

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 (cobble, 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).

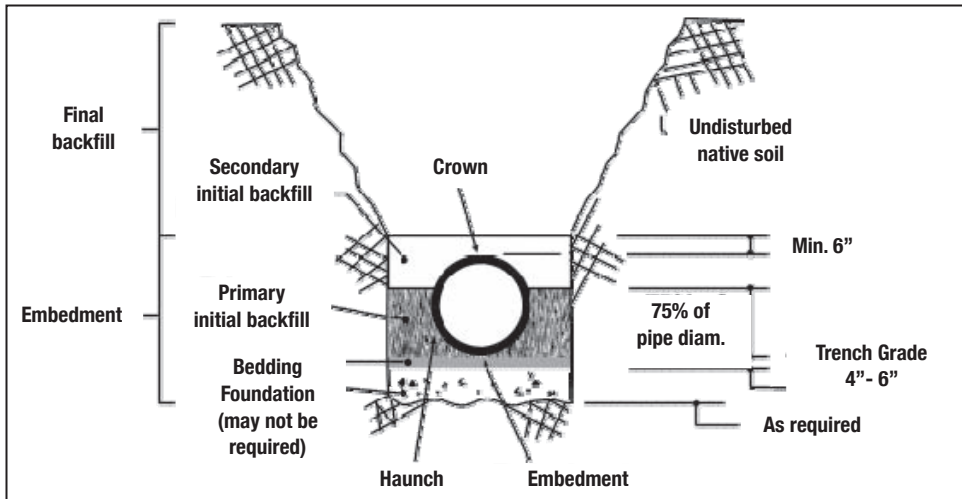


Figure 1 Pipe Trench

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.

Simplified 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/ft³ (600 kN-m/m³))." 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.

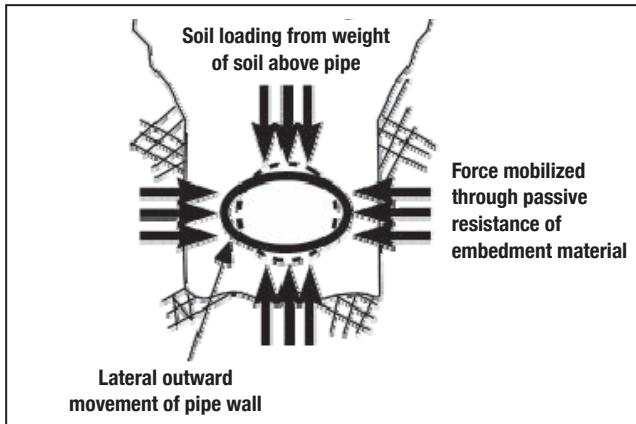


Figure 2 Mobilization of Enveloping Soil through Pipe Deformation

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.

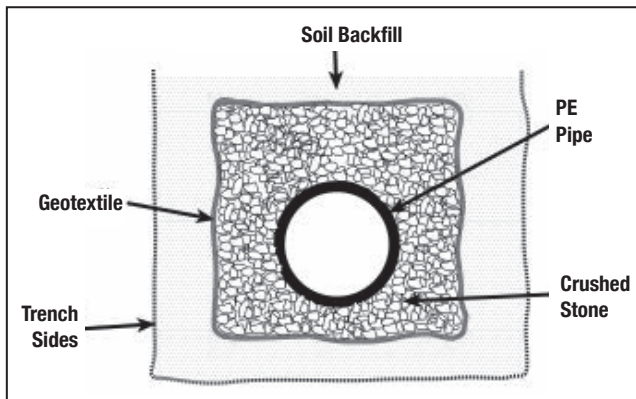


Figure 3 Installation of Geotextile Separation Fabrics

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