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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).
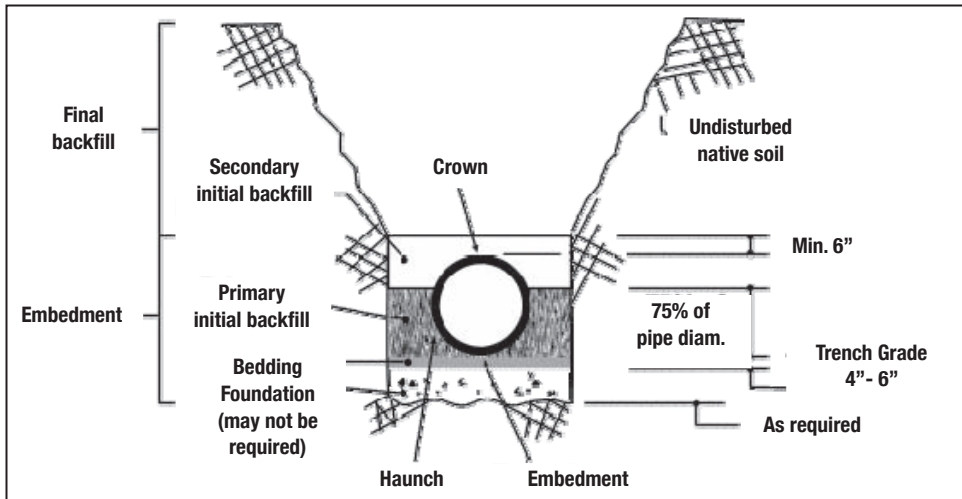
Figure 1 Pipe Trench

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.
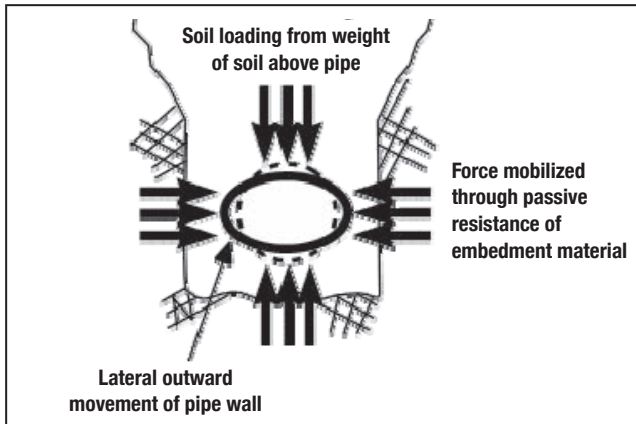
Figure 2 Mobilization of Enveloping Soil through Pipe Deformation

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.
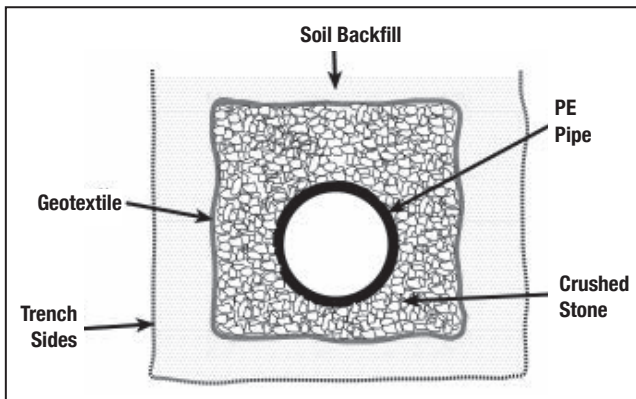
Figure 3 Installation of Geotextile Separation Fabrics

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 lII 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.
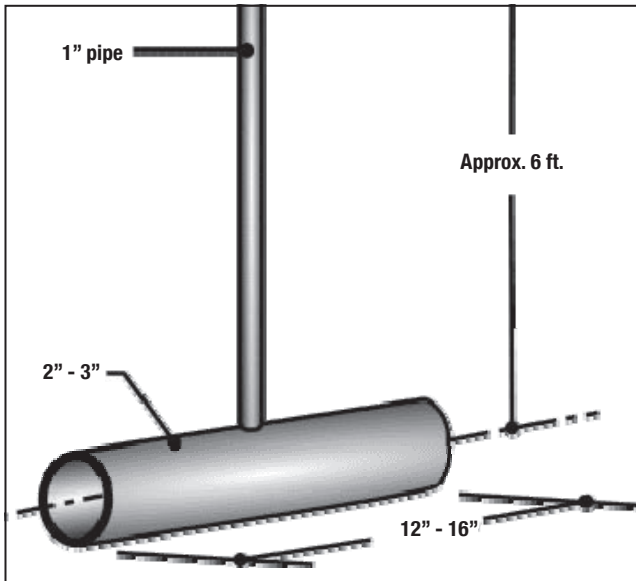

Figure 4 Tamping Tool

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 lII 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.
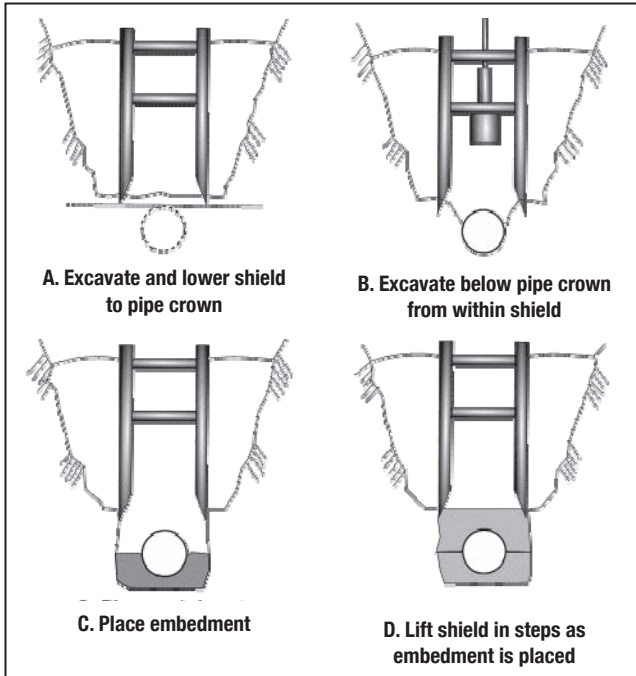
Sloping of trench walls in granular and cohesionless soils should be provided whenever the walls are more than about four feet in depth or otherwise required by state, local or federal regulations. For safety, if the walls are not sloped, they should be stabilized by alternate means such as shoring or 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.

A. Excavate and lower shield to pipe crown

B. Excavate below pipe crown from within shield

C. Place embedment

D. Lift shield in steps as embedment is placed

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.
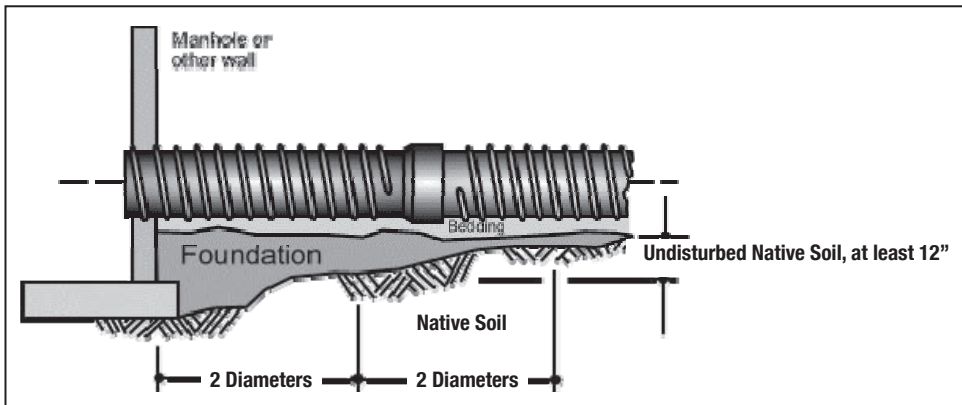
Figure 6 Pipe Support in Transition from Rigid Support to Normal Trench Support
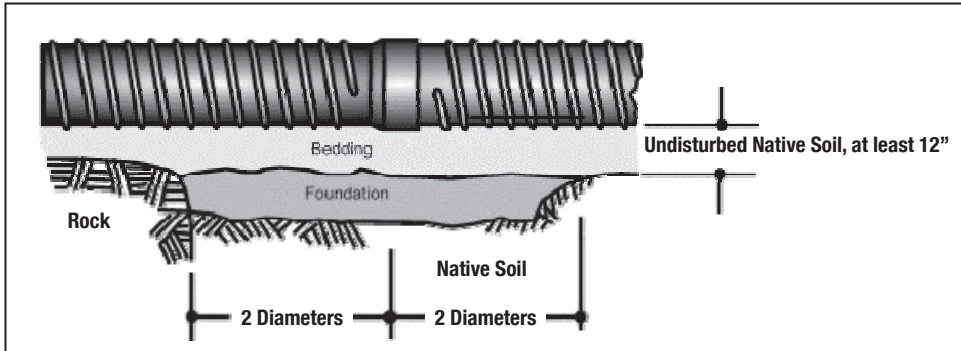
Figure 7 Proper Transition from Rock Trench Bottom to Normal Trench Support

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.
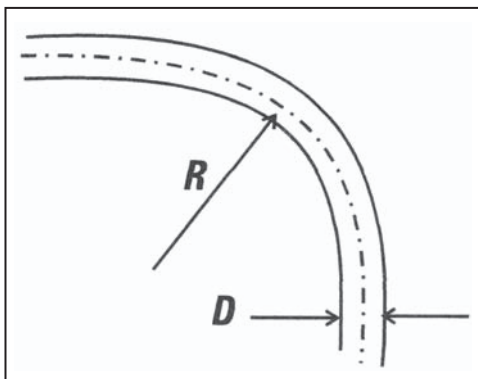
Figure 8 Bend Radius, R

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.
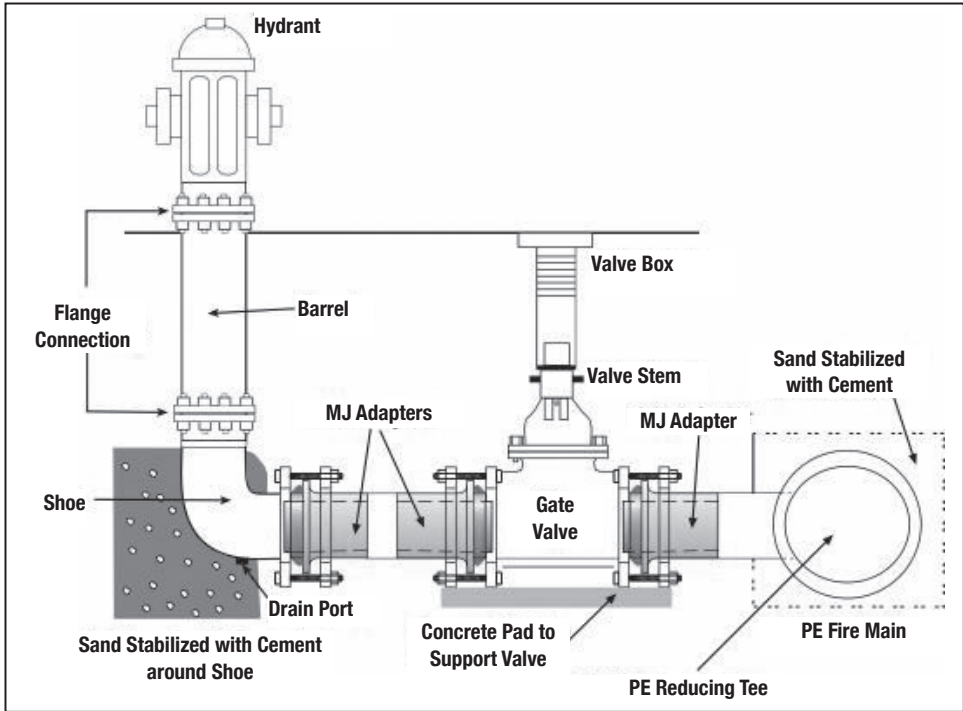
Figure 9 Typical Assembly and Support Arrangement for PE Pipe Connections
to Valves and Hydrants

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.
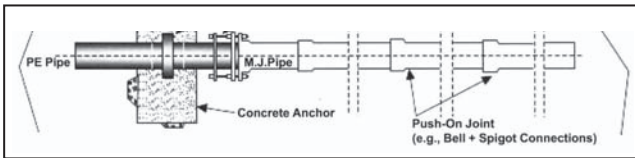
Figure A1 Pullout Prevention Technique
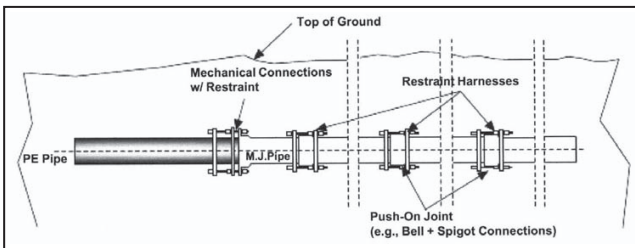
Figure A2 Pullout Prevention Technique

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/in²

$$S = \frac{P \, (DR - 1)}{2}$$

P = internal pressure, lb/in²
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.

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