVC or fiberglass flanges), followed by the mandatory re-torque 4 hours to 24-hours after the initial torque.

Seating and Sealing: By applying the higher initial **seating torque** to seat the un-marred HDPE faces, without gaskets, the final residual bolt torque (RBT) at the HDPE **sealing stress** is sufficient to contain flow-stream pressure under operating conditions.

As is discussed later, the mandatory re-torquing to the initial target torque after a 4 hour to 24 hour creep-relaxation period is done to compensate for possible bolt-creep, nut embedment, and, gasket compression-set (if gaskets are used).

- Consult the individual HDPE flange manufacturers for their recommended protocol.
- Flange-Adapter Manufacturers should verify their flange assemblies are performance rated when used with a specific style or manufacturer's LJF.
- LJF (lap-joint flange) manufacturers should verify the maximum allowable torque that can be applied to their product, and that their LJF's provide "disk" deformation in excess of the polyethylene flange-adapter's expected service life's visco-elastic creep deformation, at low residual compressive stress.

CAUTION: When bolting to fiberglass, cast iron, PVC pipe flanges, or PVC flanged valves, the "brittle" flange typically bolts to a special HDPE full-face flange adapter using lower bolt torque. Hence a soft gasket is frequently also used with "brittle" pipes. Over-tightening, misalignment, or uneven tightening can break brittle material flanges. Extreme care is advised. Refer to Appendix C, and consult with the sensitive, low-strain product manufacturer for its maximum torque limits, when bolting to "raised-face" HDPE flange adapters. When gaskets are to be considered, review **Appendix C** very carefully, to perform calculations using the seating stress, blow-out resistance, crush resistance, and other performance values obtained from the gasket manufacturer. This Tech-Note does not provide guidance on gasket selection; consult with the gasket designer to discus the parameters outlined in **Appendix C**.

Introduction:

Lap-Joint Flanges (LJF) have been used for decades. The typical polyethylene flange adapter with loose LJF is also known as a Van-Stone Flange joint. The HDPE flanged joint assembly is an engineered pressure containment connection subject to diverse forces. While simple in appearance, its design is complex due to the axial shear, radial dilation, disk-bending moments, residual interfacial sealing pressure, bolt-load versus bolt-torque, HDPE flange face creep-relaxation, LJF disc flexure, axial tension from thermal contraction of the pipe-line, some vibration, pressure-surge, pipe bending due to soil settlement, etc. The greatest contributors to flange leakage are insufficient torque, un-even torque, and flange misalignment. Written and correct bolt torque specifications and installation procedures will eliminate these problems. The flange assembly design, and written assembly specifications, are controlled by the pipeline design-engineer or project engineer-of-record.

The ideal flange-adapter joint should exhibit Compressibility, Resilience, and Creep-Resistance. The plastic flange-adapter face should be able to compress into any and all surface texture and imperfections of the mating flange. The plastic flange face should be sufficiently and elastically resilient to move with dynamic loadings to maintain seating stress. The flange-adapter face should exhibit sufficient creep-resistance so as not to permanently deform after bolt-up under varying load cycles of temperature and pressure.

The “memory” of pipe-grade HDPE makes it an ideal flange face sealing surface. It becomes its own “gasket flange”, and seals well when un-marred and torqued to meet or exceed the HDPE seating stress. When properly torqued with a flexible LJF, the HDPE flange-adapter becomes self-gasketing.

The LJF assembly is typically evaluated as a combined mechanical “spring” assembly. The torqued bolts are elastically stretched to initiate the sealing pre-load. The metal LJF (lap-joint flange) is elastically flexed (bent by the bolt-load) to maintain the pre-load and to transfer the load to the HDPE flange face. At small strains, the HDPE flange-face is elastically and visco-elastically deformed (axial compression and slight radial enlargement) so as to maintain pre-load sealing pressure on the flange-face surface. The HDPE flange face compressibility is the measure of its ability to deflect and conform to the mating flange face. This compressibility compensates for flange surface irregularities such as minor nicks, non-parallelism, metal corrosion, and variation in surface roughness or grooving depth. The HDPE flange face also exhibits Memory / Recovery / Resiliency which are measures of the elasticity of the HDPE material to recover shape and to maintain its deformation sealing pressure under varying loads across broad temperature ranges. Although the HDPE is a visco-elastic material that slightly creeps over time, at sufficient torque the flexure of the LJF and bolt stretch exceed the expected long-term compressive creep of the flange face, such that the residual sealing force exceeds the sum of the operating separation forces. In this way, the sealing pressure is maintained.

The combined “springs” of the stretched bolts, the flexed disc LJF, and the elastic component of the compressed flange-face, all serve to provide an elastic / visco-elastic, resilient “spring-seal” of the hydrostatically pressurized joint.

The key element to an effective sealing HDPE flanged joint, is to torque the bolts to a sufficiently high value to stretch the bolts, so that the LJF is flexurally distorted, and the HDPE flange-face sufficiently and continuously compressed. The joint is at equilibrium, with the compressive sealing force distributed across the sealing face and equal in magnitude to the pre-tension in the bolts. The total bolt tension must be able to constrain the joint assembly against operating pressure, surge pressure, pipe-line axial thermal contraction, and pipe bending strain from soil settlement, and flange angular alignment; all with an applied safety factor.

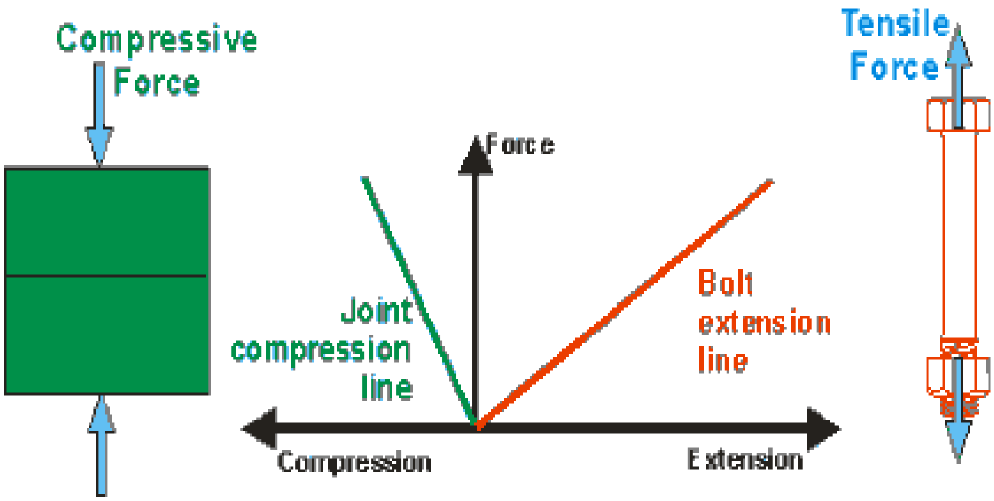


Figure 1

The total possible force required from bolting torque should equal and exceed the sum of applicable separation forces:

$$F_{Total} > \{F_{Press} + F_{Surge} + F_{Therm.Contr.} + F_{Pipe\text{-}Bend} + F_{Flng\text{-}Alignment} + F_{\%\ Variance}\}$$

Equation # 1

Caution: The component, $F_{pipe\text{-}bend}$ (forces from pipe beam-bending), in the above equation can sometimes exceed thermal contraction and hydraulic forces. HDPE flange joints are geometrically rigid assemblies, unlike the flexible HDPE pipe ring “hoop”. The rigid flanged joint cannot shed stress by ring deformation. Localized HDPE pipe beam-bending at a flanged joint due to soil settlement, water buoyancy or wave action, pipe “snaking” above ground, etc, must be managed so as to isolate the flange from beam-bending strain. External installation measures to protect PE flange joints from beam-bending strain are necessary. While additional torque can maintain the pressure seal, bending strain across the HDPE flange adapter should be limited to prevent flange adapter fracture.

NOTE:

Appendix “A” provides the method for calculation and determination of specified bolt torque at the required seating stress. Proceed to Appendix “A” to perform the required engineering calculations to determine the required target torque to be used in the Checklist following on the next page.

PROJECT'S CHECKLIST and FLANGE-TORQUE RECORD:

Project: ________________________ Flange Set Location: _______________
Connecting HDPE Flange to ___________________________ Flange.
Bolt Dia & Grade : _______________ Nut Diameter & Grade : ________________
Lap-Joint Flange Dia. & Pressure Rating: ________________________________
Lubricant Used: ______________________ Flange Temp: _____________
Torque Wrench ID #: _________________ Calibration Date: _________________
If Specified: Full-face Gasket Info: Material: ___________ Thickness:_________
Deep-Well Socket / <u>Heavy-Hex Nut</u> Wrench Size Used: ______________________

Axis off-set:_____ Angular & Facial Gap: Top_____ Bottom____ L____ R____

"Initial" Each Step Upon Completion:

______1. Visually examine and clean both flanges, bolts and nuts. Replace damaged units.
______2. Liberally Lubricate bolt threads & nut threads & flange surface under nut.
______3. If gasket is specified, insert full-face gasket. Do not use wrinkled or damaged gaskets.
______4. Number the bolt-holes in circumferential sequence stating at 12:00 position.
______5. Check Flange alignment, concentricity, angularity, and gap for acceptability.
______6. To firm the flanges squarely together, Hand Tighten, then pre-tighten all bolts in proper sequence to 10-20 foot-pounds torque, but do not exceed 20% of the TARGET TORQUE.
______7. Re-check any flange-adapter face gap and LJF gap for uniformity. ****
______8. Use the appropriate criss-cross pattern tightening in numerical sequence for Rounds 1, 2, 3, and 4 (tightening all bolts once in sequence constitutes a "round").

****** Note: Check LJF gap around the flange circumference between each of these rounds, measured at every other bolt. If any gap is not reasonably uniform around the circumference, make the appropriate adjustments by selective bolt tightening before proceeding.**

TARGET TORQUE (and 4 to 24-HOUR RE-TORQUE): ___________ foot-pounds

____ For 4-bolt, 8-bolt, 12-bolt Flanges	**______ For Large Flanges > 16 + Bolts**
____ Lubricate, Hand tight, Pre-tighten	**____ Lubricate, hand tighten, Pre-tighten**
____ Round 1 – Tighten to ____ft.lbs. (30%)	**____ Round 1 – Tighten to ____ft.lbs. (25%)**
____ Round 2 – Tighten to ____ft.lbs. (60%)	**____ Round 2 – Tighten to ____ft.lbs. (50%)**
____ Round 3 – Tighten to ____ft.lbs. (100%)	**____ Round 3 – Tighten to ____ft.lbs. (75%)**
____ Rotational (clockwise) Round	**____ Round 4 – Tighten to ___ ft.lbs. (100%)**
	____ Rotational (clockwise) Round

_____Rotational (clockwise) Round: 100% of Target Torque. Use rotational clockwise tightening sequence, starting with bolt #1, for one complete round, and continue until no further bolt or nut rotation occurs at 100% of the target torque value for each nut.

_____ 4- Hour Re-Torque & Inspection :

Re-torque to target torque value using one or two <u>sequence</u>-rounds, followed by one r<u>otational</u> round at the target torque value.

Documentation Recorded By : ____________________________ Date: _____________

Joint Technician/Mechanic:_______________________________ Date: _____________

Tightening Sequence:

Number the bolts in rotation around the Lap-Joint Flange circumference in a clockwise order, beginning with the first bolt at the top in the nominal 12:00 position, the second being the next bolt to the right, the third being the next bolt to the right, etc, until all bolts are numbered sequentially.

Following the table below, tighten the given bolt number to the desired torque value for the given round of tightening as specified on the Torque Record Checklist.

TABLE 1 [refer to ASME Document PCC-1 for Bolt Sequences]

NUMBER OF BOLTS	CRISS-CROSS PATTERN TIGHTENING SEQUENCE
4	1-3-2-4
8	1-5-3-7 >> 2-6-4-8
12	1-7-4-10 >> 2-8-5-11 >> 3-9-6-12
16	1-9-5-13 >> 3-11-7-15 >> 2-10-6-14 >> 4-12-8-16
20	1-11-6-16 >> 3-13-8-18 >> 5-10-15-20 >> 2-12-7-17 >> 4-14-9-19
24	1-13-7-19>> 4-16-10-22>> 2-14-8-20 >> 5-17-11-23 >> 3-15-9-21 >> 6-18-12-24
28	1-15-8-22 >> 4-18-11-25 >> 6-20-13-27 >> 2-16-9-23 >>>> 5-19-12-26 >> 7-21-14-28 >> 3-17-10-24
32	1-17-9-25 >> 5-21-13-29 >> 3-19-11-27 >> 7-23-15-31 >> 2-18-10-26 >>> >> 6-22-14-30 >> 4-20-12-28 >> 8-24-16-32
36	1-2-3 >> 19-20-21 >> 10-11-12 >> 28-29-30 >> 4-5-6 >> 22-23-24 >>>> >> 13-14-15 >> 31-32-33 >> 7-8-9 >> 25-26-27 >> 16-17-18 >> 34-35-36
40	1-2-3-4 >> 21-22-23-24 >> 13-14-15-16 >> 33-34-35-36 >> 5-6-7-8 >>>> 25-26-27-28 >> 17-18-19-20 >> 37-38-39-40 >> 9-10-11-12 >> 29-30-31-32
44	1-2-3-4 >> 25-26-27-28 >> 13-14-15-16 >> 37-38-39-40 >>>> 5-6-7-8 >> 29-30-31-32 >> 17-18-19-20 >> 41-42-43-44 >>>> 9-10-11-12 >> 33-34-35-36 >> 21-22-23-24
48	1-2-3-4 >> 25-26-27-28 >> 13-14-15-16 >> 37-38-39-40 >>>> 5-6-7-8 >> 29-30-31-32 >> 17-18-19-20 >> 41-42-43-44 >>>> 9-10-11-12 >> 33-34-35-36 >> 21-22-23-24 >> 45-46-47-48
52	1-2-3-4 >> 29-30-31-32 >> 13-14-15-16 >> 41-42-43-44 >> 5-6-7-8 >>>> 33-34-35-36 >> 17-18-19-20 >> 45-46-47-48 >> 21-22-23-24 >> >> 49-50-51-52 >> 25-26-27-28 >> 9-10-11-12 >> 37-38-39-40

The crisscross bolt tightening sequence and multi-round tightening are necessary to counteract the flange / bolt elastic interaction.

TABLE 2

EXAMPLES OF ESTIMATED BOLT TORQUE TO "SEAT" HDPE FLANGE FACES:

The **engineer of record** is usually responsible for establishing each flange joint criteria, and performing the required calculations to determine the initial and residual torque values.

These estimated values are based on non-plated bolts and studs, using a nut factor of K**=0.16** for lightly greased bolts and nuts. The calculations uses a HDPE flange face seating stress of **1200-psi** as a minimum and **1800-psi** as a maximum, and assumes the flanged joint is between two HDPE flange adapters (in which the contact area is largest), without a rubber gasket.

NOTE: For bolting to ductile-iron pipe, steel flanges or butterfly valves, the flange face contact area is about half, so bolt torque for that flange pair will be measurably less (refer to Table #3).

IPS Nominal Pipe Size	LJF Bolt Diameter	Number of Bolts	Initial Minimum Lubed Torque (Ft-Lbs)	Initial Maximum Lubed Torque (Ft-Lbs)	Flange OD/ ID (Inches)
2"	0.625	4	23	35	3.9 / 1.94
3"	0.625	4	33	50	5.0 / 2.86
4"	0.625	8	33	50	6.6 / 3.68
5"	0.75	8	44	66	7.5 / 4.40
6"	0.75	8	50	75	8.5 / 5.42
8"	0.75	8	80	120	10.63 / 6.76
10"	0.875	12	80	120	12.75 / 8.79
12"	0.875	12	105	160	15.00/ 10.43
14"	1.000	12	180	270	17.50 / 11.45
16"	1.000	16	180	270	20.00 / 13.09
18"	1.125	16	200	300	21.12 / 14.73
20"	1.125	20	200	300	23.50 / 16.36
22"	1.25	20	260	390	25.60 / 18.00
24"	1.25	20	290	435	28.00 / 19.64
26"	1.25	24	290-	435	30.00 / 21.27
28"	1.25	28	290	435	32.30 / 22.91
30"	1.25	28	325	488	34.30 / 24.54
32"	1.50	28	425	640	36.50 / 26.18
34"	1.50	32	425	640	38.50 / 27.82
36"	1.50	32	460	690	40.80 / 29.45
40"	1.50	36	460	690	46.00 / 35.29
42"	1.50	36	460	690	47.50 / 37.06
48"	1.50	44	460	690	54.00 / 43.43
54"	1.75	44	560	840	60.00 / 48.86

NOTE: Uniform bolt pre-load (torque), without large "scatter", is as useful as the target pre-load. Within the limits of the HDPE flange adapter, gasket, or metal LJF, higher pre-load is desirable. The higher the pre-load safely achievable, the more closely the assembly will behave like the theoretical model and seal well. Higher pre-load means that a given internal pressure will result in the least possible change in contact sealing pressure. Be consistent (avoid changes) with materials and tools when following written assembly procedures.

Train and supervise the bolting personnel. Tell the crew what is to be accomplished, why, and explain that good results are not automatically achieved. Skill and care are essential. Bolted Joint assembly is a technical skill that is not common in the construction and maintenance profession, being considered more like a specialty. There is no universally accepted testing, nor certification, of bolted-joint assembly mechanics. With no common training, certification, nor standards, it is no surprise there is +/- 25% variability in assembly torque. Specifications and instructions by the engineer, followed by trained mechanics, help to solve the dilemma.
(NOTE: Consult ASME Document PCC-1, Appendix A for training and certification of bolted joint assemblers)

TABLE 3

Examples of Estimated Bolt Torque to "Seat" the HDPE Flange Face To

A Butterfly-Valve, Steel Pipe Flange, or Ductile Iron Flange.

The engineer of record is usually responsible for establishing each flange joint criteria, and performing the required calculations to determine the initial and residual torque values.

These estimated liberally lubricated torque values assume the flanged joint connects one HDPE flange-adapter to a Butterfly-Valve or Steel Pipe flange of Schedule 40 ID, or a Ductile-Iron flange. For bolting to steel flanges or butterfly valves, the flange face contact area is just over half that of HDPE to HDPE flanges, so calculated bolt torque for this flange pair will be measurably less than the values listed in Table #2.

Dimensional flange data should be obtained for each case from the pipe flange suppliers, so as to be able to calculate the face contact area.

These estimated values are based on non-plated bolts and studs, using a K=0.16 for lightly greased bolts and nuts. These calculations use an HDPE material minimum and maximum compressive seating stress of **1200-psi to 1800-psi.**

IPS Nominal Pipe Size	**LJF Bolt Dia. (inches)**	**Number of Bolts**	**Initial Minimum Lubed Torque (Ft-Lbs)**	**Initial Maximum Lubed Torque (Ft-Lbs)**	**HDPE Flange OD Steel Pipe ID (inches)**
2"	0.625	4	22	32	3.90 / 2.067
3"	0.625	4	30	45	5.00 / 3.068
4"	0.625	8	30	45	6.60 / 4.026
5"	0.75	8	44	66	7.50 / 4.40
6"	0.75	8	44	66	8.50 / 6.06
8"	0.75	8	58	88	10.63 / 7.98
10"	0.875	12	58	88	12.75 / 10.02
12"	0.875	12	75	114	15.00 / 11.94
14"	1.000	12	140	210	17.50 / 13.13
16"	1.000	16	140	210	20.00 / 15.00
18"	1.125	16	140	210	21.12 / 16.88
20"	1.125	20	140	210	23.50 / 18.81
22"	1.25	20	160	240	25.60 / 21.25
24"	1.25	20	180	270	28.00 / 23.25
26"	1.25	24	180	270	30.00 / 25.25
28"	1.25	28	180	270	32.30 / 27.25
30"	1.25	28	180	270	34.30 / 29.25
32"	1.50	28	240	360	36.50 / 31.00
34"	1.50	32	240	360	38.50 / 33.00
36"	1.50	32	260	390	40.80 / 35.00
40"	1.50	36	310	465	46.00 / 39.00
42"	1.50	36	310	465	47.50 / 41.00
48"	1.50	44	310	465	54.00 / 47.00
54"	1.75	44	365	550	60.00 / 53.00

Train and supervise the bolting personnel. Tell the crew what is to be accomplished, why, and explain that good results are not automatically achieved. Skill and care are essential. Bolted Joint assembly is a technical skill that is not common in the construction and maintenance profession, being considered more like a specialty. There is no universally accepted testing, nor certification, of bolted-joint assembly mechanics. With no common training, certification, nor standards, it is no surprise there is +/- 25% variability in assembly torque. Specifications and instructions by the engineer, followed by trained mechanics, help to solve the dilemma. (Note: Consult ASME PCC-1, Appendix A)

APPENDIX A

Calculations, Considerations, and Guidelines

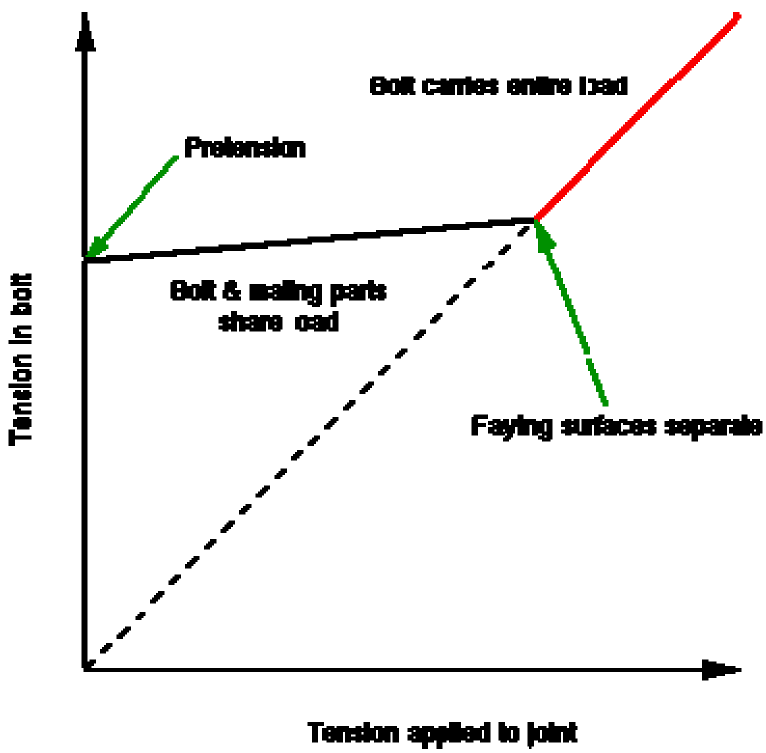


Figure 2

Bolt Pre-Load:

Within its proportional limit, the metal bolt tension is linearly related to the applied torque. A two dimensional graph plotting Total Applied Torque (y-axis) versus measured Bolt Load (x-axis) , displays a linear slope up-wards to the right. The bolt tension transmitted to the flange joint is directly dependent upon applied torque. The mechanical advantage of the torque-wrench lever and the helical threads enables one to stretch the length of the bolt between the head and the nut (this length is known and the *grip-length*), thus creating elongation (mechanical strain) resulting in tension stress in the bolt cross-section.

However, when using Torque-Control as the method for establishing flange assembly pre-load, one must understand there is a measurable variance between applied torque and theoretical bolt tension. Typically, only about 10% to 20 % of the applied torque is actually transmitted into bolt elongation. From tests, it is known that about 50% of the bolt torque is consumed by friction from the bolt-head contact face or the nut-face being rotated against its mating part. About 10% is used up in reversible twist of the bolt length. About another 30% is dissipated to overcome the friction in the bolt/nut threads. When more torque is needed to overcome friction, then less remains for bolt extension pre-load. Hence, small changes to reduce friction on the bolt-threads and under the rotating nut-face, will significantly increase the torque transmitted to bolt-extension pre-load. This is the reason a light duty grease or 30 weight motor oil should be sparingly applied to the bolt-thread and nut-thread before assembly. Metal or mineral filled lubricating greases are not usually used, because they may also enable nut loosening when subject to some vibration or repetitive pressure surge. The correct lubricant enables more bolt-extension pre-load and bolt-torque retained thru residual friction at the final torque value. In ordinary practice, the bolt-head is usually held, and the nut usually rotated. It is good specification practice to specify which is to be held, and which is to be rotated, so as to minimize variability in bolt extension by applied torque.

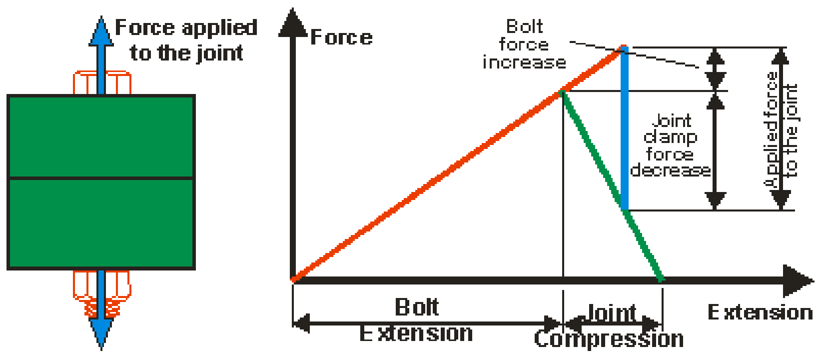


Figure 3

Bolting Basics: The Bolting Diagram

At zero pressure and no axial forces present in the pipeline, there is equilibrium between the elastic tension in the bolt and the compression in the HDPE flange. When the line is pressurized or is subjected to thermal contraction, the resulting axial force is applied across the joint and ultimately ends up being resisted by tension in the bolts. As the bolt elongates, part of the preload due to bolt torquing is reduced and the compressive stress on the mating flange faces (sealing surface) decreases. Because the HDPE flange was initially compressed, it elastically recovers and continues applying stress to the sealing surface. In this manner the HDPE flange is acting just like a gasket.

As the applied external tensile load is further increased, the bolts stretch more, thus relieving and further decreasing the compression at the sealing interface. If the flange face compression is relieved beyond the sealing force, the flange probably will leak. This decrease can only go so far, or the compression will ultimately go to zero, and there will be a gap between the sealing surfaces. The point of sealing surface separation is known as the “decompression point”. For pressurized pipelines, the external tension forces only need to decrease the pre-load down to a level near the operational working pressure, such that the working pressure exceeds the sealing pressure, and the water radially escapes / leaks.

From the diagram, it is obvious that the bolt-tension must be sufficiently high to endure external force loadings (pressure, surge, thermal contraction, beam-bending due to soil settlement, etc…), such that under all cases, the sealing pressure exceeds by a safety factor, the sum of the pipeline operating pressure plus surge pressure. Leaks will originate when the initially applied torque is not sufficient to pre-load the bolts to overcome external forces. Out of many possible contributing variables, low torque is usually the predominant, but not the only possible culprit when leaks appear.

Additionally, HDPE is a ductile, malleable material. Malleability is the ability of a material to exhibit large deformation or plastic response when being subjected to compressive force. Based on its compressive stress-strain curve, it has a compressive strength at a 2% offset strain of approximately 1600-psi, a compressive strength of approximately 2000-psi at a 3.5% offset strain, and a compressive strength of approximately 4000-psi at 6% offset-strain.

Hence, based on the sealing surface area and seal pressure, the “reverse computed” maximum bolt-load should impose less than 6% flange face compressive strain to maintain long-term, elastic, recoverable compression of the HDPE flange faces.

Figure 4 Cast Stainless Steel, Lap-Joint Flange, 6-inch IPS

The metal, Lap-Joint Flange (LJF) is an elastic, resilient, flexible “plate-spring” engineered to work with HDPE flange adapters. When the bolts are torqued, the LJF flexes and applies a uniform compression to the flange adapters. Generally, it is desirable to torque the bolts so that the average HDPE flange-adapter face thickness compression is in the 2% to 5% range. At this low level of strain, the HDPE flange face is elastically and recoverably compressed, such that when subjected to thermal pipe contraction, or vibration, or bolt stretch, the HDPE flange face recovers slightly so as to maintain the required minimum level of (pre-load) interfacial sealing pressure.

Backup rings of various thickness and pressure ratings are available. In addition to working pressure, the HDPE flange-adapter backup bolt-rings need to be sufficiently stiff (thick) to handle the sum of pressure, surge pressure, thermal contraction loads, pipe bending, and installation forces. The selected Bolt-Ring must carry the applied bolt torque, elastically, without yielding.

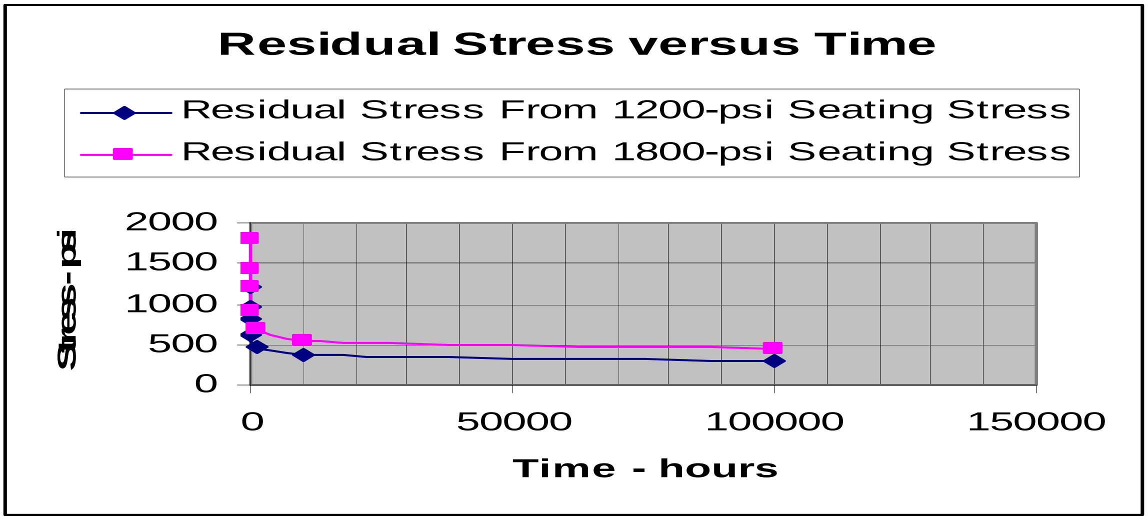


Figure 5: Residual Seating Stress versus Time, at 73° F

As shown in the Figure-5 (above), HDPE exhibits a low level of stress relaxation over a long time (creep) at 73ºF, such that the residual compressive stress diminishes to an asymptotic value of approximately 35% of the initial interfacial stress. For example, at 1800-psi HDPE initial compressive seating-stress at 73ºF, the initial bolt-torque will provide a long-term residual compressive interfacial sealing pressure of approximately 630-psi. This provides a residual sealing pressure sufficient to seal against 200-psi working pressure plus a 100% surge over-pressure. In the past, metal Lap-Joint Flanges have been initially torqued, followed by a 24-hour waiting period, followed by a re-torquing to the same initial value to compensate for slight compressive creep. For this assembly technique, the total compressive HDPE flange-face strain is the sum of the first compression strain plus the second compression strain. This is labor expensive and time consuming. By properly torquing to a higher initial value that immediately produces the same or greater total compressive flange-face strain, the time delay is eliminated, and the same or greater residual sealing stress is provided.

The residual sealing stress can be converted into bolt-torque for all flange sizes through simple mathematical formulae, as will be discussed.

- Flanged Ductile Iron Fittings (ASME B16.42; AWWA C110 & C153) are joined to HDPE pipe (AWWA C906) by means of the HDPE flange-adapter using the metal LJF. The HDPE flange-adapter provides the sealing surface. The metal LJF evenly distributes the compressive load from the bolts through the HDPE flange-face onto the sealing surface. The Ductile Iron Flange Fittings have the same ASME B16.5 Class-150 bolt-hole circle and number of bolts, as the HDPE metal LJF. The bolts should be alternately and evenly torqued, in four incremental stages, to impose about 2% to 5% compression of the HDPE flange face thickness. (Refer to Check- Sheet, Bolt Sequence: pgs. 9, 10, 11, 12)

For traditional metal-to-metal, highly rigid, standard steel, or ductile-iron flanges, elastic gaskets are required to seal the small metal strain generated by thermal expansion and contraction. The elastic gaskets preserve the rigid metal flange sealing stress by allowing them to thermally "move".

High Density Polyethylene is a compressively elastic material at small strains of less than 8%. It elastically displaces; It does not volumetrically compress. The hardness of HDPE is about 65 Shore D, slightly harder than some rubber, or Teflon gaskets. The thick face of the HDPE flange adapter enables the user to compress the flange face, through bolt torque, such that the flange face is elastically compressed. For example, a 5% squeeze on a 1" thick flange face is about 0.050". For a 3.5" thick flange-face, the elastic compression strain is 0.175-inches. This strain is the approximate thickness of a traditional elastic, resilient, reinforced rubber gasket. As the HDPE thermally strains, the flange face compression compensates for the thermal strain and maintains an elastic sealing stress greater than the operating pressure. Hence un-damaged HDPE flanges remain sealed without gaskets. The HDPE flange face is a compliant sealing material at less than 8% compressive strain.

NOTE: Some users specify sealing gaskets, based on their experience with metal flanges, but gaskets are not necessarily required for HDPE flanges at temperatures less than 140º F when the LJF is properly aligned, torqued, and the flange-adapter face is un-damaged. However, when the pipeline designer actually specifies gaskets, full-face gaskets are recommended, not the smaller ring-gaskets, as the full-face gasket bolt-holes provide for proper centering and alignment during flange-joint assembly. Gasket diameters should match the HDPE flange face OD & ID.

The contractor should comply with the torque recommendations of the specifying engineer. Alternately, the compression can be calculated by measuring the flange face thickness, torquing the bolts evenly, and re-measuring the flange face thickness, and then computing the %-compression by dividing the original flange face width by the squeezed flange face width, subtracting 1.0, then multiplying by 100 to give the % compression. Once this is done, identical flange sets can be torqued to the same value which gave the original percentage compression to seal effectively.

Because the HDPE pipe has a thicker wall and smaller ID than the Ductile Iron or Steel flanged fittings (larger ID), the metal to plastic flange face contact area is less than that of two HDPE flange-adapters being bolted face-to-face. Detailed dimensional flange data can be obtained from the HDPE flange adapter and metal flange manufacturers. To achieve the required seating stress over a smaller contact area, a measurably lower total bolt load is specified. This calculates as an obviously lower torque, proportional to the reduced sealing contact area. This compensation will still impose the HDPE flange adapter to metal flange compressive strain in the nominal 2-5% range. For this and other reasons, the bolt torque must be calculated for each installation and for each flange pair with differing sealing surface area. Refer to the torque examples presented in Tables #2 and #3, on pages 10 and 11.

COMPUTATIONAL MODEL for BOLT LOAD and BOLT TORQUE:

The Total Bolt Load is governed by the larger of either the sum total of external loads **(Eq #1)**, or the gasket seating load.

$$F_{Total} > \{ F_{Press} + F_{Surge} + F_{Therm.Contr.} + F_{Pipe\text{-}Bend} + F_{Flng\text{-}Alignment} + F_{\%\ Variance} \}$$

Equation # 1

Looking at the first two components of Equation #1, the hydraulic thrust force working to separate the flanges is equal to the working pressure rating (WPR) plus expected or allowable surge pressure, multiplied by the pipe's ID bore area. Assuming a WPR of 1.0 and an allowable surge of 1.0 x WPR, the sum is 2.0 x WPR. This is the Minimum Required Tightness (MRT). The MRT is multiplied by a Design Factor (DF) of about 1.75 to assure long term sealing and cover the last three variables noted in Equation #1 (thermal contraction should be covered separately). The design-factor also covers variability in applied torque, elastic interaction between adjacent bolts (bolt-cross-talk), flatness of flange faces and LJF's flange angular alignment, variability in the tightness factor, etc… The DF "tightness factor" is a measure of the inter-active scatter in the clamp force between bolts as a result of torque method used, calculated as the ratio of the max-tension to min-tension. This design factor (DF) for compression of the deformable HDPE is equivalent to the gasket "**m**" factor (the maintenance or multiplier factor). This larger value is defined as the Assembly Required Tightness (ART).

ART = 1.50 WPR x 1.63 DF = 2.45 WPR **Eq # 2**

To compensate for long-term stress relaxation, that force is then divided by approximately 0.35 (relaxation to 35% of the initial stress) in the HDPE polymer flange.
(2.45 WPR / 0.35 ~~> 7 WPR) This provides the much higher initial bolting/ seating force, which will diminish over time, down to the required residual long term seal force of: 2.45 WPR.

Thus, for polyethylene flanges, to seal against fluid pressure, the short-term, immediate (prior to stress relaxation), initial Minimum Operating Bolt Load is determined by :

MOBL = 7 x WPR x (Area of HDPE Pipe ID) **Eq.# 3**

Alternately, the Minimum Seating Force (MSF) can be computed using the Design Seating Stress (DSS) gasket factor "**y**", which is the compressive stress required to "seat" and deform the gasket material into the imperfections and irregularities of the mating flange joint surface, to establish a no-leak-path seal. Even if the bolt load is sufficient to provide hydraulic sealing, the fluid can still drip-leak if the HDPE flange face is not seated to conform into all seal-surface imperfections.

The HDPE Design Seating Stress, at 2% to 3% strain across the squeezed FA Hub thickness, at less than 100ºF, is in the range of 1200-psi to 1800-psi. The flange-face Minimum Seating Force (MSF) is calculated as the product of the initial design seating stress times the contact surface area. (NOTE: When seating against a ductile-iron or steel flange, the contact area is less than when bolting HDPE flanges to HDPE flanges. This reduced flange face contact area dramatically lowers the required torque.

MSF = 1800-psi x Area of Interfacial Contact **Eq # 4**

Note: Usually, for HDPE flanges, the Minimum Seating Force, MSF, slightly dominates over the Minimum Operating Bolt Load (hydro-dynamic pressure separation force), but both must be checked.

The required tensile Force per bolt, "F_b", is calculated by dividing **THE LARGER** of the Minimum Seating Force (MSF) , or, the Minimum Operating Bolt Load (MOBL), by the number of bolts, "n".

$$F_b = MSF / n \quad \text{--or--} \quad F_b = MOBL / n \qquad \text{Eq \#5}$$

The applied Torque-per-bolt is calculated from the required Force-per-bolt, F_b:

$$T_b = (K\, d\, F_b) / 12 \qquad \text{Eq \# 6}$$

Where:
T_b = Torque per bolt, in foot-pounds.
F_b = desired tensile clamp Force-per-bolt, in pounds.
d = nominal diameter of the bolt (major diameter, OD), inches.
K = Nut Factor: for friction, material, lube, coatings, etc.

This mathematical relationship is based on the provision that clean, heavy-nuts on clean SAE J429 Grade 2, or Grade 5, bolts (with rolled threads) are used.
The following nut-factor K values apply:

Dry (no lube & no plating) mid-size steel bolts	**K = 0.20**
Non-plated "black" finish –or- stainless steel …	**K = 0.30**
Lightly rusted bolts and nuts ……………………..	**K = 0.30**
Zinc Plated …………………………………………	**K = 0.25**
Cadmium Plated ………………………………..	**K = 0.20**
Oil or Grease Lubricated …...……………………….	**K = 0.15 to 0.18**
Copper or Moly based Grease / Paste …………..	**K = 0.13**
Teflon Coated Bolt and Nuts	**K = 0.09**

Note: Thirty additional K nut-factors and ranges of K values can be found in Reference #1, pages 231 and 232.

TABLE 4 : Illustration of the Relationship between:

Bolt Diameter: vs: Approx. Torque: vs: Approx. Load: vs: Tensile Stress

This table is meant to illustrate the relationship between bolt diameter, torque, load and bolt-stress. These are not maximum torques nor maximum bolt tensile stresses. In some applications, bolts may be torqued to 80% of their yield strengths, far above values shown here.

Nominal Bolt Diameter	Threads Per Inch	Root-Area of Thread sq.-in.	Initial Torque Foot-Pounds	Approximate Tension Load in Pounds per Bolt.	Approx. Bolt Stress - psi
5/8"	11	0.202	40	4,000 lbs.	19,800-psi
¾"	10	0.302	100	9,200 lbs.	30,500-psi
7/8"	9	0.419	140	11,000 lbs	26,250-psi
1"	8	0.551	240	16,200 lbs	29,400-psi
1-1/8"	8	0.728	260	16,000 lbs	22,000-psi
1-1/4"	8	0.929	380	21,200 lbs	22,800-psi
1-1/2"	8	1.405	600	31,600 lbs	22,500-psi
1-3/4"	8	1.980	700	27,700 lbs	14,000-psi
1-7/8"	8	2.304	800	27,650 lbs	12,000-psi
2"	8	2.652	900	32,500 lbs.	12,200-psi

Note: The bolts are elastically stressed at a fraction of their yield stress.

GENERAL CONSIDERATIONS:

THE POLYETHYLENE FLANGE ADAPTER:

The HDPE flange adapter is typically made using PE3408 or PE4710 pipe grade polyethylene resin with an ASTM D3350 material property cell-classification of 345464C, or better. The flange adapter has a nominal flange face OD (hub OD) equal to the diameter of the standard raised-face Class 150 dimension for raised-face steel flanges (ASME B16.5 & B16.47). The flange face thickness typically is at least 1.25 times the nominal pipe wall thickness, and usually not thicker than 1.5 times the pipe wall thickness. The radius from the flange's back-face to pipe OD is usually a minimum of 3/8" for 2" to 12" IPS; and ½" or larger for 14" to 54" IPS sizes. The fusion-end wall-thickness is nominally 10% thicker than the pipe-wall to which it will be fused, to compensate partially for pipe toe-in (in addition to "facing back" most of the pipe toe-in); and to provide the potential for 100% pipe-wall fusion-contact. The HDPE flange adapter is normally rated at the same working pressure rating (WPR) as the nominal wall thickness pipe to which it will be fused. The neck of the flange adapter is sufficiently long so as to fit in a fusion machine and provide for fusion joining twice. Stub-end flanges may require a "holder" for use in the fusion machine. This technical note applies equally to serrated face and flat face HDPE flange adapters, when the minimum seating stress is met or exceeded, and when used with or without gaskets. Testing of the self-gasketing properties of HDPE was done at temperatures less than 100ºF. Flange adapter manufacturers have internal standards regarding flange face flatness, parallelism between the seal face and the LJF back-face; seal face angular alignment to the theoretical bore centerline, etc. If questions arise regarding such technical issues, then the flange adapter manufacturer should be consulted.

THE METAL LAP-JOINT FLANGE:

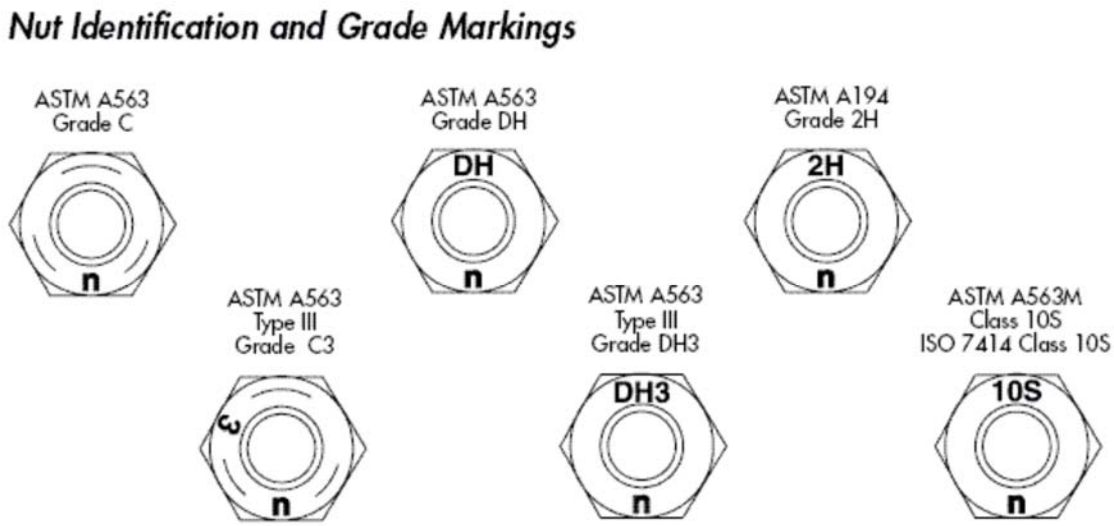
Lap-Joint Flanges can be cut from carbon steel plate, radiused, and drilled to the required bolt-hole pattern. The metallic, contoured cross-section LJF is cast from ductile-iron or stainless steel. The cast Ductile-Iron is normally ASTM A536 Grade 65-45-12. The cast Stainless Steel is normally ASTM 351 Grade CF8M (#316 stainless). The LJF OD, bolt-hole diameter, and bolt-circle dimensions conform to the ANSI /ASME B16.5 Class 150 dimensional patterns and specifications for diameters 3/4" thru 24" nominal pipe sizes (IPS & DIPS), ASME / ANSI B16.47 Ser. A - CL 150 for diameters 26" to 54", and, B16.1- CL 125; AWWA C207 - CL 150 / B, D & E flanges. The surface finish may be Plain, Painted, Hot-Dipped Galvanized, Water based epoxy coating, or otherwise corrosion protected. The LJF thickness should be sufficient in stiffness to provide the high initial seating stress, and flexible enough to deform to provide a long-term working pressure rating in excess of the operating plus surge pressures of the HDPE pipe system, with a reserve safety factor. The LJF ID must have a chamfer or radius that approximately matches the crotch radius of the HDPE flange adapter.

THE HEAVY HEX NUTS:

Nut strength is designated by proof strength or proof stress. Nuts should be selected such that the proof stress is equal to or greater than the tensile strength of the mating bolt or stud. When properly selected for compatibility, bolts and studs usually yield well before the nuts deform. Typically the carbon steel nuts are at least 100-ksi min-proof stress heavy-hex-nuts (not finish nuts) per ASTM A563 Grade A (standard specification for carbon and alloy steel nuts). The nuts are designed to be slightly softer than their matched grade of bolt. At full torque, the first few threads of the nut take most of the load, and thus yield into the mating bolt threads. After one or more uses, the nut thread will not match the bolt thread due to distortional flow of the nut metal, such that the nuts should be replaced when re-connecting a critical connection. Corrosion proof nuts are available with coatings. Flange assembly corrosion proofing (nuts & bolts) may also be applied after assembly.

Grade Identification Markings: **http://www.americanfastener.com/technical/grade_markings_steel.asp**
http://www.labsafety.com/refinfo/ezfacts/ezf269.htm

Figure 6



THE HEAVY HEX-HEAD BOLTS and ALL-THREAD ROD:

Typically the carbon steel Heavy Hex Head Bolts or all-thread rod should possess at least a 55-ksi min yield strength. The Heavy Hex Head Bolts may be SAE Standard J429 Grade 2 or Grade 5 ; The Heavy Hex Head bolts may be ASTM A325 Type 1 (or 2,3), ASTM A449, or stronger. The All-Threaded Rod may be ASTM F1554 Grade 55, ASTM A36, or stronger. Heavy Hex-Head Bolt dimensions are normally in compliance with ASME B18.2.1. Heavy hex nuts are used for bridge across the 1/8" clearance between the bolt and flange hole. The heavy hex head maximizes the bearing-load surface area under the head so as act like a "washer"; and matches the same wrench size for the heavy hex nuts. Corrosion proof materials and coatings are available.

It is recommended that the all-thread rod be cut at least one to two "rod diameters" longer than the minimum overall length, so that the all-thread stud length is sufficiently long to provide ease in assembly, and protrude at least one full thread beyond the face of the two nuts on each side of the flange assembly when made-up at final torque. Studs are normally of equal length on a single flange. Refer to ASTM F704: Standard Practice for Selecting Bolting Lengths for Piping System Flanged Joints.

Note: For pressurized connections, one cannot simply substitute any all-thread rod for a headed bolt without a significant loss in stud-strength, unless the grade of all-thread rod specified meets the minimum 55-ksi yield strength.

Bolt Identification Markings: http://www.americanfastener.com/technical/grade_markings_steel.asp
http://www.akrongear.com/bolt_head_identification.htm

WASHERS:

The Lap-Joint Flange's bolt-hole has an ID about the same diameter as that of the standard washer, thus precluding the absolute need for washers. Washers are typically used with 100-psi WPR, or higher WPR LJF's when the LJF's are powder-coated or galvanized, as washers prevent galling of the LJF top-plate by the nut rotation. The contact face of the nut should be lightly greased, just like the threaded bolt or stud. Heavy-Hex nuts have an enlarged contact surface approximating the diameter of washers.

Note : The common flat washer is made of soft metal. When used with a high strength bolt, it will be virtually impossible to achieve, and then maintain, the desired pre-load in the flanged connection due to cold-flow of the soft metallic washers. Only SAE, through-hardened (not case-hardened) heat-treated washers are normally considered. SAE washers give the smallest ID and acceptable OD.

If the application is critical, if there is frequent thermal cycling, or if the flange cannot be accessed again for re-torque if required, then conical (Bellville) washers may be considered as a helpful aid to torque retention. They act as a very stiff spring to lessen the effects of potential torque loss.

LUBRICANT:

PPI members recommend applying a thin layer of light grease or oil on the threads of the bolts and nuts, the nut face, and around the bolt-hole, as well as using the correct nut-factor (k) inserted into the torque calculation (Equation #6).
(Refer also to the example torque calculation beginning on Page 11).
Silver / copper / moly / metal-paste-lubricants are not as strongly recommended, as they lower the friction required to engage the nut, and may even enable reverse nut rotation (self-loosening) when subject to pipeline flow-stream vibration.

TORQUE WRENCH:

The Torque Wrench calibration should be recent (within in the last 4 months). The working capacity of the torque wrench is normally broad enough such that the required torque is in the middle 60% of its torque range. Beam type torque wrenches or adjustable torque wrenches are acceptable. The adjustable torque wrench is set to the specific torque value. When the torque value is reached or exceeded, the adjustable torque wrench releases and further handle rotation does not add torque to the bolt. Precision wrenches are required to do a proper job of uniform torque control during flange bolt-up.
Note: The least accurate torque control method is a hammer-wrench. The next is the air-wrench, then the torque-wrench with extension. The proper size torque-wrench is the most widely accepted. Better yet is hydraulic-wrench torque control. And the best yet are the micrometer or ultrasonic bolt-stretch measurement, or hydraulic bolt-extensioner.

THE GASKET:

IF gaskets are to be used, the gasket material should be chemically and thermally compatible with the internal fluid and the external environment. It should be of the appropriate thickness, hardness, style, and should be recommended by the gasket material manufacturer for use with polyethylene pipe flanges. Upon seating, a gasket must be capable of overcoming minor alignment and flange imperfections such as:

◷*non-parallel flanges* ◷*distortion troughs / grooves* ◷*surface waviness* ◷*surface scorings*

(When these imperfections are minor or limited, self-gasketing HDPE flanges are fully capable of sealing into and across such imperfections. Gaskets are not usually required for properly torqued self-gasketing HDPE flange assemblies, where the face of the mating flange and/ or HDPE flange adapter is un-damaged by partial width gouging across the width of the flange face.)

When gaskets harder than HDPE are used, the hard gasket seating stress may be in excess of the HDPE seating stress. When higher seating stress gaskets are used with mating metal flanges, the HDPE may seat on its side of the gasket but may not be able to seat the harder gasket into the metal on the other metal flange face. Hence, there is a limit on the gasket seating stress when other material gaskets are used.

(**Note**: IF the engineer-of-record specifies a sheet rubber gasket, it usually will be in the 60 to 75 Durometer - Shore A hardness, internally fabric-or-fiber reinforced to avoid radial extrusion from the flow-stream internal hydraulic pressure, and may be 1/8" or 3/16" thickness per the judgment of the specifying engineer. Obviously, the gasket material should be compatible with the flow-stream liquid across the expected temperature range and service life. The most widely accepted gasket design is the full-face gasket with bolt-holes, so as to hang, center, and avoid wrinkling of the gasket during installation. No lubricants, "dopes", nor sealants should be applied to the flange faces, nor gasket. If gaskets are to be used, the gasket designer should provide the specifying engineer the following information and explain how it was used in gasket selection: Material ; Thickness ; Hardness, Density ; Internal Reinforcement Type; P x T Factor : test data at 1/6" thickness (which reduces 25% to 30% for 1/8" thickness and reduces 40% or more for 3/16" thickness; ASTM F36 Compressibility; ASTM F36 Recovery; ASTM F38 Creep Relaxation : (graph or plot of compression–set versus time and sealing stress @ temp.); ASTM F152 Tensile Strength; Gasket Factors : "m", "y", and , if available : Gb, a, Gs ; and the ASTM F 104 Line Callout, or, ASTM D 2000 Line Callout)

Refer to: APPENDIX "C".

CORROSION CONTROL:

The HDPE flange adapters are corrosion resistant. The Stainless Steel LJF's are corrosion resistant. The Ductile-Iron LJF's are corrosion resistant by virtue of its oxidation layer forming over time. However, DI LJF's are not corrosion-proof, and may be painted, zinc dipped, FBE coated, Aqua-Armored™, or otherwise coated to enhance longevity. Corrosion resistant steel bolts / nuts can be specified, and, coated bolts / nuts may be used. Additional options may be cathodic protection, sacrificial anodes, mastics, tape wraps, shrink-sleeves, or encapsulation type devices and products. Refer to Appendix E

THE BOLTED CONNECTION:

If an HDPE Lap-Joint Flange Assembly leaks, there is a natural tendency to "blame the gasket" or "blame the flange". Leaks are much more complicated than that. There are two flange-adapter faces, two LJF's, perhaps a gasket, gasket centering, the bolt-size and grade, the nut grade, the flange-adapter face flatness and alignment, the interaction of the gasket and flange-adapter faces, proper bolt torque sequence, even and proper bolt loading, HDPE stress relaxation, flange-adapter face integrity (marred or dented), bolt self-loosening, low bolt-torque, and many other variables. The project engineer's written bolting specification should integrate all of these issues for clarity, proper installation, and long-term performance.

The **written bolting specification** should be supplied to the experienced pipeline contractor to assemble each different type of flange pair (i.e.: HDPE to HDPE; HDPE to Raised Face Weld-Neck Steel flange; HDPE to Ductile-Iron flat face valve, HDPE butterfly-valve-flange-adapter to metal butterfly valve: each with different contact areas and, thus, different torque requirements.)

Flange Face Inspection and Integrity:

The HDPE and Metal flange faces should be inspected to insure they are free from radial gouges across no more than 1/3rd of the face width. Some surface marring or denting is acceptable. The metal flange sealing faces should be free from rust, weld spatter, dirt, debris, etc. HDPE flange-adapter faces exhibiting surface marring or dents should limit such defects to less than 1/16" deep. (Sometimes, minor HDPE surface marring on flat-face flange adapters (not serrated faces) can be "flattened" by lightly striking the damaged area with a flat-faced 5-lb sledge-hammer to "work" the defect "flat".) The mating metal flange faces should be cleaned so as to remove preservatives, rust, corrosion, or old gasket material.

Alignment of the Flange Faces:

Align flange faces prior to bolting so that any gap is minimal. The mating flange faces should be aligned square and true.

As a general rule, the <u>axial centerline off-set misalignment</u> should not exceed 1/8" for smaller diameter pipes, up to 1/4" for large diameter pipes (24" to 54").

The <u>angular misalignment</u> of the flange-adapter face is usually limited to less than 0.005" per inch of diameter. For example: on nominal 12" diameter pipe, the flange-adapter faces can be touching on one side, with a tolerable gap of 0.060" on the other side; and for 48" pipe the flange-adapters can be in contact on one side with a tolerable gap of 0.240" on the other side.

(1/16" per foot: 0.5%)

The tolerable <u>axial gap</u> between parallel flange-adapter faces should be zero under perfect circumstances. In imperfect installations, the axial gap should be less than 1/32" on small diameter flanges, and 1/8" on large diameter flanges.

The project inspector should record measurements of off-set, angularity, gap prior to bolt-up.

Surface and above grade flanges should be supported properly to avoid beam-bending stresses in the pipe and flanged joint. Buried flanges connected to heavy appurtenances such as fire hydrants, valves, tanks, metal pipes, require a proper support foundation for the heavy component to prevent settlement with its resultant shear and bending strain on the flanged joint.

Measurement of Gaps:

During the first four rounds, take measurements of the gap between the Lap-Joint Flanges around the circumference in at least 3 to 4 places to validate that the flanges are being brought together evenly. The closure distance for each round should be about same for each position measured. The gap should be measured at four equally spaced locations for flanges with up to 8 bolts; at every other or every third bolt for flanges with more than 12 bolts. Record the gap position and gap closure distance after each rotational round. Retain this data with the Checklist on page 9. Analog or Digital calipers, linear scales, or other measuring devices are useful in measuring the gap distance.

Concentric Alignment: Flange Adapters & Butterfly Valves:

Align the LJF's to be reasonably concentric with the OD of the HDPE flange adapters. The weight of the LJF's will tend to cause them to "hang" eccentric with an un-even crescent contact area on the back face of the flange adapter. By snugging a few bolts first, the lap-joint flange can then be raised upwards and held concentrically in place by light bolt friction, so as to maximize, and make uniform, the contact area between the LJF and the flange adapter.

Butterfly valves require the rotating disk to be concentric to the HDPE flange-adapter. Typically the HDPE butterfly-flange is longer and ID tapered or beveled to accommodate the disk rotation. However, a ring spacer may be used to off-set a standard HDPE flange adapter sufficiently to enable disk rotation. After fitting the valve to the flange-adapter with light torque to frictionally hold it in place, the butterfly valve may be installed with the disk fully rotated to assist and help check valve alignment. Alternately, after lightly torquing and fitting the valve to the beveled HDPE flange adapter, operate the valve to insure full opening without interference. Re-align as required and fully tighten. This may require a crane to suspend the valve in concentric alignment while also centralizing the lap-joint flange with low torque. When both the valve and LJF are concentrically aligned, proceed with full torquing to specification.

Proper Bolt Procedure and Bolt Sequence:

Table #1 gives the proper bolt sequences to use when torquing the bolts. Each bolt should be numbered to insure it is used in the proper sequence. Keeping track of the bolting sequence on large diameter flanges can be confusing. With large numbers of un-labeled bolts, errors and skipping will occur.

Torque Progression:

When tightening pipe flange bolts, the best even loading of the bolts, and the best even compression of the HDPE flange face, is achieved by progressing through several levels to the final torque value.

For pipe flanges less than 18" nominal pipe size, the rule of thumb is the 30-30 rule. The bolts are snugged up and the flange-adapter aligned flush with the mating flange. Begin by sequentially tightening the bolts to 30% of the final torque value. Return to the first bolt, add 30% more torque, and sequentially tighten to 60% of the final torque value. Lastly, return to the first bolt, and torque to the final torque value; followed by a clockwise rotational torque check on all bolts to insure they are evenly torqued at or above the specified torque value.

For 20" and larger nominal diameter flanges, the 25-25 rule applies in which the bolts are sequentially tightened in four (25%) stages, with a final clockwise torque check.

Residual Bolt Torque (RBT) & Mandatory 4-Hour Re-torqueing

With time, the initial bolt torque will slowly decline to a residual level of about 35% of the initial bolt torque. This long term level of engineered torque is sufficient to seal the lap-joint flange assembly. The high initial bolt torque seats the HDPE flange-adapter face, and the residual bolt torque seals the flange face. This visco-elastic relaxation in torque is normal. The residual bolt torque (RBT) is the minimum torque necessary to provide the elastic HDPE face compression necessary to seal the pipe joint, with reserve included for surge pressure, bolt-tension scatter, and other variables. The high initial torque provides seating stress for no-leak path, with the residual bolt torque providing the long term sealing stress.

Re-Torque to Target Torque: The Polyethylene flange adapter and the gasket (if used) will undergo some compression set that decreases the bolt torque. About four hours or so after the first tightening to the target torque value, retighten each bolt's nut to the final target torque value. As before, retighten in the criss-cross pattern sequence and in small increments, followed by a final rotational round, to raise the torque back to its target value.

For pipes of diameters 12" and smaller, the re-torque after 4 hours is recommended.

For pipes of diameters 14" and larger, for environmentally sensitive, or for critical pipelines, a second re-torque is encouraged after an additional 4 to 24 hours.

In all cases, before pipeline and flange assembly burial, the criteria for residual bolt torque should be RBT not less than 35% of the initial target torque.

Checking RBT can be done by using a torque wrench, setting it at a low torque, and then trying to rotate the nut on the stationary bolt. Re-set to a higher torque and try again, and then again. When the nut slightly rotates while the bolt is stationary, the residual torque is then measured by the torque wrench.

Re-torquing after 4 hours to 24 hours compensates for partial seating of the plastic face and relaxation of the bolts, nut embedment, nut dilation, thread stretch, thread surface smoothing, tortional relaxation, bolt-creep, and initial gasket compression-set (if gaskets are used).

Safe Disassembly Procedures

When it is necessary to open an HDPE flanged assembly, special procedures must be adopted to insure there is no damage to the main components or personnel. The assembled flange is under tremendous compression. The resilient HDPE flange adapter face wants to recover to its pre-compression thickness. IF, one bolt is removed, its compressive load is transferred to the two adjacent bolts, increasing their tension by 1/3rd. If one more adjacent bolt is removed, the additional compressive load is transferred to the remaining two adjacent bolts, increasing their tensile load by 50%. Very quickly, one can see that un-screwing multiple bolts completely will over-load adjacent bolts causing them to be bent, or permanently stretched, or causing the metal lap-joint flange to be permanently distorted, or the HDPE flange-adapter face to be permanently distorted with a wavy face thickness with potential gaps upon re-assembly.

The correct disassembly protocol is to reverse the assembly process. Using the star pattern, rotate the nut, to un-screw it, by about 10 to 30 degrees (less than one-half of a flat on a six sided nut.) Repeat this two or three or several times more, until the assembly torque is gradually and evenly diminished, and the HDPE flange face is gradually and evenly loosened.
Once the HDPE flange face is un-bolted, the HDPE flange-adapter should drop loose or pull free from the mating flange by its own self weight. DO NOT USE WEDGE TOOLS to separate the HDPE Flange Adapter from the mating flange, as such tools will damage the sealing surface area. DO NOT HAMMER the pipe wall to “shake” the pipe loose. Lifting straps may be used on the HDPE pipe a ways back from the flange to lift the pipe, changing its effective lay length, and causing the flange face to pull-back from the mating flange, and then lift up. Once loosened, the HDPE flange adapter’s face seal surface should be protected from gouging or marring in a manner acceptable to the maintenance/project superintendent.
The un-bolted pipeline pipe invert should be cradled to bear the weight of the pipe, flange, and LJF. The LJF should not rest on the ground bearing the weight of the pipeline on the “thin” ID edge of the lap-joint flange.
The Nuts and Bolts should be removed from the ditch, cleaned and oiled, and examined to see if they may be re-used, as corrosion may have damaged the bolts. They may need to be replaced, as required, upon flange re-assembly. Rusty threads will dramatically reduce the deliverable bolt-load (sealing force) at equal torque compared to new, lightly oiled threads.

Warning: When working on pipelines that transport pressurized fluids, the contained energy may be dangerous to workers. Typically, a pipeline is depressurized before it is worked on so as to avoid injury in the event of a leak. Generally speaking, never tighten nor loosen a flange joint while the pipeline is pressurized. Always de-pressurize the pipe section before tightening or loosening flange bolts.

Employers should develop, implement and enforce a written safety program which includes task-specific training and lockout / tag-out procedures; and employers should ensure that when more than one employee is exposed to hazardous hydrostatic energy, a procedure is in place for group lockout / tag-out. It is the responsibility of the management, engineering, and operations groups to insure such written procedures exist and are followed.

Hydro-Testing & Leak Closure Guideline

Normally, after initial torque and the optional 4 - 24-hour re-torque, a hydrotest is applied, usually to 1.5 times operating pressure or 1.5 times pipe working pressure rating. Experience has shown that if the above procedures have been followed, virtually none of the flange joints will leak. Refer to ASTM F2164 for Hydro-Static Testing Procedures.

If drip or spray leaks are discovered during hydrotest, the principle corrective action is to measure the existing bolt torque with a torque wrench, increase it by 10% to 15%, and apply that larger torque to the bolt(s) in the center of the leak, and to each side of the leak. Tighten, slightly-more, each bolt adjacent to those bolts. Repeat, slightly increasing the torque on the bolts neighboring the leak, until the leakage stops and the pipeline remains sealed. Do not loosen the bolts on a pressurized pipe system! However, if 150% of the specified torque value is reached and the flange assembly still leaks, stop the hydrotest, de-pressurize, and safely disassemble the flange joint. Something else is probably wrong

NOTE: Safety in the ditch or, around pressurized pipelines is of primary concern. Strategies for fixing leaking pipelines must always include the safety manager, and possibly the corporate OSHA representative to insure the maximum safety and the minimum chance of an injury or accident. Procedures should be sufficiently thought through and rehearsed, and re-checked by project management before performing the work-plan, so as to avoid accidents, injury, or even death.

APPENDIX B

Wrench Size Chart for: <u>HEAVY HEX</u> BOLTS and <u>HEAVY HEX</u> NUTS:

Nominal Bolt and Nut Diameter		Heavy Hex Wrench Size	
1/2	inch	7/8”	(0.875”)
5/8	inch	1 1/16”	(1.063”)
¾	inch	1 ¼”	(1.250”)
7/8	inch	1 7/16”	(1.437”)
1	inch	1 5/8”	(1.625”)
1 1/8	inch	1 13/16”	(1.813”)
1 ¼	inch	2”	(2.000”)
1 3/8	inch	2 3/16”	(2.188”)
1 ½	inch	2 3/8”	(2.375”)
1 5/8	inch	2 9/16”	(2.563”)
1 3/4	inch	2 ¾”	(2.750”)
1 7/8	inch	2 15/16”	(2.938”)
2	inch	3 1/8”	(3.125”)

APPENDIX – C

GASKETS (Ref. 11)

This Technical-Note does not provide guidance on gasket specification. That is usually done by the Gasket Manufacturer. This Appendix is simply included to inform users about the parameters involved in gasket selection. Selecting gasket material for a particular application is not an easy task. Consult the gasket supplier for detailed recommendations, including “TAMP” and gasket parameters outlined below. If gaskets are to be used, PPI members strongly recommend that the flange assembly design engineer make an informed and documented gasket selection. Reference 11 is an excellent resource. Gaskets are typically specified by their cell class numbers.

Generally, as noted by several gasket manufacturers, non-reinforced rubber gaskets do not seal well with polyethylene, because the crush strength (resistance) is low, and, HDPE is “slick”, and epoxy valves and flanges are also “slick”. The operating pressure can radially extrude the gasket, and, the bolt seating pressure can compressive-set “crush” the soft rubber, resulting in loss of sealing resiliency. (Refer to Reference #14 and #15) Gaskets which work most successfully with HDPE Flanges are typically self-reinforced with fibers or filament fillers. Additionally, gasket retention is significantly influenced by the flange facial frictional force. Since the compressive load from the bolts determine the friction force between the gasket and flange face, the pressure sealing capability of the gasketed joint depends significantly upon the bolt-torque compressive load applied across the gasket. Sheet rubber has a limited shelf storage life of 2 to 5 years. Oxidation, heat and sunlight / UV have detrimental impact on rubber. Insure any reinforced rubber gasket material is less than 2 years old from date of manufacture

Not all gaskets are created equal. For example, some sheet-stock red rubber gaskets used in larger flanges are limited to an operating pressure of 80-psi or less. Some black rubbers are limited to an operating pressure of 100-psi or less. Some internally reinforced sheet rubber gaskets are limited to an operating pressure of 150-psi or less. Some micro-cellular, non-rubber gaskets are limited to 300-psi or less.

Note: Be sure to include working pressure plus surge pressure in evaluating gaskets, along with a design or safety factor applied, and with all the design parameters previously discussed in Equation #1, plus those listed here below.

When gaskets are being evaluated, the flange assembly designer should evaluate gaskets that are able capable of sealing at the clamping pressure imposed on it (seating stress) , and also resist blow-out at this load level, without suffering excessive compression set. The gasket thickness should be no thicker than that which is necessary (typically 1/8” or 1/16” thick) for the gasket to conform to the un-evenness of the mating flange, which is defined by its flange flatness and flange warpage during use. It must have adequate conformability into the micro-surface of the mating flange to create frictional forces, and there-by resist radial motion due to internal pressure (blow-out).

Epoxy coated valves and HDPE have low friction coefficients; the gasket should be internally reinforced, or have been tested with HDPE/epoxy surfaces to verify that it does not radially creep nor slip, due to the low surface friction.

Some flat gaskets for an HDPE flange to HDPE, or to Ductile-Iron, or to Steel flanges, are cut from internally reinforced elastomeric sheet rubber. The self-reinforced gasket material and the flange and the bolts are interactive, with the gasket selection (seating stress) dominating the design. The gasket selection must be appropriate for the over-all design, as specified by the joint designer, or project engineer.

(Note: When gaskets are considered, calculations should be performed using the seating stress, blow-out resistance, crush resistance, and other performance values obtained from the gasket manufacturer. **The seating stress for many rubber gaskets is limited to about 600-psi to 1200-psi.** Hence, at that compressive stress, the bolt torque is low; but thermal contraction forces and operating pressures may require a bolt torque in excess of the rubber seating stress to keep the flanges together, thus exceeding the crush strength or compression set of some rubber materials. Consult with the internally reinforced rubber gasket manufacturer to know that the rubber gasket will sustain the total bolt load and seating stress calculated in equation #1, or select better non-rubber gaskets.)

Gaskets must have:

** Zero leakage over the gasket face
** Resistance to flow-stream fluids
** Compensate flange surface alignment
** Minimum loss of clamp load bolt torque
** Exhibit sufficient Elastic Recovery
** Possess Resiliency against bolt-load
** Zero leakage (no weeping) through the gasket
** Have anti-stick properties
** Be uniformly flat
** Handle thermal strain
** Creep Resistance to sustain sealing
** Sealability
** Macro-Conformability to accommodate flange distortion and waviness
** Micro-Conformability to cold flow into the irregularities of the mating surface.

Rubber gasket compounds are typically specified (cell-classification) by ASTM D2000.
Non-Rubber, non-metallics are typically specified (cell-classification) by ASTM F104.

The Typical Gasket Specification Sheet includes data on the following **TAMP** data:

(**T**= Temperature; **A**= Application; **M**= Material; **P**= Pressure)

Color & Density	Composition	Reinforcement
P x T value	Max Pressure	Temperature Range
Min Seating Stress & Max Compressive Stress	Fluid Resistance	Hardness – Shore "A" or Shore "D"

GASKET STANDARDS AND PHYSICAL PROPERTIES

ASTM F35, Gasket Compressibility
ASTM F36, Gasket Recovery
ASTM F 37, Sealability of Gasket Materials
ASTM F38, Gasket Creep Relaxation
ASTM F152, Gasket Tensile Strength
ASTM F 145, Evaluating Flat-Face Joint Gasket Compression
ASTM F434, Method for Blow-out Testing of Preformed Gaskets
ASTM F585, Flange Gasket Leak-Rate versus "y" stresses & "m" factors
ASTM D395, Gasket Compression Set (Method B: constant deflection)
ASTM D2240, Gasket Hardness (Shore D)

Typical rubber compounds are:

Nitrile (Buna-N) – ---------------- NBR
Styrene Butadiene (Buna-S) – SBR
Polychloroprene (Neoprene) – CR
Ethylene Propylene –----------- EPDM, EPM, EPR
Isobutylene (Butyl) –------------- BR
Fluorocarbon (Viton) –---------- FKM

The gasket is a flat-spring in series with the stretchable bolts and deformable LJF (springs). The spring constant of the gasket can be combined with the other spring constants to plot a joint diagram for joint calculations. However, the softness of the gasket dominates the elastic behavior of the assembled joint. **If gaskets are used**, the minimum seating-stress, maximum crush stress, extrusion resistance, and blow-out resistance are often the predominant criteria for determining MOBL and its resultant bolt torque.

Rubber displaces; it does not undergo volumetric compression. During compressive loading, significant internal shear stresses develop. Sufficiently large shear forces can result in fracture (cracking) of the rubber matrix, such that the degree of compression must be limited.

The non-reinforced rubber gasket stiffness exhibits an initial elastic response at low compressive stress, followed by a visco-elastic response at intermediate loads, and finally its viscous response at high loads or long times. This means the gasket has large hysteresis and will eventually take a permanent set, thus allowing creep, stress relaxation and some degree of torque loss.

In some applications, or when using “softer” rubber, the entire gasket or certain locations on gaskets, may be subjected to compressive stresses of sufficient intensity to cause “extrusion” (compressive yielding). When not internally reinforced to restrain radial extrusion, the gasket’s Shape-Factor greatly affects the relaxation characteristics, especially for highly compressible materials. Some of the stress relaxation is derived from radial expansion or bulging. Thus, the greater the area for lateral expansion, the greater the relaxation. The Shape Factor **(SF)** is defined as the ratio of the area of the load bearing face to the area free to bulge.
SF = Area (load) / Area (bulge). For ring type flange gaskets, it is the area of the contact face divided by the bulge area, which is the gasket thickness (h) times the sum of the ID and OD perimeter. This mathematically computes to be:

$$\mathbf{SF = (OD - ID)/4\,h} \qquad \text{Equation \#7}$$

As the area free to bulge increases, the shape factor decreases, stress relaxation increases, the retained stress decreases, and the bolt-torque decreases, and the potential for leakage increases.

The shape factor decreases with increasing gasket thickness, thus thinner gaskets are desirable. This must be balanced against macro-conformability. However, as some compensation, the clamp-area can be made as large as possible, based upon the sealing & seating stress requirements.

The dynamic of radial extrusion (compression yielding) is as follows: As a non-reinforced, higher compressibility gasket begins to radially extrude, the gasket has to become thinner, because the volume of the gasket is conserved. As the OD enlarges, the shape factor decreases, and the stress relaxation accelerates. Then, as the sheet-gasket’s ID radially moves outward and into the gap between the hard flanges, the flow-stream pressure begins pushing and wedging and shoving the gasket outwardly, further accelerating radial extrusion with further thinning and increasing stress relaxation of the compressive load. With decreasing bolt-load, the radial extrusion becomes even easier, and will occur over time.

Use of internally reinforced or micro-cellular gaskets is one preventative measure to inhibit radial extrusion and to maintain the seal. Another prevention, is to use a gasket material which expands slightly upon contact with the flow-stream liquid, thus causing additional pressure between the flange faces.

Fabric molded into the rubber sheet artificially increases the macro-stiffness of the gasket, and provides sufficient resilience and resistance to radial extrusion, creep, and stress relaxation. The volume of rubber contained within relatively in-extensile or much stronger fibers or yarn, or wire, act like tiny cubes of confined rubber, such that the mechanical stiffness, strength, and overall properties are enhanced. However, some cloth fabrics subjected to high pressure may permit weeping radially from ID to OD, along the length of the continuous fabric. Some do not. Ask. Hence, other gaskets should also be considered and evaluated.

Typical fabric reinforcing materials may be Kevlar, cotton, steel wire, polyester, etc. The open area between woven threads, the number of layers of fabric, and the strength of the fabric will affect the gasket sealing and extrusion resistance. Again, slow “weeping” over time may be a concern.

HDPE flange adapters, subjected to sufficient torque, do not require gaskets, unless the sealing surface is damaged. When gaskets are used, re-torquing after 4 to 24-hours is strongly recommended, so as to compensate for gasket creep and compression set, and bolt-thread settlement.

IF any gasket is used for sealing ductile HDPE flange adapters, the internally, fiber-reinforced, monolithic gasket typically is of a 60 to 75 Shore-A hardness, with low compression set, higher resilience, good mechanical tear strength, high sealability, low creep relaxation, moderate compressibility, a seating stress near to polyethylene’s compressive yield stress, with good deformation recovery, and good micro-conformability.

Micro-cellular Teflon faced gaskets (exemplified by Gylon 3545) may be an acceptable choice.
Self-swelling gaskets (exemplified by Multi-Swell 3760 U) may be an acceptable choice.
Klinger 3000 green gasket is also an example of a material that performs well with HDPE.

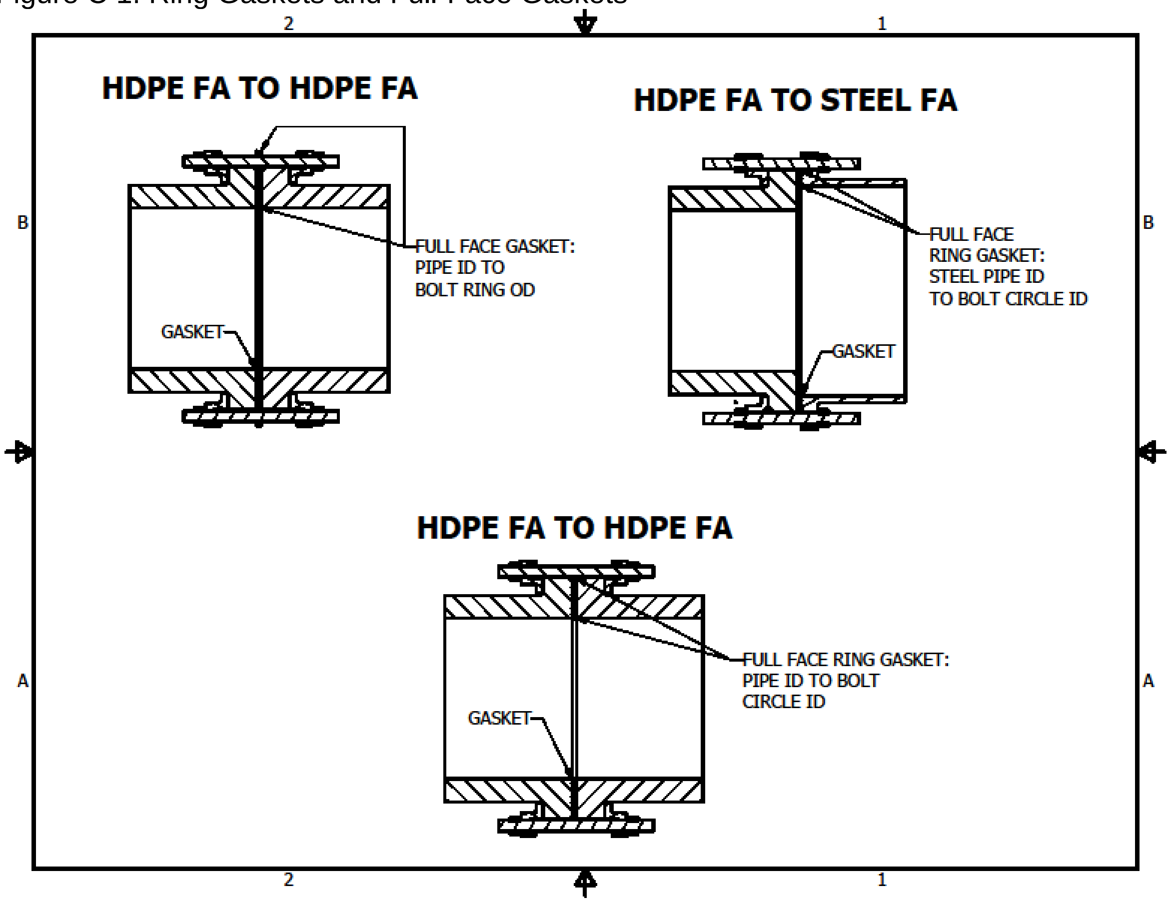
Full-Face Gaskets (HDPE Pipe ID to bolt-ring OD, with bolt-holes) are strongly recommended over Ring-Type gaskets. See: Fig C1.

NOTES: IF a gasket is used,

- The ID of the gasket in contact with HDPE flange adapter should nominally equal the ID of the HDPE flange adapter. However, when joined to flanged metal pipes such as steel or ductile iron, the ID of the gasket should equal the ID of the metal pipe in contact with the HDPE flange face.
- The flange-joint designer should specify an effective, non-blow-out, often internally-reinforced, gasket sealing material using OD and ID and thickness dimensions which meet the engineer's flange design analysis and criteria.
- ASME B16.21 dimension gaskets in capable materials have been used successfully, provided it fulfills the flange designer's analysis and criteria.
- Some “HDPE to HDPE" flanged joints incorporate a custom-dimension gasket with a smaller ID matched to the "nominal" ID of the Flange Adapter, again, provided the gasket design meets the designer's analysis and criteria.

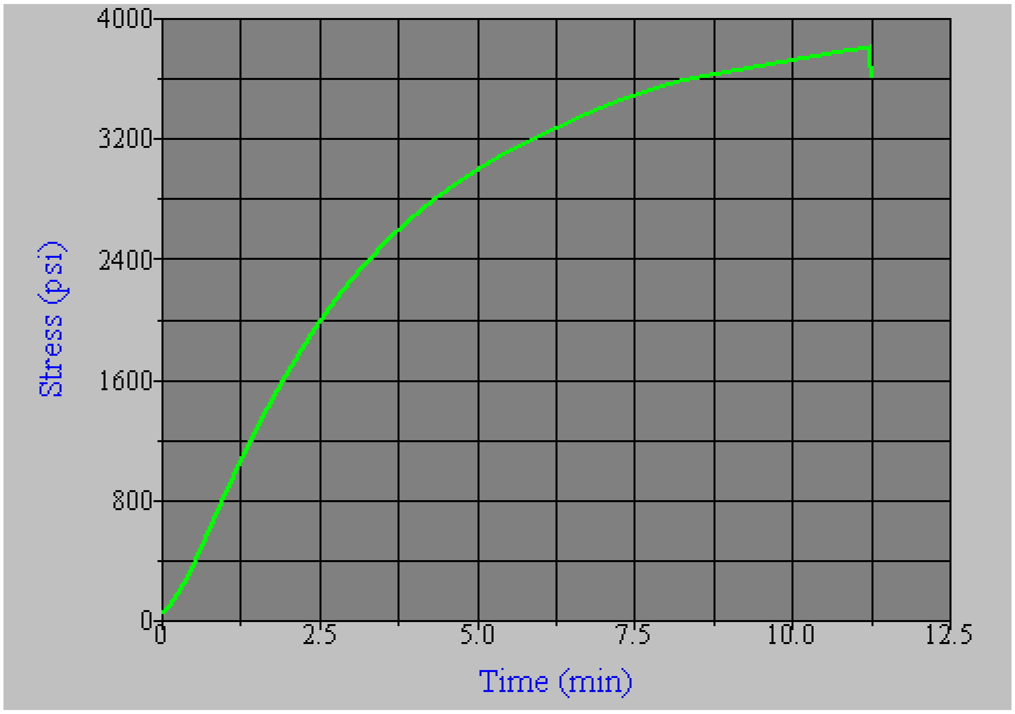
Warning: When gaskets are thought to be required, or when specified as required, the flanged assembly design should not be finalized without independent evaluation for suitability of all components. Failure to specify the proper sealing products could result in personal or property damage. Consult with all component suppliers for their guidance and recommendations.

Figure C 1: Ring Gaskets and Full-Face Gaskets



APPENDIX D

Typical HDPE Pipe Coupon Compressive Stress-Strain Curve



Note: Multiplying the compression rate (0.0068"/min) by time (above) gives the absolute strain. Because the sample is 1" thick, the absolute strain divided by the specimen thickness times 100 gives the percentage strain; stress divided by strain gives the apparent modulus at that point:

Time (minutes) :	zero	1.25	2.5	3.75	5.0	7.5	10.0
Approx. Comp. Stress:	zero	1125psi	2000psi	2600psi	2975psi	3500psi	3700-psi
Compressive Strain:	zero	0.014"	0.028"	0.042"	0.056"	0.084	0.112"
Compressive % Strain:	zero	1.4%	2.8%	4.2%	5.6%	8.4%	11.2%

APPENDIX E

CORROSION CONTROL REFERENCES

AWWA C116 / A21.16 TITLE:

Protective Fusion-Bonded Epoxy Coatings for the Interior and Exterior Surfaces of Ductile-Iron and Gray-Iron Fittings for Water Supply Service

(Fusion-Bonded Epoxy (FBE) Coating is a one-part, heat curable, thermosetting epoxy coating powder designed for corrosion protection of pipe and pipeline components in buried (only) service. FBE has a limited above ground UV exposure service life of nominally less than one year. NOTE: Only Fusion Bonded Polyester should be used above ground due to polyester's solar UV resistance.**)**

ASTM A123 / A123M-02 TITLE:

Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products

Glossary:

Adapter: A fitting used to join two pieces of pipe, or two fittings, which have differing joining systems. (i.e.: flange adapter)

Alloy Steel: a type of steel that contains another material that is added intentionally to alter the properties of the ferritic metal.

Assembly Required Tightness (ART): The total bolt-load necessary to insure a seal against flow-stream pressure when considering hydrostatic and hydrodynamic pressure and the variability of bolting efficacy under applied torque with elastic interaction between bolts considered.

Bolt Bearing Surface: The circular underside of the bolt-head that makes contact with the Lap-Joint Flange upper surface around the bolt-hole.

Bolt Stretch: The amount of tension in a bolt after the wrench has been removed. Bolt stretch determines the strength of the bolted joint.

Bolted Joint: Two pieces of metal joined together by the use of threaded fasteners.

Carbon Steel: A type of steel made of iron and carbon and no other elements.

Clamping Force: The compressive force that a fastener exerts on a joint.

Compressibility: the measure of the HDPE flange face's ability to deflect and conform to the mating flange face. This compressibility compensates for flange irregularities such as minor nicks, non-parallelism, metal corrosion, and variation in surface roughness or grooving depth.

Compressive Force: The force that occurs when opposing loads act on a material, crushing, or attempting to crush it.

Creep: the change in strain of a gasket under constant stress, (compression drift).

Design Factor: For flanges, it is the ratio of the maximum anticipated bolt load to the minimum anticipated bolt load; sometimes referred to as "scatter". It is used to insure the minimum load is applied to each bolt to insure a seal.

Flange Adapter: A device for mechanically connecting and sealing two pipe sections at full pressure rating. It is designed with a neck of pipe which is heat fused to the pipe main, and with a hub of larger diameter than the pipeline diameter. The hub face is the seating and sealing face for the joint. The hub OD fits just inside the bolts. Each plastic flange adapter must use a metal Lap-Joint Flange.

Grip Length: The length of the unthreaded portion of the bolt shank.

Head Style: The shape of the fastener head (i.e.: hex, socket, etc)

Hex Bolt: A type of bolt that has a head with six sides (flats, wrench-pads

Hex Socket: A type of driving recess with a hexagonal indentation designed to accommodate a hex wrench.

Hydrostatic Test: A pressure test of a completed fabrication to confirm acceptable quality. Typically, the vessel, pipe, or system is filled with water, and held at the selected pressure while checking for leaks.

Identification Marking: The marking on a fastener or bolt or nut that often indicates the manufacturer, the material grade, and fastener capability.

Joining: The act of connecting two separate components of a pipeline system together.

Joint: A term used to describe an individual length of pipe; the actual joining mechanism connecting two pieces of pipe.

Lap Joint Flange Assembly: This is a two piece device consisting of: **1.** a polyethylene flange adapter (stub-end), with, **2.** a loose, metal, Lap-Joint Flange. The metal LJF cross-section geometry may be a rectangular solid, or a contoured cross-section. The rectangular cross-section typically is machined from metal plate; the contoured cross-section is typically cast using molten ductile-iron or stainless-steel. The LJF is typically in flat-face contact with the polyethylene flange adapter hub, and, by definition, has a radius on the contact side of the LJF ID which mates with the fillet radius of the matching polyethylene flange-adapter (stub-end). The LJF slips over the pipe; is not welded to the pipe; is loose until bolted; and is free to rotate into bolt-hole alignment with another flange. The bolt-load is transferred to the flange adapter sealing face by the pressure of the LJF against the back-face of the HDPE hub.

Minimum Required Tightness (MRT): The total load exerted by bolt extension in equilibrium to the force generated across the full bore pipe ID by the hydrostatic plus hydrodynamic flow-stream pressure. It excludes thermal or other external mechanical forces, such as pipe bending.

Minimum Operating Bolt Load (MOBL): the minimum total bolt load required to seal against the force of internal pressures plus external mechanical and thermal loads.

Minimum Seating Force (MSF): The total bolt load required to effectively compress the HDPE flange face (or gasket) so as to embed the HDPE flange face into all contours and irregularities of the mating flange, so as to provide an elastic mechanical compliance with no possible leak-path, and to provide sufficient sealing pressure when the pipeline flow-stream is hydro-tested and operating.

Proof Load: The applied tensile load that a fastener must support without evidence of axial deformation. The proof load is just at/under the bolt's tensile yield load.

Roughness: the irregularities in the flange face surface texture from production processes.

Slip On: Metal flange ring that is slipped over a shell or pipe, and back-welded to it.

Smooth Bore: The bore of the flange coincides with the ID bore of the shell or pipeline.

Stepped Bore: The bore of the flange is different from the ID bore of the shell or pipeline.

Stress: The measure of force distributed over an area, calculated in pounds per square inch.

Stress Relaxation: the change in stress "s", on a gasket under constant strain; it is usually graphed as percent relaxation (ratio of retained stress versus initial stress) versus initial stress, for various gasket thicknesses at temp.

Surge Pressure: A transient pressure increase due to rapid changes in momentum of lowing fluids. Water-Hammer is one type of surge pressure.

Thermal Expansion (Contraction): The increase (decrease) in dimensions of a material (pipe) resulting from an increase (decrease) in temperature.

Thrust Force : The force or load resultant from momentum changes in direction of a moving column of fluid; The axial force developed at end closures like caps or valves, resulting from the hydrostatic pressure across the pipe bore area.

Torque: The multiple of a force applied to a lever arm, so as to force rotation of an object. It is usually expressed in foot-pounds.

Van Stone Flange Assembly: An alternate name for a two piece joining device consisting of a stub-end hub or adapter, with a loose, rotating, metal lap-joint flange. The hub OD is nominally equal to a "raised face" diameter. The LJF is contoured to match the hub adapter geometry. The LJF is slipped onto the flange-adapter prior to welding it to the pipe main. The LJF is loose until bolted, and is free to rotate for proper alignment to mating pipeline components. (The assembly is alternately called a lap-joint flange assembly.)

Water Hammer: Pressure surges in a pipeline system caused by sudden fluid velocity changes imposed by a pump, valve, or other component.

Waviness: that component of surface texture upon which surface roughness is superimposed; widely spaced repetitive irregularities; the combination of flange roughness and flange waviness is called "profile".

Working Pressure Rating (WPR): The maximum anticipated, continuous long term hydrostatic pressure (excluding dynamic surge pressure) a manufacturer recommends for a given pipeline component.

Yield Strength: The load at which a fastener experiences a specified amount of permanent deformation.

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LAP-JOINT STYLE FLANGE ASSEMBLY
(Based on ASME B16.5)
24-Inch Dia. Polyethylene Flange Adapters, Metal Lap-Joint Flanges, and Bolt Set

PE Compound Categorization for Potable Water Applications

TN-43/2020

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Foreword

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The Plastics Pipe Institute, Inc.
www.plasticpipe.org

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PE COMPOUND CATEGORIZATION FOR POTABLE WATER APPLICATIONS

In potable water applications, an oxidative environment can exist due to the continuous presence of disinfectant residuals in water. Accordingly, the PE pipe industry developed a testing methodology and criteria to categorize the performance of PE pipe compounds for potable water applications. This document is only intended to be used for categorization of PE compounds with respect to oxidative stability in this specific environment and is not directly applicable for any other purpose.

The categorization of PE pipe compounds can be used in conjunction with other industry documents which should provide design guidance for long-term performance under the expected service conditions. ASTM F2263[1] is the standard test method that forms the basis of the qualification testing and Section 6.8 of ASTM D3350[2] is the standard specification that defines the oxidative resistance classification (e.g., CC0, CC1, CC2, CC3). PE compounds shall be evaluated for resistance to oxidative degradation by the following test method:

Single Point Validation (SPV) Testing

The methodology uses the Jana Mode 3 Shift Functions in an approach analogous to the Popelar Shift Function[3] for the forecast of Stage II performance of PE pipe compounds. The theory behind the Jana Mode 3 Shift Functions can be found in Jana JP916[4].

Accelerated testing at a single temperature/stress condition is conducted in general accordance with ASTM F2263 with the following modifications:

1. Not less than six (6) test specimens shall be tested at 90°C and one stress chosen from Table 1.
2. Testing shall be conducted on 4” DR 11 IPS pipe meeting the dimensional requirements of ASTM D3035.
3. The flow rate shall be established such that the average ORP of the test fluid exiting the test specimens remains above 825 mV.
4. The external test environment shall be either air or non-chlorinated water.
5. All failures shall be included, and non-failures may be included, in the calculation of the log average time except as provided by item 7.
6. If non-mode 3 failures occur such that the log average time is below the minimum requirement in Table 1, testing may be conducted at a lower stress from Table 1.
7. If one specimen fails due to defective test apparatus, sample preparation or other test procedure related anomaly, then log average testing time of the remaining five specimens shall be used for compound categorization. Data from not less than five specimens is required for compound categorization.
8. The compound shall be categorized according to Table 1using log average time and the corresponding test stress.

Based on these modifications to ASTM F2263 and the application of the Jana Mode 3 Shift Functions, the minimum log average test times required for PE compound categorization are presented in Table 1. The required test times are presented at three different test stresses. Testing is only required at one stress level. The range of test stresses provides some flexibility to optimize the testing conditions based on the PE compound and an option to test at higher stresses to reduce testing time.

Table 1: PE Compound Categorization Requirements

Categorization	Test Stress, psi		
	360	400	450
	Minimum Log Average Test Time, h		
Category 1 (CC1)	2,700	1,900	1,200
Category 2 (CC2)	7,400	5,100	3,400
Category 3 (CC3)	16,200	11,100	7,400

[1] *ASTM F2263, Standard Test Method for Evaluating the Oxidative Resistance of Polyethylene (PE) Pipe to Chlorinated Water, West Conshohocken, PA*

[2] *ASTM D3350, Standard Specification for Polyethylene Plastics Pipe and Fittings Materials, West Conshohocken, PA*

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LONG TERM RESISTANCE OF AWWA C906 POLYETHYLENE (PE) PIPE TO POTABLE WATER DISINFECTANTS

TN-44/2015

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Foreword

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November 2015

LONG TERM RESISTANCE OF AWWA C906
POLYETHYLENE (PE) PIPE TO POTABLE WATER DISINFECTANTS
PPI TN-44

1. INTRODUCTION

The operational service life of a piping system depends on many factors. Resistance to disinfectants is one of these factors. Polyethylene (PE) pipes intended for potable water applications contain additives to provide resistance to the long term oxidizing effects of water disinfectants. Research programs conducted on PE piping compounds resulted in the development of a model that projects the performance of PE pipes in chlorinated (i.e. free chlorine and chloramine) potable water distribution and transmission systems.[1]

The model is based on testing in accordance with ASTM F2263, "Test Method for Evaluating the Oxidative Resistance of Polyethylene (PE) Pipe to Chlorinated Water" and projects the performance of PE pipes due to specific end use conditions. PE pipe compounds intended for potable water applications are classified for oxidative resistance in accordance with ASTM D3350. The oxidative resistance categories include CC1, CC2 and CC3 (highest performance).

CC1, CC2 and CC3 PE pipe compounds provide long term resistance to disinfectants in most potable water service applications. Table 1 shows a selection of utility specific conditions and the resultant resistance to disinfectants of pipes produced from PE4710 CC1 compounds.

Table 1: Resistance to Disinfectants at Selected Utilities for AWWA C906 Pipe

	Average US Utility	Indiana Utility-1	Indiana Utility-2	North Carolina	California Utility-1	California Utility-2
Disinfectant type		Chloramine	Chlorine	Chlorine	Chloramine	Chlorine
Average Disinfectant Residual (ppm)		1.6	1.4	0.9	1.9	0.9
Average pH		7.7	8.8	8.6	9.0	7.9
Estimated ORP (mV)[2]	650	650	740	680	650	750
Average Annual Water Temperature (^{o}F)[3]	57	57	54	68	61	64
Pipe DR and Pressure Class, PC (psi)	DR21 PC100	DR21 PC100	DR21 PC100	DR21 PC100	DR21 PC100	DR21 PC100
Average Working Pressure (psig)	70	70	70	70	65	77
Projected Oxidative Resistance under the specific operating conditions (years)	>100	>100	>100	>100	>100	>100

This technical note provides a method to determine the resistance to disinfectants for different conditions than those shown above.

[1] Jana Technical Report, "JP 916: Jana Mode 3 Shift Functions", March 2012
[2] Oxidative Reduction Potential (ORP) is a measure of the ability of a chemical substance to oxidize.
[3] The Average Annual Water Temperature (AAWT) is a weighted average of the daily water temperature, not the highest temperature observed in the system.

2. DETERMINE THE PIPE DISINFECTANT INDEX (PDI)

Based on ASTM F2263 test data, a Pipe Disinfectant Index (PDI) has been developed and normalized to reflect resistance to disinfectants. The PDI has been normalized to reflect a resistance to disinfectants of at least 50 years for a PDI ≥ 1, and at least 100 years for a PDI ≥ 2. A PDI ≥1 indicates acceptable service in the presence of disinfectants.

The procedure is outlined below along with figures, curve fit equations, tables and examples.

1. Obtain the following data:
   - Average annual water temperature, AAWT (°F).
     - If AAWT is not available from the water utility Appendix A may also be used to estimate this value.
   - Pipe Pressure Class (PC)
   - Average system working pressure
   - Average Disinfectant residuals (ppm)
   - Average Water pH,
   - Pipe Material Chlorine Category – CC1, CC2, or CC3

2. Determine the following:
   - Temperature Factor, F_{Temp} from Figure 1
   - Pressure Ratio Factor, F_{Press} from Figure 2
   - Water Quality Factor, F_{WQ} = 8.0 for chloramines; for chlorine F_{WQ} refer to Table 2
   - Pipe Material Factor, F_{Mat} from Table 3
   - Pipe Size Factor, F_{Size} from Table 4

3. Calculate the Pipe Disinfectant Index (PDI):
   - PDI = F_{Temp} x F_{Press} x F_{WQ} x F_{Mat} x F_{Size}

Figure 1

Temperature Factor F_{Temp}

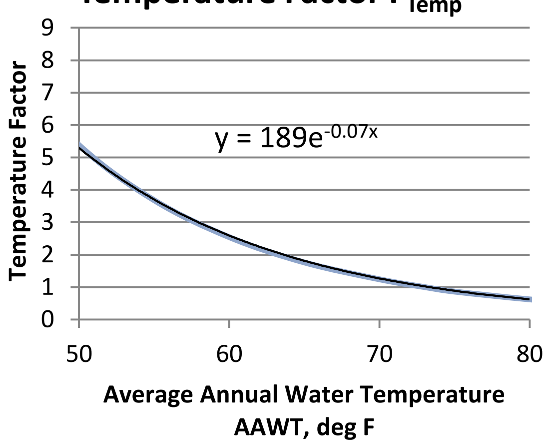
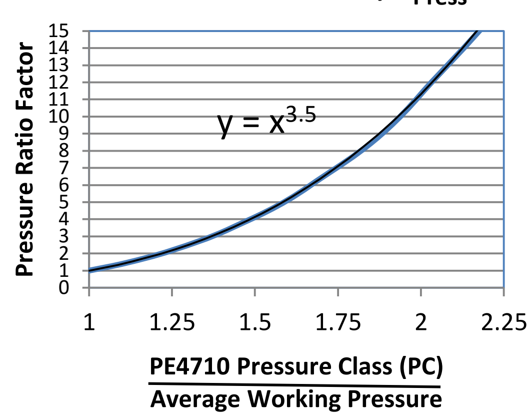


Figure 2

Pressure Ratio Factor, F_{Press}



This may also be used for PE3608, and will be conservative

Table 2: Water Quality Factor – F_{WQ}[4]

		Average Water pH										
		6.5	**6.75**	**7**	**7.25**	**7.5**	**7.75**	**8**	**8.25**	**8.5**	**8.75**	**9**
Average Disinfection with Chlorine Residual (ppm)	**0.5**	2	2.1	2.3	3	3.9	6.1	10	10	10	10	10
	0.7	1.5	1.7	2	2.4	2.9	3.8	5	6.9	9.8	10	10
	1	1.2	1.3	1.5	1.7	2.1	2.6	3.4	4.6	6.1	8.9	10
	1.5	1	1.1	1.2	1.4	1.6	2	2.6	3.4	4.4	6.4	9.1
	2	0.8	1	1.1	1.2	1.4	1.8	2.3	3	3.9	5.7	8.2
	2.5	0.8	0.8	0.9	1.1	1.3	1.6	2	2.7	3.5	4.9	7.2
	3	0.8	0.8	0.9	1.1	1.3	1.5	1.9	2.5	3.2	4.4	6.4
	4	0.7	0.7	0.8	0.9	1.1	1.3	1.7	2.2	2.7	3.8	5.5
If the pH and residual Chlorine values are in-between the values shown above, select F_{WQ} by rounding the value of residual chlorine and/or pH to the nearest tabulated number.												

Table 3: Pipe Material Factor – F_{Mat}[5]

Chlorine Category	Material Factor, F_{Mat}
CC1	0.16
CC2	0.45
CC3	1.0

Table 4: Pipe Size Factor – F_{Size}

Nominal Pipe Size	Size Factor, F_{Size}
4”	1.0
>4”	Data Under Development[6]; use 1.0 as a conservative value

[4] The Water Quality Factor, FWQ has not been determined for HDPE pipes used in the presence of chlorine dioxide as a secondary disinfectant. The use of chlorine dioxide as a secondary disinfectant is rare and estimate to be used in <1% of U.S. water utilities.

[5] Resins categorized as CC2 and CC3 are readily available.

[6] The effect of disinfectants is known to decrease as the pipe diameter increases and wall increases. The size factor will be greater than 1.0, so model projection is conservative for sizes larger than 4”. However the specific value is currently undetermined. For pipes < 4”, a separate document is being prepared.

3. EXAMPLES

Example 1: 24” DIPS DR21 (PC100) PE4710 CC1 category
Average Annual Water Temperature, AAWT = 64^{o}F
Average Chlorine disinfection residual = 0.9ppm
Average water pH = 7.9
Average working pressure = 77psi

- From Figure 1, for T = 64°F, $\underline{F_{Temp} = 2.1}$
- From Figure 2, $\frac{PC}{WP} = \frac{100}{77} = 1.3$, $\underline{F_{Press} = 2.5}$
- From Table 2, for pH7.9 and 0.9ppm, select pH8 and 1.0ppm $\underline{F_{WQ} = 3.4}$
- From Table 3, for CC1, $\underline{F_{Mat} = 0.16}$
- From Table 4, for Pipe Size >4” $\underline{F_{Size} = 1}$
- Calculate Pipe Disinfection Index, PDI
  $\rightarrow$ $\text{PDI}=F_{Temp} \times F_{Press} \times F_{WQ} \times F_{Mat} \times F_{Size}$
  $\rightarrow$ $\text{PDI} = 2.1 \times 2.5 \times 3.4 \times 0.16 \times 1 = \mathbf{2.9}$

Example 1 Result: PDI≥ 2, therefore the pipe is resistant to the disinfectant conditions for at least 100 years.

Example *2*: 12” IPS DR17 (PC125) PE4710 CC2 category
Average Annual Water Temperature, AAWT = 78^{o}F
Average Chlorine disinfection residual = 0.7ppm
Average water pH =7.5
Average working pressure = 100psi

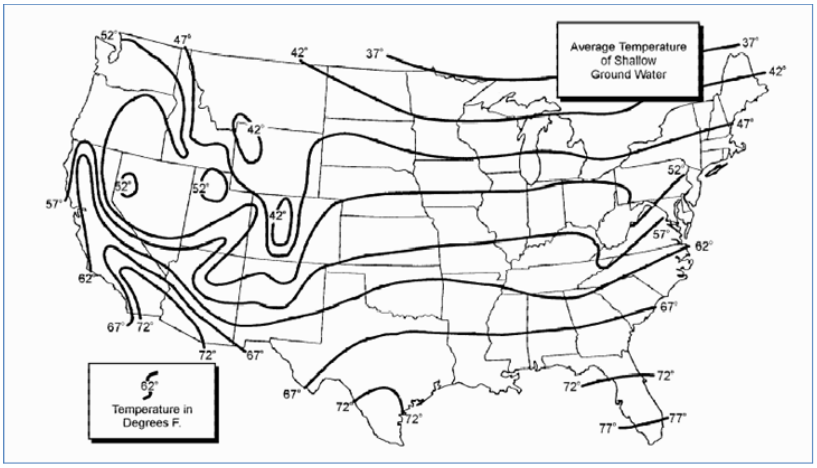
- From Figure 1, for T = 78°F, $\underline{F_{Temp} = 0.8}$
- From Figure 2, $\frac{PC}{WP} = \frac{125}{100} = 1.25$ $\underline{F_{Press} = 2.2}$
- From Table 2, for pH7.5, chlorine 0.7ppm $\underline{F_{WQ} = 2.9}$
- From Table 3, for CC2, $\underline{F_{Mat} = 0.45}$
- From Table 4, for Pipe Size >4” $\underline{F_{Size} = 1}$
- Calculate Pipe Disinfection Index, PDI
  $\rightarrow$ $\text{PDI}=F_{Temp} \times F_{Press} \times F_{WQ} \times F_{Mat} \times F_{Size}$
  $\rightarrow$ $\text{PDI} = 0.8 \times 2.2 \times 2.9 \times 0.45 \times 1 = \mathbf{2.3}$

Example 2 Result: PDI≥2, therefore the pipe is resistant to the disinfectant conditions for at least 100 years.

Appendix A

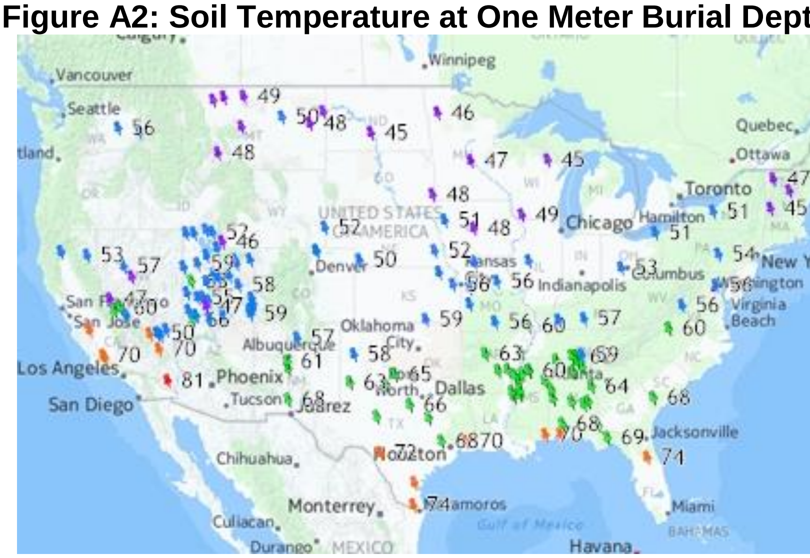
The average annual ground temperature at the pipe's burial depth may be used to estimate the value.[7] Figure A1 provides ground temperature data at typical pipe burial depths. Figure A2 represents recent data from USDA regarding annual average soil temperature at selected observation points throughout the U.S. and is consistent with Figure A1.

Figure A1: Average Annual Water Temperature Guidance



Source: U.S. Environmental Protection Agency (prepared from data included in Collins, W.D., 1925, Temperature of Water Available for Industrial Use in the United States, United States Geological Survey, Water Supply Paper 520-F).

Figure A2: Soil Temperature at One Meter Burial Depth



Source: United States Department of Agriculture (USDA), National Resources Conversation Service (NRCS), Soil Climate Analysis Network (SCAN) data (2014-15).

7 E.J. Mirjam Blokker and E.J. Pieterse-Quirijns, *Modeling temperature in the drinking water distribution system*, 104 AWWA JOURNAL 11 (2013).

PLASTICS·PIPE·INSTITUTE®

Mechanical Couplings for Joining Polyethylene Pipe TN-45/2012

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Foreword

This report was developed and published with the technical help and financial support of the members of the PPI (Plastics Pipe Institute, Inc.). The members have shown their interest in quality products by assisting independent standards-making and user organizations in the development of standards, and also by developing reports on an industry-wide basis to help engineers, code officials, specifying groups, and users.

The purpose of this technical report is to provide important information available to PPI on a particular aspect of polyethylene pipe butt fusion to engineers, users, contractors, code officials, and other interested parties. More detailed information on its purpose and use is provided in the document itself.

This report has been prepared by PPI as a service of the industry. The information in this report is offered in good faith and believed to be accurate at the time of its preparation, but is offered "as is" without any express or implied warranty, including WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. Consult the manufacturer for more detailed information about the particular joining procedures to be used with its piping products. Any reference to or testing of a particular proprietary product should not be construed as an endorsement by PPI, which does not endorse the proprietary products or processes of any manufacturer. The information in this report is offered for consideration by industry members in fulfilling their own compliance responsibilities. PPI assumes no responsibility for compliance with applicable laws and regulations.

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The Plastics Pipe Institute, Inc.
www.plasticpipe.org

October 2012

MECHANICAL COUPLINGS FOR JOINING POLYETHYLENE PIPE

1.0 Introduction

The use of polyethylene piping material has steadily increased over the past half century and today it's the material of choice for natural gas piping systems up to 12" size. Mechanical couplings and fittings played a vital part in this evolution, especially in the earlier years, when distribution service line installations were the most common application. Many of these mechanical fittings were metallic and connected to steel or cast iron main piping with a PE outlet connection for the service line. Both plastic and metallic mechanical fittings have provided the industry with fast and easy pipe joining, and repair and transition techniques. Their nearly 50 years of performance history is testimonial to the safe and reliable service these fittings provide.

This document will provide a historical time line to assist material engineers, when assessing older PE systems, and to determine what the governing requirements were for mechanical fittings at the time of their installations. It will also review the specified regulatory requirements for mechanical pipe joints, both in general terms and how they should be interpreted for mechanical joints for PE piping.

An outline of recommended mechanical fitting performance capabilities will be provided to assist material engineers in product selection. It includes any ASTM Test Methods or Standard Specifications available to provide guidance in how to evaluate the performance capability of mechanical fittings.

Some of the most common types of mechanical fittings will generically be described. Some mechanical fitting designs are proprietary to a specific manufacturer. Use recommendations and compliance to regulations should be reviewed with the fitting manufacturer prior to installation. Mechanical fittings do not require highly skilled laborers and typically do not require special equipment to be installed. With each design, it is essential that the manufacturer's installation instructions are followed to obtain optimum performance.

2.0 Definition/Designs

There are primarily five different mechanical coupling designs or technologies for joining PE currently in use in North America. All require the use of an internal stiffener when used with PE pipe to prevent long-term creep of the pipe away from the compression forces. These designs can be classified by the method used for completion. These are:

- Tightening of bolts and nuts
- Tightening of compression nut (also referred to as "nut follower").
- Stab or insertion style
- Hydraulic pressure
- Use of an external compression or "completion" ring

Tightening of Bolts

This design is characterized by the use of multiple bolts and nuts being tightened to grip and seal on the polyethylene (figures 1a, 1b). These types of mechanical couplings can also be used to join polyethylene to steel or cast iron gas piping, or ductile iron water piping.

The tightening of the bolts brings together internal gripping rings and a sealing element. As the bolts are tightened, the outer ring, commonly called the retaining ring, forces the gripping mechanism or ring and sealing gasket into a state of compression onto the polyethylene, thus creating restraint and a gas tight seal. The tightening of nuts and bolts is to a specified torque value prescribed by the manufacturer's installation instructions.

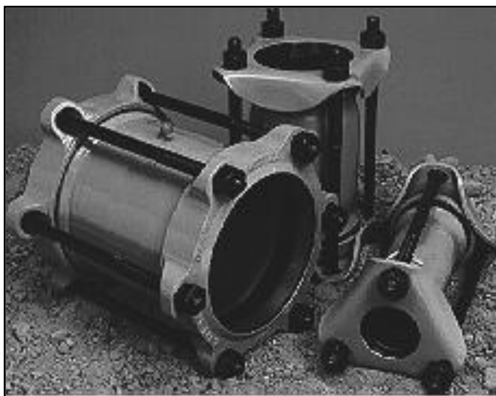

Figure 1a – Steel body, bolt together coupling

Figure 1b – Plastic body, bolt together coupling

Tightening of Compression Nut *(Nut Follower)*

With this design, the operator is required to tighten a nut to a stop or prescribed torque value. As with the "bolt" design fitting, as the operator tightens the nut down, the internal gripping ring and sealing gasket are brought down onto the polyethylene pipe to restrain and seal. In some designs, there is a prescribed torque value, however in others; the operator is required to tighten the fitting to a stop point located on the coupling body. The gas seal and restraint (grip) are dependent upon the amount of tightness the operator applies to the compression nut. Examples of compression nut style couplings are depicted in figures 2a and 2b below.

Figure 2a – Cast body compression coupling

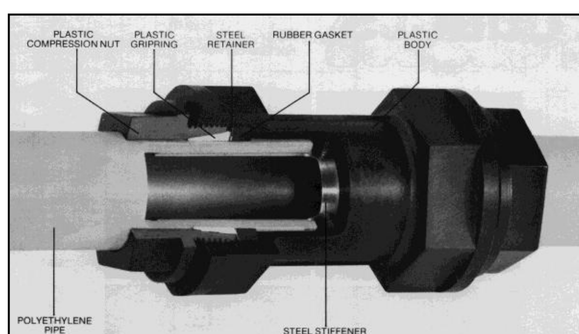

Figure 2b – Nylon body compression coupling

Stab or Insertion

The "stab" or insertion style coupling requires no tightening of bolts or compression nut. With the stab type, the seal and restraint are accomplished through independent components. The coupling contains either single or multiple rubber orings that provide a seal on the outside diameter, inside diameter or both diameters of the polyethylene tubing which has been inserted into the fitting. In the case of an outside diameter seal fitting, the inside diameter of oring is smaller than that of the outside diameter of the polyethylene tubing, thus compressing the rubber oring onto the PE tubing surface and coupling body surface creating a gas tight seal. Likewise, for the inside diameter sealing coupling version, the sealing oring would have a larger diameter than the inside diameter of the tubing, again, compressing the tubing wall to the oring creating a gas seal.

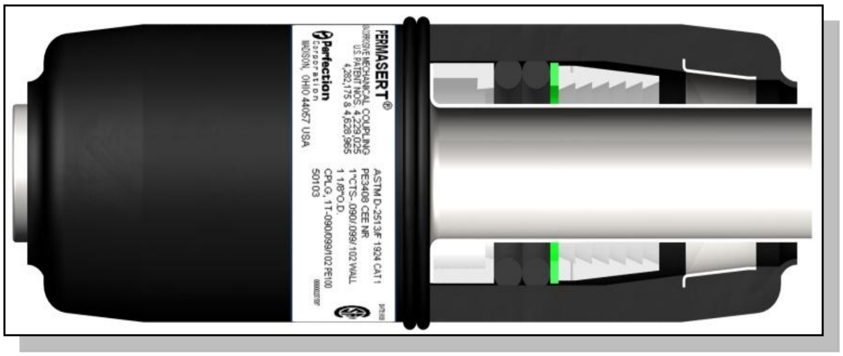

Figure 3 – Polyethylene stab type coupling

Hydraulic Pressure

This type of joining method is no longer commonly used on polyethylene, however because there may exist product in the operator's system we review the technology here. This type of coupling involves a steel body product with two hydraulic port holes. Internally, there are gripping plates and seals that are forced onto the piping via hydraulic fluid pressure. Use of this fitting requires that the operator use and maintain a hydraulic pump. The hydraulic hose is attached to the fitting body and hydraulic fluid is pumped into the fitting body thus forcing the gripper and sealing mechanisms onto the pipe. Fluid pressure is measured on a pressure gauge attached to the pump. Installation pressure is predetermined by the manufacturer and detailed in the installation instructions.

Figure 4 – Hydraulic style coupling

External Compression Ring

For the mechanical coupling using an external compression or "completion" ring, the operator inserts the polyethylene over an insert stiffener. The insert stiffener may or may not be integral to the fitting body and can be smooth or serrated. Prior to this step, the operator slides the compression ring over the outside of the polyethylene tubing. After the polyethylene has been inserted, the compression ring is brought over the coupling body and/or polyethylene. This interference fit creates a compressive force between the polyethylene and the insert stiffener. The assembly typically requires the use of a special tool to bring the compression ring onto the fitting body. This design may or may not contain an elastomeric sealing element, in some designs the compression of the PE onto the griping element and/or internal stiffener also creates the seal. Assembly is complete when the compression ring has been brought into contact with a stop on the coupling.

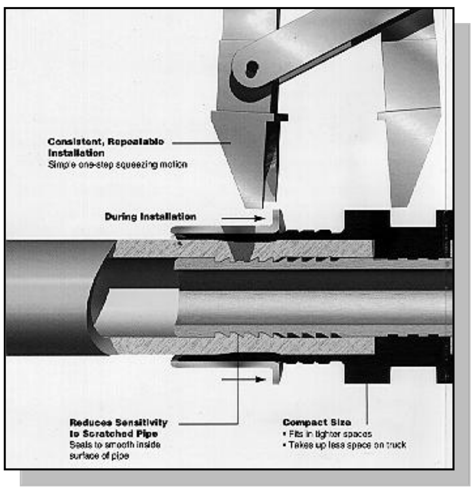

Figure 5 – External Compression Ring style coupling

3.0 Compression Couplings Background

When plastic pipe was first designed and developed for the natural gas distribution industry in the 1960's, the dimensions were called IPS and CTS or Iron Pipe Size and Copper Tubing Size. The outside diameter (OD) of IPS pipe was based on the corresponding iron pipe outside diameter so that the same fittings that were used for metal pipe could also be used for plastic pipe. For example, nominal 2" IPS PE pipe has an outside diameter of 2.375", which is the OD of metal pipe.

When mechanical compression couplings were first used for plastic gas pipe in the early 1960's they provided a leak-tight seal only, and this seal was based on the OD dimensions. These first compression couplings, which were originally designed for metal pipe, provided the necessary gas-tight seal, but did not provide resistance (restraint) to pull out. As the use of plastic pipe and particularly PE pipe, increased, the compression coupling manufacturers began to design their couplings specifically for plastic pipe. In the case of PE pipe, this included an insert stiffener to provide the needed rigidity to the PE to improve the required seal. By the late 1960's, some compression coupling manufacturers also began to design their fittings with pullout resistance in addition to leak-tight seals. By 1980, there were several manufacturers that sold compression couplings that provided both a leak-tight seal and gripping mechanisms that provided pullout restraint.

In their 1972 report, “Comparison of Long-Term Sealing Characteristics of Compression Type Couplings on Steel & Polyethylene Pipe” Dresser Manufacturing stated, “A new mechanical design was initiated to develop a mechanical joint for PE. Requirements were obviously long-term reliable sealing ability and a joint locking strength equal to the longitudinal strength of the plastic pipe being joined, as required by (our interpretation) the DOT regulations Volume 35, number 61, paragraph 192.273 (a)”. This statement indicates that Dresser Manufacturing interpreted the code as meaning that a compression coupling needed to have restraint to pullout and they were manufacturing couplings to meet that requirement. The mechanical couplings manufactured by Dresser in sizes 2” IPS and below had a locking feature to prevent pullout. This had been the industry standard since the late 1960’s.

In the late 1970’s as a result of two compression fitting pullout failures in Fremont, Nebraska and Lawrence, Kansas, the DuPont Company published an article, “Pull Out Forces on Joints in PE (Polyethylene) Pipe Systems”, in which the joint strength for compression fittings ½” to 1” was deemed “equal or greater” than pipe strength. DuPont deemed compression fittings larger than 1” to have joint strength “less” than pipe strength.

As a result of several more industry gas pipeline failures due to PE pipe pulling out of a non-restraint compression coupling, some manufacturers now include caution statements in their literature, such as, “When pipe pullout could occur as a result of forces other than that caused by internal line pressure of 150 psig maximum, pipe joint MUST be anchored. Failure to anchor pipe joint could result in escaping line content and cause property damage, serious injury or death”.

4.0 Industry Codes/Standards for Mechanical Couplings

I. DOT Part 192

The key section dealing with compression couplings in the original DOT Part 192 was Part 192.273, which required that “the pipeline must be designed and installed so that each joint will sustain the longitudinal pullout or thrust forces caused by contraction or expansion of the piping or by anticipated external or internal loading.” Other sections of Part 192 that affect compression coupling design and installation are 192.143, 192.161, and 192.321. Also, DOT Part 192.703 requires that each segment of pipeline that becomes unsafe must be replaced.

In 1980, after the Fremont, Nebraska and Lawrence, Kansas compression coupling pullout incidents, Part 192 was revised to incorporate additional mechanical joint requirements in Part 192.283. These new requirements included procedures for qualifying joining procedures for mechanical joints and qualifying person to make such joints, including a pullout test that requires the pipe to neck down with at least 25% elongation to qualify the joining procedure.

II. AGA Plastic Pipe Manual

The industry document that the gas companies rely on the most for general guidelines on installing plastic pipe is the AGA Plastic Pipe Manual. This manual is prepared by plastics piping experts in the AGA Plastic Materials Committee, both gas companies and manufacturers, to assist the users with proper installation and maintenance of plastic pipe. The original 1977 AGA Manual references DOT Part 192.273 and states, "The installed joint must effectively 'sustain longitudinal pullout or thrust forces caused by contraction or expansion of the piping or by anticipated external or internal loading.' Such provision may be made in the design of the joint or in the installation or a combination of both".

The 1977 AGA Manual also states, "Earth movement, ground movement and third party construction activity can impose stresses on the pipe which can be transmitted to joints. In most situations it is desirable to have pipe joints which are as strong as the pipe itself in the axial (longitudinal) direction. Mechanical joints not specifically designed for use with plastic pipe may not provide complete resistance to pullout."

Later versions of the AGA Plastic Pipe Manual were updated to reflect the new mechanical joint requirements in DOT Part 192.283.

III. ASTM F17

The industry standard that the gas companies rely on the most for product requirements when installing plastic pipe is ASTM D 2513. This is a consensus standard prepared by plastics piping experts in ASTM F17, both gas companies and manufacturers, that is referenced by DOT in Part 192. Early versions of ASTM D 2513 stated, "Mechanical joints categorized by 8.14 should be engineered to provide adequate resistance to pullout caused by thermal contraction and earth movement, or both, anticipated during its service life".

D 2513 also stated, "Earth settlement, internal pressure and ground movement can impose stresses on the pipe which when in the vicinity of joints can be transmitted to the joints themselves. It is desirable to have pipe joints that are as strong as the pipe itself in the longitudinal (axial) direction. For those mechanical joints made with fittings which are not designed to restrain the pipe against pullout forces which could be experienced, provisions must be made in the field to prevent pullout. Another somewhat limited alternative is to use long sleeve-type fittings which permit limited movement without loss of the pressure seal. Otherwise, provisions must be made in the field to prevent pullout through suitable anchoring at the joint".

In 1980, while DOT Part 192 was being revised to incorporate additional mechanical coupling requirements in Part 192.283, ASTM D 2513 was also revised. Mechanical fitting categories were established based on the fitting leak-tightness and the fitting pullout resistance.

- A category 1 fitting provides both a seal and full pullout restraint.
- A category 2 fitting provides a seal only.
- A category 3 fitting provides seal and limited restraint, equivalent to the anticipated thermal stresses occurring in a pipeline.

Note 9 was also revised to state, "The ability to restrain pipe or tubing to its yield as specified above does not guarantee that a properly installed joint will prevent pullout under actual long-term field conditions. Joints that cannot pass this test would be expected to pullout under actual long-term field conditions. To date, this test is the best available for disqualifying unsound joints".

In more recent years, standards for mechanical fitting design and performance have been written specifically for natural gas distribution systems that contain performance requirements intended to establish minimum requirements for longitudinal force capability and to verify pullout resistance. Separate standards now exist for both plastic and metal bodied compression fittings that impose the same level of pullout resistance regardless of the compression design type. ASTM F1948 - Standard Specification for Metallic Mechanical Fittings for Use on Outside Diameter Controlled Thermoplastic Gas Distribution Pipe and Tubing and ASTM F1924 - Standard Specification for Plastic Mechanical Fittings for Use on Outside Diameter Controlled Polyethylene Gas Distribution Pipe and Tubing require full resistance to pullout forces equal to that which would cause permanent deformation of the PE pipe. Additional requirements for long-term pullout resistance include a "dead weight" or constant tensile load joint test that subjects the joint to an internal pressure and longitudinal force to achieve a defined stress in the PE pipe.

IV. National Transportation Safety Board (NTSB) Recommendations

In 1985, NTSB reported that it had determined that the probable cause of a mechanical joint failure was the gas company's failure to understand the limitations of the coupling, which led to the pullout of the PE pipe from the coupling. This NTSB Report prompted AGA to issue a memo to all its member companies regarding NTSB Recommendation P-85-30. In this memo, AGA stated, "When using couplings to join plastic pipe, we urge you to consider the forces anticipated to act on the coupling and assure that these forces will not exceed the capabilities of the coupling". This NTSB Report also led to DOT Advisory Bulletin in 1986 (ADB-86-02) on mechanical couplings. This advisory bulletin was intended to inform natural gas pipeline operators to review procedures for using mechanical couplings, and to ensure that coupling design, procedures, and personnel qualifications meet Part 192.

Most recently, on March 4, 2008, as a result of more compression coupling pullout failures, PHMSA issued Advisory Bulletin ADB-08-02 on mechanical couplings. This ADB states, "PHMSA advises operators of gas distribution pipelines using mechanical couplings to do the following to ensure compliance with 49 CFR Part 192: (1) Review procedures for using mechanical couplings, including the coupling design and installation and ensure that they meet manufacturer's recommendations. PHMSA also advises operators of gas distribution pipelines using mechanical couplings to consider taking the following measures to reduce the risk of failures of mechanical couplings:

(4) Use Category 1 fittings only if mechanical couplings are used on pipe sizes ½" CTS to 2" IPS.
(6) Consider whether to adopt a full replacement program if there are too many unknowns related to couplings in service."

5.0 Conclusion

Although there have been some incidents of joint failures in the long history of the use of mechanical compression fittings installed on PE pipe, the overall performance record of these mechanical joints has been excellent. Most accidents can be attributed to misuse or misunderstanding of the fitting capabilities at the time of installation. Resulting design and performance requirement improvements, along with an increase in the understanding of the application and limitations of different types of compression fittings has served to ensure that modern compression jointing technologies are safe and reliable.

Well defined installation instructions ensure that compression fittings can be easily and quickly installed, and that they are installed consistently and correctly.

With an understanding of the piping system and its anticipated operating conditions a system designer can confidently select the proper fitting design needed to provide trouble-free service.

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Guidance for Field Hydrostatic Testing Of High Density Polyethylene Pressure Pipelines: Owner's Considerations, Planning, Procedures, and Checklists
TN-46/2013a

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Foreword

This technical note was developed and published with the technical help and financial support of the members of the Plastics Pipe Institute. The members have shown their interest in quality products by assisting independent standard-making and user organizations in the development of standards, and also by developing reports on an industry-wide basis to help engineers, code officials, specifying groups, and users.

This technical note has been prepared to provide those responsible for the maintenance of existing HDPE pipelines with suggested general guidelines for the repair of those lines that have been subjected to third party or other unforeseen damage. These guidelines constitute a set of basic operations that have been demonstrated by test and experience to produce satisfactory repairs with commercially available materials. Each specific procedure must be acceptable to, and qualified by, the operator having legal responsibility for the performance of the piping system. This document was not intended to provide system design information. Go to the PPI website at www.plasticpipe.org for different system design documents.

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June 2013

GUIDANCE FOR FIELD HYDROSTATIC TESTING OF HIGH DENSITY POLYETHYLENE PRESSURE PIPELINES :

OWNER'S CONSIDERATIONS, PLANNING, PROCEDURES, AND CHECKLISTS

Purpose of Field Testing:

Hydrostatic testing is universally known and accepted as the primary means of demonstrating the fitness for service of a pressurized component. It is the responsibility of the owner, through its agents (engineer, contractor, or hydro-test company) to develop its own safe and appropriate hydro-test plan, taking into consideration all the elements presented in this and other reference documents, in order to access and accept the installed pipeline from the contractor. After hydrotest, a pipeline or pressure vessel component may usually be expected to safely contain its intended operating pressure. However, even after a successful hydro-test, leakage or forced ruptures may occur later, for a variety of other reasons. The pre-commissioning hydro-test is simply one tool for evaluating a pipeline. The purposes of hydrostatic field testing of polyethylene pressure pipes using water are several, including:

- To access the installed structural integrity of the pipeline for acceptability.
- To try to reveal the occurrence of faults or defects in the pipe laying procedures, as exemplified by damaged pipe or fusion joints non-conforming to the qualified fusion procedures.
- To try to reveal the occurrence of faults in the assembly procedures for pipeline components, as exemplified by tapping bands or saddles, flange sets, or Mechanical Joint assemblies.
- To try to validate that the pipeline will sustain an acceptable level of over-pressure slightly greater than its design pressure, without leakage.

Note: Field testing is not intended to supplement or replace product standard test requirements.

The factors which affect the hydro-testing of HDPE pipe during commissioning procedures are: the creep characteristics of the PE pipe, the percentage volume of trapped air in the pipeline, and temperature variations. The self-limiting creep expansion of HDPE pipe is normal behavior for plastic materials when an internal pressure is applied, and is not an indication of a leak.

History:

Polyethylene pipe is a lower modulus visco-elastic material that dilates in diameter (creep-strains) when subjected to higher stress during hydrotest. This means that for a fixed volume of clean fill water, the hydrostatic pressure will decline slightly during the test time, as the polyethylene molecular chains stretch and align under high stress. This pressure decline does not mean the polyethylene is leaking. It is a visco-elastic material parameter that requires adjustments to the hydrostatic test procedure as compared to rigid elastic metallic pipes. This effect is more noticeable in larger diameter HDPE pipes, due to the large mass of clean fill water. Alternately, to hold constant pressure, an additional volume of make-up water will be required to fill the expanded volume of the stretched pipe diameter. Neither of the above two observations means that a leak is present in the pipeline.

There are two test methods which can be used, depending upon the objectives of the test program. The easiest and quickest method suitable for all pipe diameters is the Modified Rebound Method originally developed by Lars-Eric Janson in the 1980's. As a similar alternate, ASTM F2164 instructs to fill and then thermally stabilize the pipeline with no air entrapment, pressurize the pipeline at test pressure for 4-hours, slightly reduce the pressure, and then observe the pressure for one hour to remain essentially constant (within 5% variation) to achieve an acceptable test. The Plastic Pipe Institute's **Handbook of Polyethylene Pipe** describes general hydrostatic testing, based on ASTM F2164. (www.plasticpipe.org/pdf/chapter02.pdf)

The concept behind hydro-testing is to strain the pipe, fittings and appurtenances. Any defects from manufacturing or flaws from construction are typically forced by stress intensification to reveal themselves by weeping, leaking, or rupture. Any remaining defects are considered sub-critical within a tolerable flaw size limit, and should remain stable thereafter at the lower operating pressures. Hydro-testing provides the normal level of assurance for leak integrity and the absence of flaws that exceed an intolerable flaw size. Generally speaking, the higher is the ratio of test pressure to actual operating pressure, the more effective is the test, within material stress limits.

Field Hydro-testing of Polyethylene Piping and Pipelines:

Hydrostatic pressure testing requires adopting an appropriate combination of method, pressure, time duration and length of test section. The test parameters and test details usually are determined with due consideration for the following:

- Pipe material
- Pipe diameter and working pressure rating
- Length of test section
- Duration of the test
- Magnitude of the test pressure and planned rate of pressurization
- Presence of air in the pipeline
- Potential movement of pipeline thrust restraints
- Limiting pressure for thrust and anchor supports
- Accuracy of test equipment
- Ambient temperature changes during testing (stability of the temperature)
- Presence of small leaks in hydrotest equipment or connections used
- Potential for leaks in the pipeline

Note: It is advisable to begin testing early during the pipeline installation to confirm adequacy of the fusion, laying, embedment procedures, and then later to progressively increase the length of test section, as experience is gained. Polyethylene pipe lengths as long as 1000 meters, or 3000 feet, have been commonly tested.

Definitions: (Refer to Appendix B)

Selection of Test Pressure:

The pipeline operator or owner is responsible for approving the type of test, the length of test, and the test parameters, as recommended by qualified advisors to the owner/operator. The hydrostatic pressure test is a leak test intended to validate the integrity of the pipeline. The test pressure is never less than the designed operating pressure. The maximum hydrostatic test pressure is based on the pipeline component with the lowest design pressure rating. The hydrostatic test pressure is usually between 1.25 times the nominal operating pressure and 1.5 times the Design Pressure Rating of this component. The maximum hydrostatic test pressure must be recorded at the lowest point along the pipeline, and must be compensated for temperatures other than 73ºF.

The ASME Code for Pressure Pipe, in B31.4, requires the hydro-test at 1.25 times the MAOP (maximum allowable operating pressure) for steel pipe. Typically, for ductile, visco-elastic HDPE pipe, the hoop-stress during hydro-test should exceed 30% of the specified minimum yield stress (SMYS) but remain less than 42% of the SYMS. The following test pressure ratios for HDPE pipe may be used, as decided by the pipeline owner, depending upon the owner’s needs and test objectives.

1.0 x Operating or Design Pressure

1.25 x Operating or Design Pressure

1.50 x Operating or Design Pressure

For example:

1.00x Design Pressure Rating for PE4710	(1000-psi pipe hoop-stress)
1.25 x Design Pressure Rating fro PE4710	(1250-psi pipe hoop-stress)
1.50 x Design Pressure Rating for PE4710	(1500-psi pipe hoop-stress)

The hydrostatic test pressure is a short-term test. The short-term tests for polyethylene pipe use the short-term strength (eg: stress intensity) of HDPE.

HDPE Material	**HDS@73ºF**	**Multiplier**	**Test Pressure**	**Hoop-Stress**
PE3608	800-psi	1.50	1200-psi	(75%HDB)
PE4710	1000-psi	1.25	1250-psi	(78%HDB)
PE4710	1000-psi	1.50	1500-psi	(94%HDB)

Stress within straight pipe is simple, but stress in fittings is more complex. Within elbows, tees and wyes, the local stress intensifications can raise the local stress to higher stress values, unless the fabricated fittings are sufficiently wall thickened to compensate for geometric effects. The design pressure ratings of installed fittings should be recorded prior to hydro-test, and, the test pressure should be based on a multiplier times the pressure rating of the pipeline component with the lowest pressure rating in the test section at its elevation in the test section at the test temperature.

Many owners opt for intermediate test pressures giving hoop-stress intensities above 1000-psi hoop-stress. Again, the maximum hydrostatic test pressure is based on the pipeline component with the lowest design pressure rating. The hydrostatic test pressure is usually between 1.25 times the nominal operating pressure and 1.5 times the Design Pressure Rating of this component. The maximum hydrostatic test pressure must be recorded at the lowest point along the pipeline (or compensated for by water elevation head to a different point in the pipeline), and must be compensated for temperatures other than 73ºF.

Three hydro-test parameters are: the hydrostatic test pressure, ratio of hydrostatic test pressure to actual operating pressure, and the pipe’s estimated hoop-stress during test. These should be calculated and recorded as follows:

Hydro-test Pressure = _____-psi (approved by Authorizing Agent(s)) EQ-1

R = hydro-test pressure / operating pressure EQ-2

Estimated pipe hoop-stress = (hydro-test pressure x (DR-1)) / 2 EQ-3

Selection of Test Section Lengths:

The pipeline length tested shall be either the whole pipeline, or a section of the entire pipeline capable of being isolated, dependent upon the length and diameter, the availability of water, the disposability of the water, and the spacing between sectioning valves or blind flanged ends. Based upon elevations and distance, the pipeline shall be divided into test sections such that:

1. The hydrostatic test pressure at any point in the test section is (i) not less than the design pressure, and, (ii) not more than 25% to 50% above the design pressure rating of any pipeline component; and
2. Water is available for the test together with facilities for its disposal, in accordance with regulatory requirements, after test.

When the pipeline is longer than 3000-feet, the pipeline may need to be tested in several sections. Where long lengths are tested, radio, cell phone, or other communication means may be required between test operators for safety, to coordinate test activities and keep the test within desired time limits.

Very long test sections may incorporate a large number of mechanical and flanged connections, which must be checked for leakage. The longer the test section becomes, the harder it is to locate a leak or to discriminate between a leak and other effects such as entrapped air being dissolved into solution under pressure. Prior to testing execution, a pre-assessment should be made as to what the recorded pressure versus time curves should look like, and how to read or interpret the actual recorded pressure data, so that acceptance or corrective action can be taken by experienced, trained, and qualified operators.

Selection of Fill-Rate:

Slowly fill the test section of the pipeline with water at ambient temperature. Filling is ideally supplied from the lowest point such that the water's entry is submerged and under a "pool" of water inside the pipeline, thus avoiding frothing, air entrainment and air being dissolved into the test water. A slow, submerged, fill velocity will prevent air entrainment and dissolving when the water stream is cascading through downward slopes along the pipeline. Dissolved air can be eruptive leading to a large surge pressure event, and can disguise a possible leak. Obviously the high point air vents should be open and monitored. After filling, allow 3-hours to 24-hours for the system to reach thermal equilibrium, AND, to allow time for any dissolved air to "breathe" and exit the system vents. The period of stabilization will depend upon the volume of water within the pipeline. The recommended slow fill-rate Q, in gpm, is based on the pipe inside diameter D, in inches, and an axial filling velocity of less than 10-feet per min calculated as follows:

$$Q_{gpm} = 0.402\ D^2_{inches}\ .$$

A firm urethane foam pig or swab, pushed by the fill water, may be used to assist in air removal, especially where the pipeline undulates and air pockets may be trapped.

Pre-Testing Checklist :

- **Prior to carrying out any testing activities, many precautions and considerations must be addressed.**
- **THE PLASTIC PIPE INSTITUTE MAKES NO CLAIMS THAT THE LIST BELOW IS COMPREHENSIVE. THERE ARE OTHER CONSIDERATIONS FOR EACH PROJECT. EACH PIPELINE OWNER MUST DO ITS OWN DUE-DILLIGENCE TO COMPILE ITS OWN COMPREHENSIVE HYDROTEST MANUAL, PRE-TEST CHECKLIST, TEST PROCEDURES, AND ACCEPTANCE CRITERIA.**

TEST PLANNING

- Has all the pipeline construction been completed, inspected and signed off?
- Has it been verified by QA/QC that the proper pipe material, diameters, DR's, flange ratings, fittings ratings, are in accordance with the drawings and specifications?
- Has the last fusion joint been allowed to cool sufficiently to ambient temperature?
- Has the pipeline been cleaned of all construction debris and foreign matter?
- Are the facilities available for preparations for testing?
- Have local authorities/ citizens been notified of the intent to conduct hydro-testing?
- Are all foreign construction materials removed from the trench in contact with the HDPE pipe?
- Are there any point loads on any fittings? (remove them)
- Are the PE pipelines supported by backfill or otherwise restrained by sandbags to prevent lateral movement or axial contraction under test pressure?
- Where cast concrete has been used, has the concrete cured in excess of 7-days?
- Will the hydro-test be scheduled to occur in dry weather, so that leaks may be detected? (testing in wet weather or in water filled trenches is not recommended)
- Have the proper environmental and regulatory permits been obtained for access to sufficient volumes of fill water, post-test water analysis and treatment, and proper disposal of the test water?
- Has the pipeline elevation profile and filling procedure been analyzed for the fill velocity potential against dynamic surge pressure during filling, which might over-pressure local components, especially in low elevations?
- Has the volumetric rate of fill, fill method, and fill procedure been finalized?
- Has the rate of initial pressurization, prior to full pressure hydro-test, been finalized?
- Has the test plan manual been approved, circulated to all operators, and understood by all participants in pre-test safety and quality meeting? (sign-in sheet)
- Are some bolted joints going to be left exposed for visual inspection and possible re-torquing during or after testing?
- If desired, is compacted embedment and trench fill going to be placed so that certain specified joints, fittings, service connections, or valves are exposed, in accordance with the owners test plan?
- Have all high elevation points and lateral "dead-legs" been identified with provisions made to properly install adequately sized air vent valves of sufficient volume & pressure capacity? Has it been verified that all vent points are installed in the "open" position, for proper operation during filling? Blind-flanges may be used as high-point vents when they are snuggly bolted and subjected to low filling pressure, such that trapped air is pushed out past the snug gasket, until the fill-water reaches it and sprays out, thus indicating that all air is expelled, followed by the mechanic fully torquing the flange per the approved bolting procedure with just static head against the blind.
- Has an emergency response plan been considered (as appropriate) in the event of a dramatic rupture during hydro-test?

- Has a temporary, foam pipe-pig launcher and receiver been considered so as to make filling the pipeline easy, and to prevent entrapped “pockets” of air?
- Has the Hydro-testing Schedule and Milestone plan been fully developed, reviewed approved, understood and implemented?
- Has the contractor’s list been published of nominated personnel who are to supervise the pressure testing operation, including their qualifications, tasks, and responsibilities, and limits of authority?
- Are supporting documents such as P&ID and isometric drawings available for the hydro-test section, which conform to the as-built configuration?

EQUIPMENT

- Are all blind-flanged ends (blanks) and valves restrained and supported?
- Are all intermediate valves open and capable of passing or venting entrapped air?
- Has all the equipment been reviewed for capacity to perform its function without fault during the test?
- Have all gages, dead-weight testers, data recorders, temperature recorders, water volume meters, etc, been calibrated within the last year; are certificates on file? Are the gages permanently identified with traceability to calibration records?
- Are at least two calibrated pressure gages or instruments placed into the test system to be used as a cross-check for gage accuracy? Typically, one calibrated pressure gage is placed at each end and then monitored, to assure the entire test section was pressurized. When an additional dead-weight tester is used, the pressure readings shall be recorded at a minimum of ½-hour increments. When a calibrated pressure recorder is used, it shall record continuously during the test. Any pressure gage used shall have sufficient pressure range to 150% of the maximum allowable test pressure.
- Are all temporary tools such as hoses, connection fittings, flanges, blinds, isolation valves, etc, rated higher than the maximum hydrostatic pressure?
- Is an adequately sized and calibrated hydro-test Safety Relief Valve installed and checked for proper operation; and, set for 5 psi higher than the maximum test pressure expected at its point of installation?
- Are properly sized drain ports correctly installed at the lower position along the pipeline, so as to enable emptying of the pipeline as required by contract specifications? Have provisions been made for treatment and disposal of the hydro-test water? Note: when draining is started, have provisions been made to open the upper air vents, to avoid a vacuum internal to the pipeline and to facilitate speed of draining?
- Are the test heads restrained? Blind flanges are fully restrained. Mechanical ends that are not end load resistant shall be temporarily strutted or anchored to withstand the test pressure thrust without movement. Temporary supports shall not be removed until the pipeline is de-pressurized and shall have signs noting the load limits on temporary fittings and supports.
- Does the hydrostatic pressurizing pump have its own calibrated safety relief valve?
- Has the pressurizing equipment been placed in the proper position and checked for proper operation without leakage?
- Is the pressurization pump “right-sized”? Too small of a pump will extend the test duration, and too large of a pump may inhibit adequate control of the test pressure.

SAFETY

- Has there been a safety meeting to review the safety measures and safe practices that are being employed?
- Will test operators be supplied radio or cell phone communications so that the test progress at remote, non line-of-sight sections can be monitored for venting, or possible leaks or other problems?
- Has a safety perimeter or boundary been established along the pipeline, surrounded or marked by posts supporting yellow safety-tape or safety-line, to assure unnecessary personnel and equipment stay out of the area during pressurized testing?
- Have the on-site hydro-testing personnel filed their OQ (operator qualifications) validating that they have experience and training (contractor licenses, professional degrees, professional certifications, work history) to participate and perform hydro-testing activities, plot pressure-time curves, make calculations, and otherwise work in their assigned role during the hydro-test, in a safe and knowledgeable manner?

- Have all personnel authorized to participate in the hydro-test, been adequately instructed in the test plan, and have they been issued the required personal protective equipment?
- Inclusion Zone: Has the access to the test ROW or test zone been limited to only those trained and qualified persons who are necessary to perform the test?
- Exclusion Zone: Has a safety perimeter or boundary been established along the pipeline, surrounded or marked by posts supporting yellow safety-tape or safety-line, to assure un-necessary personnel and equipment stay out of the area during pressurized testing? (Note: During testing or de-watering, there are possible unrecognized hazards that may not have been completely controlled, such as unexpectedly high pressures from internal malfunctions or equipment failures, rupture of the pipe or fusion joint, un-detected flaws. Such situations may develop forces large than the designed capacities of the anchorages. All non-essential persons should be excluded from the test zone.)

TESTING

- Is testing going to be conducted against a closed valve? Testing should not be conducted against closed valves unless they are mechanically restrained and it is possible to check for leakage past the valve seat. Best practice is to blind-flange before the closed valve.
- Have provisions been made to remove all trapped air at high points? In non-accessible zones, high velocity water flushing can laterally “move” the air from those zones if the water velocity exceeds about 2 to 4 feet per second. This may take large volumes of water and large pumps, but can be effective to move the air bubble to a vent location, when repeated a few times. The methods of removing trapped air are pigging, flushing, venting.
- Has removal or isolation been accomplished on all monitoring pressure-gages, control-valves, relief valves, rupture disks, orifice plates, diaphragm instruments, expansion joints, compressors, lower pressure pumps, etc , which could be damaged during the high pressure test?
- Have the proper drain ports of adequate size been installed correctly in the specified low-elevation points to permit draining of each zone of the hydro-test section?
- Will the fill rate be controlled to at or less than 10-feet per minute axial velocity? This fill velocity avoids air entrainment when the filling water is cascading through downwards gradients along the pipeline (hence preventing the potential eruption of dissolved air like that occurring from a shaken bottle of soda water.)
- Has it been verified that proper tags, tag-outs, signs, and notifications have been implemented/ applied/installed?
- Has it been verified that check-valves (CV) are not being pressurized against the flapper/ seat? When the pipeline has check-valves, assure the CV does not block the flow of the water to other pipe sections included in the test (remove the CV flapper, or block the CV flapper in the “open” position.)

POST-TESTING

- Have the temporary de-watering lines been secured against movement or de-coupling? Note: During de-watering, significant and sudden pressure variations will occur within the mainline and be transferred into the temporary de-waterline lines. These variations can be caused by changes in pig velocity thru bends, or, changes in pig and water velocity due to changes in pipeline elevation. Also, air by-passing the pig combining with entrapped air can accumulate stored energy. These sudden changes produce instant over-pressure surges transferred into the temporary de-watering lines which can result in movement, rupture, or de-coupling of those lines. These violent reactions can damage equipment, cause bodily harm, and have killed workers, when the temporary lines were not properly anchored and coupled. The project safety analysis should include safe-guards against lack of anchoring, worn coupling, and excessive and variable system pressures; and for installed anchoring, restraint, and control of de-watering piping, written procedures, and adequate employee training. Pipeline operators are required to protect employees and the public during hydro-testing: 49 CFR 192.515(a) states that: “each operator shall insure that every reasonable precaution is taken to protect its employees and the general public during testing.”
- Have the Hydrotest Data, record types, and final Report Forms and format been prepared and approved for use?

The Hydro-Test Method:

The Test Method Evolution:
In the USA, in the 1980's and 90's, the prevailing hydro-test method was presented in the Plastic Pipe Institute **Technical Report # 31** (TR-31), which described a constant pressure test method, with allowable make-up water volumes to compensate for the diameter creep strain of the viscoelastic HDPE pipe. Out-of-Print copies of PPI TR-31 are available from www.plasticpipe.org .

The prevailing hydro-test method used in the USA today is **ASTM F2164**: **"Standard Practice for Field Leak Testing of Polyethylene Pressure Pipe Systems Using Hydrostatic Pressure."** It is essentially a hydrostatic "pressure rebound method". This standard practice is available for purchase at: www.astm.org . The derivation of the "Pressure Rebound Method" is given in Appendix "A" to this document.

In summary, the pressure rebound method is a world-wide accepted method for testing HDPE pipes for integrity of all pipe, joints, and components.

The Method: The Pressure Rebound Test procedure includes three phases.

Preliminary: Phase I:

- Fill and vent and purge the pipe system of trapped air to less than 4% trapped air by volume. (This can be validated, as will be described later.) The pipeline shall be full of water, but not positively pressurized (other than the natural hydrostatic head) for 60-minutes prior to the start of the re-bound hydro-test.
- Start the test timer at T= "zero" minutes. Rapidly pressurize the test section to the specified test pressure (**STP**) in less than 10 minutes, if possible. Hold the STP for 30 minutes by repetitively injecting small volumes of make-up water into the test section to sustain, but not exceed, the STP, as the HDPE molecules creep-strain and "stretch", as the pipe slightly expands. Inspect exposed joints and connections for visible leaks during this time period.
- At T= 30 minutes, valve-off and isolate and record the confined specified test pressure (STP) as P_{30}. Allow the test pressure to decay for an additional 60 minutes, until the timer is T= 90minutes.
- Measure and record the residual test pressure as P_{90} at T= 90 minutes.
- If P_{90} > 70% of STP, this phase has passed and proceed to Phase II.
  If P_{90} is $\leq$ 70% of STP, then the test has failed, either because of a leak or because of excessive trapped air dissolving into the water.

Secondary: Phase II: Air Volume Assessment

If any trapped air or dissolved air content is "low" compared to the water volume filling the pipe system, then the pressure drop should be fairly linear upon a quick release of a partial volume of water from the pipeline. If the dissolved air or trapped air content is "high", then, even though a small volume of test water is quickly released, the test pressure will not drop much because the air will expand to fill the space.

In this phase, the P_{90} test pressure is reduced, per the instructions below, by bleeding out a small volume of pressurized test water, and, the volume of water that is bled out is measured by a calibrated meter or by measuring receptacles (gallons, buckets, barrels).

- The Air Volume Assessment is performed as follows:
  1. Quickly (< 5minutes) and safely bleed out water from the pipeline so as to reduce the pressure by 10% to 15%. Accurately measure and record the pressure drop as **ΔP.**
  2. Accurately and safely measure and record the water volume bled out as **ΔV.**
  3. Calculate: $\Delta V_{max\ allowable} = 1.2\ V\ \Delta P\ \{ (1/E_w) + (D / t\ E_R) \}$ = ___ **gallons.**

Where:	1.2	=	air allowance factor.
	V	=	test pipe section volume of water, in gallons.
	ΔP	=	measured pressure drop, in "psi".
	t	=	nominal pipe wall thickness, in inches.
	D	=	pipe inside diameter, in inches.
	E_w	=	Bulk modulus of water, in psi (from chart below).
	E_R	=	HDPE pipe modulus, in psi (from chart below).

Bulk Modulus of Water, E_W (The resistance to volume change when subjected to pressure)

Temperature	Bulk Modulus
5ºC – 41ºF	301,600-psi
10ºC – 50ºF	306,000-psi
15ºC – 60ºF	310,400-psi
20ºC – 68ºF	314,750-psi
25ºC – 77ºF	320,500-psi
30ºC- 86º F	323,450-psi

HDPE Pipe-Grade Material Modulus, E_R

Temperature	1-hour test	2-hour test	3-hour test
5ºC – 41ºF	143,600-psi	134,900-psi	130,500-psi
10ºC – 50ºF	130,500-psi	123,300-psi	118,900-psi
15ºC – 60ºF	118,900-psi	113,150-psi	108,800-psi
20ºC – 68ºF	108,800-psi	103,000-psi	98,630-psi
25ºC – 77ºF	100,080-psi	94,275-psi	91,375-psi
30ºC -- 86ºF	92,825-psi	88,475-psi	87,024-psi

- When $\Delta V \leq \Delta V_{max\ allowable}$, Phase II passes; proceed to the main test, Phase III.
- If $\Delta V > \Delta V_{max\ allowable}$ **, the test has failed,** and the cause must be corrected. Upon correction, the preliminary and secondary phases are to be repeated until passing.
- When excessive air is entrained or trapped in the pipeline, the pressure response is increasingly non-linear. The above air assessment test validates that minimal air is trapped and the test result will be indicative of the leak integrity of the pipeline, as illustrated in AS/NSZ Standard 2566-2 Appendix M and WRc's IGN 4-01-03 :

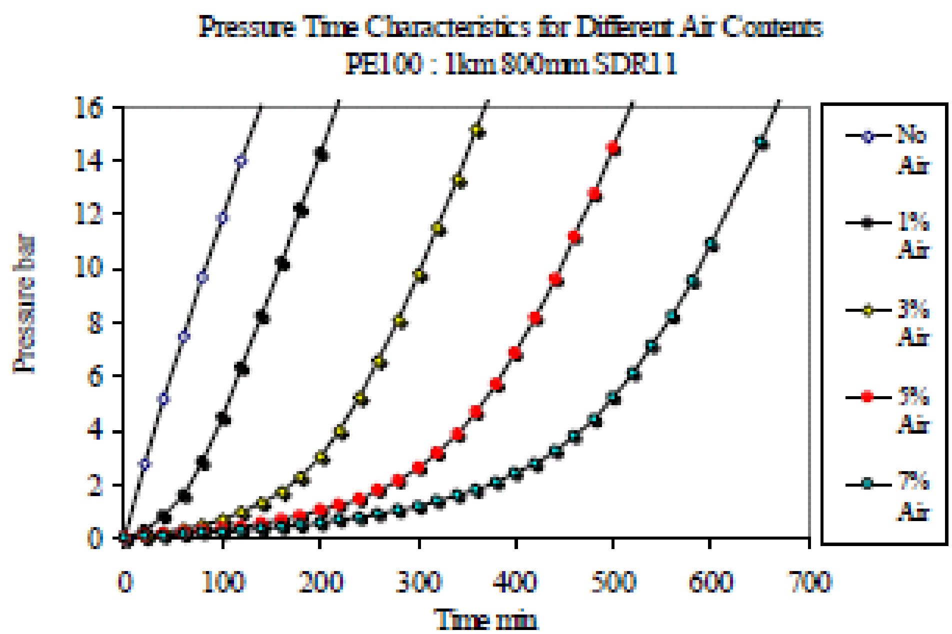

Figure A2.1: Pressure Rise Characteristics for 1 km of 800mm SDR 11 PE 100 Pipe

Final: Phase III

After the pressure was dropped about 10% to 15 %, and while the above air assessment calculations are being made, the pressure internal to the HDPE pipe should stabilize and remain constant within +/- 5% of the Phase III reduced test pressure. Because the HDPE pipe molecules have been "stretched" during the preliminary "expansion" phase, upon lowering the water test pressure, the molecules will elastically work to revert to their original length, and hence should compress the final test volume of water causing the final Phase III test pressure to “rebound” and rise slightly. This is a natural effect from visco-elastic HDPE material. If the plot of re-bound pressure versus time shows a continuous falling of pressure, the pipeline is leaking and the test fails. Ordinarily, the Phase III re-bound test time is 30-minutes. In some cases this test duration may be extended to one-hour. If the Phase III observation test duration is extended to 90-minutes, the initial pressure-rise may be followed by a flat stable pressure followed by a slight drop as visco-elastic creep resumes later in this extended period. The standard Phase III observation and approval period is 30-minutes per European Hydro-test Standards, with a possible extension to one hour per ASTM F2164 , if required for all observations along the pipeline length. The test shall not be acceptable when there is a failure of any pipeline component, or any measurable or visible leakage. The test shall be acceptable when the Phase III reduced pressure rebounds or remains static for 30-minutes. If the hydro-test fails, the cause should be corrected and a full procedure re-test conducted after a suitable “rest and relaxation” period, prior to the re-test. The typical chart below, from AS/NZS 2566-2 Appendix M, illustrates a typical successful hydro-test:

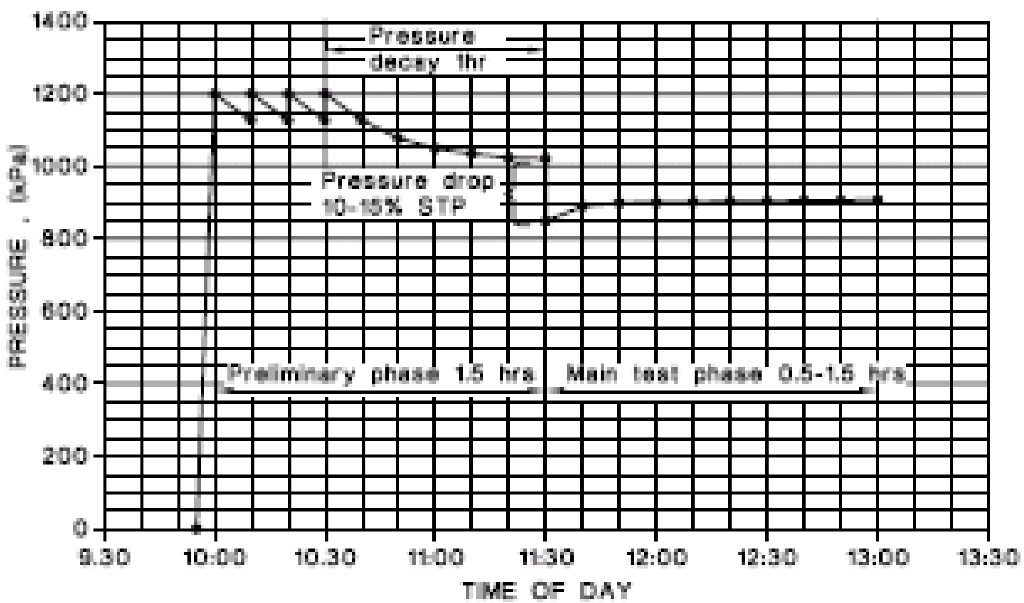

FIGURE M5 TYPICAL SUCCESSFUL MODIFIED REBOUND TEST FOR A PE PIPELINE

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Source : AS/NZS 2566-2, Appendix M
www.saiglobal.com

De-Pressurizing, and Draining the Test Section:
After the hydro-test has been successfully completed, the elevated pressure within the test section is to be safely reduced in accordance with the test plan. When the test section is ready to be drained, the air vents specified shall be opened and the water drained from low points, at a flow-rate in accordance with the test plan. The hydro-test water shall be re-used, treated, or drained to an approved water-way, after-which all connections shall be closed or otherwise re-instated. Remove all temporary blinds, supports, test connections.

The Test Report:
The pressure test report should include full details of all work associated with the hydro-test, including the planning documentation, safety training, pre-test meeting minutes, the hydro-test-plan, the hydro-test documentation, any leak corrective actions, the certified test results, and the sign-offs for acceptance.

Items also to be included are:

- Pipeline test section length versus elevation chart showing heights of air vent valves, gage locations, filling and drain points, pressure rating of the pipe and pressure rating of all fittings and appurtenances included in the test.
- Notations of leakage, failure, or rupture of any thrust blocking, pipe, fitting, joint, connection, etc.
- Location and nature of any leaks that were repaired.
- Test Water temperature and ambient temperature.
- Plot of test pressure variation by test time duration for each phase.
- The plot of the pressure decay graph & its interpretation; explanation of variances.
- All calculations for Phase I, Phase II, and Phase III.
- Verification of visible inspection of any exposed pipeline components.
- Date and times of the hydro-testing; gage and instrument calibration records.
- Reference Standards used as guidelines for the hydro-testing.
- Signature acceptance of hydro-test results by: test contractor, owner, principal contractor.

Note: A typical re-bound test report, with signatures, is illustrated on the next page.

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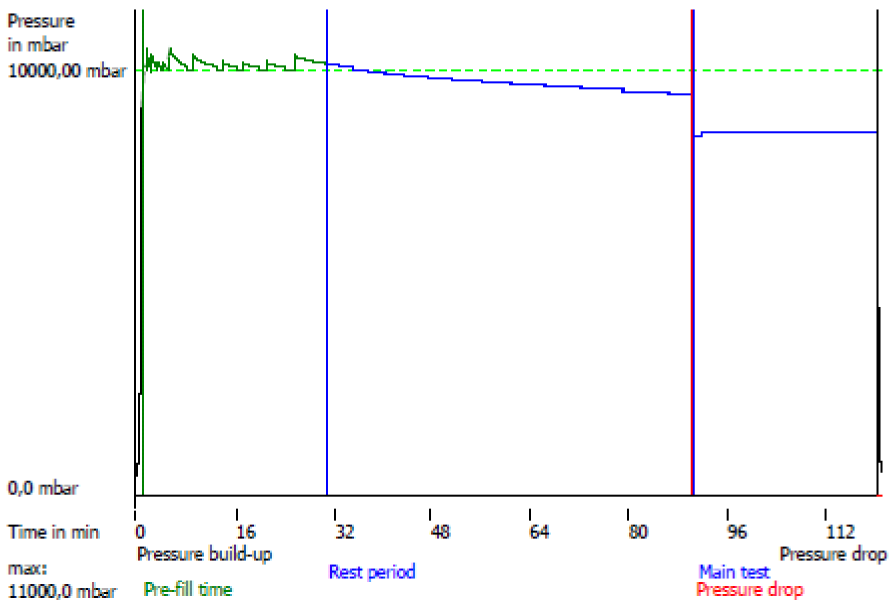
Client:
Moritz Bau

Principale cont.:
Ingenieurbüro Max

Pressure test report Pipe - Water/EN805



Location	: 46°45'29"Nord 14°20'53"Ost		
Location	: 9300 Sankt Veit an der Glan	Drawing No.	: 11865
Street	: Handwerkstraße	Section no.:	: 1
Tester	: Herr Sklarz	from manhole	: 1
Test equipment	: DPK1000LVW SN:060627	to manhole	: 2
Order no.	: 5	Length of test section	: 34,0 m
Test date	: 18.10.2006 11:17:21	Pipe profile	: Circle
Test method	: Water/EN805	Diameter	: 110 mm
Test category	: Water 805		
Test section	: Pipe	Pipe no.	:
Material	: PE 100	Internal protection	: without
Remark	:		
Sensor	: PMC131 0 - 20000mbar	Sensor test	: 01.01.2006
Approval	: Werksprüfung		

Test pressure	: 10000,00 mbar	Pre-fill time/Rest period	: 30:00 / 60:00 min
Permiss. water removal	: 463 ml	Main test	: 30:00 min
Act. water removal	: 419 ml	Result	: bestanden
?p - pressure drop	: 9452,5 mbar / 8403,8 mbar		

------------------- Testing contractor

------------------- Client

------------------- Principale contractor

Reminder: The following elements are identified as contributing factors to variation in the pressure test results, and should be considered when interpreting the test data:

- Length of the test section
- Diameter of the pipe
- Measurable temperature changes
- The range of the test pressure imposed on the test section
- The rate of pressurization
- The presence of some air in the pipeline
- Relative movement or slippage of mechanical fittings
- The stiffness and compaction of the soil around the pipe to resist pipe expansion
- The accuracy of the testing apparatus.

Commissioning:

The hydrostatically proven pipeline shall be commissioned for operation following the written standard start-up procedures and practices adopted or instituted by the local authority, or owner, or the owner's representative.

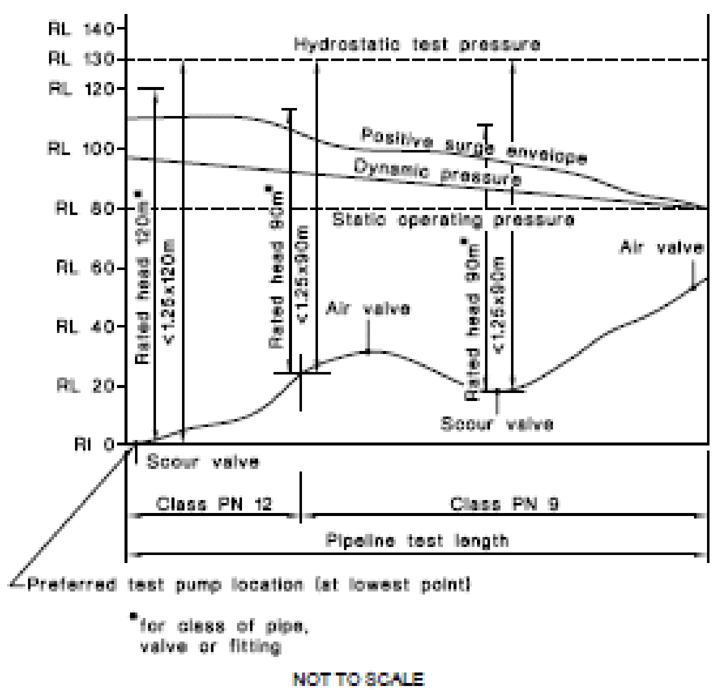


FIGURE M1 TYPICAL PRESSURE PIPELINE UNDER FIELD HYDROSTATIC TEST

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www.saiglobal.com

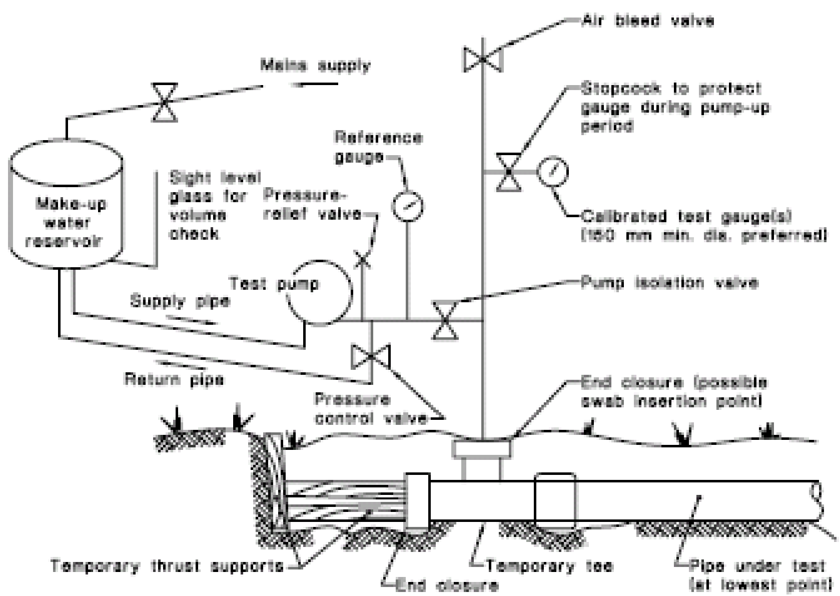

FIGURE M2 TYPICAL FIELD PRESSURE TEST EQUIPMENT LAYOUT

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APPENDIX A – DERIVATION OF THE PRESSURE REBOUND METHOD

The original pressure rebound method was developed and proven by Dr. Lars-Eric Janson in the 1990's. Svensk Vatten of Sweden published an extensive report on the procedure and technology in 1997, as VAV Project #78, "P78", titled "Anvisningar för täthetsprovning av tryckledningar tillverkade av polyolefiner (PE, PP och PB)".

> It can be found at : VAV Publication P78, Svenskt Vattens Vattenbokhandel: http://www.svensktvatten.se/ ; search the Vatten Book Publications for "P78".
>
> Additional guidance on P78 is offered at: http://www.svensktvatten.se/Documents/Kategorier/SVU/Rapporter/SVU-Rapport_2011-10.pdf

Additionally, The British Water Research Center, WRc, published a simplified version in its "Guide to the Pressure Testing of Water Supply Pipelines and Sewer Rising Mains", 1999, which is contained within in the "WRc Polyethylene Pipe Systems Manual", 2002 (3rd edition). It also published extensive guidance on the practical use, and the limits of use, of the pressure rebound method at:

http://www.water.org.uk/home/member-services/wis-and-ign/current-documents/ign-4-01-03-v2-march-2011.pdf

Also, the British Standards community of pipe manufacturers published BS **EN805**:2000: "Water Supply: Requirements for Systems and Components Outside Buildings". This standard hydro-testing practice outlines a similar pressure re-bound method. It is available from:

http://shop.bsigroup.com/en/ProductDetail/?pid=000000000019983094

The Australian hydro-test pressure rebound method is further described in their standard:

> **AS/NZS 2566.2**: including Appendix M, available from: www.standards.com.au
> Additional notes on hydro-testing are available from: http://www.pipa.com.au/images/pdf/TP005.pdf

APPENDIX B – DEFINITIONS

Design Pressure Rating: the pressure the polyethylene pipe is engineered to sustain indefinitely at 73F, without concern for pressure rupture. This pressure capability is based on the hydrostatic design stress (HDS) of the material and the pipe dimension ratio (DR).

Design Pressure: the nominal operating pressure at which the pipeline is designed to function continuously. It is usually at or less than the design pressure rating.

Hydrostatic Test Procedure Manual : the written test plan manual with instructions and checklists by which the hydrostatic testing will be conducted in conformance with the owner's requirements for equipment, methods and procedures, data analysis, and basis for acceptance and approval of the hydro-test prior to pipeline commissioning. The test procedures to be adopted will vary with individual pipelines and the requirements outlined in the contract documents.

Independent Hydrostatic Testing Firm: a qualified and experienced business or corporation (usually unrelated to the pipeline construction company), which conducts pipeline hydrostatic testing as a regular function of its business, using experienced employees or operators certified by the company as qualified to conduct hydrostatic testing. The role of the independent hydro-testing company's designated representative is to witness the pressure test for the prescribed time, ascertain the extent of the test, record the necessary data, and forward the results and data package, as required, to the prime contractor, or engineer, or owner. The representative does not approve the "test"; the pipeline owner or operator must verify, approve, and certify the "test".

Polyethylene Hydrostatic Pressure Testing : Hydrostatic pressure testing (or 'hydro- testing') is a non-destructive method of testing the integrity of newly constructed or modified HDPE pipelines by temporarily filling the test section with a liquid, usually water, and then the pressure of the liquid is raised to a specified maximum pressure, compensated for temperatures higher than 73ºF and measured at the lowest point in the pipeline (or compensated by water elevation head to a different point in the pipeline) which is maintained for a specified period of time. Any ruptures or leaks revealed during the test must be repaired or closed, and the test repeated, after a delay for elastic recovery, until no problems are noted.

Hydrostatic Pressure Testing Manager/Operator/Engineer: the person, qualified by experience or training, in overall charge of conducting the hydro-test of the subject pipeline. This person may be a contracted Independent Hydrostatic Testing Firm employee, or, a person nominated or approved by the pipeline owner-operator as its management representative, subject to review of the person's credentials.

Jurisdictional Authority : the individual, organization, office, governmental agency or official, authorized engineer, owner, or designated agent having the responsibility for approving or accepting procedures, equipment, or installations.

Designated Agent : The owner, engineering firm, hydro-test subcontractor, and the prime contractor may each have a designated individual authorized to review procedures, equipment, test data, etc…, and, for their respective parties, to approve by signature all test plan manuals, procedures, checklists, data, etc.

RECOMMENDATIONS FOR AWWA C901 SERVICE TUBES IN POTABLE WATER APPLICATIONS

PPI TN-49

2017

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Foreword

RECOMMENDATIONS FOR
AWWA C901 SERVICE TUBES IN POTABLE WATER APPLICATIONS

This technical note was developed and published with the technical help and financial support of the members of the Plastics Pipe Institute (PPI). These members have shown their commitment to developing and improving quality products by assisting standards development organizations in the development of standards, and also by developing design aids and reports to help engineers, code officials, specifying groups, contractors and users.

The purpose of this technical note is to provide general information about the history of the development of high-density polyethylene (HDPE) conduit and the various standards which apply to these products. The technical note may also be used as a guide for selecting appropriate standard specifications for users and specifiers.

The PPI has prepared this technical note as a service to the industry. The information in this report is offered in good faith and believed to be accurate at the time of its preparation, but is offered “as is” without any express or implied warranty, including WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. Additional information may be needed in some areas, especially with regard to unusual or special applications. Consult the manufacturer or material supplier for more detailed information. A list of member manufacturers is available on the PPI website. PPI does not endorse the proprietary products or processes of any manufacturer and assumes no responsibility for compliance with applicable laws and regulations.

PPI intends to revise this technical note within 5 years or sooner if required, from the date of its publication, in response to comments and suggestions from users of the document. Please send suggestions of improvements to the address below. Information on other publications can be obtained by contacting PPI directly or visiting our website.

The Plastics Pipe Institute, Inc.

www.plasticpipe.org

This Technical Note, TN-49, was first issued in June 2017

RECOMMENDATIONS FOR AWWA C901 SERVICE TUBES IN POTABLE WATER APPLICATIONS
PPI TN-49

1. INTRODUCTION

On June 11, 2017, the American Water Works Association approved the newly revised and updated standard ANSI/AWWA C901-17 "Polyethylene (PE) Pressure Pipe and Tubing, ¾ In. (19 mm) Through 3 In. (76 mm), for Water Service." The Standard now requires the use of only high performance PE4710 compounds with SDR9/SIDR7 for service tubes and requires that "PE Compound used in potable water service applications shall be classified [for resistance to the oxidative effects of disinfectants] as CC2 or CC3 per ASTM D3350..."

Based on these AWWA C901 requirements, this PPI Technical Note provides a quick and simple guide for the selection of PE water service tubes for use in potable water applications with chlorine and chloramine disinfectant residuals. Users can compare their operating conditions to the Quick Selection Table to determine whether additional analysis is required. Most users will find their operating environment readily satisfied by specifying compounds with the highest oxidative resistance performance class, e.g. CC3, and will achieve projections of 100 year+ resistance to the disinfectants.

This Technical Note addresses chlorine and chloramine usage as a secondary disinfectant. Chlorine Dioxide (ClO_2) as a secondary disinfectant residual is not covered by this guidance. At this time, PE pipe is not recommended with these ClO_2 applications because further research is needed to determine performance. Refer to the pipe manufacturer for ClO_2 applications.

2. BACKGROUND

Polyethylene (PE) pipes intended for potable water applications contain additives to provide resistance to the long-term oxidizing effects of water disinfectants. Research programs conducted on PE piping compounds resulted in the development of a model that projects the performance of PE pipes in long-term chlorinated potable water service.[1] The model is based on accelerated testing of many PE compounds in accordance with ASTM F2263 *Test Method for Evaluating the Oxidative Resistance of Polyethylene (PE) Pipe to Chlorinated Water* and the model allows the projection of the performance of PE pipes to specific end-use service conditions.

PE pipe compounds specified for potable water applications are categorized for oxidative resistance performance in accordance with ASTM D3350 based on ASTM F2263 testing. Per AWWA C901, the acceptable oxidative resistance categories are CC3 (highest performance) and CC2. To simplify the quick selection method for AWWA C901 sizes, PPI TN-49 guidance is based on the use of the highest category PE compound, CC3.

[1] Jana Technical Report, "JP 916: Jana Mode 3 Shift Functions", March 2012

3. QUICK SELECTION METHOD

The operational service life of water service tubing piping system depends on many factors. The long-term resistance to disinfectants is one of these factors. To simplify the selection of PE service tubes in the vast majority of applications, PPI developed the TN-49 Quick Selection Table (Table 1 below) to provide users with an easy to assess 100-year oxidative resistance pipe solution.

Users specifying PE compounds with CC3 categorization and with operating conditions within Table 1 designated ranges have projected resistance to disinfectant conditions of at least 100 years.

For example:

- Utility A, using a PE 4710 CC3 compound, has an average annual water temperature of 60°F, an average **chlorine** residual of 1.1 ppm, average pH of 7.4, and an average working pressure of 125 psi. The chlorine residual and pH values are within the Quick Selection Table ranges, so the Quick Selection method applies and confirms the resistance to disinfectant conditions of at least 100 years for all AWWA C901 sizes.

- Utility B, using a PE 4710 CC3 compound, has an average annual water temperature of 73°F, an average **chloramine** residual of 2.2 ppm, average pH of 6.8, and an average working pressure of 250 psi. Table 1 indicates that there are no limits on chloramine residual and pH values. Thus, the Quick Selection Table confirms the resistance to disinfectant conditions of at least 100 years for all AWWA C901 sizes.

Table 1: TN-49 Quick Selection Table

PE Compound Oxidative Resistance Category	PE 4710 CC3				
Average Annual Water Temperature (°F)*	≤ 73				
Residual Disinfectant Type	**Chloramine**	**Chlorine**			
Average Disinfectant Residual (ppm)	No limit	≤ 2.0			
Average pH	No limit	≥ 7.0			
Nominal Pipe Size (inches)**	≥ ¾	¾	1	2	3
Average Working Pressure (psig)	≤ 250	≤ 142	≤ 152	≤ 181	≤ 202
Projected Oxidative Resistance under the specific operating conditions (years)	≥ 100 years				

* The Average Annual Water Temperature (AAWT) is a weighted average of the daily water temperature, not the highest temperature observed in the system, experienced by the pipe or tubing. In situations where the service lines are buried just beneath the pavement, a higher water temperature estimate for the AAWT may be required.

** Dimensional Ratio SDR 9/SIDR 7 per AWWA C901

Users with operating conditions or pipe compound choice that fall outside the designated ranges in Table 1 should conduct an additional analysis per PPI TN-44[2] using factors for AWWA C901 sizes (i.e. F_{size}) specified in Table 2. Future updates to www.HDPEapp.com will include this analysis.

Table 2: F_{size} Factor for use in TN-44 calculations for AWWA C901 Pipe and Tubing

Nominal Pipe Size (inches)	**¾**	**1**	**1.25**	**1.5**	**2**	**3**
F_{size}	0.22	0.28	0.34	0.40	0.52	0.76

[2] PPI Technical Note 44, "Long Term Resistance of AWWA C906 Polyethylene (PE) Pipe to Potable Water Disinfectants", Plastics Pipe Institute, Inc., USA, 2015

4. SPECIFYING THE PE PIPE COMPOUND

PE 4710 pipe compounds shall conform to the latest editions of AWWA C901, NSF Standards 14 & 61 and ASTM D3350. The outside diameter shall be based on the IPS, CTS or SIDR sizing system. The specifier should append the required chlorine category (CC) class to the typical ASTM D3350 cell classification call-out. Examples of call-outs are provided below; refer to ASTM D3350 for other cell classifications:

- PE 445574E CC3 - for colored with UV stabilizer meeting CC3 minimum oxidative resistance performance class
- PE 445574C CC3 - for black with a minimum of 2% carbon black meeting CC3 minimum oxidative resistance performance class

5. CASE STUDIES

Table 3 (below) shows case studies under the specific operating conditions for 10 utilities as analyzed per PPI TN-49. In all these applications, AWWA C901 PE4710 pipe is projected to provide at least 100-year resistance to chlorine and chloramine residual disinfectants; note that these systems include utilities with high average working pressure (Colorado, 250 psi), high average temperature (Florida, 79 °F) and high average Cl_2/Low pH (Nevada, 1.1 ppm / 7.8). For conditions outside the TN-49 Quick Selection Table, PPI TN-44 was used to confirm projected performance of at least 100 years.

Table 3: Resistance to Disinfectants at Selected Utilities

Utilities Location	IN-1	CA-1	FL	TX	IN-2	NC	CO	CA-2	NV	MI
Residual Disinfectant Type	Chloramine*				Chlorine					
Nominal Size (inches)	¾" to 3" (SDR9/SIDR7 per AWWA C901)									
Average Disinfectant Residual (ppm)	1.6	1.9	1.4	2.5	1.4	0.9	0.5	0.9	1.1	1.5
Average pH	7.7	9.0	9.3	7.3	8.8	8.6	7.9	7.9	7.8	8.0
Average Annual Water Temperature (ºF)	57	61	79	72	54	68	50	64	70	48
Average Working Pressure (psig)	70	65	70	125	70	70	250	77	100	100
Projected Oxidative Resistance under the specific operating conditions (years)**	≥ 100 years									

* In 2014, it was "estimated that approximately 30% of municipal water utilities use monochloramine for residual disinfection … and that number is expected to increase to 60% as more-stringent DBP [Disinfectant By-Product] regulations go into effect…" Ref: Nagisetty, R., Rockaway, T. and Willing, G., *Drinking Water Quality Concerns from Chloramine-Induced Degradation of Elastomeric Compounds*, AWWA Journal, Sep. 2014.

**** Projected oxidative resistance under the specified operating conditions. In assessing the above case study examples, a projected life of at least 100-years was confirmed using both PE4710 CC2 and CC3, referring to PPI TN-44 as appropriate.**

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General Guidelines For Squeezing Off Polyethylene Pipe in Water, Oil and Gas Applications

TN-54

2017

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Foreword

GENERAL GUIDELINES FOR SQUEEZING OFF POLYETHYLENE PIPE
IN WATER, OIL AND GAS APPLICATIONS

This report was developed and published with the technical help and financial support of the members of the PPI (Plastics Pipe Institute). The members have shown their interest in quality products by assisting independent standards making and user organizations in the development of standards, and also by developing reports on an industry-wide basis to help engineers, code officials, specifying groups, and users.

This report has been prepared by PPI as a service of the industry. The information in this report is offered in good faith and believed to be accurate at the time of its preparation, but is offered "as is" without any express or implied warranty, including WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. Any reference to or testing of a particular proprietary product should not be construed as an endorsement by PPI, which does not endorse the proprietary products or processes of any manufacturer. The information in this report is offered for consideration by industry members in fulfilling their own compliance responsibilities. PPI assumes no responsibility for compliance with applicable laws and regulations.

PPI intends to revise this report from time to time, in response to comments and suggestions from users of the report. Please send suggestions of improvements to the address below. Information on other publications can be obtained by contacting PPI directly or visiting the web site.

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GENERAL GUIDELINES FOR SQUEEZING OFF POLYETHYLENE PIPE IN WATER, OIL AND GAS APPLICATIONS

1.0 INTRODUCTION

Squeeze-off is a technique used to control the flow of fluids including oil, dry or wet gas, multiphase fluids, non-potable oilfield water or potable water in polyethylene pipe by compressing the pipe between parallel bars until the inside surfaces make contact. The flexibility and toughness of polyethylene pipes allow the pipe to recover from a properly made squeeze-off without a measurable loss in service life. When properly performed, the operator can obtain a complete flow shut-off. Squeeze-off can be useful for making installation tie-ins, performing maintenance to system components, as well as for emergency repairs.

2.0 OPERATOR EXPERIENCE

Squeeze-off should only be performed by persons that have received training from an authorized instructor and that have a strong working knowledge of polyethylene and squeeze-off procedures. The operator should have training on the size of equipment being used to perform the squeeze-off. This document is a guide only, and should not be used in place of training by an authorized squeeze-off instructor. Failure to follow proper procedures can result in pipe failure or leakage due to compressively over strained pipe from improper squeeze-off. If following manufacturers procedures, ensure that the tool/procedure were qualified using ASTM F1734 Standard Practice for Qualification of a Combination of Squeeze Tool, Pipe, and Squeeze-Off Procedures to Avoid Long Term Damage.

3.0 GUIDELINES FOR SQUEEZE-OFF OF PE PIPES

Tool Location – Center the squeeze-off tool squarely on the pipe. This will allow the pipe to flatten freely without coming in contact with the tool frame or abutments. Locate the squeeze-off tool a minimum distance of 3x the pipe diameter, or 12 inches, whichever is greater, from any fusion joint, mechanical connection, prior squeeze-off point, or second squeeze-off tool.

Tool Operation – Operate the squeeze-off tool at a rate slow enough to allow stress relaxation in the pipe to occur. ASTM F1041 Standard Guide for Squeeze-Off of Polyolefin Pressure Pipe and Tubing recommends a maximum compression rate of 2 inch per minute or less is appropriate. See Table 1 for example squeeze times. This slow rate is particularly helpful when pipe becomes stiff in cold weather. Squeeze the pipe until flow ceases or the mechanical stop is contacted, whichever comes first. Continuing to operate the squeeze-off tool beyond this point can cause pipe or tool damage.

Tool Removal – Remove the squeeze off tool in a controlled manner. Avoid sudden release of mechanical or hydraulic pressure. Controlled release is necessary so flow control may be quickly reestablished if required. ASTM F1041 recommends a maximum release rate of 0.5 inch per minute or less is appropriate. See Table 1 for recommended release times. Rerounding the pipe is an option which should be exercised on the basis of improvement in flow or other concerns, rather than damage mitigation. If rerounding is performed, reround the pipe by rotating the squeeze-off tool 90° and applying enough force to round the pipe or by using a special tool designed for this purpose. Do not exceed the maximum compression rate when re-rounding the pipe.

Post Squeeze-off Considerations – After the squeeze-off tool has been removed, inspect the squeezed section for any damage. Procedures should include actions to be taken if damage is found. Procedures should not allow the same area to be squeezed off more than once. When an emergency condition requires squeeze-off without regard for possible pipe damage, the procedure should include actions to be taken based on the likelihood the pipe has been damaged and may require a reinforcement clamp or similar to be installed on the squeezed pipe section.

Other conditions may require a second squeeze-off tool in line to achieve complete flow shut-off. Squeeze-off is not suitable for repeated flow control at the same location or to throttle or partially restrict flow. Valves or other flow control devices are more suitable for those situations. ASTM standards F1041, F1563 and F1734 provide guidance and requirements for squeeze-off tools, operating procedures, and qualification procedures.

Table 1. Example Polyethylene Pipe Squeeze-Off Compression & Release Times

IPS SIZE	DR	AVG ID (in.)	Squeeze Time (2 in./min.)	Squeeze Time <32° F (1 in./min.)	Release Time (0.5 in./min.)	Release Time <32° F (0.25 in./min.)
1	9	1.005	0.5 min	1.0 min	2.0 min	4.0 min
	11	1.062	0.5 min	1.1 min	2.1 min	4.2 min
2	9	1.816	0.9 min	1.8 min	3.6 min	7.3 min
	11	1.917	1.0 min	1.9 min	3.8 min	7.7 min
	17	2.079	1.0 min	2.1 min	4.2 min	8.3 min
3	9	2.676	1.3 min	2.7 min	5.4 min	10.7 min
	11	2.825	1.4 min	2.8 min	5.7 min	11.3 min
	17	3.064	1.5 min	3.1 min	6.1 min	12.3 min
4	9	3.440	1.7 min	3.4 min	6.9 min	13.8 min
	11	3.633	1.8 min	3.6 min	7.3 min	14.5 min
	17	3.939	2.0 min	3.9 min	7.9 min	15.8 min
6	9	5.064	2.5 min	5.1 min	10.1 min	20.3 min
	11	5.348	2.7 min	5.3 min	10.7 min	21.4 min
	17	5.799	2.9 min	5.8 min	11.6 min	23.2 min
8	9	6.593	3.3 min	6.6 min	13.2 min	26.4 min
	11	6.963	3.5 min	7.0 min	13.9 min	27.9 min
	17	7.549	3.8 min	7.5 min	15.1 min	30.2 min
10	9	8.218	4.1 min	8.2 min	16.4 min	32.9 min
	11	8.678	4.3 min	8.7 min	17.4 min	34.7 min
	17	9.409	4.7 min	9.4 min	18.8 min	37.6 min
12	9	9.747	4.9 min	9.7 min	19.5 min	39.0 min
	11	10.293	5.1 min	10.3 min	20.6 min	41.2 min
	17	11.160	5.6 min	11.2 min	22.3 min	44.6 min
14	9	10.702	5.4 min	10.7 min	21.4 min	42.8 min
	11	11.302	5.7 min	11.3 min	22.6 min	45.2 min
	17	12.254	6.1 min	12.3 min	24.5 min	49.0 min
16	9	12.231	6.1 min	12.2 min	24.5 min	48.9 min
	11	12.916	6.5 min	12.9 min	25.8 min	51.7 min
	17	14.005	7.0 min	14.0 min	28.0 min	56.0 min
18	9	13.760	6.9 min	13.8 min	27.5 min	55.0 min
	11	14.531	7.3 min	14.5 min	29.1 min	58.1 min
	17	15.755	7.9 min	15.8 min	31.5 min	63.0 min
20	9	15.289	7.6 min	15.3 min	30.6 min	61.2 min
	11	16.145	8.1 min	16.1 min	32.3 min	64.6 min
	17	17.506	8.8 min	17.5 min	35.0 min	70.0 min
22	9	16.818	8.4 min	16.8 min	33.6 min	67.3 min
	11	17.760	8.9 min	17.8 min	35.5 min	71.0 min
	17	19.256	9.6 min	19.3 min	38.5 min	77.0 min
24	9	18.347	9.2 min	18.3 min	36.7 min	73.4 min
	11	19.375	9.7 min	19.4 min	38.7 min	77.5 min
	17	21.007	10.5 min	21.0 min	42.0 min	84.0 min

Note 1: Squeeze and Release Times are Calculated off of the Inside Diameter.
Note 2: For Size Classes (DIPS, CTS), Diameters and DR's Not Shown Please Contact the Manufacturer.

4.0 PREVENTING PIPE DAMAGE

Tests have shown that when squeeze-off is performed correctly and the tools used meet the ASTM guidelines and requirements found in F1563 Standard Specification for Tools to Squeeze-Off Polyethylene (PE) Pipe and Tubing, squeeze-off can be performed without compromising the expected service life of the pipe. However, the installer or operator must take care during the squeeze-off procedure to prevent damage to the pipeline. The list below contains some areas that require extra attention during squeeze-off to prevent pipe damage.

- Ensure the tool meets the requirements of ASTM F1563 and that the tool is installed square to the pipe with the squeeze plates parallel to each other.

- Verify that the squeeze-off tool is sized appropriately for the diameter and DR of pipe to be squeezed off. The squeeze-off tool should contain stops that limit the squeeze as to not over stress the pipe. Make sure the correct stops are installed in the tool before starting.

- After the squeeze-off tool has been removed, the pipe should be closely inspected for any signs of damage. Any pipe suspected of damage during a squeeze-off should be reinforced, replaced or removed from service. The area of the squeeze-off should be marked on the pipe and also in the GIS software if appropriate.

- Cold weather increases the pipe's susceptibility to damage. Compression and release times should increase by double in cold weather (32°F and below). For pipe that is in above ground applications, consideration may be given to pre-warming the pipe, however this should not replace the increase in compression and release times.

5.0 SAFETY CONSIDERATIONS

Jobsite safety requirements should be fully understood and observed. This guideline does not purport to address all of the safety considerations associated with its use. It is the responsibility of the user of this guideline to establish and follow the appropriate safety and health practices.

Ensure the squeeze-off tool, and its 'STOPS', meet the requirements of ASTM F1563 and that it is sized appropriately for the diameter and DR of pipe being squeezed. Visibly inspect the pipe for cuts, scrapes or gouges before installing the squeeze off tool onto the pipe. Do not squeeze on pipe sections containing deep scratches (>10% of pipe wall thickness). Do not squeeze the pipe in the same place more than once.

5.1 Static Electricity Concerns for Gas Squeeze-Off

Polyethylene pipe is a poor conductor of electricity. As a result polyethylene pipe builds up a static charge when it is in gas service (distribution or gathering) due to the gas flow across the inside surface of the pipe. During squeeze-off, the velocity of the gas flowing through the flattening section increases. This increases the rate and amount of static charge build-up.

In addition to the potential for pipe damage due to static discharge, the buildup of a static charge represents an explosion hazard. Where there is a flammable or combustible environment in conjunction with static charges, arc preventing safety precautions are necessary. Additional information on arc prevention and tool grounding is available through the AGA Plastic Pipe Manual (www.AGA.org) and through the squeeze-off tool manufacturers. It is recommended that all operators performing squeeze-off have grounding procedures in place to be used during squeeze-off, and that all personnel involved in squeeze-off operations receive training on those procedures and understand the hazards involved.

Guidelines for Use of Mini-Horizontal Directional Drilling for Placement of High Density Polyethylene Pipe

TR-46

2009

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FOREWORD

Guidelines for Use of Mini-Horizontal Directional Drilling

for Placement of High Density Polyethylene Pipe

This report was developed and published with the technical help of the members of the PPI (Plastics Pipe Institute, Inc.). The members have shown their interest in quality products by assisting independent standards-making and user organizations in the development of standards, and also by developing reports on an industry-wide basis to help engineers, code officials, specifying groups, and users.

The purpose of this technical report is to provide important information available to PPI on a particular aspect of polyethylene pipe butt fusion to engineers, users, contractors, code officials, and other interested parties. More detailed information on its purpose and use is provided in the document itself.

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Guidelines for
Use of Mini-Horizontal Directional Drilling for Placement of High Density Polyethylene Pipe

Table of Contents

1. Scope

1.1 These guidelines describe the design, selection considerations, and installation procedures for the placement of polyethylene (PE) pipe or conduit belowground using mini-horizontal directional drilling (mini-HDD) equipment. The primary focus of this document is on pipe constructed of **high density polyethylene (HDPE) with a material designation code of either PE3608 or PE4710**. For convenience, the term "HDPE" is used as a generic term to refer to either material, PE3608 or PE4710, with the distinction, if any, clear from the context. Information is also provided for pipe of medium density polyethylene (MDPE) PE2406/2708 material. Related properties for these materials are provided in the Plastic Pipe Institute Handbook of Polyethylene Pipe.(**1**)[1] The pipe may be supplied in continuous lengths on a reel or discrete segments assembled together, typically by fusion, in the required length. Applications include pipe for conveying fluids, such as natural gas, oil, and water, as well as ducts or conduits for containing communications (telephone, CATV, ...) or electric power supply cables. Recent applications also include those requiring precise grades, such as gravity sewers.

1.2 IEEE Std 1333 describes the use of this technology for placing insulated electric power cables, including related conduit applications. The use of mini-HDD for directly placing more vulnerable communications cables is not recommended. Such cable should be placed within HDPE duct or conduit which may be installed following the present guidelines.

1.3 Horizontal directional drilling (HDD) represents a form of trenchless technology. The equipment and procedures are intended to minimize above and below ground surface damage, restoration requirements, and disruption to traffic, with little or no interruption of existing services. *Mini*-horizontal directional drilling (mini-HDD), also know as "guided boring", is typically used for the relatively shorter distances, shallower depths, and smaller diameter pipes associated with local distribution lines, in comparison to *maxi*-horizontal directional drilling (maxi-HDD), typically used for longer distances, greater depths, and larger diameter pipes, such as major river crossings. ASTM F 1962 provides detailed information and guidelines for the placement of polyethylene pipe using maxi-HDD technology.

1.4 In contrast to ASTM F 1962, from which the present guidelines are partially derived (see Section 7 and Appendices B and C), the present document is intended to provide useful information for the less sophisticated mini-HDD technologies and installations, as reflected in the corresponding planning and design practices. Thus mini-HDD warrants a more conservative and limiting design approach than used in ASTM F 1962. The objective is to provide an outline and brief description of proper procedures to be followed for mini-HDD operations, with reference to existing industry standards and guides that provide greater detail, as appropriate. However, it is also the intention of this document to provide useful details for specific aspects that may not be conveniently available in other sources. Examples of the latter include drill rig setup information, such as setback distances, as a function of drill rod characteristics and rig setup parameters, as well as a simple

[1]The boldface numbers in parentheses refer to the list of references at the end of this standard.

methodology for selecting the strength (wall thickness) of HDPE pipe as a function of route geometry.

1.5 For convenience, the dimensions and other quantities are provided in the customary inch-foot-pound units.

2. Referenced Standards and Specifications

ASC C2, *National Electrical Safety Code*, Institute of Electrical and Electronic Engineers

ASCE 108, *ASCE Manuals and Reports on Engineering Practice No. 108, Pipeline Design for Installation by Horizontal Directional Drilling*

ASTM D 2657, *Practice for Heat-Joining of Polyolefin Pipe and Fittings*

ASTM D 3035, *Specification for Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Controlled Outside Diameter*

ASTM F 512, *Standard Specification for Smooth-Wall Poly(Vinyl Chloride) (PVC) Conduit and Fittings for Underground Installation*

ASTM F 714, *Specification for Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter*

ASTM F 1962, *Standard Guide for Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossings*

ASTM F 2160, *Standard Specification for Solid Wall High Density Polyethylene (HDPE) Conduit Based on Controlled Outside Diameter (OD)*

CI/ASCE 38, *Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data*, American Society of Civil Engineers.

IEEE Std 1333, *IEEE Guide for Installation of Cable Using the Guided Boring Method*

OPSS 450, Ontario Provincial Standard Specification *Construction Specification for Pipeline and Utility Installation in Soil by Horizontal Directional Drilling,*

OSHA 3075, *Controlling Electrical Hazards*

GR-356, Telcordia Technologies *Generic Requirements for Optical Cable Innerduct and Accessories*

TIA/EIA-590A, *Standard for Physical Location and Protection of BelowGround Fiber Optic Cable Plant*

3. Terminology

3.1 "Horizontal Directional Drilling" (HDD) is a technique for installing product pipes, including utility lines, below ground using a surface-mounted drill rig that launches and places a drill string at a shallow angle to the surface and has tracking and steering capabilities.

3.1.1. The drill string creates an initial (pilot) bore hole, of several inches diameter, in an essentially horizontal path or shallow arc which may be enlarged during a secondary operation, or sequence of such operations, through use of a reamer. The product pipe or utility line is typically installed during the final reaming operation, or, if necessary, as a separate, last step in the process. The predetermined path of the bore is maintained by tracking the path of the pilot bore using a manually operated overhead receiver or a remote (wireline or wireless) tracking system, and performing steering and path corrections by controlling the orientation of the drill head. The drill head has a directional bias, such as a slanted face or mud motor on a slightly bent portion ("bent sub") at the leading drill rod. Turns and corrections are accomplished by pushing the drill string forward with the drill head oriented in the direction desired. Continuous rotation of the drill string allows the drill head to bore a straight path. Soil penetration is accomplished using high pressure, low volume fluid jets and/or mechanical cutting. The drilling fluid volume is controlled to avoid or minimize the creation of voids during the initial boring and back-reaming operations. The drilling fluid serves several purposes, including stabilization of the bore hole, removal of cuttings, lubrication for the drill string and product pipe, and cooling the drill head and transmitter electronics. Typically, the resultant slurry created by the combination of the drilling fluid and soil cuttings gradually solidifies into a solid mass encapsulating the product pipe.

3.1.2 "Mini-Horizontal Directional Drilling" (mini-HDD) is a class of HDD typically employed for boring segments less than 600 feet in length, at depths up to 15 feet, and placing pipes up to 12 inches diameter. The equipment is characterized by a thrust or pullback capability of up to 20,000 lbs, with a torque less than 950 ft-lbs. Mini-HDD machines weigh less than 9 tons.(**2**)

3.1.2.1 Mini-HDD equipment is typically used for installing ducts and conduits for local distribution utility cables (electric power, communications) and gas lines beneath local streets, private property, and along right-of-ways. Smaller mini-HDD machines, sometimes referred to as a "micro-HDD" equipment, are appropriate for installing pipes for service lines or laterals to homes or businesses. Recent improved technology and greater experience gained by contractors (excavators) have also allowed mini-HDD equipment to place lines on an accurate grade, including gravity sewer lines. The creation of the pilot bore hole and the reaming operations are typically accomplished by fluid jet cutting and/or the cutting torque provided by rotating the drill string. The locating and tracking systems typically require a manually operated overhead (walkover) receiver to follow the progress of the initial pilot bore, although remote tracking/steering systems are available. Figures 1 and 2 illustrate typical mini-HDD equipment and pilot boring and back-reaming operations, including product pipe or utility line placement.

3.1.3 "Maxi-Horizontal Directional Drilling" (maxi-HDD) is required for installations far beyond the capability of mini-HDD technology. Maxi-HDD is capable of accurately boring holes on the order of a mile in length, and placing pipes of 48 inches or greater, at depths up to 200 ft. Thrust/pullback and torque capability can be as much as 100,000 lbs and 80,000 ft-lbs, respectively, and the machines may weigh as much as 30 tons.(**2**), or greater. Maxi-HDD is therefore appropriate for placing pipes under large rivers or other major obstacles. The corresponding equipment and technology are very sophisticated relative to that of mini-HDD, including wireline or wireless tracking systems, and the applications tend to be individual, relatively complicated major installations, requiring the services of experienced engineers throughout the process, including during the planning, design and installation phases. Maxi-HDD machines typically utilize mud motors on a bent-sub for cutting in soil or rock formations. ASTM F 1962 provides detailed information and appropriate practices for maxi-HDD operations.

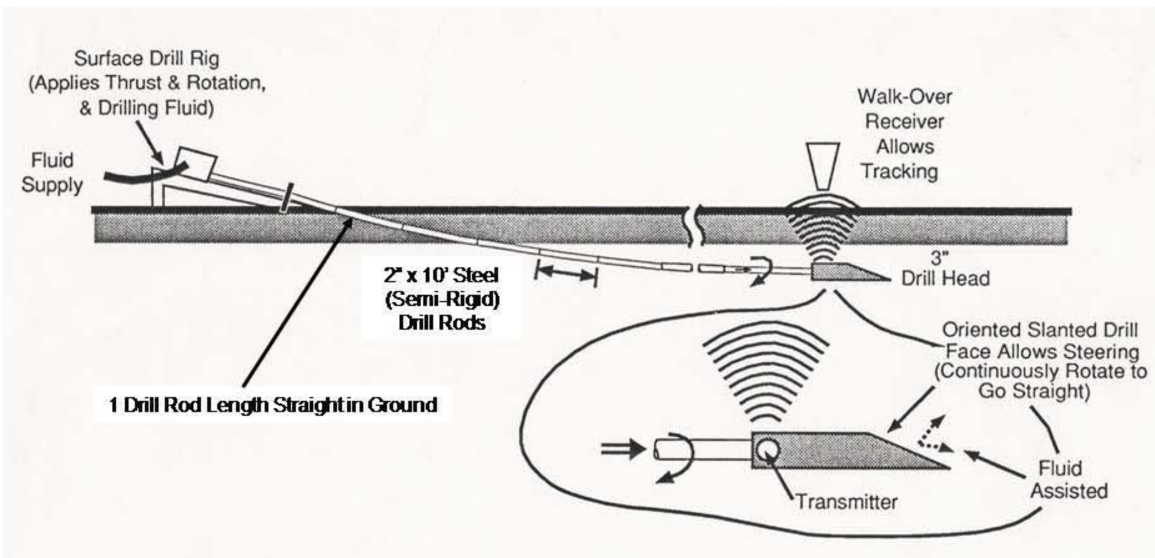

Figure 1 Typical Mini-HDD Equipment and Pilot Boring Process
(Source: Outside Plant Consulting Services, Inc.)

3.1.4 "Midi-Horizontal Directional Drilling" (midi-HDD) is a category that is intermediate to mini-HDD and maxi-HDD, with regard to equipment capabilities and planning and engineering effort. Midi-HDD may be employed for boring paths up to 1,000 feet in length, at depths as much as 75 feet, and placing pipes up to 24 inches diameter. Midi-HDD equipment may be used for crossing beneath rivers and roadways. It is noted that the distinctions between mini-HDD, midi-HDD and maxi-HDD vary, depending upon the reference, and is not always entirely consistent with that indicated in Section 3.1.2.(**3**) *Guidelines for the use of midi-HDD machines and practices may be obtained from the present guidelines, as suggested herein, and/or ASTM F 1962, depending upon the particular application and the judgment of the contractor or engineer*.

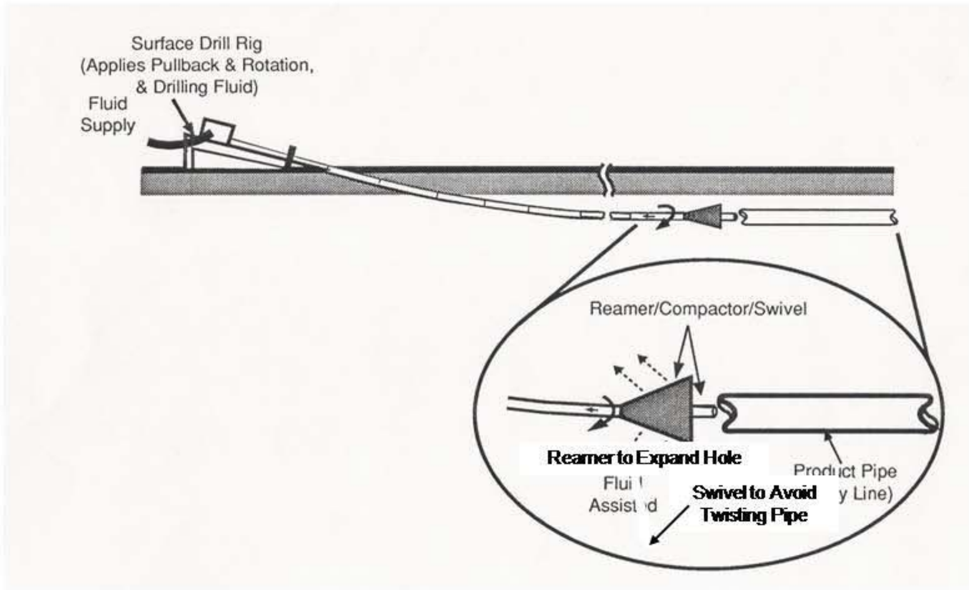

Figure 2 Typical Mini-HDD Back-Reaming and Pipe Pullback Process
(Source: Outside Plant Consulting Services, Inc.)

3.2 The "Dimension Ratio" (DR) is the ratio of pipe outer diameter to minimum wall thickness, such as used in ASTM D 3035, ASTM F 714 or ASTM F 2160. Higher DR values therefore correspond to thinner, weaker pipes and lower values to thicker, stronger structures.

3.2.1 The "Standard Dimension Ratio" (SDR) is a specific ratio based upon the Iron Pipe Size (IPS) system.

3.3 The degree of bending to which a drill rod, or product pipe, may be subject, without damage or degradation, is a function of the size and material of the item. There are several alternative measures of the degree of allowable curvature as presently used in the industry; see Figure 3.

3.3.1 The "Radius of Curvature", or "Bend Radius", is the distance from the center of the circular path or configuration, in a plane, to the perimeter.

3.3.2 The "***90°*** Bend Radius is the distance along a 90° portion (quadrant) of the perimeter of the circular path.

3.3.3 The "Degrees per Rod" is the angular change along a single rod length.

3.3.4 The various measures for quantifying the allowable curvature are related by the following formulae:

90° Bend Radius (ft) = 90 x Rod Length (ft) / Angular Change (deg/rod) (1a)

Radius of Curvature (ft) = 90° Bend Radius (ft) / 1.57 (1b)

Radius of Curvature (ft) = 57.3 x Rod Length (ft) / Angular Change (deg/rod) (1c)

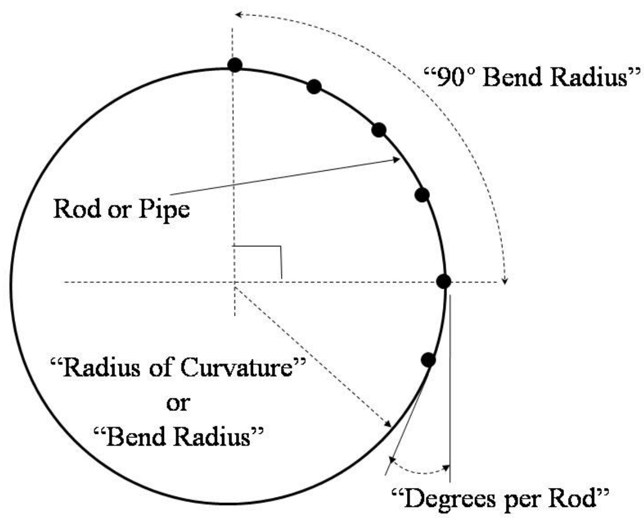

Figure 3 Rod or Pipe Curvature Terminology
(Source: Outside Plant Consulting Services, Inc.)

Figure 4 illustrates the above relationships. See Appendix A for examples quantifying the bending capability of typical drilling rods, using the various terms. There is significant quantitative difference between the 90° Bend Radius and Radius of Curvature. The latter (Radius of Curvature) is approximately $^{2}/_{3}$ of the 90° Bend Radius. For convenience, except where otherwise indicated, the Radius of Curvature (Bend Radius) measure will be used in the present document.

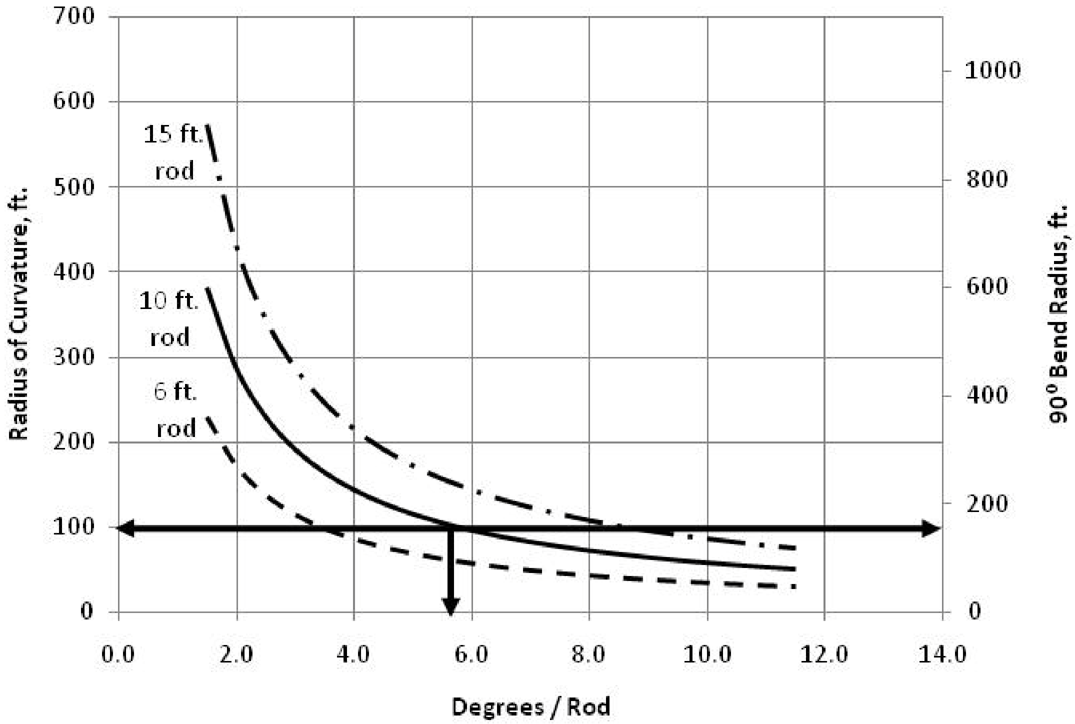

Figure 4 Allowable Curvature Relationships
(Source: Outside Plant Consulting Services, Inc.)

4. Preliminary Site Investigation

Section 4 describes the background information that would assist the contractor or engineer in planning the project, in order to help ensure an efficient, successful installation during the later construction phase. This investigation includes an evaluation of surface and subsurface conditions to determine the compatibility of the site with the proposed directional drilling operation. Of particular importance is the need to understand the presence and nature of **existing belowground utilities**, as discussed in Section 4.2 in order to avoid damage to such lines.

4.1 *General Considerations*

4.1.1 Unlike maxi-HDD installations, typical mini-HDD projects may be brief undertakings, requiring as little as a single day, such as for a road crossing, or less for a service line, to extended periods of many months or more for a large scale upgrade of degraded utility distribution lines serving an entire community. The feasibility and desirability of using mini-HDD for a particular project, as opposed to a larger machine (e.g., midi-HDD), or open-cut trenching, depends upon many factors, including soil conditions, location of other utilities, environmental aspects, and particular features and characteristics of the existing area. The size and anticipated duration of the project is an important consideration with respect to the amount of preliminary planning and investigations that may be practical.

4.1.2 For relatively extensive projects, such as for upgrading utility lines across a community, the owner of the facility to be placed or his representative (e.g., a geotechnical engineer), or the (potential) contractor, should perform a preliminary site investigation well in advance of the construction. Ideally, the owner would conduct as much of the preliminary investigation as possible to allow a meaningful and equitable bidding process. The contractors would conduct additional investigations to assist them in the bidding process, as well as to provide guidance for the actual construction, following awarding of contracts. For projects of very limited duration, the contractor may perform only a brief study, to verify the general feasibility and determine the equipment and resources required to successfully complete the task.

4.1.3 The presence of special obstacles or situations must be considered. For example, the presence of pollutants or contaminants in the construction area must be identified, including corresponding arrangements for spoil disposal.

4.2 *Existing Belowground Utilities*

4.2.1 Mini-HDD technology was primarily developed as means of installing new utility lines in developed areas, including residential applications, and at various crossings of limited extent, with minimal surface damage. However, in order to avoid damage to belowground facilities, public or private, as well as to judge the magnitude of the effort, it is essential to understand the nature of such lines and structures, including types and likely locations and depths. Information obtained at the preliminary stage will help guide the subsequent more detailed inspections and locations required immediately prior to, and during, the actual construction stage.

4.2.2 The new distribution lines will generally be placed along the main right-of-way (ROW), and associated service lines will typically be installed laterally beneath the individual properties. Since minimum specified clearances must be maintained from existing lines in the ROW, the available remaining space within the ROW should be verified, as a measure of the potential difficulty of the installation. New distribution cables will routinely be crossing existing service lines for individual buildings, residences or structures, which will be exposed during the construction stage (Section 6.2.3). In addition to the utility service lines, the presence and frequency of privately installed electric or lawn sprinkler lines within the community should be considered.

4.2.3 **Important regulations and damage prevention procedures are discussed in Section 6.**

4.3 *Surface Investigation*

4.3.1 The surface area of immediate interest corresponds to that specified or desired by the owner of the new facility, consistent with the utility network architecture, including the number and size of pipes required, and their termination points.

4.3.2 The contractor should review the construction site to verify there is sufficient room for the drill rig and auxiliary equipment, vehicles, trailers, at both ends of the bore. The drill rig working areas should be reasonably firm, level, and suitable for the movement of rubber tires or treads. For PE pipe of relatively large diameter, not provided on a reel, for which pipe prefabrication is necessary, appropriate space must be provided for the fusion equipment, as well as an area for temporarily placing the assembled pipe. The presence of possible interfering aboveground structures or overhead power or telephone lines should be considered with regard to equipment movement.

4.3.3 The ability for the tracking and monitoring system to function properly may be hampered by the local conditions, along the path to be bored. Conventional walkover receivers require direct overhead access, while more sophistical systems may allow remote tracking. Potential sources of interference to the electronic locators of mini-HDD tracking systems include overhead structures or wire lines, as well as steel-reinforced concrete sidewalks, driveways, and roads.

4.3.3 The use of drilling fluids requires that a source of water, preferably potable, be available for mixing. Although drilling fluids are not considered hazardous materials, excess fluid and associated spoils must be disposed of properly. The location of an appropriate disposal area, consistent with local regulations, should be identified in advance of the construction, as part of the preliminary or planning phase.

4.3.4 Although noise levels associated with mini-HDD equipment are generally not excessive, there may be restrictions on work hours in areas near residential buildings, hospitals, or other institutions.

4.4 *Subsurface Investigation*

4.4.1 The effectiveness and efficiency of most belowground construction operation is dependent upon the soil conditions, and is especially relevant for HDD technology. Directional drilling installations must simultaneously penetrate and maneuver through the soil, using less aggressive techniques than conventional open-cut trenching. Problematic soil conditions can slow progress and/or lead to damage to public and private property and safety hazards. It is therefore important to perform an investigation of the local soil characteristics and ground conditions, including potential obstacles, to verify the feasibility of employing mini-HDD for the proposed project, as well as to result in more realistic cost estimates and avoid inequities to the owner or contractor. In order to be cost-effective, however, the extent of the subsurface investigation, should be compatible with the magnitude of the overall project.

4.4.2 The soil investigation should attempt to evaluate conditions at the nominal placement depth of the product pipe. Mini-HDD technology is capable of placing utility lines or pipes as deep as 15 ft. In many cases, however, the desired or required depth for utility distribution lines will be relatively shallow -- possibly within six feet of the surface. (Greater depths may complicate subsequent repair and maintenance procedures.) Such mini-HDD installations will also likely be in established areas, including residential communities. Thus, the relevant belowground conditions are not necessarily that of virgin soil at greater depths, but that of disturbed or filled areas, possibly including various debris or obstacles resulting from prior construction activities.

4.4.3 For relatively large scale projects, the investigation may include a review of published reports from various government agencies (e.g., state or county soil conservation service reports, U. S. Geographic Survey, U. S. Army Corps of Engineers reports). However, in recognition of the possible lack of correlation of such virgin soil studies relative to the possibly disturbed conditions, at shallow depths, as described above, records from previous local construction projects, of large or small extent, would be of particular value, if available from other utilities or owners. The latter information may also reveal the presence of belowground structures, including those that may have been abandoned. Construction information and experiences from previous local projects involving trenchless methods, requiring boring of any type, would be most relevant.

4.4.4 *Soil Investigation Tests* – If warranted by the scope of the project, existing subsurface information may be supplemented by local soil tests, at strategic locations and relevant depths, to verify the conditions. Possible characteristics to be evaluated include standard classification of soils, standard penetration test values, rock type and strength and (Mohs) hardness.(ASCE 108) ASTM F 1962 provides reference ASTM test methods for soil evaluation studies, as appropriate. More extensive information is available elsewhere.(**3**)

4.4.5 For some mini-HDD applications, such as large scale upgrades of distribution facilities in established areas, random blockages due to man-made debris would not be evident based upon soil testing at a limited number of locations. Depending upon the depths of interest, object dimensions, and soil conditions, existing technology (e.g., ground penetrating radar) may be capable of electronically scanning the subsurface to detect obstacles of various sizes. Such technologies are continuing to evolve and their practicality, including economic feasibility, will depend upon the local conditions and concerns.(CI/ASCE 38)

4.4.6 *Suitability of Soil Conditions* -- Table 1 indicates the suitability of horizontal directional drilling as a function of the general characteristics of the soil conditions in the area and depths of interest.(**2**)

4.4.6.1 The indications of applicability in Table 1 assume that the contractor and crew is trained and experienced in the use of mini-HDD equipment and technology, employs appropriate equipment for the specific soil condition (drill head, reamers, ...), and has a working knowledge of drilling fluids. The proper use of drilling fluids is a critical aspect of HDD operations, the importance of which is often underestimated. Preferably, contractors have successfully completed industry training courses or seminars specifically addressing mini-HDD methods, and have a minimum of one year field experience, and completed 30,000 ft of construction in related projects.

4.4.6.2 “Marginal” conditions will generally result in a lower success rate, but which may be positively impacted by greater contractor experience and training, and the use of consulting services by industry suppliers. Some applications may not be economically feasible for directional drilling using present technology; see Section 4.5.

Table 1 Applicability of Mini-HDD (or Midi-HDD) for Various Soil Conditions (2)

Soil Conditions	Applicability	
	Mini-HDD	Midi-HDD
Soft to very soft clays, silts, and organic deposits	Yes	Yes
Medium to very stiff clays and silts	Yes	Yes
Hard clays and highly weathered shales	Yes	Yes
Very loose to loose sands (above water table)	Yes	Yes
Medium to dense sands (below water table)	Yes	Yes
Medium to dense sands (above water table)	Yes	Yes
Gravels and cobbles less < 2 - 4 in. diameter	Marginal	Marginal
Soils with significant cobbles, boulders, and obstructions > 4 - 6 in. diameter	No	Marginal
Weathered rocks, marls, chalks, and firmly cemented soils	Yes	Yes
Slightly weathered to unweathered rocks	Marginal	Marginal

4.5 *Non-HDD Situations*

4.5.1 Although the present guidelines focus on the use of mini-HDD technology for the installation of polyethylene pipe and conduit, as the method of choice established areas, it is recognized that in some cases other techniques may be more appropriate. Table 1, for example, provides guidelines for evaluating the feasibility of mini- (or midi-) HDD as a function of soil conditions. Problematic situations may represent isolated portions of a larger overall project, for which individual lines may be installed using alternate methods.

4.5.2 If the conditions, as described above, are not conducive to the use of mini-HDD, it is possible that more conventional methods may be acceptable for isolated situations. Open-cut trenching may be feasible in areas that would not require extensive restoration expenses. Cable plowing techniques, such as may be deployed for placing utility cables or service lines (telephone, CATV, electric power), resulting in minimal surface damage, may be feasible, depending upon the aboveground obstacles to ripping a narrow path along the surface. These methods often require, or benefit from, the simultaneous use of plastic pipe for providing the intended function (e.g., fluid flow) or protection and future maintenance capability (e.g., cables).

5. Safety and Environmental Considerations

Section 5 discusses potential safety issues and related procedures during buried construction, with special emphasis on means to avoid or minimize risks during mini-HDD operations. Employees must be trained to prevent injuries to themselves during the operation of the equipment and be prepared to mitigate the effects of accidents. Electric power and gas line strikes are specifically addressed. Although not considered to be hazardous materials, the proper handling and disposal of drilling fluid is also discussed.

5.1 *General Considerations*

Safety is a primary concern in any construction activity, including those utilizing HDD Such issues may be considered to fall into two categories -- those directly related to the setup and operation of the equipment itself, and those associated with the proper implementation of utility location, identification and marking procedures intended to avoid contacting and damaging existing utilities. Section 5 addresses the equipment usage issues and Section 6 primarily focuses on procedures to eliminate or reduce hazards associated with damaging existing utilities, including during the initial boring or back-reaming operations.

5.1.2 *Equipment Usage* – It is necessary to ensure that injury does not result to construction personnel or bystanders as a result of the operation of the drill rig and auxiliary equipment. Therefore, it is essential that bystanders, as well as personnel not directly required in the operation, be excluded from the immediate vicinity of the mini-HDD equipment and, to the extent practical, from along the entire bore path. Barriers and warning signs should be visibly placed at the equipment or associated hardware.

5.1.3 *Traffic Control* – Since a primary advantage of HDD, as compared to conventional construction practices, is the minimal disturbance to the landscape and disruption of normal traffic flow, it is important to maintain proper vehicular control. The combination of warning lights, traffic cones and flagmen must be used to ensure a safe working environment for the construction personnel as well as non-construction related passersby.

5.1.4 *Shoring* – Although HDD is a “trenchless” construction method, a limited number of discrete pits are typically required, such as for utility terminations, exposing existing utilities at crossings, to collect excess drilling fluid and spoils, or possibly to clear local blockages. When a worker is required to perform tasks in excavations where a cave-in hazard exists or the excavation is in excess of 5 ft depth, shoring, sloping, or shielding methods must be used to provide employee protection.(ASC C2)

5.2 *Safety Training*

Both the contractor and its employees are responsible for ensuring proper safety procedures are followed. The employer must provide access for appropriate training and safety courses, and the employees must be aware of their capabilities and limitations for any assigned work; see Section 5.9. This is particular the case for operators of mechanized equipment.(ASC C2) As a minimum, all drill unit operators and associated personnel, including those in the vicinity of the drill rig or at the opposite (exit) end of the bore, should have received training in first aid and CPR and be familiar with the hazards of working in the vicinity of electrical lines.(IEEE Std 1333) (OSHA 3075) **The following brief recommendations and guidelines are not intended to replace or diminish the need for proper safety training programs, as provided within the industry or from equipment manufacturers**.

5.3 *Work Clothing*

Proper clothing includes that which should be worn during mini-HDD installations, as well as that which is not appropriate, since it may cause injuries. Protective safety glasses and/or goggles and head gear should be worn at all times, as well as electrical insulating boots and gloves. All protective items should be regularly inspected and maintained to preserve their insulating properties. Potentially **hazardous apparel**, to be avoided, includes **unnecessarily loose clothing or jewelry** since these items may become snagged on moving mechanical parts.

5.4 *Machine Safety*

Due to the potential hazards of operating mechanized equipment of any type, it is important for mini-HDD personnel to exercise special care and comply with accepted industry practices. The drill rig equipment includes chain drives, gear systems, and vises used in combination with heavy drill rods which are inserted, removed, advanced or retracted, representing opportunities for personal injury. Safety shields must not be removed, overridden or compromised in any manner. The mini-HDD equipment, including electrical strike safety features, must be checked at the beginning of each work day to verify proper operation.

5.4.1 *Hydraulic Fluid* – In comparison to the more visible hazards represented by the moving mechanical components, serious injuries may be inflicted by the less apparent hydraulic oil used to power the drill rig. High pressure fluid can penetrate skin or cause blood poisoning. Operating pressures are on the order of several thousand psi, and may lead to leaks at vulnerable connections and damaged hoses. The hoses and connectors must be properly maintained to minimize the risk of leaks and the system pressure should be relieved before disconnecting any hydraulic lines. **Suspected leaks must not be checked using exposed parts of the body**.

5.4.2 *Drilling Fluid* – Similar precautions as above (Section 5.4.1) apply to drilling fluid used to for soil cutting and reaming. The drilling fluid supplements the mechanical cutting provided by the drill head or reamer and, depending upon the equipment design and operation, may also reach several thousand psi within the drill rod assembly, and may lead to leaks at vulnerable connections and damaged hoses. Drilling fluid hoses and connectors must be properly maintained to minimize the risk of leaks and, before inserting or removing individual drill rods from the drill string, the drilling fluid pressure at the rig must be relieved to avoid high velocity fluid squirting from the joint. The reduced drilling fluid pressure level must be verified by the corresponding pressure gauge to verify the pressure has been relieved before disconnecting any rods. As above, **suspected leaks must not be checked using exposed parts of the body**.

5.4.2.1 Due to the possibility of soil clogging the drilling fluid ports of the drill head or reamer, the attempt to relieve pressure at the rig may not result in an immediate loss of pressure within the drill string. In such cases, special care is required when disconnecting the rod. Clogged drill components should be cleared prior to continuing the operation, possibly requiring the drill string to be retracted or exposed.

5.4.2.2 The exit point for the pilot bore represents a potentially hazardous location, from which a safe distance must be maintained by all personnel. The drilling fluid pressure should be relieved as soon as the drill head emerges at the far end, as well as when the reamer emerges from the entry point at the rig end.

5.5 *Electrical Strike*

Although the risk of striking existing belowground utilities or structures is greatly diminished by following proper industry practices, including those described in Section 6, it is difficult to ensure that such an event may not occur. Particular dangers exist with respect to striking electrical or gas lines due to their widespread usage and hazardous nature. **The contractor must follow State or local regulations regarding belowground construction.** Although reluctant to deliberately disrupt service to customers, in some cases the **electric power utility may be requested to shut off service** in the area during the construction activity. These situations may include those where it is difficult to reliably locate or track the progress of the drilling operation due to uncontrollable interference or similar problematic environments. In such cases, as a minimum precaution, the electric power utility should be requested to **disable the automatic reclosure of circuit breakers** (restoration of power), to prevent personnel exposure after the initial open circuit condition (loss of electric power). As a result of these special requests, the utility will be especially aware of the construction activities, leading to more rapid response in the event of an accident.

5.5.1 **An electrical strike safety system must be employed**, and checked at the beginning of each work day to verify proper operation. Such equipment typically includes an electrical strike sensing system, supplemented by grid mats, ground rod, barriers, and proper electric bonding hardware for connecting the components. Workers must wear proper clothing (Section 5.3). All personnel should wear electrical insulating boots and gloves at all times.

5.5.2 A successfully completed pilot bore does not ensure that a utility line may not be damaged during the subsequent reaming or pullback operation, as the bore hole is enlarged. In the event of an electrical strike during the latter operation, exposure to hazardous voltage may exist at both ends of the bore. For example, if several pre-reaming operations are performed, steel (conductive) drill rods are inserted at the bore exit point to maintain the path as the rods are removed at the bore entry. In such cases, grid mats, ground rods, and an electrical bonding system must be used at the bore hole exit, as well as in the vicinity of the drill rig. In comparison to metallic product pipe, the non-conducting nature of plastic pipe essentially eliminates or greatly reduces corresponding risks at the bore exit point (pipe entry) during final pullback of the product pipe.

5.5.3 Specific emergency steps following an electrical strike are provided within industry guidelines, and include precautions regarding equipment and worker movement. The **facility operator must be contacted immediately** and a call to **911** should be made for emergency response.(**4**)

5.6 *Natural Gas Line Strike*

Since it is difficult to accurately locate existing plastic pipe lines, there is a correspondingly greater risk of striking such facilities. **The contractor must follow State or local regulations regarding such belowground construction.** In some cases, the **gas utility may be requested to shut off service** in the area during the construction activity. Such situations may include those where it is difficult to reliably locate or track the progress of the drilling operation due to uncontrollable interference or similar problematic environments. As a result of these special requests, the utility will be especially aware of the construction activities, leading to more rapid response in the event of an accident.

5.6.1 Specific emergency steps following a gas line strike are provided within industry guidelines, and include shutting and abandoning equipment, and evacuating the area of workers and the public. The **facility operator must be contacted immediately** and a call to **911** should be made for emergency response.(**4**)

5.7 *Damage to Existing Utilities*

In general, the facility operator and "One-Call Center" or equivalent, (see Section 6.1.1) should be contacted as soon as possible following damage (break, nick, gouge, ...) to other facilities. If there is **danger,** such as due to leakage of gases or liquids, the **facility operator must be contacted immediately** and a call to **911** should be made for emergency response.(**4**)

5.8 *Environmental*

Drilling fluid serves many useful functions, including aiding soil penetration, removal of spoils, bore hole stabilization, lubrication for the drill rods and product pipe, and cooling of the drill head and transmitter electronics. Typical drilling fluid components are not hazardous materials, with the waste material usually considered as excavation spoils, not requiring special disposal procedures. The volume of spoils to be removed from the site may be significantly reduced by means of drilling fluid recirculating systems. The most common additive is bentonite, a naturally occurring type of clay. If clay represents a large component of the native soil in the construction site, a polymer additive may be more appropriate. The bentonite or polymer material used should be National Sanitation Foundation certified. The additive materials should be chemically inert, biodegradable, and non-toxic, and petroleum-based or detergent additives should not be used.(OPSS 450)

5.8.1 *Contaminated Area* – Although the bentonite-water, or commonly used polymer-water, slurry, is not inherently a hazardous material, special disposal may be required when drilling in an area known to be contain toxic pollutants. In such cases, disposal must be in accordance with local laws and regulations, and it may be necessary to de-water the spoils, transport the solids to an appropriate disposal site, and treat the water to meet disposal requirements. It may be also necessary to add grouting to the drilling fluid to ensure proper sealing of the bore hole to eliminate a possible passage for contaminants. Special drilling fluid pumps may then be required.

5.8.2 *Collection Pits* – In order to maintain a neat, orderly work site, occasional small pits must be available for collecting the excess drilling fluid or slurry exiting from the bore hole. A clean work site will help ensure the installation of a clean product pipe, reducing the need to later flush out mud or debris from within the pipe. Excessive drilling fluid and mud in the area may impair the connections and associated grounding characteristics of the equipotential grid mat system. Pits may already be present or required such as for utility access or connections at the ends or along the bore (Section 8.4), thereby serving as convenient receptacles. If not otherwise present, small pits should be provided at the ends, and possible intermediate points to serve this function. The pits should be emptied as necessary.

5.9 *Proficiency*

It is required (ASC C2) that employees operating mechanized equipment, including mini-HDD machinery, be qualified for their tasks, and that their employer (contractor) ensure that the operators and other workers in the vicinity have demonstrated proficiency in their duties, particularly safety issues. Primary personnel must have proper training, including classroom and field experience. Industry based HDD training and/or certification courses are available from equipment manufacturers, as well as professional organizations.(**5**, **6**)[2]

5.9.1 *Submissions* – The contractor should submit the following information to the owner or its representative (OPSS 450):

- Work plan outlining the procedure and schedule to be used to execute the work
- List of personnel, including backup personnel, and their qualifications and experience
- Traffic control plan
- Drilling fluid management plan including potential environmental impacts and emergency procedures and associated contingency plans
- Safety plan including the company safety manual and emergency procedures.

[2] HDD training and/or certification courses are available from the Center for Underground Infrastructure Research and Education, at the University of Texas at Arlington (www.cuire.org), and the North American Society for Trenchless Technology (www.nastt.org).

6. Regulations and Damage Prevention

In order to help avoid the potential hazards described above, proper procedures must be adopted to reduce the likelihood of damaging existing utilities. Section 6 therefore discusses such practices, including “call-before-you dig” (811); locating and marking existing utilities, as well as exposing, when appropriate; avoiding mechanized digging within the required tolerance zone; and the use of Subsurface Utility Engineering.

6.1 *General Considerations*

Following proper procedures and regulations will help avoid damage to existing belowground facilities, and also reduce safety and environmental hazards for the workers and the public. Government issued permits are required prior to performing any significant construction. The owner of the facility to be installed is responsible for obtaining the permit, possibly with the cooperation and assistance of the contractor. Permits are typically issued by a municipality, county and/or state, depending upon the impacted areas. In some cases, approval may be required from additional agencies (e.g., Environmental Protection Agency). Permits provide approval for crossing beneath roads and railroads, and for installing lines along the right-of-way or within easements. The permits may specify construction requirements to protect existing facilities as well as the public. In some cases, the allowable or required method(s) of construction are specified, including directional drilling and/or open-cut trenching.

6.1.1 *“Call Before You Dig”* – The proliferation of belowground utilities, often mandated by State or local regulations, results in increasing difficulties in avoiding damage to existing facilities when placing new buried lines. Most states have therefore instated damage prevention laws which address the responsibilities of the facility owners (i.e., owners of existing subsurface utilities) and that of contractors placing the new product pipe. These laws typically require the contractor to follow a “**call-before you dig**” procedure, using a universal **811** number. Each facility owner should belong to a local "**One-Call**" type notification service. The contractor must provide an advance notification of several days to the One-Call center, to allow the various utilities to locate and mark their facilities. Notification is typically required within an interval 48 to 240 hours (2 to 10 days) in advance of actual construction, excluding weekends and holidays.(TIA/EIA-590A) (**4**)

6.1.2 *Other Information Sources* – When a One-Call service, or equivalent, does not exist in a particular area, or where regulations do not require facility owners to belong to such a service, the contractor should check local record centers to identify and contact all possible facility owners, as part of the utility location process, prior to initiation of construction. Sources for obtaining such information include various public records, including those of the local municipal or county public works departments, state public service commission, state corporation commission or attorney general office, or directly from utilities, private companies or institutions known to provide service or have facilities located in the area in question. If a known utility or facility owner does not send a representative or make other arrangements to mark its lines, the contractor should attempt to obtain as much information as possible from the owner, to aid in its location.(TIA/EIA-590A)

A particularly important example of the need for properly identifying all utilities relates to municipal sewer lines, which are usually not registered with a One-Call bureau. The consequence of not locating such lines has resulted in the occurrence of “cross-bores”, in which the boring operation penetrates a sewer line or lateral and pulls back a gas line, without any immediate obvious indication that this has occurred. At some time in the future, a cleaning operation of the lateral may then result in damage to the gas line, with potential hazardous consequences. **It is critical to avoid or prevent the occurrence of such cross-bore events.**

6.2 *Locating and Marking*

All existing belowground facilities, including lines and structures, must be identified, located, and marked -- including electrical and communications (telephone, CATV) cables; natural gas, water and sewer lines; pipes carrying other liquids, chemicals, or gases; and oil tanks or other possible structures. Industry accepted damage prevention procedures such as outlined in CI/ASCE 38, TIA/EIA-590A and other sources(**4**), and briefly summarized herein, should be followed by the contractor to reduce the possibility of damage to existing facilities.

6.2.1 Prior to the arrival of the locators, the mini-HDD contractor should mark the path of the proposed bore route, preferably using a white line or flags, and indicate its name or other means of identification. Although it is the responsibility of each individual facility owner to mark the location of its utility lines, pre-construction meetings with the contractor are useful, and may be particularly important for unusual or difficult projects. Such meetings may be necessary when requesting temporary disruption of electric or gas service, to reduce likelihood of associated safety hazards. In general, belowground facilities within a minimum lateral distance of 10 ft of the proposed bore path should be marked, unless within a greater distance is specified by State or other regulations. Other facilities known to be the vicinity, but believed to be beyond the 10 ft, or otherwise required minimum distance, should be confirmed by the corresponding owner. The actual paths and depths of identified utility lines are typically not provided during this preliminary process. They may subsequently be determined by the owner of the proposed pipe line or its representative, or the mini-HDD contractor, as described below; see also Section 6.4

6.2.2 *Locating Equipment* – Typical locating equipment and procedures are based upon the transmission of an electrical signal along an available metallic (conducting) element of the utility line of interest, in combination with an aboveground receiver. The lateral position, and to some extent the depth, are determined by the characteristics of the received signal. For non-metallic (non-conducting) lines or facilities, a metallic tracer wire or discrete electronic markers may have been deliberately placed to facilitate future detection. In other cases, transmitting devices may be able to be placed within plastic or other non-conducting pipe to provide an electronic signal at the surface. Improved methods continue to evolve based upon other technologies, including acoustical techniques and ground penetrating radar.

6.2.3 ***Exposing Existing Facilities*** – When exposing existing utilities to verify depth non-aggressive “pot-holing” techniques, including manual tools (with electrically-insulated/non-conducting handles) or vacuum type excavators, must be used. It is particularly important to visibly expose and verify the location of lines transporting electricity or gas, oil or petroleum products, or other flammable, toxic or corrosive fluids or gases. In general, **utility lines must be routinely exposed at all anticipated crossings** with the planned bore path, such as where the route along a right-of-way crosses laterals or service lines to residences or other structures (see Section 8.5.4).

6.2.4 *APWA Uniform Color Code* – The paths of existing belowground facilities should be marked, using paint, flags or equivalent, or flags, based upon the Uniform Color Code developed by the Utility Location and Coordination Council (ULCC) of the American Public Works Association (APWA):

White	proposed construction path
Red	electric power
Orange	communications
Yellow	gas, oil, steam, petroleum
Green	sewer, drain
Blue	water, irrigation, slurry
Fluorescent pink	temporary survey markings

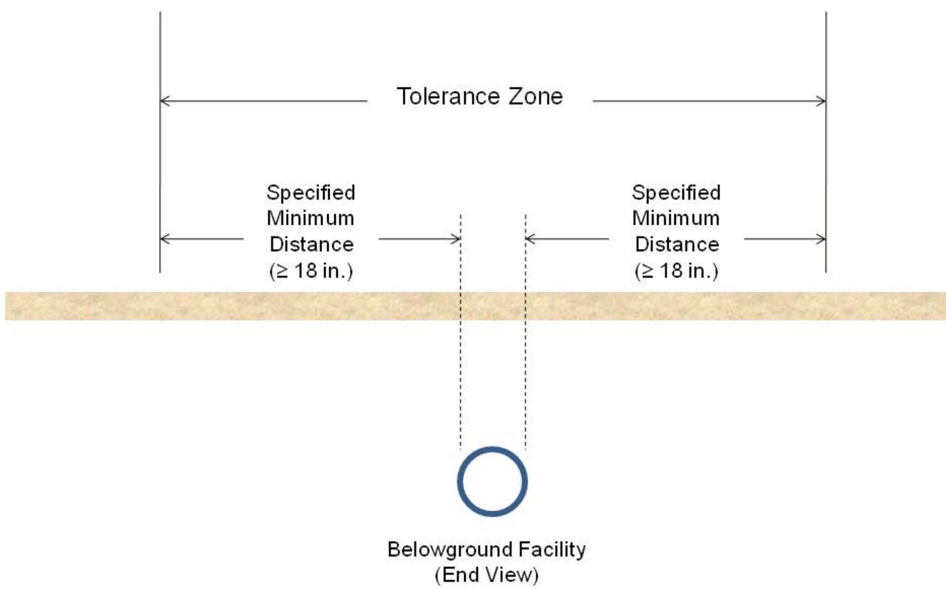

Figure 5 Tolerance Zone

6.3 *Tolerance Zone*

The tolerance zone (Figure 5) defines the region within which the contractor must use non-aggressive methods of digging, such as manual tools or vacuum excavation. **The width of the zone is specified by local regulations and varies among the states.** A minimum of 18 inches from the outer edges of the facility is recommended, unless a greater distance is specified by State or local regulations.(**4**) For relatively close adjacent parallel utility lines (within twice the minimum specified distance laterally from each other), the tolerance zone is determined from the outer edge of the outermost utility line on each side. No portion of the cutting tool for the pilot bore, or the reamer used to expand the hole, is allowed to enter the tolerance zone.

6.4 *Subsurface Utility Engineering*

Subsurface Utility Engineering (SUE) refers to an engineering process for obtaining reliable information regarding belowground utility lines, including types and specific (lateral and depth) locations. The general principles and techniques of SUE are provided in CI/ASCE 38, which defines four general levels of quality based upon the amount and detail of information obtained for characterizing the existing facilities. Quality Level D is the lowest level, corresponding to the least detailed and/or least reliable information, with Quality Level A the highest level, corresponding to the most detailed and/or most reliable information. Although the higher quality levels are more costly to achieve, such information is required for some stages of the mini-HDD construction process.

6.4.1 *Quality Level D* – The minimum level of information is based upon existing utility records. Such information is primarily useful for the purposes of project planning and route selection only.

6.4.2 *Quality Level C* – In addition to the information from Quality Level D, this level includes information obtained from a field visit and a survey of above-ground facilities, such as manholes, valve boxes, posts, etc., and correlation of this information with existing utility records. As a result, the presence of additional belowground utilities, or erroneously recorded location information of utility lines, may be determined. Although such information may be adequate for areas with minimal belowground facilities, or where possible repair is not a major issue, this quality level would typically not be sufficient for proceeding with construction in established areas.

6.4.3 *Quality Level B* – In addition to the information from Quality Level C, the use of surface locators for identifying and marking the existing utility lines, as previously described in Section 6.2, results in more useful, reliable information.

6.4.4 *Quality Level A* – In addition to the information from Quality Level B, the highest quality level includes the use of non-aggressive digging equipment at critical points to expose the utility to determine the precise horizontal and vertical position of underground utilities, as well as the type, size, condition, material, and other characteristics. Mini-HDD operations include such locating procedures at crossings and other critical locations, as described above (Section 6.2.3).

7. Pipe Design and Selection Considerations

Section 7 provides a simplified method for selecting the appropriate strength (wall thickness) for the PE pipe to be installed using mini-HDD. In particular, the procedure presented herein provides a means of selecting the pipe strength to avoid collapse due to hydrostatic pressure at the desired placement depth, as well as to withstand the required pulling loads during installation. This methodology is based upon a simplification of ASTM F 1962, sometimes referred to as the "PPI" method(**1**), which was originally developed by extending an existing method applicable to HDPE pipe(**7**) by incorporating several additional physical considerations. The procedure in ASTM F 1962 has been adopted in several commercially available products for performing initial design calculations for the installation of HDPE pipe.(**8**, **9**) It is recognized that other design tools also exist, which do not necessarily provide equivalent results.(**10**, **11**)

7.1 *Objectives*

The pipe selection process for HDPE pipe is equivalent to determining the minimum wall thickness, or maximum DR value that is sufficient to withstand the long-term operational loads as well as the stresses due to the installation process. Similar to its decision to select HDPE pipe based upon its various advantageous properties, including its compatibility with HDD and other pulling processes, it may be assumed that the owner of the facility will specify a pipe diameter and minimum wall thickness consistent with the long term operation of the facility, based upon independent technical analysis provided by its own staff and/or with industry support. This includes the ability to satisfy internal fluid flow requirements and withstand internal pressure for pressurized lines (water, gas, petroleum, ...) in combination with external pressures due to soil and surface loads (e.g., traffic) at various depths and conditions. Such design considerations are addressed in various sources, including the **"Plastic Pipe Institute Handbook of Polyethylene Pipe**".(**1**) These operational design loads may be assumed to be essentially independent of the installation method. In contrast, the HDD process imposes its unique installation loads due to the tensile forces imposed on the pulling end of the pipe, and the temporary hydrostatic pressure associated with the drilling fluid/slurry at the installed depths. (There is an additional limitation that recommends a minimum depth of cover during the mini-HDD installation, based upon avoiding possible negative effects at the ground surface, such as surface heaving or drilling fluid leakage, as described in Section 8.1.3.) **The appropriate pipe minimum wall thickness will be the greater of the values necessary to safely withstand (1) the various long-term operational (including soil and surface) loads and (2) the short-term installation (and pre-operational) loads associated with the mini-HDD operation.** *The present guidelines primarily focus on the latter issues*.

7.1.1 *Mini-HDD Applications* – ASTM F 1962 provides a methodology for selecting HDPE wall thickness for pipe installed by maxi-HDD, including for river crossings, in order to withstand the installation process. Such operations are typically major events, requiring extensive preliminary investigations and engineering planning, analysis and support, including the use of software tools, as available. For these applications, it is necessary and desirable to perform as accurate engineering analyses as possible, consistent with the present capabilities, in an attempt to reduce the likelihood of significantly over- or under-designing the pipe, either of which may lead to serious economic consequences. Such considerations do not generally arise in mini-HDD applications, which are often part of a large-scale upgrade of facilities in a community or geographic area. Mini-HDD operations typically comprise short, shallow installations and detailed calculations of pipe stresses and loads due to the installation forces are generally not necessary or practical. Thus, the relatively complicated, extensive analyses, such as provided in ASTM F 1962, are not appropriate for the present purposes. However, if the pulling distances are relatively long, or the pipe relatively deep, or a thin-walled product is being considered, it is advisable to perform a limited, approximate analysis to provide confidence in a successful installation. *The present pipe selection guidelines, derived from those in ASTM F 1962, therefore provide a simplified methodology for selecting or verifying the minimum wall thickness consistent with withstanding the installation loads, based upon reasonable assumptions and approximations.*(**12**)

7.2 *Minimum Wall Thickness Based upon Depth*

During the back-reaming and pullback operations (Figure 2), the mini-HDD drilling fluid creates a relatively dense slurry that applies hydrostatic pressure symmetrically around the pipe circumference. Under sufficient hydrostatic pressure, in combination with local drilling fluid pressure, the pipe may deform and collapse. Appendix B provides the collapse strength of HDPE (including PE4710 material, as well as MDPE) pipe for various wall thicknesses (DR) values, under idealized conditions, and also describes the basis for estimating the corresponding allowable (reduced) mini-HDD depths for practical applications. The criteria are based upon a consideration of the installation phase as well as the post-installation (but pre-operational) phase, and incorporate reductions consistent with various degradations described in ASTM F 1962, including a safety factor of approximately 2-to-1.

The information in Appendix B indicates that essentially all the **commonly used wall thicknesses (e.g., DR 7.3 to DR 17) would be sufficiently strong for depths to approximately 15 ft**, the typical limit for mini-HDD installations, assuming HDPE pipe. For depths greater than 15 ft, thinner wall (or MDPE) pipe, or special situations, the adequacy of the product for the application should be verified using the information in Appendix B. In general, the use of very thin-walled product pipe (e.g., > DR 17) is not recommended for typical mini-HDD installations. For example, DR 21 may be adequate for very shallow depths, such as 7 ft or less, but is normally not used. The use of such products requires special practices or precautions (Appendix B.3.5).

As discussed in Section 7.1, the pipe should be independently analyzed by the owner, or its engineering consultant, to verify sufficient strength during the operational phase for withstanding long-term soil and surface loads (e.g., for relatively shallow buried pipe), such as may be imposed for conventional installations, using accepted industry practices.

The allowable depths as determined in Appendix B and indicated above assume an **empty pipe** during the installation and pre-operational phase, in the absence of internal fluids or pressure, which would offset the effects of the external pressure due to drilling fluid/slurry. Although some HDD installations, such as more complex maxi-HDD installations, or possibly some midi-HDD applications, may deliberately allow the pipe to be filled with water or drilling fluid in order to reduce pull loads due to buoyancy effects, as well as the net effective hydrostatic pressure, during installation, such practices are not typically employed in mini-HDD operations; see Appendix B. Depending on the application, however, the beneficial effects, are more likely to be present during the later operational phase, and may be reflected in the long-term design considerations by the facility owner.

7.3 *Minimum Wall Thickness Based upon Pulling Load*

7.3.1 *Safe Pipe Pull Tension* – Table 2 provides the safe pull tension for HDPE **(PE3608)** for a variety of pipe sizes. The safe pulling load (lbs) is based upon a safe tensile stress of 1,350 psi (**1**), as applied to the pipe cross-section. This characteristic accounts for the effective cumulative tensile load duration on the pipe, assumed to be 1 hour, and a significant reduction relative to the nominal tensile test strength of HDPE to limit non-recoverable viscoelastic deformation.(**13**) For MDPE pipe, the tabulated values must be adjusted by a factor of approximately 0.80 and, for PE4710 material pipe, increased by a factor of approximately 1.05.

Table 2 Safe Pull Tension (lbs), HDPE (PE3608) Pipe, 1 hour

Nominal Size	**Pipe Diameter to Thickness Ratio (DR)**						
	7.3	**9**	**11**	**13.5**	**15.5**	**17**	**21***
2-in.	**2,998**	**2,505**	**2,096**	**1,739**	**1,530**	**1,404**	**1,085**
3-in.	**6,511**	**5,439**	**4,551**	**3,777**	**3,324**	**3,049**	**2,356**
4-in.	**10,762**	**8,991**	**7,524**	**6,244**	**5,494**	**5,040**	**3,895**
6-in.	**23,327**	**19,488**	**16,307**	**13,533**	**11,909**	**10,924**	**8,442**
8-in.	**38,399**	**32,080**	**26,844**	**22,278**	**19,603**	**17,982**	**13,897**
12-in.	**86,398**	**72,180**	**60,398**	**50,125**	**44,108**	**40,461**	**31,268**

* Not recommended for typical mini-HDD installations; see Section 7.2.

7.3.2 *Peak Tension* – The following equation provides an estimate of the peak force applied to the pipe as it is pulled throughout the bore hole:

$$\textbf{Tension (lbs) = [Bore Length (ft) x Buoyant Weight (lbs/ft) x (1/3)] x (1.6)}^{n} \qquad (2)$$

The buoyant weight may be conveniently (approximately) determined as

$$\text{Buoyant Weight (lbs/ft)} = \tfrac{1}{2}\,[\text{Pipe Outer Diameter (in.)}]^2 - \text{Pipe Weight (lbs/ft)} \qquad (3)$$

and n is equal to the number (or fraction) of 90° route bends due to cumulative route curvature, or

$$n = n_1 + n_2 \qquad (4)$$

The quantity $\mathbf{n_1}$ **is the effective number of *deliberate/planned* 90° route bends**, and n_2 is the cumulative curvature (90° route bends) due to the unplanned undulations. For example, as illustrated in Figure 6, if a deliberate horizontal (planar) bend of 45° to the right, in order to avoid an obstacle or follow a utility right-of-way, is followed by another 45° horizontal bend to the left, each 45° bend is equal to half of a 90° bend, corresponding to a total of ½ + ½ = 1 full 90° bend; i.e. $n_1 = 1$. The quantity $\mathbf{n_2}$ is described in Section 7.3.2.1.

The pipe weight (lbs per foot) in Equation 3 is available from the manufacturer (based upon the diameter and DR rating), or may be determined by weighing a sample length. Alternatively, Figure 7 may be used to determine the approximate buoyant weight for use in Equation 2.

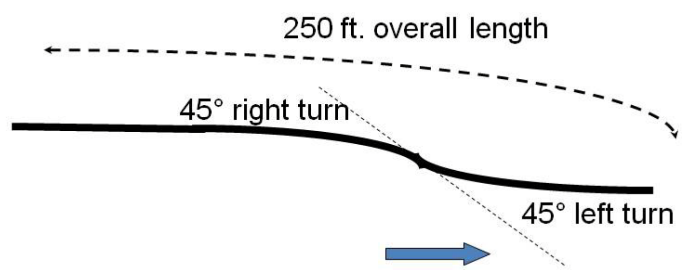

Figure 6 Deliberate/Planned and Unplanned Path Curvature

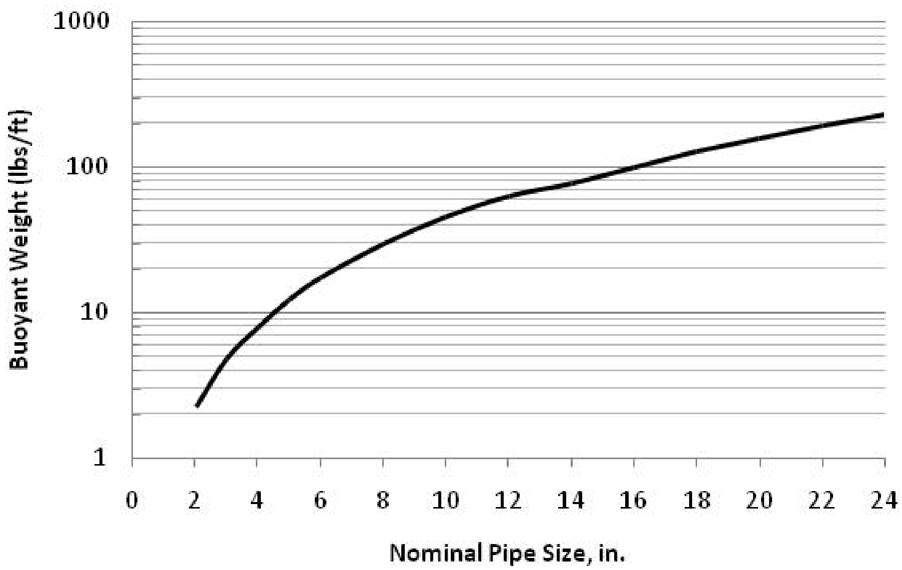

Figure 7 Buoyant Weight of HDPE Pipe
(Source: Outside Plant Consulting Services, Inc.)

7.3.2.1 *Unplanned Path Curvature* – The quantity **n_2 is the effective cumulative *unplanned* curvature**, due to path corrections, and resulting bore hole undulations. Although such a quantity will obviously vary among installations due to soil conditions, expertise of the crew, etc., the following rule may be used to provide a reasonable estimate for a mini-HDD operation using typical **2-inch drill rods**:

$$n_2 = \text{Bore Length (ft) / 500 ft} \qquad (5)$$

i.e., there may be assumed to be effectively one 90° bend, due to path corrections, for each 500 ft of path length. For the path illustrated in Figure 6, the application of Equation 5 results in additional effective route curvature n_2 = 250 ft / 500 ft = ½. Thus, the total route curvature is calculated as $n = n_1 + n_2 = 1 + ½ = 1½$.

7.3.2.2 *Drill Rod Diameter* – The magnitude of unplanned path curvature provided by Equation 5 is intended to be applicable to a typical mini-HDD operation using steel drill rods of approximately 2-inch diameter. Larger diameter drill rods are stiffer and therefore result in more gradual path deviations and corrections, resulting in a reduced level of path undulations. Thus, when applying the above procedures to mini- (or midi-) HDD equipment employing **different diameter (larger or smaller) rods**, the following value of n_2 should be used

$$n_2 = \text{[Bore Length (ft) / 500 ft] x [2-in / Rod Diameter (in.)]} \qquad (6)$$

For example, a 4-inch diameter drill rod would correspond to one 90° bend every 1,000 ft. The results of Equation 6 are illustrated in Figure 8.

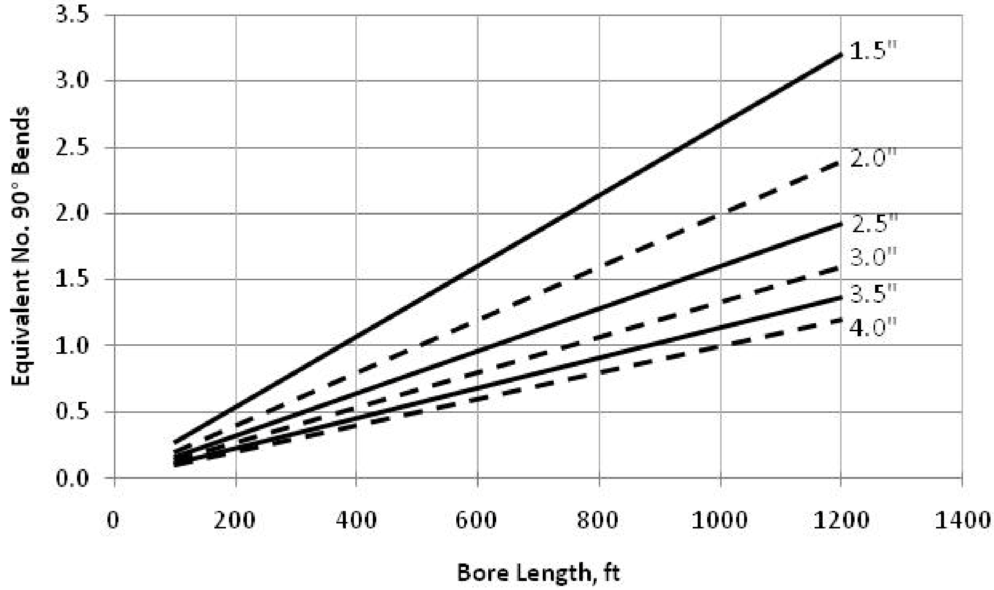

Figure 8 Unplanned Curvature, n_2
(Source: Outside Plant Consulting Services, Inc.)

Although, in principle, this same rule may be extrapolated to maxi-HDD, using corresponding large diameter drill rods, it is considered excessively conservative for such well-planned, well-controlled installations, as discussed below.

7.3.3 *Pipe Selection* – The estimated tension as calculated from Equation 2 must be compared to the safe pulling load of Table 2, for which it is required that the former not exceed the latter; i.e.,

$$\text{Tension (Equation 2)} \leq \text{Safe Pull Tension (Table 2)} \qquad (7)$$

Appendix D provides examples of its application.

The use of Equation 7 provides a reasonable estimate of practical placement distances using mini-HDD, and is analogous to the procedure incorporated in ASTM F 1962 for maxi-HDD installations. *The present mini-HDD calculations, however, will generally result in considerably shorter possible placement distances than that corresponding to application of the methodology and equations provided in ASTM F 1962, which may also include the use of anti-buoyancy techniques to reduce buoyant weight to significantly reduce required pull loads. The shorter placement distances for mini-HDD are also due to the increased drag ("capstan effect") generated by the additional route curvature characteristic of mini-HDD installations, especially that due to path corrections*[3] *(Equations 5 and 6), which are more*

[3] Due to the quantitative significance of the unplanned path curvatures due to path corrections – and the wide variability of such effects – in some cases it may be considered desirable to apply a load factor (> 1.0) to the tension predicted by Equation 2; see Appendix C.4 and Appendix D. This would somewhat further reduce the recommended placement distances.

likely and of greater magnitude and significance than that encountered in typically well-controlled maxi-HDD installations. (See IMPORTANT NOTE.)

Appendix C provides details regarding the technical basis and development for the above methodology.

7.4 *Results*

As discussed above, Equation 7 may be used to predict the pulling load as a fraction of the safe pull tension, as a function of route length, for various situations. Figure 9 illustrates the results for a nominally straight bore (i.e., $n_1 = 0$), for various HDPE (PE3608) pipe strengths, independent of diameter, for typical 2-inch drill rods. For example, based upon pull load only, the DR 11 pipe may be installed in a segment length of more than 1,050 ft, beyond the nominal upper limit of mini-HDD capability, without anticipated problems. Based upon the allowable depth information in Appendix B, the same pipe may be installed as deep as 55 ft, again well beyond the capability of mini-HDD equipment. These results indicate that DR 11 HDPE pipe should have adequate physical strength for essentially all practical mini-HDD applications. DR 11 pipe should also be readily capable of withstanding reasonable field handling, which is not directly considered by the analyses. The corresponding placement limit for DR 11 pipe of the PE4710 material would be somewhat greater (almost 1,100 ft), while the placement distance for the MDPE material is approximately 950 ft. Maximum recommended lengths would be reduced for routes with additional planned bends ($n_1 > 0$); see Appendix D.

IMPORTANT NOTE

The indicated mini-HDD allowable bore lengths in Figure 9 are significantly lower than that achievable with typical maxi-HDD operations. The estimated mini-HDD pull loads assume (1) the absence of water ballast within the pipe, which otherwise greatly reduces the buoyant weight and associated frictional drag, and (2) the presence of additional route curvatures due to path corrections characteristic of typical mini-HDD operations. The latter phenomenon, for example, would significantly reduce practical placement distances for pipes of any material. Thus, the implementation of anti-buoyancy measures and/or avoidance of unnecessary path curvatures, such as representative of well-planned and executed maxi-HDD installations, correspond to practical placement distances several times that shown in Figure 9. ASTM F 1962 may be used to determine such practical placement distances.

Based on Figure 9, all DR values would be acceptable for the nominal limit (600 ft) of mini-HDD, assuming the corresponding depth limits are satisfied (Appendix B).

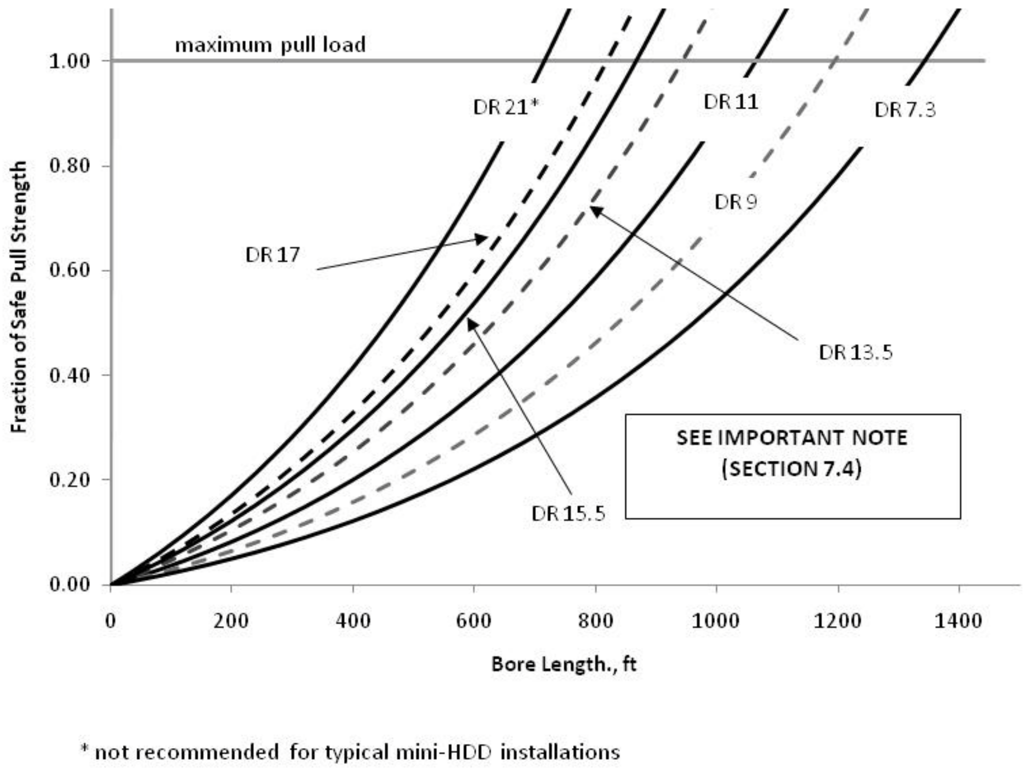

Figure 9 Predicted Mini-HDD Pull Load vs. Safe Pull Tension, HDPE (PE3608) Pipe Nominally Straight Path, 2-inch Drill Rods
(Source: Outside Plant Consulting Services, Inc.)

7.5 *Comments*

A determination that the selected pipe (DR) meets the design criteria as described in Section 7 should not be misconstrued to encourage or allow reduced care or skill in the recommended industry practices, such as summarized in other sections of this guide. The selection procedures are based upon the assumption that proper drilling procedures are followed. For example, a prematurely collapsed bore hole may impose pipe loads significantly greater than those assumed in the present analyses, leading to an unsuccessful installation. Conversely, the determination that a particular pipe size and strength does not meet the present design criteria for a desired bore route does not ensure that the installation will fail. The methodology is based upon a degree of inherent conservatism (see Appendix C) such that it would be expected that, in many cases, individual selected pipes falling short of the criteria would nonetheless be successfully installed by the mini-HDD process, albeit in the absence of the greater assurance provided by the present design practices.

8. Bore Path Planning and Drill Rig Setup

Section 8 addresses the planning of the bore path, consistent with meeting the requirements of the project owner, including placement depth, as well as corresponding drill rig setup information, which is dependent upon the equipment parameters (e.g., allowable drill rod curvature). The information provided supports the design of the bore path in both the vertical and horizontal planes. Commercially available software tools may also be used to help perform these functions.(**8**, **14**)

The information provided in this section comprises elements of the design (e.g., planning bore path trajectory) and actual construction or implementation operations, both of which are typically performed by the contractor for mini-HDD installations of relatively low complexity. For more complex HDD operations, such as maxi-HDD installations, these functions would typically be performed separately, by different individuals or organizations.

8.1 *General Considerations*

8.1.1 *Bore Path Planar (Horizontal Plane) Trajectory* – The owner or its representative (engineer) will provide the general requirements for the path of the product pipe, including position within the right-of-way, identification of road or local obstacle crossings (e.g., laterals or service lines to residence or building), etc. The precise location for each segment, however, will be determined on-site, in advance of the operations, by the selected contractor and utility engineer, depending upon the location of existing utilities and other site specific conditions, consistent with the procedures of Section 6.

8.1.2 *Specified Depths* – The nominal desired depth of placement will also be specified by the owner, including minimum and maximum, consistent with that of existing utilities. The general depths of existing facilities may be initially judged based upon the preliminary investigations, at a corresponding level of confidence, but in critical cases, such as planned crossings of other lines, depths must be visually confirmed (Sections 6.2.3 and 6.4.4). A minimum depth of cover of 36 inches is typically desired to reduce the likelihood for surface movement, drilling fluid penetration to the surface, as well as a tendency for the drill head to rise to the free surface during the initial pilot boring operation, thereby complicating the steering operation, although greater depths are generally recommended depending upon the bore hole size, as discussed below Excessive depths, however, may not be practical for future maintenance activities.

8.1.3 *Minimum Depth of Cover* –Typical industry guidelines recommend a minimum ratio of approximately 10-to-1 for depth of cover to final bore hole diameter to avoid surface heaving effects, for a compaction process in appropriate (compatible) soil conditions.(**15**) The use of pneumatic penetrating missiles ("moles") is an example of a compaction process. In such cases, spoils disposal is absent or minimized and the displaced soil is compacted into the surrounding walls of the hole. Similarly, for mini-HDD installations creating a final bore hole diameter of less than 4-inches, the hole is also primarily formed by a compaction process, with a relatively small amount of soil removed by the drilling fluid. In contrast, for larger holes, the mini-HDD operation utilizes drilling fluid techniques to remove at least a portion of the spoils during the initial boring or reaming operations. A disproportionately greater volume of drilling fluid would be required to remove the soil from the bore hole in a soil removal process, in comparison to a compaction process. It is the responsibility of the contractor to understand and utilize drilling fluid technology properly, including to form the bore hole without surface heaving, and with little or no fluid penetration at the surface.

Figure 10 shows recommended depth of cover for conditions compatible with the nominal 10-to-1 ratio for a compaction process, as well as a 5-to-1 ratio for a mini-HDD spoils removal process, at a minimum of 36 inches, as a function of final bore hole diameter. It is noted that the final bore hole size for mini-HDD operations is nominally recommended to be at least 50% greater than the pipe outer diameter(s). Such recommendations for depth of cover are recognized as only a guide, since the tendency for subsequent ground movement, as well as penetration of drilling fluid to the surface, and other possible effects, are dependent upon local soil characteristics and construction variables.(**3**, **16**) However, if a lower depth of cover than that indicated in Figure 10 is necessary, it is recommended that the final bore hole size be gradually enlarged using several (one or more) pre-reaming passes, prior to the final pullback of the pipe, accompanied by careful monitoring of the drilling fluid pressure; see Section 9.3.1.

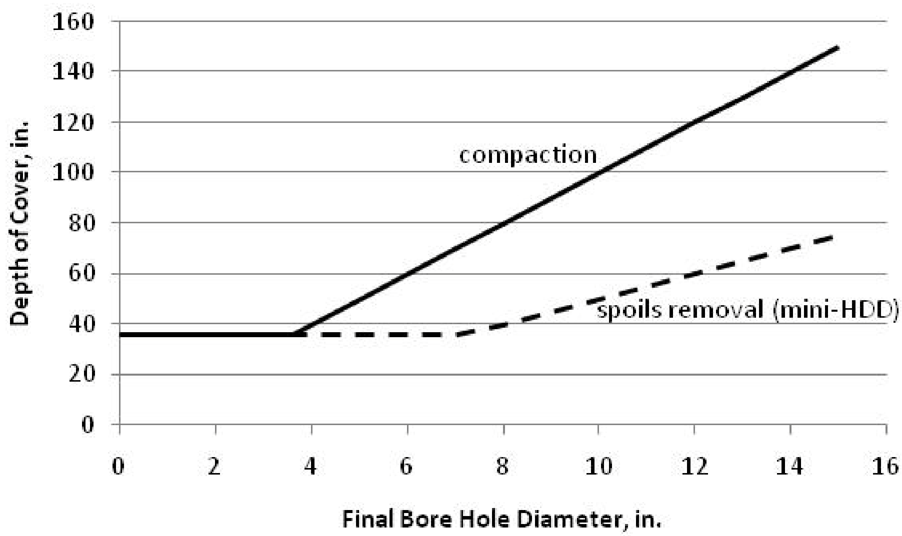

Figure 10 Recommended Minimum Depth of Cover
(Source: Outside Plant Consulting Services, Inc.)

8.2 *Steering & Drill Rod Constraints*

The planned path must be consistent with the steering capability of the drill string, based upon the allowable radius of curvature (bend radius) of the steel drill rods, including the presence of joints, as specified by the manufacturer of the rods; see Section 3.3. The bending limitation considers the yield strength of the steel material, as well as the fatigue characteristics of the rods at lower stress levels. A drill rod may be able to withstand a single bend cycle corresponding to a relatively sharp radius of curvature, but the rotation of the rod during the boring operation results in repeated flexure which may eventually cause fatigue failure due to the cumulative effect of a large number of such cycles. The diameter of the drill rod is the primary parameter affecting its allowable bend radius, and corresponding steering capability. The specific drill rod characteristics are reflected in the detailed information provided in Section 8.4.

8.3 *Product Pipe Constraints*

The allowable radius of curvature (bend radius) of the product pipe will be provided by the pipe manufacturer. For pipe constructed from plastic or other very flexible material, the bend radius limitation of the drill rods is sufficiently large to be compatible with that of the product pipe. In particular, PE pipe is sufficiently flexible such that the corresponding bends and path curvatures imposed on the pipe during an HDD installation will not be significant.

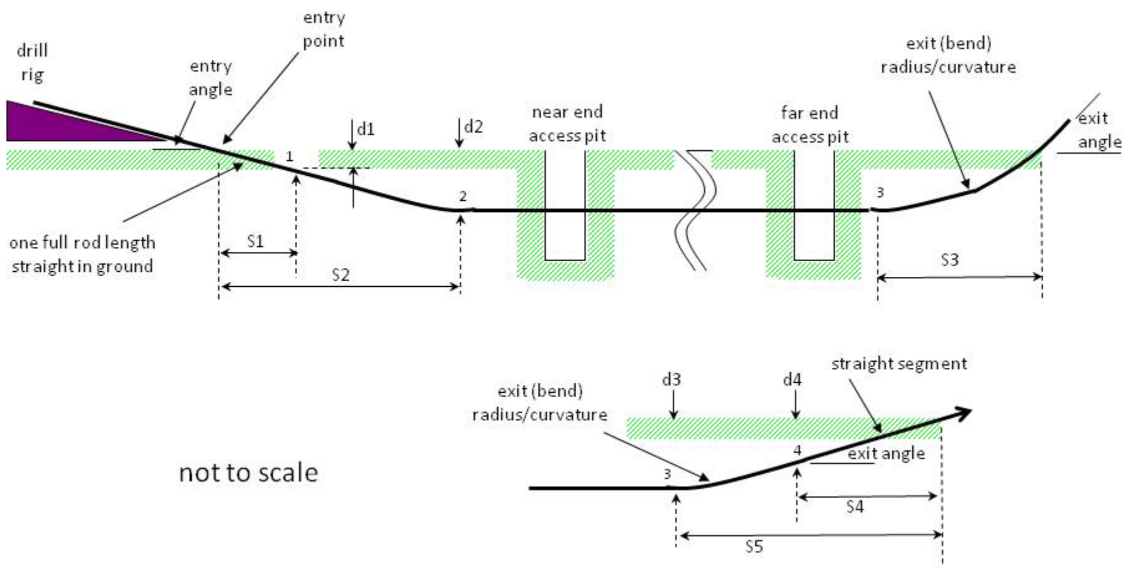

Figure 11 Drill Rig Setup and Related Distances
(Source: Outside Plant Consulting Services, Inc.)

8.4 *Bore Path Profile (Vertical Plane)*

Figure 11 illustrates a typical mini-HDD bore profile trajectory, including occasional pits along the route. These pits may be required for pipe splicing, completing lateral connections, or to expose existing utilities. The pits may also be useful for collecting drilling fluid from the boring or reaming operations. The characteristics of the drill rods, as described in Section 3.3, including bending capability and rod length, and the entry angle of the rod to ground surface, will essentially determine the depths achievable at the beginning of the bore path. Although Figure 11 is conveniently shown for a level ground surface, the information presented may be readily interpreted relative to a uniformly sloped uphill or downhill surface.

8.4.1 *Angle Measurement* – In HDD operations, the angle of the drill rig (entry angle) relative to the surface, as well as the local angles established at the drill head during the pilot boring process, determine the path of the bore hole. The angles may be in a vertical plane (elevation), such as the drill rod entry angle, or in a horizontal plane (azimuth), during turns, or a combination of both directions. The angle may be commonly measured in degrees or, for elevation angle, in percent grade (vertical rise or drop per unit horizontal distance, times 100). **The angle in degrees is approximately equal to half the percent grade**, as illustrated in Figure 12. Typical drill racks allow an entry angle in the range of 5° – 25° (10% – 45% grade).

8.4.2 *Setback Distance* – In order to achieve a specified depth at a particular point towards the beginning of a pilot bore operation, the front of the drill rig must be located an appropriate distance rearward from the point of interest. This setback distance depends not only upon the depth at the point of interest, but also on the desired orientation (percent grade) of the bore at that point. In Figure 11, point 1 is directly along the entry path of the drill rod, at which the resulting bore path is inclined at the entry angle, and for which the setback distance corresponding to reaching the depth d1 is designated as S1. S1 represents the minimal setback distance for achieving a specified depth, independent of the orientation of the bore path, beyond which the trajectory may become level.

Knowledge of such setback requirements is important with respect to determining the location and position of the drill rig, consistent with available space or feasible or convenient setup locations.

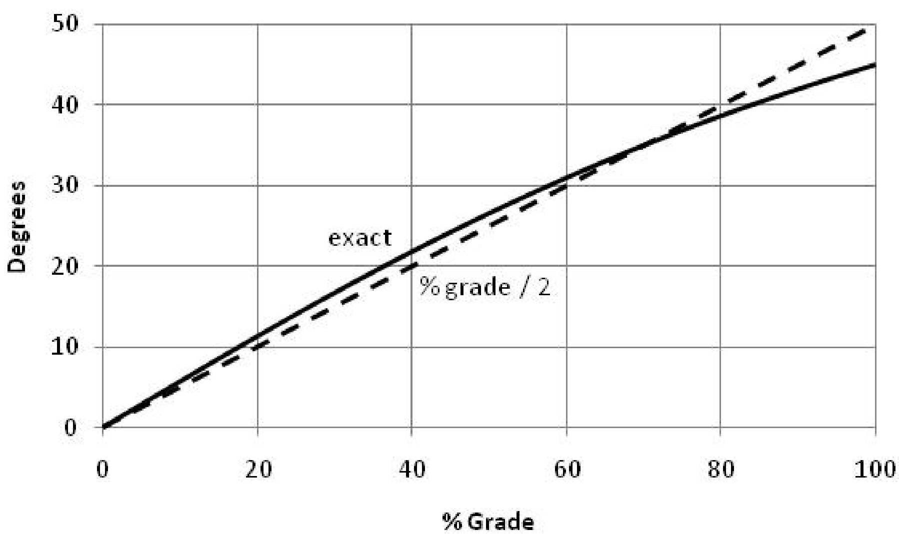

Figure 12 Degrees vs. Percent Grade

8.4.2.1 *Setback Distance to Level Trajectory* – Beyond point 1, the drill rods are steered such that the bore path trajectory becomes level at point 2 (Figure 11), correspond to a depth d2 and setback distance S2. The distance S2 is significantly greater than the corresponding to S1, assuming the same depth of interest. The greater distance is required to allow the drill rods to establish an upward curvature consistent with achieving a horizontal orientation. In this case, it is also assumed that the bore is initiated along a straight path, at the entry angle, without any curvature or steering for a distance equal to one full drill rod length (e.g., 10 ft, for typical mini-HDD equipment) in the ground.(**17**) This is a recommended practice to avoid bearing loads at the front of the drill rig. The upward desired curvature is introduced during the placement of subsequent drill rods.

8.4.2.2 *Minimum Depth for Level Trajectory* – Due to the recommendation that the first drill rod be placed in the ground without any curvature or steering, and the subsequent path curvature consistent with the bending capability of the rod, there is a minimum depth at which the trajectory will become level, depending upon the entry angle and rod characteristics. This depth is designated as $(d2)_{min}$.

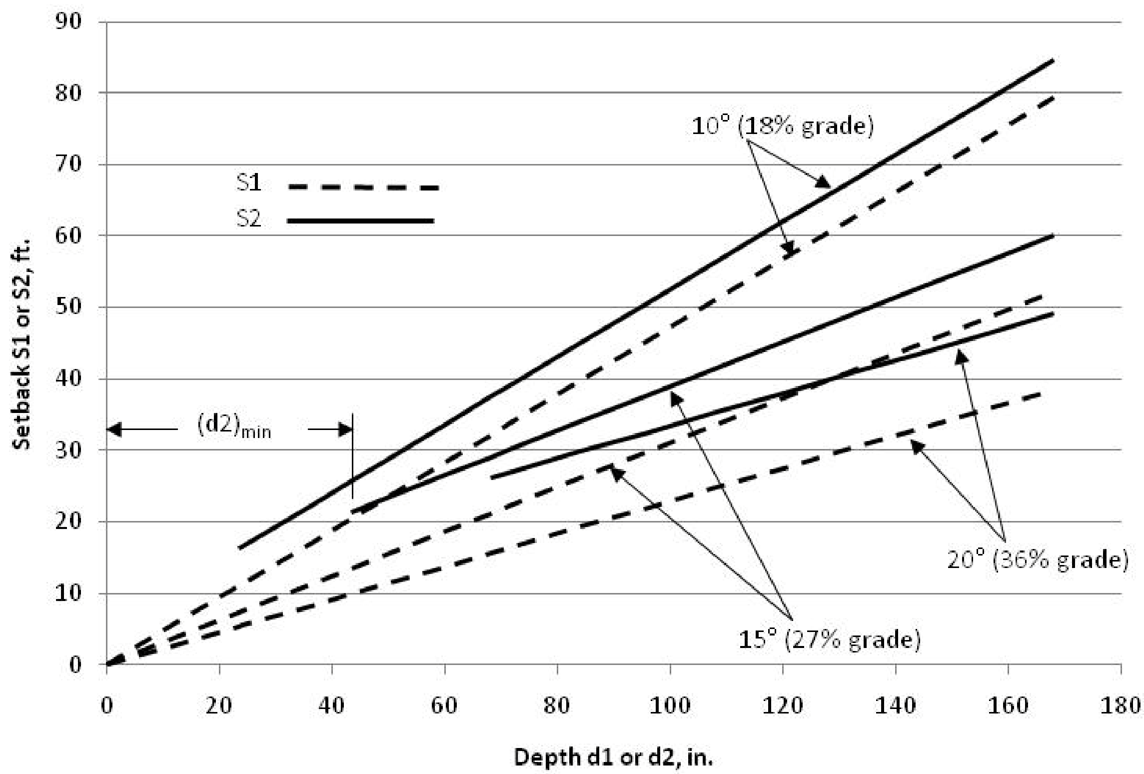

Figure13 Drill Rig Setback Distance
Drill Rods: 6 ft Long, 60 ft Radius of Curvature
(Source: Outside Plant Consulting Services, Inc.)

8.4.3 *Setback Guidelines* – The above setback distances S1 and S2, as a function of depth, d1 or d2, respectively, are shown in Figures 13, 14 and 15 for several drill rods, including lengths of 6 ft, 10 ft and 15 ft, with corresponding allowable radii of curvature of 60 ft, 100 ft and 150 ft. These figures also indicate the minimum depth $(d2)_{min}$, and corresponding minimum setback distance S2, at which the trajectory may become level.

Thus, for the typical 10 ft drill rods of Figure 14 and an entry angle of 15°, a depth d1 of 72 inches will be achieved at a setback distance S1 of 22 ft based upon an inclined (non-level) trajectory. In comparison, a setback distance S2 of 36 ft is required to reach the same depth (72 inches) at a level trajectory. Figure 14 also indicates that this particular drill rod (10 ft length and 100 ft allowable radius of curvature) and entry angle are not consistent with achieving a level trajectory at depths shallower than 72 inches. If it is necessary to remain within a specified maximum depth along the entire path, including in the vicinity of the entry point, a shallower entry angle and/or sharper bend radius, would be required. If necessary, the trajectory could exceed the desired depth at the beginning of the bore, and rise to the proper depth further along the path, at a correspondingly greater setback distance.

The results indicated in Figures 13 – 15 are based upon steering consistent with the specified physical characteristics of the drill rods. For reduced (less severe) bending or curvatures, and/or longer length rods, the distances S2 required to achieve a level trajectory at a given depth, will be greater than that indicated.

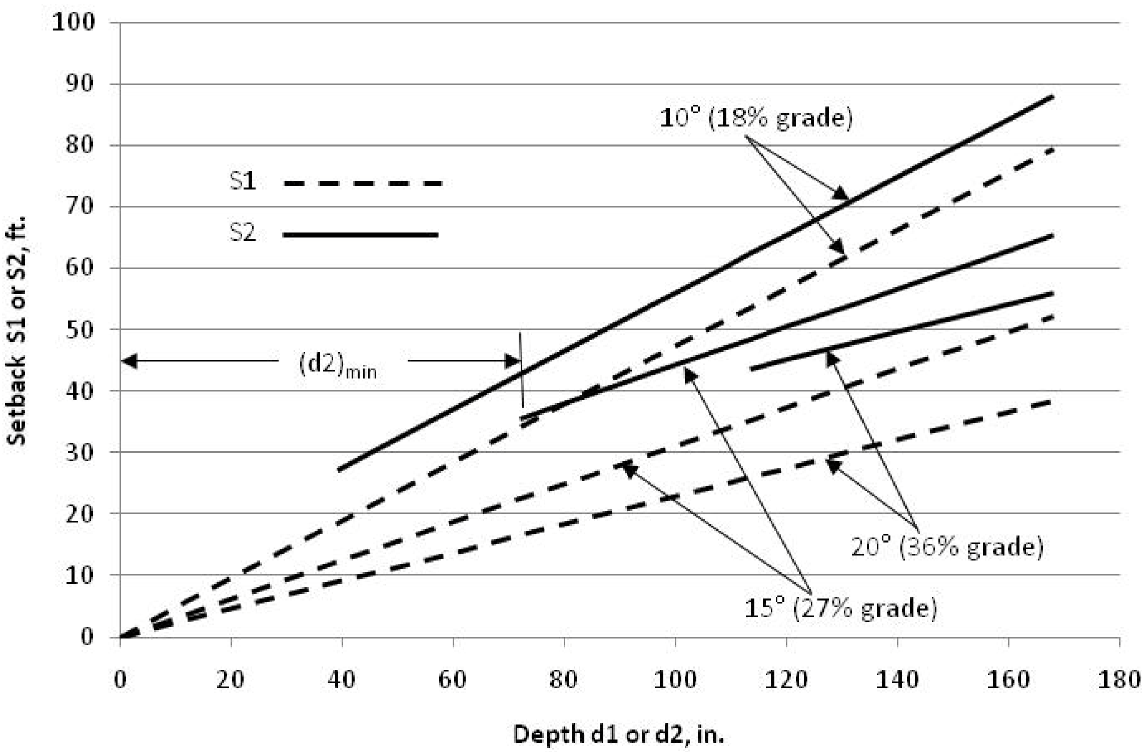

Figure 14 Drill Rig Setback Distance
Drill Rods: 10 ft Long, 100 ft Radius of Curvature
(Source: Outside Plant Consulting Services, Inc.)

Appendix E provides additional information on setback distances, including formulae that may be used to generate additional setback guidelines for drill rods with differing characteristic than those considered in Figures 13 – 15. Appendix F provides examples in their application.

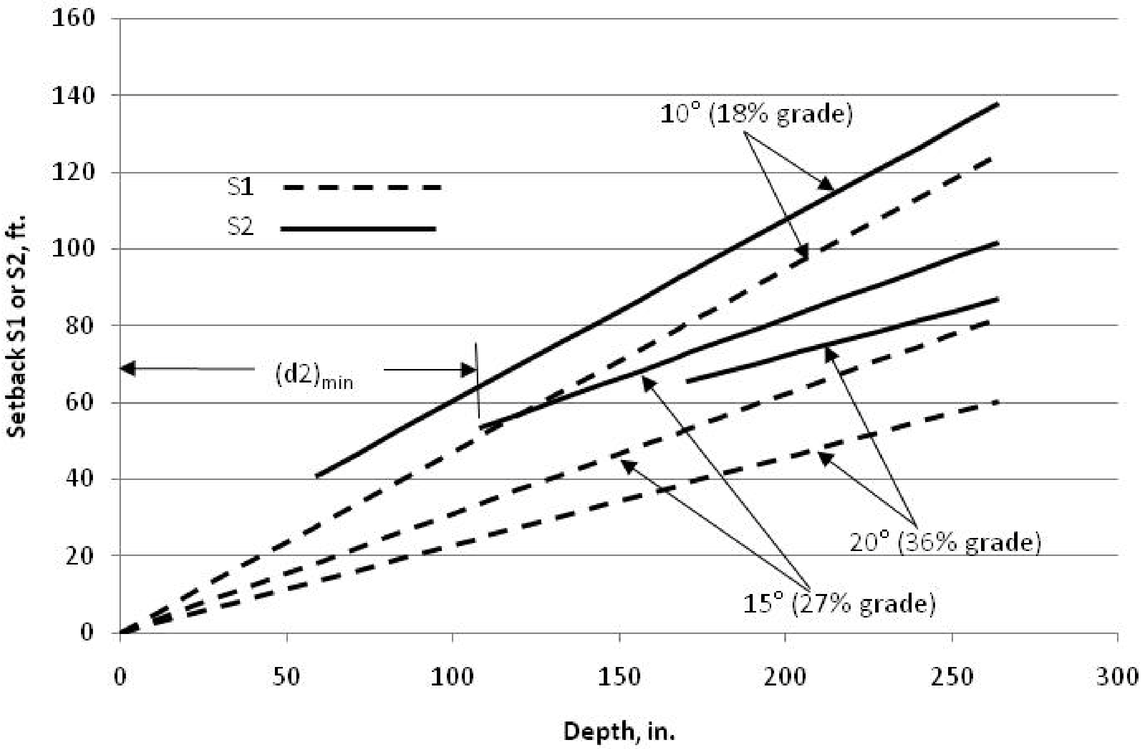

Figure 15 Drill Rig Setback Distance
Drill Rods: 15 ft Long, 150 ft Radius of Curvature
(Source: Outside Plant Consulting Services, Inc.)

8.4.4 *Depth/Setback Implications* – If the determined setback distances or drill rod angle consistent with the project *maximum* depth specifications are not practical, consideration should be given to receiving approval from the owner allowing increased depths in the vicinity of the entry point, with a gradual transition to the preferred depth along the balance of the route. If necessary, smaller diameter, more flexible, drill rods (e.g., Figure 13) may be considered if consistent with anticipated thrust and torque loads. Smaller bend radii than that recommended by the rod manufacturer may be considered by the contractor if it is recognized that reduced service life may result for the drill rods. If the steering conditions in the soil preclude a sufficiently sharp upward turn, mechanical assistance may be provided at the entry pit to apply an upward bending moment on the rod.

8.4.5 *Distance to Rise to Surface from Level Trajectory* – Figures 16 – 18 show the horizontal distances required for the head of the drill string to reach the surface from a point 3, on a level trajectory, from its present depth d3, as indicated in Figure 11. The minimum distance to reach the surface, designated S3, corresponds to that of steering upward at the minimum allowable radius of curvature of the drill rod. Alternatively, if it is desired to exit the ground at a specific angle, a greater horizontal distance will generally be required. For example, it may be desired to exist at a relatively low angle to facilitate the subsequent pipe entry into the bore path, which will require a greater horizontal rise distance, designated S5, than for a larger angle.

Knowledge of such distances is important with respect to determining the location for feeding of the product pipe into the bore path during the pullback phase. Such locations must be compatible with available space at the far end of the bore path.

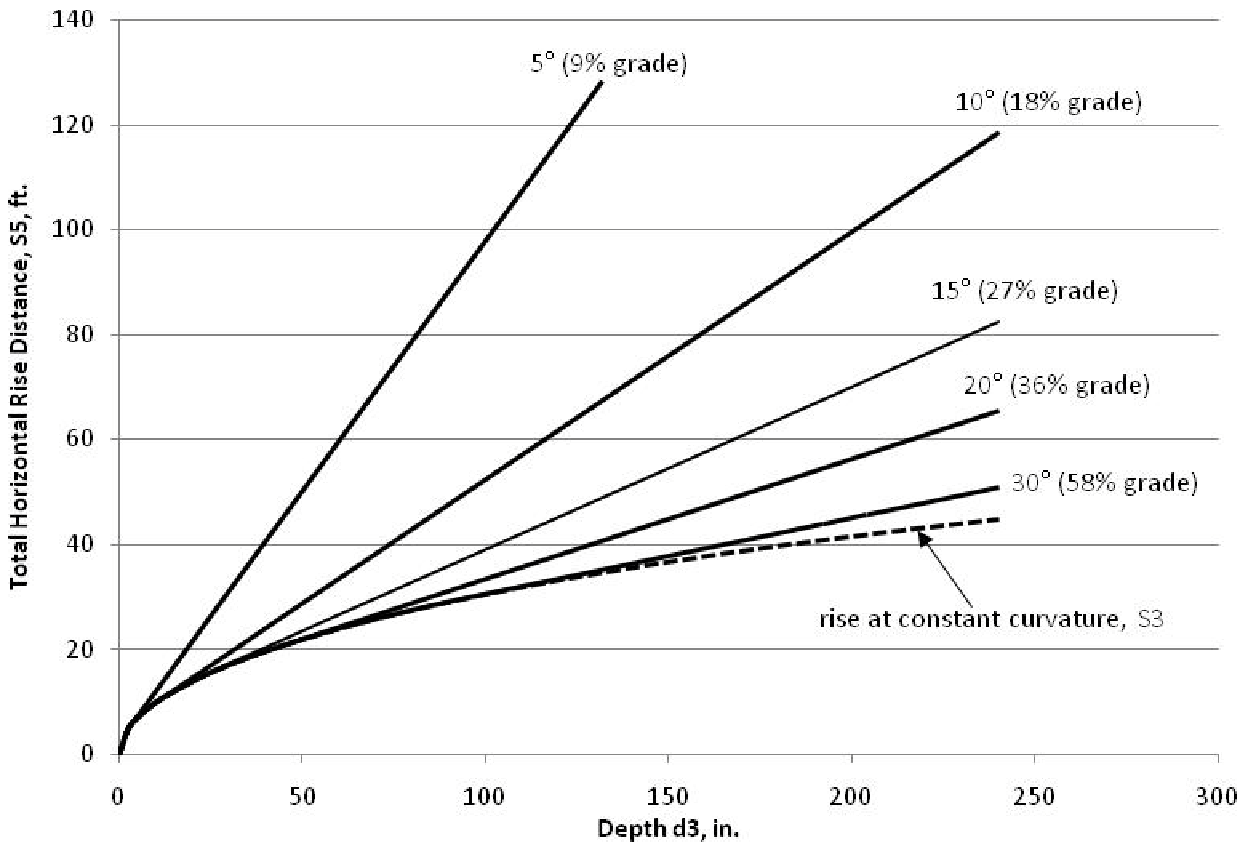

Figure 16 Distance to Rise to Surface
Drill Rods: 60 ft Radius of Curvature
(Source: Outside Plant Consulting Services, Inc.)

Assuming the typical drill rod of Figure 17 (100 ft allowable radius of curvature[4]), the shortest rise distance, S3, from a level trajectory at 100 inches depth, d3, is approximately 40 ft, in comparison to approximately 100 ft (S5) for an desired exit angle of only 5°; see Figure 11. The maximum possible exit angle is limited by the depth. For this drill rod, relatively high exit angles (e.g., greater than 20°), are not possible at depths less than approximately 72 inches. Figure 19 illustrates exit angles for a rise at the indicated constant curvature.

[4] The rod length is not a factor for the distance to rise to surface.

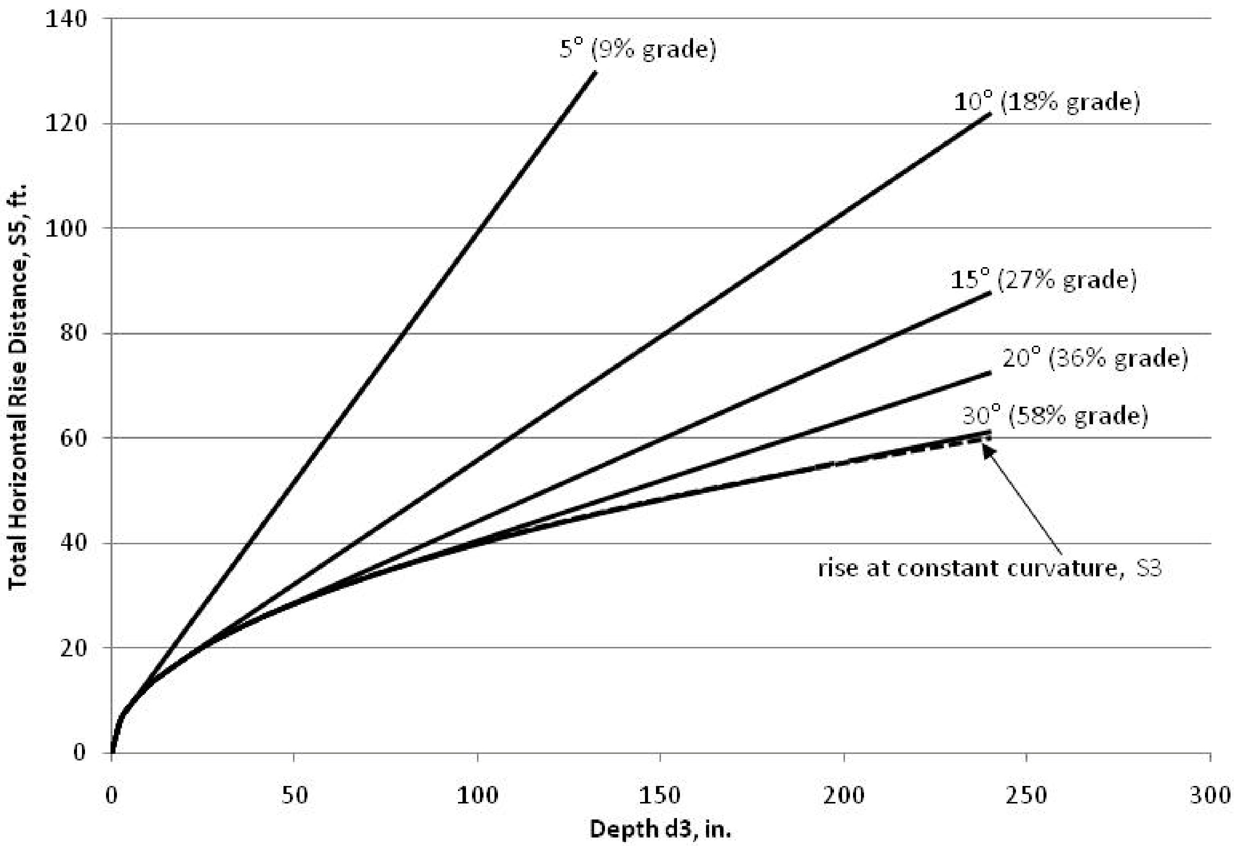

Figure 17 Distance to Rise to Surface
Drill Rods: 100 ft Radius of Curvature
(Source: Outside Plant Consulting Services, Inc.)

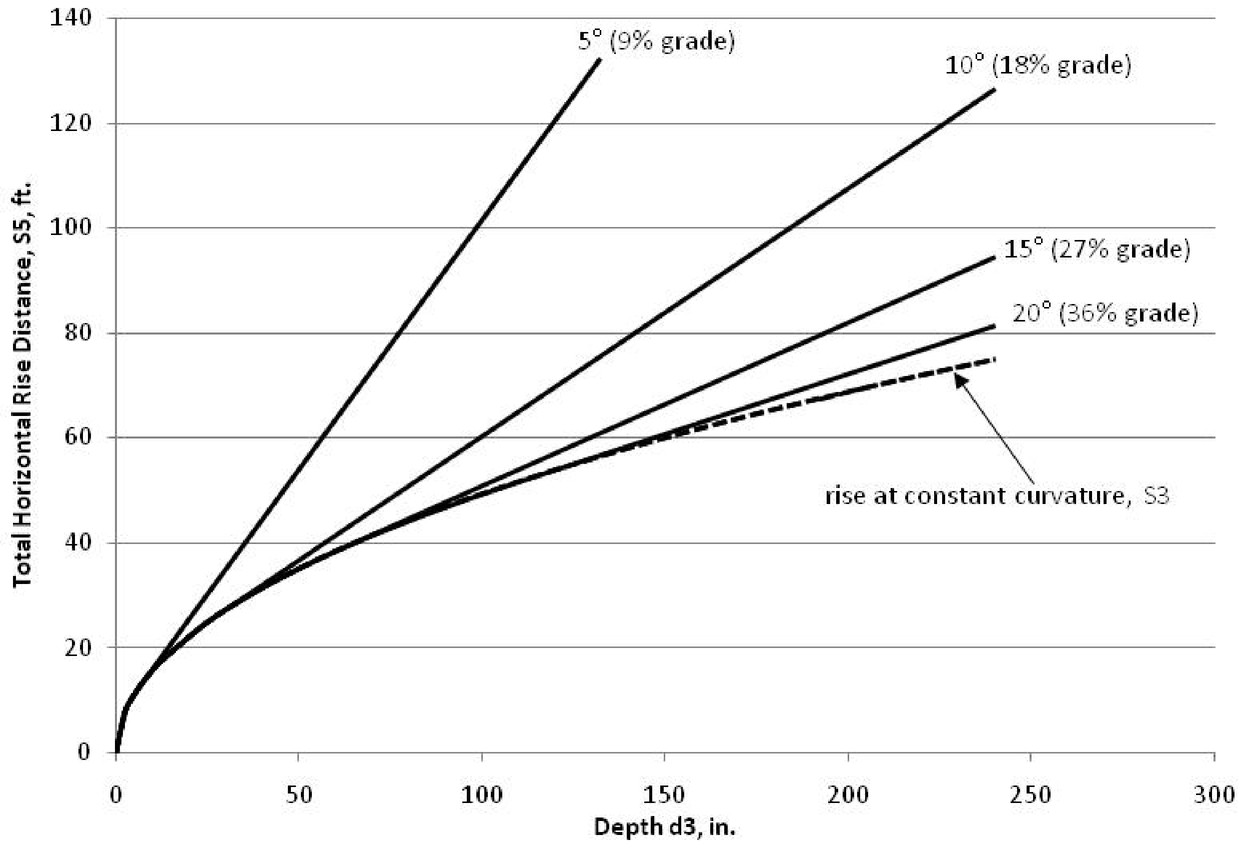

Figure 18 Distance to Rise to Surface
Drill Rods: 150 ft Radius of Curvature
(Source: Outside Plant Consulting Services, Inc.)

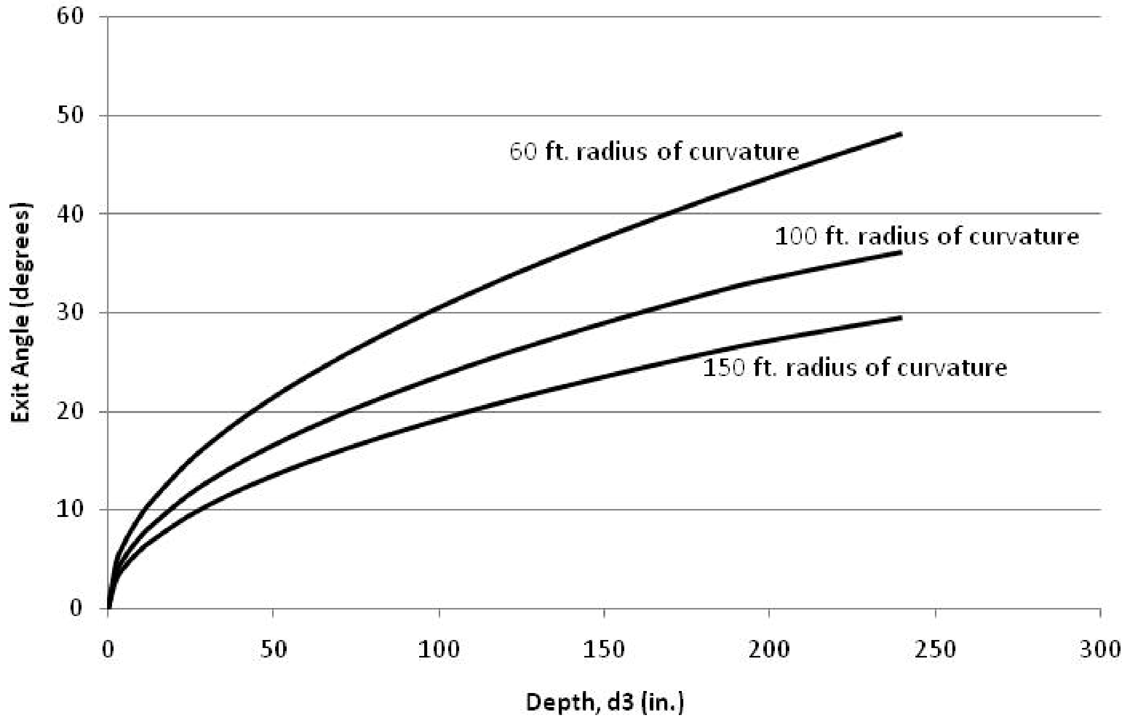

Figure 19 Exit Angle for Rise at Constant Curvature
(Source: Outside Plant Consulting Services, Inc.)

8.4.8 *Distance to Exit at Specified Grade* – Considering a drill head oriented at an upward grade, Figure 20 shows the horizontal distance, S4, required for the head of the drill string to reach the surface from a point 4, on an inclined path, from its present depth d4; see Figure 11. The information may also be used to determine the horizontal distance corresponding to a specified rise distance from any point on an inclined path. The present d4 and elevation angle is available from the drill head locating system. The vertical rise results in Figure 20 directly correspond to the local percent grade (fraction of horizontal distance) of the trajectory.

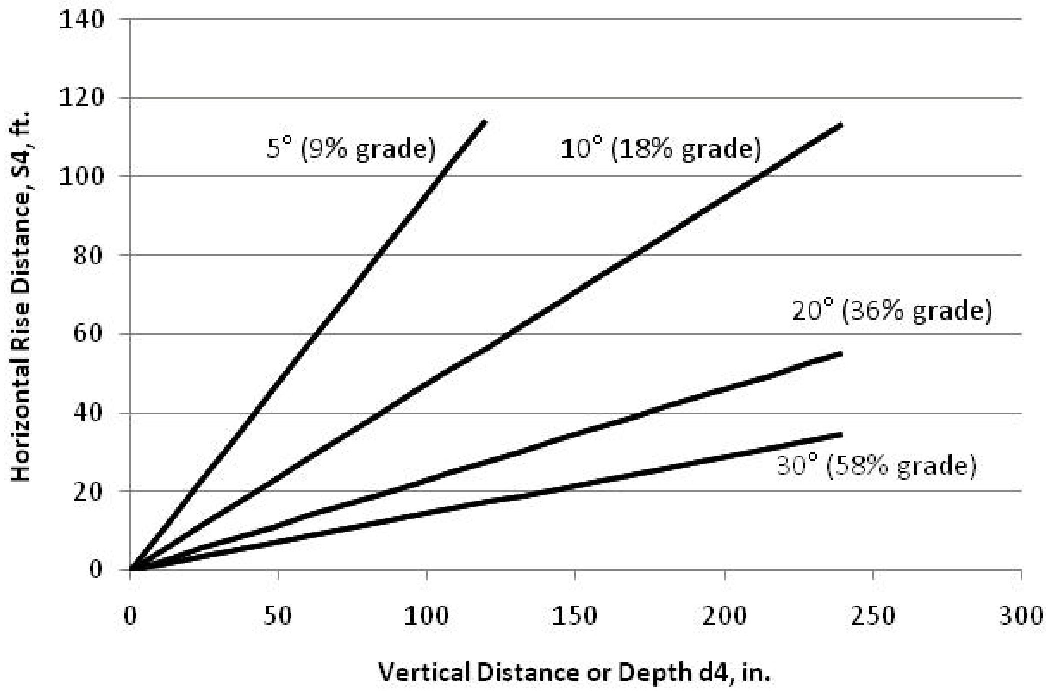

Figure 20 Horizontal Distance to Rise Vertical Distance or to Surface

Appendix E provides additional details and formulae that may be used to generate guidelines for cases not explicitly considered in Figures 16 – 20. Appendix F provides examples in their application.

8.5 *Bore Route (Horizontal Plane)*

In plan view, the bore path should be as direct as possible, consistent with available right-of-way, utility architecture, existing utilities and other obstacles, as well as the capability of the mini-HDD system, considering the recommended bend radius of the drill rods and ability to steer within the soil. This includes paths for pipes for distribution lines or for services to individual residences or structures. In many cases, a visual survey and simple sketch may be sufficient for defining the bore route. In more complicated situations, a transit or other type survey may be required. In general, a proposed bore path plan view and profile layout should be prepared indicating the surface grade and important surface features, location of existing below ground utility lines, reference points, etc. The bore path layout should also show anticipated access pits for utility connections or lateral service lines, and the bore depth of the pipe to be placed, especially at critical points such as access pits, and at other reference points along the route.

8.5.1 *Surface Grade* – For convenience, previous discussions (Section 8.4) are based upon a level grade. For relatively regular surfaces, the actual (average) grade may be approximately determined using a taut string, or a series of such, spanning the distance between the entry and exit points. The string may also provide a reference for verifying the proper depth during the actual operation in the presence of minor surface depressions or irregularities (compared to depth), and serves as a basis from which to interpret the guidelines of Section 8.4, which assume a uniform level surface grade. In general, the bore should attempt to follow a path at the nominal specified depth below the average surface profile. For large surface depressions or mounds (e.g., of height greater than the depth of interest and extending over a long expanse, on the order of the drill rod bend radius or greater), including peaks and valleys, the bore should attempt to follow a path at the specified depth below the local average surface grade.

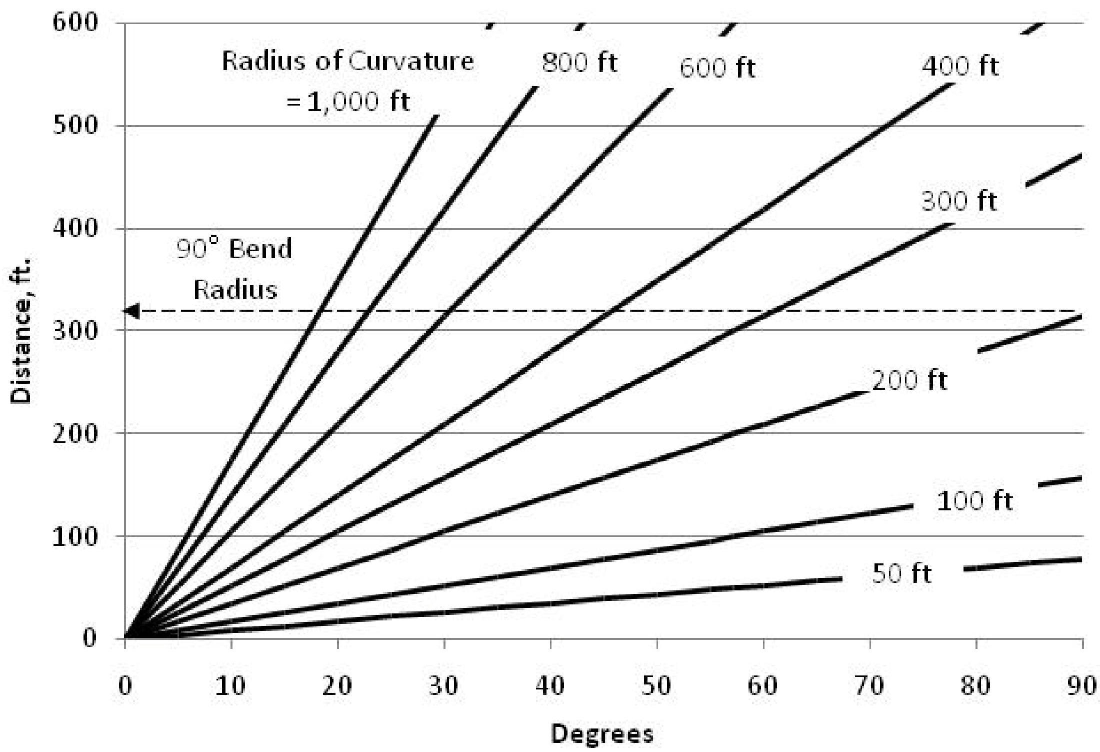

Figure 21 Radius of Curvature for Angle and Distance
(Source: Outside Plant Consulting Services, Inc.)

8.5.2 *Path Curvature* – Although the presence of obstacles or ROW geometry may impose deliberate path curvature (Figure 6), the bore plan should attempt to minimize such deliberate bends and curves, whether left/right or up/down. Such trajectories are difficult to follow and may lead to over-steering and excessive bends, resulting in increased stresses in the drill rods and greater required pulling forces during the installation of the pipe; see Section 7.3. The average radius of curvature, or 90° bend radius (see Section 3.3), of a path segment may be estimated based upon the distance along the path segment and the angular change, as follows:

$$\text{Radius of Curvature (ft)} = 57.3 \times \text{Distance (ft)} / \text{Angle (deg)} \qquad (8a)$$

$$90° \text{ Bend Radius (ft)} = 90 \times \text{Distance (ft)} / \text{Angle (deg)} \quad (8b)$$

Thus, a change of 20° along a 100 ft path segment corresponds to a path radius of curvature of 287 ft and a path 90° bend radius of 450 ft. Figure 21 illustrates the radius of curvature corresponding to the angular change and distance along the path. The 90° bend radius, defined as the distance for accomplishing a 90° angle, is equal to the radius of curvature multiplied by 1.57; see Section 3.3.4, Equation 1b. For example, the 90° bend radius corresponding to a 200 ft radius of curvature is equal to 200 ft x 1.57 = 314 ft, which is seen to agree with the distance traversed for a 90° bend, as indicated in Figure 21.

8.5.3 *Proposed Bore Path* – Figure 22 shows a sample bore plan, comprising a straight path in the planar view, which may be used as the basis of subsequent as-built drawings, illustrated in Figure 24.(**17**) Although not explicitly shown in the sample, reference points should be included.

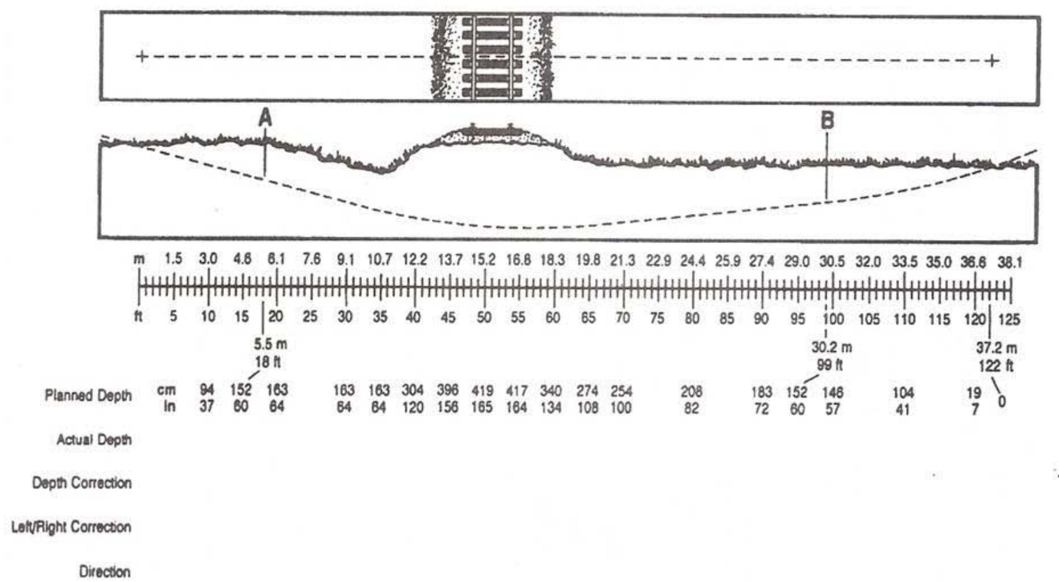

Figure 22 Initial Bore Plan
(Source: Ditch Witch®)

8.5.4 *Accuracy and Tolerance* – Section 6.3 (Figure 5) discusses the tolerance zone, with respect to existing facilities, which must be avoided by any part of the drill or reamer. To help maintain the required separation, it is recommended that the proposed bore path, including the outer edge of the cutter/reamer, be an additional 18-inches laterally offset from the outer edges of the tolerance zone, corresponding to a total 36-inch initially planned separation. For the case of the bore path crossing an exposed utility, adequate physical separation may be visually verified as the drill head or reamer passes above or beneath the existing line. In the rare event in which it is not feasible to expose an existing utility at a crossing, the position of the line must be otherwise accurately established or verified and the proposed bore path must **provide a minimum of 24-inches separation, or greater if required by State or local regulations**, between the outer edge of the cutter/reamer and the closest portion of the utility, whose depth has been determined as well as reasonably possible during the identification and location process (Sections 6.2 and 6.4). The owner may place additional restrictions on the allowed deviation from the proposed bore, in both vertical and horizontal directions. (See Section 9.5.1.) Soil conditions, including cobbles and other encountered obstacles, as well as attempts to conform to relatively sharp bends, may result in unintentional bore path deviations. More frequent verification of the position of the drill head during the pilot bore phase will help detect potential discrepancies as soon as possible, and facilitate path corrections; see Section 9.4.3.

9. Implementation

Section 9 discusses the overall sequence of operations, and appropriate procedures, during the actual pipe installation. These operations include drill rig positioning, pilot boring, tracking, steering, reaming and pullback. It is beyond the scope of these guidelines to provide detailed operational procedures for the various mini-HDD and auxiliary equipment. It is therefore assumed that the contractor has provided evidence of proficiency (see Section 5.9).

9.1 *Drill Rig Positioning*

The drill rig unit is positioned as determined in Section 8, consistent with the desired product pipe depth and bore route. The unit must be properly secured, typically by means of anchors driven into the ground, by impact or screwing, located at the front of the machine. Proper anchoring is especially important for soft or sandy soils. It is important to ensure that there are no utility lines or other facilities (service lines, sprinkler systems, ...) that may be damaged immediately beneath the anchors, which are driven several feet into the ground.

9.2 *Pilot Bore*

Figure 1 illustrates the initial pilot bore operation, including the drill head and assembly of drill rods. The actual size and type drill head selected should be appropriate for the soil conditions, considering the ability to penetrate and accomplish the desired steering. Depending upon the mini-HDD equipment, soil penetration is accomplished using high pressure, low volume fluid jets and/or mechanical cutting. Section 3.3, Section 8.2 and Appendix A discuss bending limitations of the drill rods and their implications for a mini-HDD operation. Overly aggressive steering corresponds to excessive bending of the rods, which may shorten their life due to cumulative fatigue as the drill rods rotate in a bent configuration. In addition, in order to minimize lateral bearing loads at the front of the rig, and avoid potential difficulties in the insertion of additional rods, steering should not be attempted until one rod length (e.g., 10 ft) has been inserted straight (while rotating) into the ground. Proper care and handling of the drill rods is important to avoid damage during the insertion or removal of rods from the drill string, and should conform to the manufacturer's guidelines. In general, the threads must be coated ("greased") when inserted into the drill string. Improper torque during connection may result in loosened, and possibly disconnected, rods.

9.3 *Drilling Fluid Usage*

Drilling fluids are used to remove cuttings and spoils and help support and stabilize the bore hole, as well as to provide possible cutting assistance during the boring or back-reaming operations. The fluids provide lubrication during the various phases of the HDD process (pilot boring, reaming, pullback), to reduce the required torque and thrust or pullback loads imposed on the equipment. Reduced friction is an important factor in minimizing the required tensile forces applied to the product pipe (Appendix C). The drilling fluid also cools the drill head to avoid premature damage to the cutters and/or failure of the internal transmitter. The volume of fluid required depends upon the size of the pilot bore and especially that of the subsequent expanded hole (Section 9.6), and on the role of the fluid in accomplishing the ground penetration. If mud motors are required, such as for rocky conditions, considerably greater volumes of drilling fluid will be required, for which the use of drilling fluid recirculating systems is recommended. An important element in the proficiency of the crew is an adequate understanding of the proper use of drilling fluids, and the appropriate types for various ground conditions.(**3**, **18**)

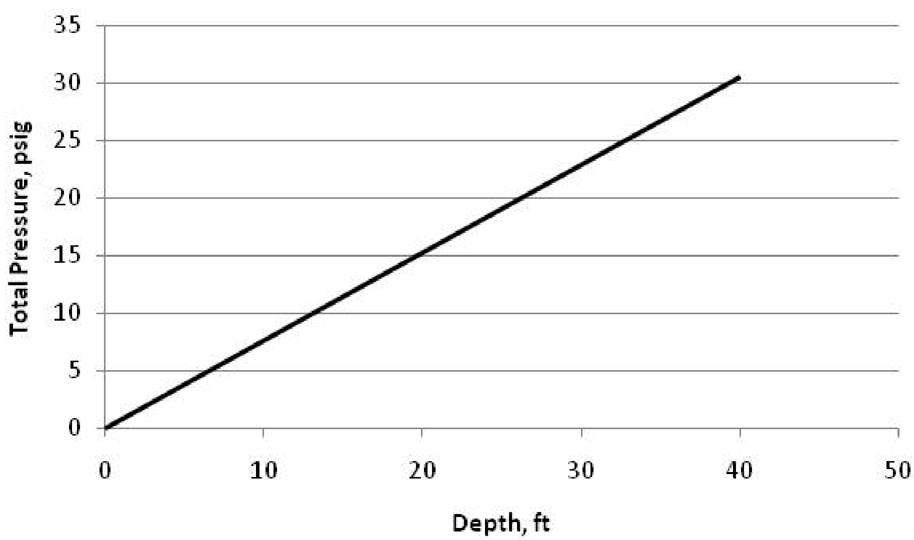

Figure 23 Recommended Limit on Total Drilling Fluid Pressure
(Source: Outside Plant Consulting Services, Inc.)

9.3.1 *Drilling Fluid Pressure* – A possible problem in HDD operations is the appearance of drilling fluid at undesired surface locations, or possible heaving, sometimes as a result of excessive drilling fluid pressures. Excessive applied drilling fluid pressures may also contribute to premature pipe collapse (Appendix B). Figure 23 may serve as a guide for the upper limit on the total pressure to be maintained within the bore hole, including that due to the weight of the drilling fluid/slurry and the incremental pressure applied at the drill head or back-reamer (Section B.3.4). Additional information and recommendations may be obtained from other industry sources.(**3**) Commercially available equipment is available to monitor drilling total fluid pressure and thereby help avoid impending problems.(**19**)

9.3.2 *Inadvertent Fluid at Surface* – Due to the combination of drilling fluid pressure and possible local fissures in the soil, it is possible that fluid may penetrate to the surface at an intermediate point along the bore path. In such cases, the material should be promptly remediated or removed. In order to avoid uncontrolled surface penetration in sensitive areas, several deliberately placed vertical holes from the surface to the bore hole can serve as a vent to locally relieve the fluid pressure. Such procedures may be appropriate at the edges of paved areas including driveways. Any vented fluid should be cleaned immediately after completion of the installation of the pipe, and the vent holes re-filled. See Section 9.10 for additional information.

9.3.2.1 *High Risk Situations* (**20**) – Extra caution should be employed in situations with a high risk of inadvertent returns:

- Fractured rock (pre-existing flow paths or presence of joints)
- Coarse grained permeable soils (gravel, cobble and boulders)
- Considerable elevation differences between the entry side and pipe side
- Areas where HDD vertical depth of cover is insufficient
- Artificial features (existing exploratory bore holes).

9.4 *Tracking and Steering*

9.4.1 *Communications* – During the pilot boring operation, the primary responsibilities are those of the drill rig operator and the locator, typically using a walkover receiver, as indicated in Figure 1. The locator provides information to the operator on an ongoing basis to allow path corrections to follow the planned bore path as closely as possible. For systems that directly transmit the locating information to a display at the drill rig, much of this function is accomplished automatically but communications are still required to coordinate operations and avoid hazardous situations. Radio communications should be used for distances exceeding that for convenient voice communication (e.g., 50 ft) or when out of sight. If communications are disrupted, the drilling operation must be halted until communications are restored. (IEEE Standard 1333)

9.4.2 *Interfering Signals* – To the extent possible, potential sources of interference to the tracking system should be identified and eliminated. For example, electronic signals previously applied to existing utility lines or tracer wires to facilitate their location (Section 6.2) should be removed prior to the boring operation. It is also possible that some existing lines, such as dielectric (non-metallic) fiber-optic cables, may utilize a tracer wire that continuously carries a characteristic signal to facilitate cable location. If suspected to be present, and in the same frequency band used by the mini-HDD tracking system, the responsible facility owner should be contacted to temporarily remove such signals.

9.4.3 *Location Interval* – The bore path must be visibly marked at each location point. In order to accurately follow the planned path, the bore head position should typically be determined at a minimum of once each rod addition. More frequent determinations (e.g., each half rod length) are recommended when negotiating turns or path corrections, or in sensitive areas such as the vicinity of other utilities. Since the drill head position (e.g., roll angle) may vary somewhat immediately after soil penetration, it may be beneficial to rotate the drill string in place (without thrust, with fluid flow) for several rotations before taking a reading.

9.4.4 *Steering* – In areas with cobbles or other obstacles that may divert the drill head, measurements should be made whenever contact with such obstacles is suspected. Such incidents can lead to significant departures from the intended path, possibly towards adjacent facilities, which may require immediate correction. If not acceptable to gradually steer back to the desired path, it may be possible to retract the rod somewhat and attempt to pursue a path closer to that intended.

9.5 *Records*

9.5.1 *Pilot Bore Position* – Figure 24 shows the actual “as-built” path of the pilot bore based upon the tracking information, corresponding to the original bore plan of Figure 22.(**17**) The deviations from the intended path in both the horizontal and vertical directions are provided. This information, and/or related drawings and supplemental information, may be used to provide a record of the installation, to be submitted to the owner; see Section 10.4. The drawings should reference permanent existing structures or features (e.g., curbing), and preferably indicate the relationship to existing utilities, especially at crossings of such lines. Unforeseen obstacles encountered during the drilling process should also be indicated. Software tools are available for facilitating the preparation of the drawings.(**8**, **14**, **21**)

9.5.2 *Other Information* – Figure 24 also includes information related to the actual boring operation such as steering commands (drill head orientation). Additional information related to the boring or reaming operation, such as type and size (diameter) drill head, reamer and/or compactor; drilling fluid type and volume; duration of pilot bore and/or back-reaming operation, may be useful for subsequent operations in the project area (see Section 4.4.3). In general, a daily log book, or equivalent, should be maintained by the contractor to provide a permanent record of the operation, including the above information.(**3**)

9.5.3 *Product Pipe Position* – The recorded path information is based upon the tracking information obtained during the pilot bore operation, and assumes that the reamer closely follows the original path. In practice, however, it is not uncommon for the reamer to deviate somewhat from the pilot bore path, due to various effects, including a tendency for the reamer to cut corners as it is pulled around curves and bends. Although such discrepancies may be significant in cases of very close proximity to other utilities, it is not generally considered to be a major issue, similar to the tendency of the installed product pipe to float above (or sit below) the centerline of the final bore hole corresponding to the difference in their diameters.

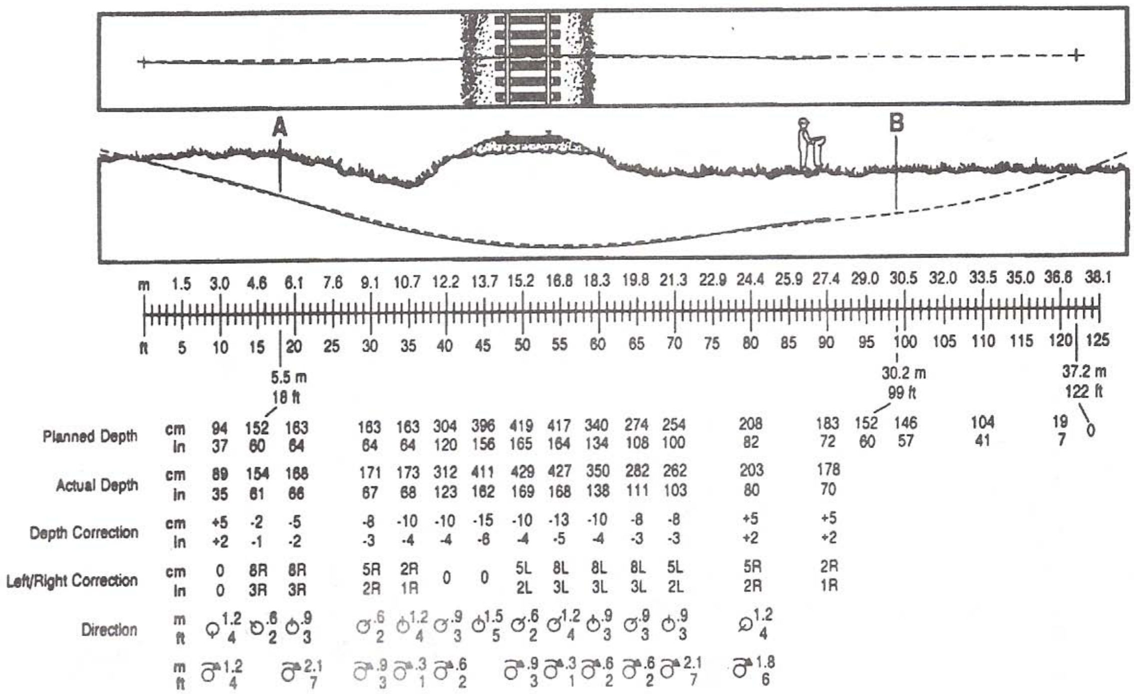

Figure 24 Final "As-Built" Pilot Bore Path

(Source: Ditch Witch®)

9.6 *Reaming*

9.6.1 *Final Hole Diameter* – With the exception of very small diameter pipes, such as 1- to 1½-inch HDPE innerduct (GR-356) for utility cables, most mini-HDD operations require the expansion of the initial pilot bore hole, as illustrated in Figure 2. The increased size is necessary to accommodate the relatively large diameter of the pipe, including pulling grips, as well as to facilitate spoils removal and avoid unnecessarily large pullback forces on the pipe. A final hole diameter at least 50% greater than the outer diameter of the pipe (or pipe bundle) is recommended. The back-reaming and pullback operation typically requires greater time, machine load, and drilling fluid volume than the initial pilot bore due to the creation of the larger hole. The soil conditions will determine the appropriate type of reamer.

9.6.2 *Pre-Reaming* – In some cases, the mini-HDD operation requires more than the two stages illustrated in Figures 1 and 2. A simultaneous back-reaming/pullback operation is adequate for product pipes up to approximately 4-inch nominal size. For larger sizes, however, a pre-reaming operation(s) is recommended, allowing relatively large holes to be created in stages. Although time-consuming, this procedure reduces the required torque and thrust loads at the mini-HDD equipment, and reduces the likelihood of subsurface voids, surface heaving or settlement, and undesirable drilling fluid appearance at the surface. The hole diameter should be expanded in increments of 6 inches or less during a single pass. In order to maintain the original path during the pre-reaming operation, drill rods must be available at the pilot bore exit and connected to a swivel at the rear of the reamer and pulled into the hole. Due to potential hazards associated with expanding the hole in the presence of existing electrical facilities lines, it is important to closely adhere to the electrical safety aspects discussed in Section 5.5.2 to avoid electrical shock at the bore exit end where the rods are added, as well as at the drill rig.

9.7 *Connecting the Product Pipe*

9.7.1 *Assembly* – A major advantage of polyethylene pipe is its availability in continuous lengths on a reel, or in a coil, for a wide range of diameters (possibly 6-inches or greater). For HDPE products not available in continuous lengths, discrete lengths of HDPE pipe may be readily fused in the field, without an appreciable loss in the tensile capability required for HDD pulling operations.(ASTM D 2657) In the latter case, the pipe should be assembled prior to the pullback operation to maintain continuity during the pipe placement process and avoid unnecessary delays. Significant interruptions may lead to increased drag and resulting pulling forces, including eventual loss of integrity and collapse of the bore hole, preventing further movement of the pipe.

9.7.2 *Gripping* – Appropriate gripping hardware and utilization should be compatible with the inherent safe pulling load (Section 7.3.1) of the product during the pullback operation and also ensure that debris or slurry does not enter the pipe. Improper gripping may result in slippage or premature pipe rupture at the grip connection. Although some, more sophisticated, HDD operations, including maxi-HDD, may deliberately allow drilling fluid to enter the cavity to minimize or eliminate buoyancy effects, which tend to increase pulling loads (Section 7), as well as to offset the effects of external pressure, typical mini-HDD installations do not employ this procedure. Many HDPE pipes installed by mini-HDD are used to deliver fluids, or are pre-lubricated to facilitate cable installation. Allowing slurry to enter the interior of the pipe would require careful subsequent flushing or risk possible degraded functionality.

9.7.2.1 *Hardware* – A relatively convenient gripping method, appropriate for a relatively wide range of pipe sizes, utilizes a wire mesh grip that squeezes the outer surface of the pipe as tension is applied, and is properly used in combination with an internal dowel inserted into the pipe to prevent crushing as well as the entry of debris or slurry. (If the dowel or equivalent is not employed, the exposed end of the duct must be taped closed.) The wire mesh grip should be initially taped to the pipe outer surface to prevent initial loosening until tension is applied. Although convenient to use, such grips may not be fully compatible with the safe pulling load of the pipe. Another type of gripping hardware utilizes a tapered threaded shaft, in the appropriate size range, that engages the interior surface of the pipe. A particularly effective hardware design grips both the interior and exterior surfaces of the pipe. Using any hardware type, several pipes in a bundle may be pulled simultaneously. A separate grip should be used for each pipe, and the position of the grips should be staggered, to avoid a large bulge.

9.7.3 *Swivel* – In order to prevent the transmission of torsional loads to the pipe(s) due to the rotating drill rods or back-reamer, a swivel should be mounted behind the rods or reamer, to which the pulling line(s) and gripping hardware are connected; see Figure 2. The swivel must be appropriate for drilling operations, compatible for use in soil and slurry. For non-breakaway type swivels (Section 9.7.4.2 discusses breakaway swivels), the load rating should be at least as large as the total safe pulling loads of the bundle of pipes to be installed, but not excessively greater. Inefficiencies in overly large swivels may impose significant torque on small pipes.

9.7.4 *Breakaway Link* – Section 7 provides a methodology for selecting the pipe strength (wall thickness, DR) for a mini-HDD operation, providing confidence that the product pipe will safely withstand the installation stresses. Nonetheless, for some applications it may be desirable to ensure that the integrity of the product pipe has not been compromised by excessive tensile loads. In general, attempting to monitor the pulling load on the pipe by observing the hydraulic pressure at the control panel, which reflects the pulling load imposed on the drill rig, is not appropriate. Such loads are not necessarily experienced by the pipe, but include the pullback force necessary to ream or compact the hole, or pull the drill rods through the path. One viable alternative is to mount a tension monitoring system between the swivel and the product pipe.(**19**) A more common procedure would be to install a breakaway link between the main swivel and the grip at the pipe, to ensure that the allowable tensile strength is not exceeded. The rating of the breakaway link should be compatible (i.e., slightly lower than) with the safe pulling load of the product pipe. In the event of a broken link, due to excessive pull load, the pipe should attempted to be withdrawn from the pipe entry end. The likely reason for failure should be determined and, assuming the predicted pull load is verified to be acceptable (Section 7), the installation repeated. If necessary, a new bore path may have to be created.

9.7.4.1 *Multiple Pipes* – When installing a bundle of pipes, the pull loads may not be equally or proportionally distributed among the individual units, and an individual pipe may experience excessive stress. Thus, it is preferable to use an individual breakaway link connected to each pipe, rather than a single link rated at the cumulative strength of the bundle.

9.7.4.2 *Breakaway Swivel* – When pulling a single pipe, if a breakaway swivel is used as the breakaway link, and is not specifically designed for direct exposure to soil, the use of such a breakaway swivel does not reduce the need for the main swivel described in Section 9.7.3. When pulling multiple pipes in a bundle and individual breakaway swivels are used for each pipe (Section 9.7.4.1), a separate main swivel behind the reamer is again required to prevent twisting of the bundle itself.

9.8 *Handling the Pipe*

The following procedures should be followed when handling or installing the pipe during the mini-HDD operation:

- Avoid supporting pipe on surface that may cause abrasion during pullback
- Minimize back tension on pipe, to prevent escalating effects at pulling end
- Avoid pulling around sharp bends, to avoid pipe collapse (kinking); see comments below

- Pull additional 3 - 4% length at pipe exit to allow for temporary elongation (stretch) and subsequent recovery.

When exposed to sharp bends, the pipe is vulnerable to local collapse. For example, the pipe is vulnerable when it is fed directly out of an access pit (Figure 11) where it may be desired to interface with aboveground communications or power equipment. Special care should be used, including local support of the pipe as it is bent. In general, the pipe is particularly vulnerable when pulled around bends while under tension. Thus, the procedure of using the tensile capability of the drill rig (or other equipment) to pull the pipe out of an access pit, directly from the surface, requires caution, and should be avoided, if possible. If necessary, sharp bearing corners should be cut and relieved to reduce the degree of curvature where the pipe is pulled around the corners of the pit.

To account for possible recovery ("relaxation") of temporary elongation in the polyethylene pipe, an additional amount of pipe equal to 3 – 4% of the bore length should be pulled from the pipe exit. The pipe should not be cut or terminated for several hours, or approximately the time required for the actual pullback operation.(**1**)

9.9 *Potential Causes of Failure or Problems*

HDD operations should only be performed by trained and experienced contractors (Section 5.9). Nonetheless, such operations may encounter various difficulties, including:

- Loss of drilling fluid or loss of circulation (flow)
- Obstructions (cobbles, debris, foundations, ...)
- Hydrolock
- Line and Grade Problems
- Bore hole collapse
- Failure of drill rods or downhole tooling
- Surface collapse or heaving
- Inadvertent drilling fluid returns (surface, waterways, ...); see Section 9.10
- Striking or damaging existing utility
- Product pipe failure or damage
- Product pipe stuck in bore hole.

Prevention practices for contingency plans and methods for mitigating such problems are available in industry guidelines.(**3**, **20**)

9.10 *Containment of Inadvertent Drilling Fluid Returns*

In the event of inadvertent, uncontrolled returns, there are a variety of containment measures that may prove useful, depending upon the anticipated volume, access, environmental sensitivity of the area contaminated and adjacent areas and soil and weather conditions. Possible methods include the use of silt fencing, hay or straw bales, or sand bags. If insufficient, additional techniques are available.(**20**)

10. Completion

Following installation of the pipe, it is necessary to confirm the viability of the new facility, as well as to provide a permanent record of the actual placement location. Section 10 addresses these practices and also indicates the need for final site cleanup.

10.1 *Inspection*

It is assumed that the owner, or its representative, of the pipeline facility being installed, has had an inspector on-site, or has regularly visited the area, to verify the progress of the operation and that the construction is consistent with recommend practices, such as those provided herein or available from the industry.(**3**, **4**, **5, 6**) It is essential that pipeline facility being installed be visibly inspected prior to filling the various pits that may be present. In particular, the route should be inspected at openings or pits provided for access, as well as any areas where existing utilities have been exposed, such as at crossings with the new pipe. The depth of the pipe may be conveniently verified at such locations.

10.2 *Pipe Testing*

Depending upon the application, the integrity of the pipes should be verified. Any mud or debris that may have entered the pipe should be expelled, and the pipe flushed if necessary. Facilities to be used to transport fluids (gas or liquid) should be checked for leakage, pressurized if necessary. For pipes or conduits to be used for the installation of cables, a mandrel or equivalent should be inserted (pulled, blown, ...) to verify a clear passage. If necessary, a pull line may be installed simultaneously during this procedure. For a project involving the placement of a large number of pipes or conduits for cable applications such verification may be performed on a sampling basis to maintain quality control of the overall process, as specified by the owner.

10.3 *Site Cleanup*

After approval by the owner, the pits should be filled as soon as possible, the soil compacted, and the surface area restored, as reasonable. Surface mud and drilling fluid must be cleaned from the site and be properly disposed (Section 5.8). All equipment, tools, and miscellaneous debris must be removed.

10.4 *Certified Record ("As-Built") Drawings*

Information showing the final "as-built" location of the pipe must be submitted to the owner, who should confirm that all appropriate information is included (Section 9.5.1). The information should be sufficient to create a certified record of the new utility pipe. The drawings provided by the contractor may be used to verify the pipe was placed at the proper location and depth, or within acceptable limits. Ideally, the information provided should correspond to the actual position of the pipe within the final expanded bore hole. This position can differ from the final pilot bore path (Figure 24) due to possible deviation of the reamer during the expansion of the bore hole, as well as movement of the pipe within the oversized bore hole. The accurate determination of the final pipe position may be expensive, requiring exposure at discrete points or use of special surveying tools inserted within the pipe. Such accuracy may not be required by the owner. As a minimum, however, deviations of the pipe (center) position from the planned bore path (Figure 22) should be provided if exceeds 6 inches vertically or 12 inches laterally.(**4**) However, as a check on the general quality of the installation, the owner may elect to verify the approximate location or depth at several discrete points along the path by careful digging, or by use of an internal transmitter placed within the pipe path in combination with a surface locator.

APPENDICES

A. Drill Rod Bending or Steering Capability

A.1 *Typical Characteristics*

The bending capability of the drill rod may be specified by various parameters, including those described Section 3.3. In general, the degree of allowable bending or curvature will depend upon the characteristics of the steel drill rod, including yield and fatigue resistance, as well as the capability of the threaded joints to withstand the associated bending stresses. In general, the allowable radius of curvature or 90° bend radius will be proportional to the outer diameter of the drill rod.

Consider the following **example**: The manufacturer of a 10 ft long drill rod, of 2-inch diameter, specifies an allowable "90° bend radius" of 157 ft. Equation 1b then indicates that the "radius of curvature" may be calculated as:

Radius of Curvature (ft) = 90° Bend Radius (ft) / 1.57
= 157 ft / 1.57
= 100 ft

Thus, the distance from the center of the circle to the perimeter (100 ft) is considerably less than the minimum allowable distance around a 90º quadrant; see Figure 3. A misunderstanding of the difference between these two terms may lead to overstressing of the rods; e.g., if bent to create a circular path of only 100 ft around a 90º quadrant. Conversely, assuming that the distance from the center of the circle to the perimeter must be a minimum of 157 ft is under-utilizing the steering capability.

For the same drill rod, Equation 1a may be rearranged to quantify the maximum angular change per drill rod:

Angular Change (deg/rod) = 90 x Rod Length (ft) / 90° Bend Radius (ft)
= 90 x 10 ft / 157 ft
= 5.7º / rod

A similar result may be obtained by rearrangement of Equation 1c:

Angular Change (deg/rod) = 57.3 x Rod Length (ft) / Radius of Curvature (ft)
= 57.3 x 10 ft / 100 ft
= 5.7º / rod

These values describing the bending -- or maximum steering -- characteristics of the postulated 2 ft x 10 ft drill rod are representative of the capability of typical mini-HDD machines; see Section A.2. These limitations apply to bends in a horizontal (plan) or vertical (profile) plane, as well as an inclined plane or three-dimensional path.

A.2 *Significance of Rod Dimensions*

As an approximate guide, longer drill rods, of the same size (diameter) and design as that considered in the above example, would typically be characterized by the same (minimum) radius of curvature or 90° bend radius, but proportionally greater allowable angular change per rod. Alternatively, similar designed drill rods of the same length, but larger diameter, would correspond to a proportionally greater required (minimum) radius of curvature or 90° bend radius.

Thus, considering another **example**, for an assumed drill rod of 15 ft length and $2^7/_8$-inch diameter, the radius of curvature or 90° bend radius would be expected to be greater than that of the previous (Section A.1) 2 ft x 10 ft rod by a factor of 2.875 ÷ 2.0, or approximately 1.44, corresponding to 226 ft or 144 ft, respectively. The angular change per rod, which is inversely proportional to the radius of curvature or 90° bend radius, would be reduced by a factor of **1.44**, but increased by a factor of 15 ft ÷ 10 ft, or **1.5**, to account for the greater length, resulting in

Angular Change (deg/rod) = 5.7º / rod x **1.5** / **1.44**
= 5.9º / rod

In practice, the actual limits may be somewhat different, due to the design details, including the capability of the threaded joints.

It is noted that the bending limits as described above are more liberal than the industry rule of thumb (ASTM F 1962) that the radius of curvature (feet) for a steel pipe or rod should not be less than 100 times the diameter (inches), corresponding to 200 ft minimum for the 2-inch drill rod of Example 1. This is considerably more restrictive than the manufacturer allowed minimum radius of curvature of 100 ft.

B. Maximum Allowable Depth (Pipe Collapse/Buckling) – Theoretical Development

The following methodology, for application to mini-HDD installations, is based upon techniques similar to that provided in "Simplified Methodology for Selecting Polyethylene Pipe for Mini (or Midi) – HDD Applications", by Slavin(**12**), which are derived from the procedures provided in ASTM F 1962.

B.1 *Allowable Net External Pressure* – ASTM F 1962 provides the basic equation for determining the critical (buckling) pressure, P_{cr} :

$$P_{cr} = 2\,E \cdot f_o \cdot f_R \,/\{(1 - \mu^2) \cdot (DR - 1)^3\} \qquad \text{(B-1)}$$

where E is the material modulus of elasticity, μ the Poisson's ratio, f_o the ovality compensation (reduction) factor, and f_R the tensile stress reduction factor. Poisson's ratio may be is assumed to be 0.45 (**1**), while the effective modulus E for the viscoelastic HDPE pipe depends upon the load duration. The factor f_o accounts for initial or subsequent out-of-roundness due to imposed loads on the pipe (buoyancy, longitudinal bending, possible soil pressure, ...), and f_R recognizes a potential reduction in collapse strength in the presence of significant tensile loads, such as during the mini-HDD installation phase.

B.2 *Idealized Allowable Head of Water* – The critical pressure, P_{cr} , as given above may be expressed in terms of an equivalent hydrostatic head (ft) of water, for idealized conditions in which the ovality reduction factor, f_o , and tension reduction factor, f_R , are assumed equal to 1.0, and at a nominal temperature of 73° F. Since the (effective) material stiffness, E, is dependent upon the load duration, the critical pressure is also dependent upon duration. Table B.1 is based upon the corresponding HDPE (PE3608) characteristics provided in The Handbook of Polyethylene Pipe (1), and is applicable to any diameter HDPE pipe. For MDPE pipe, the tabulated values must be adjusted by a factor of 0.80 and, for PE4710 material, increased by a factor of 1.05. The indicated depths assume an **empty pipe**, in the absence of internal fluids or pressure, which would beneficially offset the effect of the external pressure, as discussed below. Although some HDD installations, such as more complex maxi-HDD installations, may deliberately allow the pipe to be filled with water or drilling fluid during installation, as discussed below, such practices are not typically employed in mini-HDD operations. Depending on the application, however, the beneficial effects may be present during the later operational phase, and may be reflected in the long-term design considerations by the facility owner.

Table B.1 Ideal Critical Pressure (Water Head, ft) for Unconstrained HDPE (PE3608) Pipe (73° F)

Duration	Pipe Diameter to Thickness Ratio (DR)						
	7.3	**9**	**11**	**13.5**	**15.5**	**17**	**21**
"Short Term"	2,896	1,414	724	371	238	177	91
1 hr	1,714	837	429	219	141	105	54
10 hrs	1,436	702	359	184	118	88	45
100 hrs	1,205	588	301	154	99	74	38
1,000 hrs	**1,019**	**498**	**255**	**131**	**84**	**62**	**32**
1 yr	880	430	220	113	72	54	28
50 yrs	649	317	162	83	53	40	20

B.3 *Adjusted Allowable Depths* – Since the drilling fluid is of significantly greater density than water, the idealized pressure head (ft) values of Table B.1 must be reduced by a factor equal to the specific gravity of the drilling fluid/slurry relative to water. A specific gravity of 1.5 is conservatively assumed for the mud slurry. The values must be further adjusted (reduced) for possible initial elevated temperature as well as the aforementioned ovality and tensile load factors. Furthermore, the effect of the local hydrokinetic pressure of the drilling fluid during the pullback process, in addition to the hydrostatic pressure corresponding to the head (depth), should be considered.(ASTM F 1962) Since the depths in Table B.1 are based upon differential pressure, the addition of water within the pipe during the installation (and pre-operational) phase would have a dramatic impact, essentially tripling the corresponding final allowable depths. Although such practices are not typical for mini-HDD installations, they may be advantageously employed for special cases (Section 3.5.1), including some midi-HDD applications.

B.3.1 *Short-term Collapse* – There are two phases to be considered with regard to possible short-term collapse of the pipe, as associated with the installation process. During the actual installation phase, the relatively high 1 hour strength, corresponding to the effective cumulative tensile load duration on the pipe, would be appropriate, in combination with anticipated values of f_o and f_R during this period, as well as the local hydrokinetic pressure of the drilling fluid. For the post-installation (but pre-operational) phase, a relatively low 1,000 hour collapse strength is conveniently employed as the maximum period during which the drilling fluid is assumed to apply hydrostatic pressure on the pipe, subsequent to which it is assumed to thicken and set sufficiently to provide adequate lateral support for the pipe.(**22**, **23**) For this post-installation phase, the tension reduction factor, f_R , is equal to 1.0, in the absence of significant tensile load, and there is no hydrokinetic pressure increment. The effect of possible initial elevated material temperatures, due to conditions at the surface prior to installation, is ignored, assuming the pipe adjusts to local belowground temperatures during the installation process.

B.3.2 *Ovality Factor*– Based upon the ovality reduction factor provided in ASTM F 1962, and consistent with the present simplified approach, it is reasonable to assume a maximum overall value of f_o of approximately 0.65 to account for ring deformation due to initial ovality plus that induced during installation (e.g., buoyancy or longitudinal bending, aggravated by tension-induced wall bearing pressure), or possibly due to some degree of soil-induced loads. This corresponds to an ovality of approximately 5%, a reasonable ring deflection limit.(**1**)

B.3.3 *Tension Reduction Factor* – ASTM F 1962 provides the tensile stress reduction factor f_R as a function of the average stress on the pipe cross-section. For stress levels corresponding to that of the safe pulling load (Table 2), f_R is equal to 0.65.(**13**) However, for tensile loads that are significantly less than the safe load, as would be typically experienced, f_R would be closer to the 1.0 level. The likelihood of experiencing a tensile load equal to the predicted value (i.e., equal to the safe pull tension), based on placement at the somewhat conservatively determined maximum recommended length, simultaneously with placement at the maximum recommended depth, is assumed to be low.

B.3.4 *Hydrokinetic Pressure* – ASTM F 1962 assumes the incremental hydrokinetic pressure applied at the drill head or back-reamer to be as much as 10 psi (equivalent to 23 ft of water head). However, the actual value should also be limited to that which would avoid heaving or fluid leakage at the surface due to the total pressure, including that due to the hydrostatic pressure head. In general, the lower the mud slurry density, the greater the allowable hydrokinetic fluid pressure that may be applied. Thus, although a specific gravity of 1.5 is conservatively assumed for the mud slurry for the purposes of these guidelines, lower values are recommended in practice.(**3**) Figure 23 shows recommended total pressure based upon the simplified assumption that the pressure due to the drilling fluid/slurry may be as high as the overburden pressure due to the soil(OPSS 450), with an assumed density of 110 lbs/ft^3, but also no greater than 10 psi above that due to the hydrostatic pressure of the drilling fluid/slurry. Excessive pressures may also contribute to premature pipe collapse.

B.3.5 *Maximum Allowable Depth* – Both the 1 hour installation and the 1,000 hour post-installation strengths should be considered relative to the applied loads, as described above. Based upon the above discussions, and considering the various factors and their applicability, the **1,000 hour** installation conditions are assumed to be the more restrictive. Thus, these values, as reduced by the slurry density (1.5) and ovality factor (0.65), plus a suggested safety factor of 2-to-1, to account for deviations from the above assumptions, provide the allowable maximum depths based upon the short-term (installation and pre-operational) considerations. These factors correspond to a **net reduction of 4.6** for the values indicated in Table B.1, and result in allowable depths ranging from greater than 200 ft. for DR 7.3 to as low as only 7 ft for DR 21. With the exception of the latter, which would require special precautions, such as the use of water ballast (Section B.3), essentially all the HDPE pipes should be sufficiently strong for mini-HDD applications, typically limited to 15 ft depth. The additional margin provided by the safety factor may help account for a possibly extended period for the drilling fluid/slurry to thicken and provide the anticipated lateral support (Section B.3.1).

B.3.5.1 *Special Cases* – For cases in which the above assumptions may not be considered to be sufficiently conservative, it may be desired to use a greater safety factor or a longer term collapse strength. Such cases may include non-pressurized applications, or pressure applications (water, gas, ...) for which the pipe may not become operational for an extended period, and which are also below groundwater level(**13**). The allowable depths may then be correspondingly reduced. Alternatively, the practice of filling and maintaining the pipe with water during the installation process, until the pipeline becomes operational and pressurized, may be considered.

C. Pulling Tension Prediction – Theoretical Development

The following methodology, for application to mini-HDD installations, is based upon the techniques provided in "Simplified Methodology for Selecting Polyethylene Pipe for Mini (or Midi) – HDD Applications"(**12**), which are derived from the procedures provided in ASTM F 1962.

C.1 *Maxi-HDD Geometry* – Figure C.1 illustrates a typical geometry for a maxi-HDD installation, corresponding to a river crossing, consistent with ASTM F 1962. The overall path includes the three segments spanning the pipe entry to exit point (L_2, L_3, L_4). An additional "excess" length (L_1) corresponds to that remaining after the span has been accomplished. Thus, the projected length of the actual crossing, L_{bore} , is given by

$$L_{bore} = L_2 + L_3 + L_4$$

In some cases, the intermediate horizontal segment, L_3 , may be of zero length. In general, the depth of the crossing, H, is small compared to distances $L_2 + L_4$, due to the typically low pipe entry angle, α, and exit angle, β.

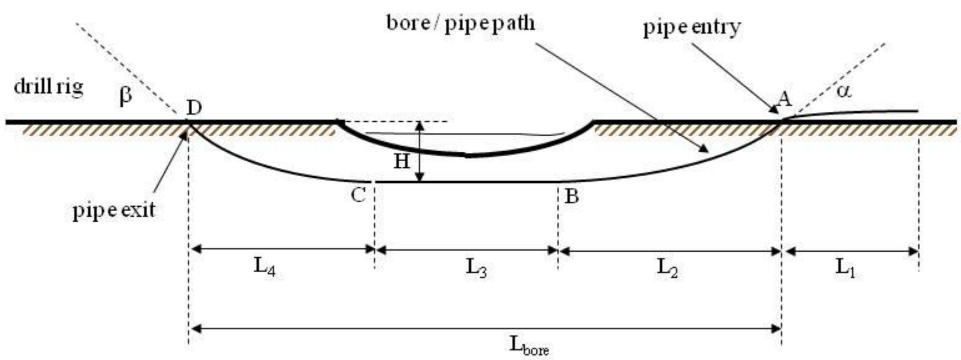

Figure C.1 Nominal Maxi-HDD Route (River Crossing)
(Source: Outside Plant Consulting Services, Inc.)

C.2 *Pull Load Equations* – Using the above terminology, ASTM F 1962 provides a set of equations to estimate the required pull force as the pipe traverses the route. Thus, T_A , T_B , T_C , and T_D correspond to the predicted pull forces with the leading end of the pipe at points A, B, C and D (Figure C.1):

$$T_A = e^{\nu a\,\alpha} \cdot \nu_a \cdot w_a \cdot (L_1 + L_2 + L_3 + L_4) \qquad \text{(C-1a)}$$

$$T_B = e^{\nu b\,\alpha} \cdot (T_A + \nu_b \cdot |w_b| \cdot L_2 + w_b \cdot H - \nu_a \cdot w_a \cdot L_2 \cdot e^{\nu a\,\alpha}) \qquad \text{(C-1b)}$$

$$T_C = T_B + \nu_b \cdot |w_b| \cdot L_3 - e^{\nu b\,\alpha} \cdot (\nu_a \cdot w_a \cdot L_3 \cdot e^{\nu a\,\alpha}) \qquad \text{(C-1c)}$$

$$T_D = e^{\nu b\,\beta} \cdot (T_C + \nu_b \cdot |w_b| \cdot L_4 - w_b \cdot H - e^{\nu b\,\alpha} \cdot [\nu_a \cdot w_a \cdot L_4 \cdot e^{\nu a\,\alpha}]) \qquad \text{(C-1d)}$$

where w_a and w_b are the empty (above ground) and buoyant weights of the pipe, respectively, and ν_a and ν_b. are the corresponding coefficients of friction; the angles α and β are expressed in radians[5]. For HDD installations for which the buoyant forces dominate -- i.e., in the absence of anti-buoyancy techniques, such as filling the product pipe with water or drilling fluid to serve as ballast-- the peak required tension will tend to occur towards the end of the installation. Thus, as described below, for the present purposes, an estimate of T_D is sufficient for determining the appropriate pipe strength.

C.2.1 *Coulomb Friction Model* – Equations C-1 are based upon conventional Coulomb friction. In this mathematical model, drag forces on the pipe are proportional to the local normal bearing pressure applied at the pipe surface, with the proportionality constant designated as the "coefficient of friction". Bearing pressures are due to the combination of several effects, including the dead (empty) weight of the pipe where above ground, the buoyant weight of the submerged pipe (possibly reduced by anti-buoyancy measures), or bending forces associated with pulling a stiff pipe around a curved surface. For the case of PE pipe, of low bending stiffness relative to that of the steel drill rods that created the gradually curved bore hole path, the corresponding bearing and drag forces are not significant.

C.2.2 *Capstan Effect* – There is, however, another important source of bearing pressure acting at bends that is independent of the pipe stiffness, or weight or buoyant forces, and is due to the local tension tending to pull the pipe against the inner surface of the curved path. This phenomenon is referred to as the "capstan effect" (i.e., the operating principle of the "capstan winch") and is the basis of the exponential terms in Equations C-1. Such effects are independent of the direction of curvature, or the sharpness of the bend (radius of curvature) and accumulate exponentially along the path. The capstan effect results in a local amplification factor at each discrete bend of finite angle, or, for a gradual bend, an amplification effect distributed along the path, with magnitude dependent upon the total cumulative traversed angle. For an idealized weightless, perfectly flexible pipe:

$$F_2 = F_1 \cdot e^{\nu \theta} \qquad \text{(C-2)}$$

F_1 represents the axial tension at the entry point of a bend of magnitude θ (radians), ν is the local coefficient of friction between the product pipe and bore hole wall surface, and F_2 is the required axial tension at the exit point of the bend. In practice, the effect of the actual weight, or possible stiffness, of the pipe, is reflected in the preceding tension, F_1 . Due to the exponential compounding character of the tension increase, discrete route bends or gradual accumulating curvature, may represent the dominant source of drag, essentially controlling practical placement distances.

C.3 *Simplification for Mini-HDD* – Equations C-1, and the ASTM F 1962 procedures in general, were originally developed for use by experienced or knowledgeable engineers, for application to a maxi-HDD project. On the other hand, application to potentially problematic

---

[5] The angle in radians is equal to the angle in degrees x (π / 180). For relatively small angles, such as typical HDD bore entry or exit, the angle in radians is approximately equal to the percent grade divided by 100.

mini-HDD installations would be desirable, although not practical, for most mini-HDD projects. Thus, the reduction of these equations to a relatively simple calculation, although at a possible loss of precision, is desired.

C.3.1 *Simplifying Assumptions* –Equations C-1 may be simplified for the present case of interest -- i.e., typical mini-HDD installations of PE pipe -- based upon the following assumptions:

- No anti-buoyancy techniques employed
- Coefficients of friction, ν_a and ν_b , equal to 0.5 and 0.3 respectively
- Pipe entry angle, α, and exit angle, β, equal to 20°
- Depth of crossing, H, small compared to overall bore length, L_{bore}
- Peak pull force, T_D , occurs at the end of the installation, T_D .

These assumptions are reasonable and/or conservative, and result in a simplification of Equation C-1d:

$$T_D \approx L_{bore} \cdot w_b \cdot (1/3) \qquad \text{(C-3)}$$

Although it is possible, under appropriate conditions and actual installations, that the pull force may achieve its maximum level prior to point D, based upon the above assumptions, the predicted tension at point D would be the maximum, or reasonably close in magnitude to a previously occurring (predicted) maximum value.

C.3.2 *Additional Path Curvature* – Equations C-1 and C-2 account for the capstan effect due to the deliberate route bends illustrated in Figure C.1 for a well controlled maxi-HDD installation. However, mini-HDD installations tend to be accompanied by additional path curvature due to possible planned course deviations to avoid previously identified obstacles, as well as inevitable unplanned path corrections, depending upon the operator skill and soil conditions. The above estimate of T_D by Equation C-3 must therefore be modified to account for a corresponding increase in the required pull force. These effects may be conservatively included in the analysis by applying the exponential term in Equation C-2 to Equation C-3, such that

$$T_D^1 = T_D \cdot e^{\nu b\,\theta} \qquad \text{(C-4)}$$

where T_D^1 represents the net final tension, and the angle θ is equal to the total additional route curvature. The angle θ is conveniently expressed as an equivalent number of 90° route bends, n, or fraction thereof, where each 90° route bend is equal to (π/2) radians; thus,

$$\theta = n \cdot (\pi/2) \qquad \text{(C-5)}$$

Using the previously assumed value of ν_b of 0.3, combining Equations C-3, C-4 and C-5 yields

$$\mathbf{T_D^1 \approx [L_{bore} \cdot w_b \cdot (1/3)] \cdot (1.6)^n} \qquad \text{(C-6)}$$

which corresponds to Equation 2 (Section 7.3.2).

C.3.2.1 *Effective Number of Route Bends* – The total number of effective 90° route bends may be expressed as

$$n = n_1 + n_2 \qquad \text{(C-7)}$$

where n_1 is the number of deliberate/planned 90° route bends, and n_2 is the cumulative effective number of 90° bends due to the unplanned undulations. See Section 7.3.2 and Figure 6 for a further description of the interpretation and determination of the effective number of route bends.

C.3.2.2 *Unplanned Route Curvature* – It is noted that the cumulative effective number of 90° bends due to the unplanned undulations, n_2 , is difficult to predict since this will obviously vary among installations due to soil conditions, expertise of the crew, … The final effective curvature experienced by the product pipe during the pullback operation may also be impacted by the reaming process, which may tend to straighten the path somewhat, and by the amount of clearance between the product pipe and bore hole diameter, with greater clearances reducing the imposed pipe curvature. The suggested values provided by Equations 5 and 6 are intended to represent the general magnitude of the unplanned curvature experienced by the product pipe, as based upon limited experiences, including analyses of sample as-built data provided in mini-HDD equipment operator manuals.(**17**, **24**) These levels are not necessarily intended to be conservative for such mini-HDD applications, and significant variability may be anticipated.

C.3.2.3 *Drill Rod Size* – The linear dependence of the unplanned route curvature, n_2 , on rod diameter, as indicated in Equation 6, is consistent with maintaining an equivalent stress level in the steel rod, and corresponds to approximately one-third that typically allowed by bending specifications provided by drill rod manufacturers, as illustrated in Appendix A. Although, in principle, this same rule may be extrapolated to maxi-HDD, using corresponding large diameter drill rods, it is considered excessively conservative for such well-planned, well-controlled installations.

C.3.3 *Buoyant Weight* – In order to apply Equation C-6 (or Equation 2, Section 7.3.2), it is necessary to determine the buoyant weight, w_b , of the portion of the PE pipe submerged in the drilling fluid, along route segments L_2, L_3, and L_4 (Figure C.1). ASTM F 1962 provides general formulae for calculating the buoyant weight of the pipe under various conditions, including empty, filled with water, and filled with drilling fluid. For the present mini-HDD case of interest, for which the pipe is assumed to be **empty**, and, as suggested in ASTM F 1962, the specific gravity of the drilling fluid (mud), γ_b , is conservatively assumed equal to 1.5, the formula for calculating the buoyant weight reduces to Equation 3, Section 7.3.2.

C.4 *Application* – The guidelines for maxi-HDD provided in ASTM F 1962 require that the predicted peak tensile stress be no greater than the corresponding safe pull stress, without the imposition of any additional explicit design/safety factor. However, the corresponding determination of the peak tensile stress includes that due to the average tensile load applied across the pipe cross-sectional area, as predicted by Equations C-1, plus the bending stresses at path bends, as well as the stress increment due to hydrokinetic pressure from the drilling fluid flow along the length of the pipe. In comparison, the simplified methodology as provided in the present mini-HDD guide does not account for the latter two effects. For this reason, and the acknowledged lower degree of control in mini-HDD operations, including anticipated wide variability in unplanned path curvature (Appendix C.3.2.2), as well as the various simplifications used to arrive at above Equation C-6 (or Equation 2), an additional load factor (> 1.0) may be applied to the tension term on the left side of Equation 2 or C-6 for those applications in which a more conservative design may be desired. This would effectively reduce the recommended maximum placement distances; see Appendix D.

D. Examples of Load Prediction and Pipe Selection

D.1 *Load Prediction (Comparison to Field Data)*

The best measure of the validity of the presented simplified methodology for predicting the pull load on a PE pipe during a mini-HDD operation is a comparison to actual field data. The ideal field data would be that directly measured by an in-line force gauge at the leading end of PE pipe, as it is installed during a mini-HDD (or midi-HDD) operation. Fortunately, such data is conveniently available.

D.1.1 *Case 1* – One source provides data obtained during a trial of a commercially available product for monitoring tension at the leading end of the pipe.(**19**) In particular, a detailed plot of force vs. installed length is provided for a 6-inch DR 11 HDPE pipe installed in a nominally straight, 460 ft route. The data shows a monotonically increasing tension, reaching a peak load of approximately 3,500 lbs at the completion of the installation. In this case, a drill rig, with 15 ft long, 3.5-in. diameter drill rods was employed, and Equation 6 (vs. Equation 5) must be used to estimate the unplanned path curvature. The following physical properties and characteristics define the installation:

Bore Length	=	460 ft
Drill Rod Diameter	=	3.50 inches
Pipe Outer Diameter	=	6.625 inches
Pipe Weight	=	4.7 lbs/ft
Buoyant Weight	=	½ [Pipe Outer Diameter (in.)]^2 – Pipe Weight (lbs/ft)
	=	½· (6.625 in.)^2 – 4.7 lbs/ft
	=	17.2 lbs/ft
n_1	=	0 (no deliberate route bends)
n_2	=	[Bore Length / 500 ft] x [2-in. / Rod Diameter]
	=	[460 ft / 500 ft] · [2-in./ 3.5-in.]
	=	0.53 (additional equivalent number of 90° bends)
n	=	$n_1 + n_2$
	=	0.53

Thus, Equation 2 predicts a peak pull load of

Tension (lbs)	=	[Bore Length x Buoyant Weight x (1/3)] x $\mathbf{(1.6)^n}$
	=	[460 ft x 17.2 lbs/ft x (1/3)] x $(1.6)^{0.53}$
	=	3,383 lbs

which is within 3% of the measured load.

In general, such precision cannot be expected in most cases, and the present agreement is considered to be somewhat fortuitous. The methodology used is an over-simplification of a complicated process, which in many cases would be expected to result in pull loads deviating to a significantly greater extent from the levels predicted. It is also interesting to consider the impact of the unplanned curvature effect, reflected in the n_2 (or n) term. Ignoring this term (i.e., assuming n_2 = 0) would result in a predicted tension of less than 2,650 lbs --

underestimating the measured load by 25%. The results are illustrated in Figure D.1 (Case 1).

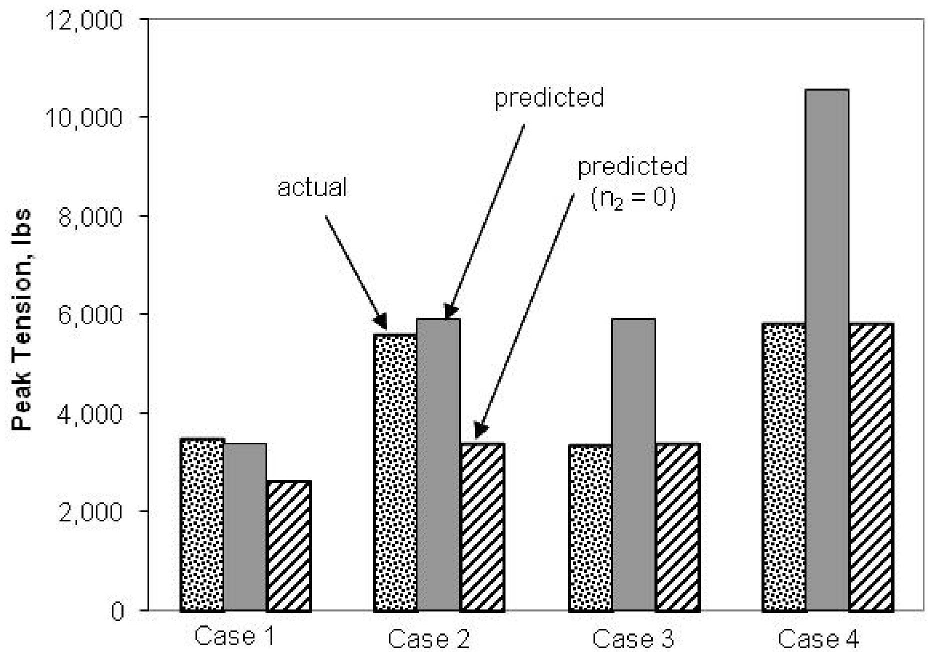

Figure D.1 Actual vs. Predicted Tension for Mini-HDD Installations

D.1.2 *Cases 2, 3, 4* – Another source provides data obtained during a series of three experimental installations, using and reusing the same 590 ft long nominally straight bore hole path, pre-reamed as necessary to approximately 50% greater than the outer diameter of the pipe.(**25**) Two of the installations placed a 6-inch DR 11 MDPE pipe (Case 2 and Case 3) and the third placed an 8-inch DR 17 HDPE pipe (Case 4). The installations were accomplished using drill rods assumed to be of approximately 2-in. diameter. The recorded peak pull loads were 5,620 lbs., 3,372 lbs., and 5,845 lbs., in the sequence described, and in general were experienced prior to the end of the operations. These loads compare to predicted levels of 5,924, 5924, and 10,580 lbs., using the present methodology in a manner similar to that of Case 1. The results for the three sets of data are also illustrated in Figure D.1.

D.1.3 *Discussion* – The results demonstrate that the proposed simplified model is able to predict the general magnitude of the experienced peak tensile load during a mini (or midi) - HDD operation, within a factor of two or better, based upon the limited sample size. In general, the degree of agreement is excellent, depending upon whether the additional tensile load due to unplanned bore path curvature (n_2) is included in the estimate. In some cases (Case 1 and Case 2), such considerations result in outstanding agreement, while in other cases (Case 3 and Case 4) the agreement is excellent without considering the additional tension due to this effect. A possible explanation for the latter is the repeated use of the same bore hole, for the purposes of the three field experiments, with subsequent reaming/pullback operations resulting in a somewhat straighter path than that corresponding to the estimated magnitude of unplanned curvature, more likely to be present in practical applications.

In spite if the demonstrated good-to-excellent agreement in the sample cases above, a wide variability must be anticipated when considering mini-HDD installations in general, due to the complexity of the soil-pipe interaction, variable soil conditions, operator skill, ... Such factors, for example, will impact the degree of unplanned path curvatures, demonstrated to be of importance in some cases, but only roughly estimated by Equations 5 and 6. The possible use of a load or safety factor (> 1.0) applied to the tension, as discussed in Appendix C.4, attempts to account for the wide variability associated with such effects in mini-HDD (and some midi-HDD) installations; see design example of Appendix D.2.

D.2 *Pipe Selection (Design Example)*

The appropriate wall thickness of an HDPE pipe, for a given diameter, may be conveniently determined by the application of the method provided in Sections 7.2 and 7.3. As an example, consider the feasibility of using typical mini-HDD equipment to install a relatively long 700 ft segment of 4-inch DR 11 HDPE pipe along a route including one deliberate 90° planar bend, and placed at a relatively large depth of 30 ft.

D.2.1 *Pull Strength* – The following physical properties and characteristics define the proposed installation:

Bore Length = 700 ft

Drill Rod Diameter = 2.0 inches

Pipe Outer Diameter = 4.50 inches

Pipe Weight = 2.3 lbs/ft

Buoyant Weight = ½ [Pipe Outer Diameter (in.)]^2 – Pipe Weight (lbs/ft)
= ½· (4.50 in.)^2 – 2.3 lbs/ft
= 7.8 lbs/ft

Alternatively, using Figure 7, an approximate buoyant weight of 8.0 lbs/ft, independent of DR rating, is conveniently employed for the present purposes.

n_1 = 1.0 (one deliberate 90° bend)

n_2 = [Bore Length / 500 ft] x [2-in. / Rod Diameter]
= [700 ft / 500 ft] · [2-in./2-in.]
= 1.4 (additional equivalent 90° bend)

n = $n_1 + n_2$
= 2.4

Thus, Equation 2 predicts a peak pull load of

Tension (lbs) = [Bore Length x Buoyant Weight x (1/3)] x $\mathbf{(1.6)^n}$
= [700 ft x 8.0 lbs/ft x (1/3)] x $(1.6)^{2.4}$
= 5,767 lbs

Equation 7 then requires that this predicted installation load, 5,623 lbs, be no greater than the relevant safe pull tension (nominal 4-inch pipe, DR 11) indicated in Table 2 for HDPE pipe, which corresponds to 7,524 lbs. The DR 11 pipe therefore has an apparent safety factor equal to 7,524 lbs / 5,767 lbs, or 1.30. Table 2 also indicates that a DR 13.5 pipe should have adequate tensile strength, but with a lower safety factor (1.08). Considering the potential issues discussed above (Appendix C.4 and D.1.3), the responsible engineer may decide to select the thicker wall DR 11 product.

Whereas the present example specifically considers a 4-inch pipe, for a given DR value, the predicted pull load and the safe pull tension are both proportional to the square of the outer diameter. The conclusions are therefore independent of the pipe diameter. It is noted that the use of the DR 11 pipe in a nominally straight route of more than 1,000 ft-- significantly beyond the generally accepted limit for mini-HDD applications -- is also predicted to be acceptable based on estimated pull loads (see Section 7.4 and Figure 9). The PE4710 pipe material would allow somewhat longer corresponding distances or greater margin.

D.2.2 *Collapse Strength* – Regarding the potential vulnerability to collapse during the installation or post-installation (but pre-operational) phase, while it is subject to the hydrostatic pressure due to the drilling fluid/slurry, prior to its assumed "solidification", Appendix B indicates that DR 11 HDPE pipe may be placed at a depth of 55 ft (= 255 ft / 4.6), independent of pipe diameter. Thus, the relatively high 30 ft proposed installation depth is well within the capability of the DR 11 wall thickness. -The allowable depth of a DR 13.5 pipe (= 131 ft / 4.6), however, would be somewhat less than the 30 ft specified, indicating the need for the DR 11 product.

D.2.3 *Discussion* – The relatively difficult, aggressive mini-HDD installation of the design example demonstrates that a DR 11 HDPE pipe represents a reliable selection for essentially all mini-HDD (as well as many midi-HDD) applications. For DR 11 MDPE pipe, with a reduced tensile capability of approximately 80% that of HDPE, the maximum placement distances would be reduced, but can still satisfy design conditions of the design example, although without any margin. In addition, a corresponding placement depth of 80% that of the HDPE (PE3608) product, or 44 ft, would be considered safe for this type pipe, and consistent with the design conditions. Thus, if desired by the owner, MDPE would also be adequate for many mini-HDD installations, including the present design example. Thinner walled pipe (higher DR rating) may also be a reasonable selection in many cases, but should be verified by specific calculations for the route of interest. The PE4710 material would provide a somewhat greater margin in tensile capability than the PE3608 product as well as greater allowable depth (58 ft).

It is emphasized that the present methodology for pipe DR selection does not ensure that a weaker, thinner-walled pipe would not be successful in practice in individual installations, but, as in most design procedures, the methodology provides reasonable or conservative estimates of the capability of the pipe to withstand the application, and serves as a warning that a weaker product may be marginal or inadequate.

E. Drill Rod Characteristics and Implications – Theoretical Development

The physical characteristics of the drill rods, in combination with the geometry associated with the drill rig entry and desired bore path exit angle, provide restrictions on the bore path configuration and mini-HDD operation. These include required minimum setback distances as well as horizontal distances required to rise to the surface.

E.1 *Setback Distance* – In order to achieve a specified depth at a particular point at the beginning of a bore, the front of the drill rig must be located an appropriate distance rearward ("setback") from the point of interest, designated as point 1 or point 2 in Figure 10. The depth d1, at point 1, is achieved with the bore path on a downward trajectory at the bore entry angle β[6], with the drill rig setback a corresponding distance S1. The both greater depth d2 and associated setback distance S2 correspond to point 2, at which the bore path has achieved a horizontal trajectory. The distance S1 depends upon the entry angle established by the drill rig, but the distance S2 is also dependent upon the drill rod characteristics, including bending capability (allowable radius of curvature) and individual drill rod length.

E.1.1 *Setback Distance S1 along Non-Level Trajectory* – Setback distance S1 corresponds to a bore path segment comprising a straight line extending from the entry point of the drill rod directly towards the point of interest, point 1 (Figure 11):

$$
\begin{aligned}
S1 &= d1 / \tan\beta \\
&\approx d1 / \beta \qquad \text{(E-1)}
\end{aligned}
$$

where the bore entry angle β is expressed in radians. This formula corresponds to a drop at a constant grade angle, and is shown as the dotted lines (S1) in Figures 13 – 15. The depth of the bore path will continue to increase beyond point 1, over the distance required for the drill rods to develop a concave-upward curvature to achieve a horizontal trajectory, as determined below.

E.1.2 *Setback Distance S2 at Level Trajectory* – As a general industry recommendation, the bore path should be initiated without any curvature or steering for a minimum distance equal to one full drill rod length in the ground.(**17**, **24**) This practice is intended to avoid or minimize lateral bearing loads at the front of the drill rig. Steering may be introduced following the placement of subsequent drill rods, including the introduction of concave upward curvature to achieve the desired level trajectory at point 2, at depth d2. The minimum setback distance for S2 corresponds to a path with the first drill rod(s) inserted such as to continue the straight (sloping) trajectory, to descend as rapidly as possible, and the subsequent rods placed with the leading rod then creating a path at the minimum allowable radius of curvature, or

$$
\begin{aligned}
S2 &= \ell \cos\beta + R_{rod} \cdot \sin\beta + [d2 - \ell \sin\beta - R_{rod} (1 - \cos\beta)] / \tan\beta \\
&\approx R_{rod} \cdot \beta / 2 + d2 / \beta \qquad \text{(E-2)}
\end{aligned}
$$

where ℓ is the length of the drill rod length and R_{rod} its minimum radius of curvature. Equation F-2 is the basis of the distances S2 presented in Figures 13 – 15.

---

[6] The bore path entry angle β corresponds to the pipe exit angle, as illustrated in Figure C.1.

E.1.3 *Minimum Depth to Level Trajectory* – Based on the geometric restraints established by the bore entry angle and allowable minimum radius of curvature of the drill rods, as well as the recommendation that the first rod be placed in the ground in a straight configuration, there is a minimum depth at which the trajectory may be able to become level. The minimum possible depth for d2 may be calculated by:

$$(d2)_{min} = \ell \sin\beta + R_{rod} \cdot (1 - \cos\beta)$$
$$\approx \ell \beta + R_{rod} \cdot \beta^2 / 2 \qquad \text{(E-3)}$$

This value is explicitly indicated in Figures 13 – 15, for various drill rods, for the case of a 15° (27% grade) bore entry angle.

E.2 *Horizontal Distance to Rise to Surface* – The geometric restraints associated with the allowable minimum radius of curvature of the drill rods again dictates the rate at which the bore path can divert from its present horizontal trajectory (e.g., point 3, Figure 11) at depth d3 to reach the ground surface.

E.2.1 *Rise at Constant Curvature* – Assuming the drill rods are steered consistent with their maximum bending capability (minimum radius of curvature), the minimum distance S3 to reach the surface is given by:

$$S3 = \sqrt{2 \cdot d3 \cdot R_{rod}} \times \sqrt{1 - \frac{d3}{2 \cdot R_{rod}}}$$
$$\approx \sqrt{2 \cdot d3 \cdot R_{rod}} \qquad \text{(E-4)}$$

These values are shown as the dotted lines (S3) in Figures 16 – 18. The resulting bore exit angle α[7] will be determined by the depth d3, as given by:

$$\alpha = \arccos\,[1 - d3/R_{rod}]$$
$$\approx \sqrt{2 \cdot d3 / R_{rod}} \qquad \text{(E-5)}$$

Corresponding exit angles based upon this equation are provided in Figure 19.

E.2.2 *Exit at Specified Angle* – The distance S3 is shorter than that corresponding to the distance S5 indicated in Figure 11. The latter distance corresponds to a path that rises from the depth d3 partially on an arc and then (from point 4) continues along a straight path at a specified bore exit angle (grade) α:

$$S5 = R_{rod} \cdot \sin\alpha + [d3 - R_{rod}\,(1 - \cos\alpha)] / \tan\alpha$$
$$\approx R_{rod} \cdot \alpha + [2 \cdot d3 - R_{rod} \cdot \alpha^2)] / 2\,\alpha \qquad \text{(E-5)}$$

These values are also shown in Figures 16 – 18, as a function of the specified exit angle, for which the maximum possible exit angle is limited by the depth d3, consistent with Figure 19.

E.2.3 *Horizontal Rise Distance along Fixed Grade* – For a drill head oriented at an upward angle α, the horizontal distance S4 to rise to the surface from a point 4 (Figure 11) from a depth d4 is

$$S4 = d4 / \tan\alpha$$

---

[7] The bore path exit angle α corresponds to the pipe entry angle, as illustrated in Figure C.1.

$$\approx \quad d4 / \alpha \qquad \text{(E-6)}$$

Analogous to Equation E-1, this formula corresponds to a rise at a constant grade, and is shown in Figures 20, for various angles.

Appendix F provides examples in the application of the above equations, as reflected in Figures 13 – 20.

F. Example of Drill Rig Setup and Bore Path Geometry

F.1 *Drill Rig Setup*

The information provided in Section 8, including Figures 10 – 20, may be used to help plan the drill rig setup, and verify the feasibility of performing the operation within the local space restraints. For example, consider a utility requiring several hundred foot section of six inch pipe to be placed along a right-of-way using HDD equipment, with the following product, placement and site characteristics:

Pipe Outer Diameter = 6.625 inches

Drill Rods = 15 ft long x 150 ft allowable radius of curvature

Uniform Depth of Cover = 60 inches

Available setback distance (S2, preceding point 2, Figure 11) = 35 ft

Available rise distance (S3 or S5, beyond point 3, Figure 11) = 40 ft

Desired Exit Angle = 5°

F.1.1 *Required Setback Distance* – The utility specified depth of cover is consistent with that recommended in Section 8.1.3. This may be verified by considering a final bore hole diameter of approximately 50% greater than the pipe outer diameter, or approximately 10 inches (6.625 x 1.50), and comparing the specified 60 inches to the minimum cover of 50 inches indicated in Figure 10.

Considering the shallowest entry angle (10°) indicated in Figure 15, the minimum depth $(d2)_{min}$ required to achieve a level trajectory is approximately equal to the 60 inches desired[8]. However, the corresponding setback distance S2 of approximately 40 ft exceeds the available space of 35 ft. Increasing the entry angle in an attempt more rapidly reach the desired depth is not a solution since the minimum depth to achieve a level trajectory, at greater entry angles, will now be greater than that desired. Unnecessarily deep placement is undesirable with respect to possible future repair and maintenance activities.

One possible solution is to use a smaller HDD rig, utilizing drill rods of 10 ft length and 100 ft allowable radius of curvature (Figure 14), for which the setback distance S2 at low entry angle (10°) is approximately equal to the 35 ft available. The shorter drill rig also increases the available setback distance by approximately 5 ft.

Another alternative would be to gain permission for the pipe to be somewhat shallower than the desired 60 inches towards the entry point of the path, with the desired (level trajectory) depth achieved slightly further along the route. Thus, for the original 15 ft drill rods, Figure 15 indicates that the available 35 ft space is approximately 5 ft less than the approximately 40 ft necessary to achieve the level trajectory, and that a slightly shallower (non-level trajectory) depth will be experienced for this short segment.

Still another alternative is for the utility to agree that the objective depth may be exceeded towards the beginning of the bore, beyond which the path may be adjusted to gradually rise to

[8] For the present purposes, the difference between the centerline of the bore path, as indicated in Figure 13, and the reduced depth of cover corresponding to the pipe protruding above the centerline, is ignored.

the desired 60 inch depth. In this case, the 60 inch depth may be achieved along a path at the entry grade after a setback distance S1 of only 30 ft (Figure 13).

F.1.2 *Required Horizontal Distance to Rise* – Figure 17 indicates that steering the 150 ft radius of curvature drill rods such that they rise from the 60 inch level depth at their maximum recommended bending capability, will result in an exit angle of 15°. Based upon the information in Figure 18, this rise to the surface may be accomplished within a horizontal distance S3 approximately equal to the 40 ft available space. Such a large exit angle is, however, significantly greater than that originally specified (5°). In order to exit at the desired 5° angle, an available distance S5 of more than 60 ft would be required (Figure 18). In this case, the use of a smaller drill rig, with more flexible rods, would provide only a minor reduction in the required horizontal rise distance S5 (Figures 16 and 17), and not represent a practical solution.

As a result of the above considerations, additional discussions with the utility may be warranted, in order to obtain a better understanding of the space restriction at the pipe entry (bore exit) end of the installation. It is possible that the utility had originally specified a low bore exit angle, as well as reserved additional space at that end, in order to accommodate relatively rigid (non polyethylene) pipe products. In such cases, significant space is required to facilitate assembly, layout and/or feeding of the pipe product into the completed bore hole. The use of PE may therefore alleviate the problem, due to its availability in continuous lengths, greater physical flexibility and easier handling. In particular, the relatively large (15°) bore exit angle, achievable within the originally specified 40 ft, should not be an issue with a PE product.

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