Coachella Valley Water District
Pipe Materials for Non-Pressurized Pipeline Projects

1.0 Introduction

This document provides technical information and design guidelines for selecting and designing non-pressurized pipeline projects within the service area of the Coachella Valley Water District (CVWD) using the pipe materials that have been approved by CVWD.

2.0 Pipe Material Selection Overview

All the generally available materials commonly used for non-pressurized pipe installations are suitable for use in the CVWD's system; however, CVWD has narrowed the range of options to the materials discussed below. Since the specific nature of a given project can dictate the preferred material(s) for a particular installation, each pipe material, lining, and coating should be evaluated carefully and ultimately determined by the Engineer of Record depending on the anticipated installation challenges and conditions of service from both an operations *and* a maintenance point of view. The pipe materials for consideration based upon CVWD's native soil conditions and gravity applications include:

- Flexible Pipes
  - Thermoplastic-based materials such as polyvinyl chloride (PVC), high-density polyethylene (HDPE), and polypropylene (PP);
  - Thermoset plastic pipe, or fiberglass composite-based materials;
  - Ductile iron pipe (DIP)
- Rigid Pipes
  - Vitrified Clay Pipe (VCP);
  - Reinforced Concrete Pipe (RCP) with a corrosion resistant liner (such as T-lock®).

The following sections will focus on the above materials presenting a qualitative overview of the characteristics for each pipe material and a summary of the pipe materials options. Each proposed pipe material is evaluated based on available sizes, exterior protective coatings (if required), and interior protective linings (if required). In the event that special conditions require the evaluation of other materials not discussed herein (such as, DIP), those materials will need to be addressed on a case-by-case basis by CVWD Engineering. This evaluation is only for pipelines with gravity flow conditions; not for design of pipelines with surcharge conditions or for pressure/force main applications.

While this document presents an overview of appropriate pipe materials for consideration for projects located in the CVWD service area, further evaluation and development of the site specific standard technical specifications and details of the installation are the responsibility of the Engineer of Record for the proposed improvements.

3.0 Flexible Pipes

Flexible pipes derive essentially all of their external load-carrying capacity from the interaction of the pipe with the embedment soils. During the installation and trench consolidation processes these types of pipes will deflect slightly to accommodate these actions resulting in a small deformation of the geometry that in turn creates a state of static equilibrium. Flexible pipes include thermoplastic pipes, thermoset plastic pipes, and ductile iron pipe (DIP). Even though DIP is used by a few agencies for gravity sewers, this material is mostly used for pressure sanitary sewers (force mains) and siphons, and it is not recommended as an appropriate general use material for CVWD's gravity sewer projects due to factors such as its internal corrosion potential, external corrosion due to corrosive soils (which are really exacerbated when the pipeline is installed below the water table), cathodic protection requirements, and general economic non-competitiveness in larger sizes.

3.1 Thermoplastic Pipe Types

Thermoplastic materials include a variety of plastics that can be softened by heating and hardened by cooling through temperature ranges that are specific to each plastic. Thermoplastic pipe products considered appropriate for CVWD projects are polyvinyl chloride (PVC) pipe, high density polyethylene (HDPE) pipe, and polypropylene pipe.

3.1.1 Polyvinyl Chloride (PVC)

Non-pressurized PVC pipe is available in both a solid-wall and a dual-wall (profile wall) construction. Solid-wall piping is available in the 4-inch to 15-inch size range in two thickness ratios, SDR 35 and SDR 26 (SDR, or standard dimension ratio is the diameter of the pipe divided by its wall thickness). These two SDR's provide the installer with the standard stiffness pipe and a higher stiffness (heavy wall) pipe to provide the needed handling performance during the installation process. SDR 35 pipe is formulated to produce a resistance to deflection of 46 pounds per linear inch per inch (pii) of deflection (46pii, or SN 46). SDR 26 pipe is formulated to deliver a resistance to deflection of 115pii. There is at least one manufacturer who has extended their size range of the SDR 35 PVC up to 24-inch diameter. Dual-wall PVC pipe construction is available in the 4-inch to 36-inch size range. Dual-wall construction was initially offered to extend the size range of the standard stiffness (46pii). Solid wall PVC in sizes greater than 15-inches was not cost competitive to the alternative materials. PVC pipe typically comes in lengths of 13, 14 or 20 feet for wastewater applications with the standard gasketed bell and spigot ends. Because PVC is not deleteriously affected by soil conditions or typical municipal sanitary sewer flow, coatings or linings are not required. However, it should be understood that the PVC formulations necessary to achieve the required stiffness class in solid wall pipe typically has fillers that may be affected (leached) by certain commercial or industrial effluents. Design considerations in these areas must consider long-term performance in these situations. PVC pipe is applicable for both trenched and trenchless installations.

3.1.2 High Density Polyethylene Pipe (HDPE)

HDPE pipe is another flexible conduit pipe that relies on the surrounding bedding matrix in order to support internal and external loading. While solid wall pipe is commonly available in sizes up to 48 inches, generally, large diameter HDPE sewer pipe is manufactured with an extruded wall profile. The profile is designed to provide pipe wall strength while minimizing the amount of material used. Weholite is an example of this type of pipe. It is generally available in the size range of 24-inch to 78-inch, but Weholite manufacturers typically have the capability of manufacturing on demand in the size range from 18-inch to 132-inch. The interior surface is “smooth” walled while the exterior surface may be “smooth” or corrugated depending on the manufacturing process and related ASTM standard. Profile wall HDPE joints are primarily accomplished by thermal fusion extrusion welding; while solid wall materials are butt-fused. In some instances these pipes are made with standard gasketed bell and spigot joints.

Special training and thermal fusion equipment by the pipe manufacturer is required. A properly welded joint results in a leak proof joint which is as strong as the surrounding pipe. Lay lengths are available up to 50-feet. HDPE is not deleteriously affected by soil conditions or sanitary sewer flow, therefore, coatings or lining are not required. HDPE is not typically filled with inert materials to achieve stiffness as are the solid wall PVC products, but the design engineer still must consider atypical solutions of commercial and industrial effluents which can cause long-term harm to the material. HDPE can be furnished with integral manholes.

HDPE is applicable for both trenched and trenchless installations. HDPE is available for non-pressurized pipelines in the standard sizes previously mentioned; however, trench conditions in installations over 10-ft deep may not be suitable for welding the joints at this depth.

3.1.3 Polypropylene

The Polypropylene alternative is touted for having high-purity as well as strength and rigidity. It has relatively high resistance to corrosion and chemical leaching and resistance to physical impact. Segments can be joined by thermal fusion in the field, but recently have become available in a gasketed bell and spigot construction. Currently, this pipe material alternative is available in the size range 12-inch through 60-inch. The minimum pipe stiffness is 46pii. It is currently offered by only a single manufacturer (ADS Pipe) and has only been marketed in the last few years. Therefore, there are not a lot of historical applications to show longevity and maintenance history. This material is on the CVWD’s radar for possible inclusion as an acceptable alternative at some point in the future but it’s not used at this time. Standard lengths are 20-feet, but a 13-foot length is available which would be highly desirable for deeper installations requiring trench safety shielding.

3.2 Thermoplastic Pipe Installation Requirements

All the thermoplastic plastic pipe materials discussed above should follow the installation guidance given in ASTM D2321; *Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications* (or a similar standard that is applicable to the particular flexible pipe material being installed).

The soil support for a buried pipe installation can be expressed as the elastic modulus (E') of the soil or the composite constrained soil modulus (M_s). M_s is a function of the constrained modulus of the backfill material and the native soil, M_{sb} and M_{sn}, as well as the trench width. For pipe installations in soft native soils where M_{sn} is lower than M_{sb}, the composite modulus, M_s, will be lower than the backfill modulus, M_{sb}. ASTM D2321 advises that a minimum width of embedment material is required to ensure that adequate embedment stiffness is developed to support the pipe. Under poor native soil (MH, CH, OL, OH, PT; or CL, MH, or any soil beginning with one of these symbols, with <30% retained on the #200 sieve, if the native soil is able to sustain a vertical cut as is depicted in Figure 1, this minimum embedment width is recommended to be 0.5 pipe diameters (O.D.) on either side of the pipe as shown. If the native soil cannot sustain a vertical cut, the minimum embedment width shall be at least one pipe diameter on either side of the pipe. Also, the trench width shall not be less than that required per Section 6.3 of ASTM D2321.

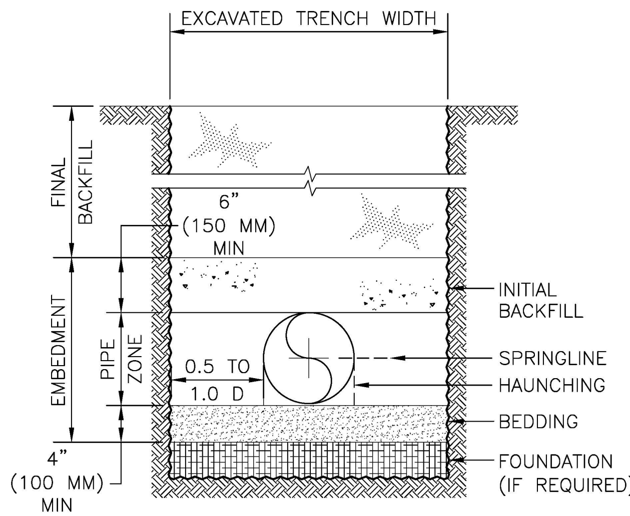


Figure 1

Soil modulus is a measure of the soil's stiffness which, in turn, is a measure of the level of structural support it can provide. In buried piping design it is sometimes referred to as the "constrained" soil modulus which calls to the designer's attention that as the height of the pipe cover increases so does the apparent stiffness of the embedment soil. This is due to the confining pressure exerted by the fill above in conjunction with the trench sides and bottom. In the case where the embedment soil is different than the native soil material, a composite modulus must be derived to reflect the actual in place performance of the pipe embedment.

The embedment material shall typically be Class II granular material or Class I crushed angular granular material as specified in the Table 1 below. Select Class III materials may be suitable for shallow depth sewers when installed above the water table. When coarse and open-graded material is placed adjacent to a finer material, fines may migrate into the coarser material under the action of a hydraulic gradient from groundwater flow into the trench. Significant hydraulic gradients may arise in the pipeline trench during construction when water levels are being controlled by various pumping or well-pointing methods or after construction when permeable under-drain or embedment materials act as a drain under high groundwater levels. Field experience shows that migration can result in significant loss of pipe support and continuing deflections that may exceed design limits. The gradation and relative size of the embedment and adjacent materials must be compatible in order to minimize migration. In general, where significant groundwater flow is anticipated, avoid placing coarse, open-graded materials, such as SC I, below or adjacent to finer materials unless methods are employed to impede migration. Where incompatible materials must be used, they must be separated by filter fabric designed to last the life of the pipeline to prevent wash-away and migration. The filter fabric must completely surround the bedding and pipe zone backfill material and must be overlapped over the top of the pipe embedment zone.

Table 1. Soil classification by material type

Soil Class	Soil Type	Description of Material Classification
I	—	Manufactured angular, granular material, ¼ to 1 ½ inches size, including materials having regional significance such as crushed stone or rock, broken coral, crushed slag, cinders, or crushed shells
II	GW	Well graded gravels and gravel-sand mixtures, little or no fines, clean
	GP	Poorly-graded gravels and gravel-sand mixtures, little or no fines, clean
	SW	Well-graded sands and gravelly sands, little or no fines, clean
	SP	Poorly-graded sands and gravelly sands, little or no fines, clean
III	GM	Silty gravels, gravel-sand-silt mixtures
	GC	Clayey gravels, gravel-sand-clay mixtures
	SM	Silty sands, sand-silt mixtures
	SC	Clayey sands, sand-clay mixtures
IV	ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands. Liquid limit (LL) less than 50
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays. LL less than 50
	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts. Liquid limit 50 or greater
	CH	Inorganic clays of high plasticity, fat clays. Liquid limit 50 or greater
V	OL	Organic silts and organic silty clays of low plasticity. Liquid limit 50 or less.
	OH	Organic clays of medium to high plasticity. Liquid limit 50 or greater.
	PT	Peat, muck, and other highly organic soils

Symbols for soil type are according to the Unified Soil Classification Designation, ASTM D2487

When supports such as trench sheeting, trench jacks, trench shields or boxes are used, the installer must make sure that the support of the pipe and its embedment is maintained throughout the installation process. Sheeting must be sufficiently tight so as to prevent washing out of the trench wall from behind the sheeting. Unless otherwise directed by the engineer, sheeting driven into or below the pipe zone should be left in place to preclude any loss of support of the foundation and embedment materials. When the installer chooses to cut off the top of the sheeting, this cut should be made at least 1.5 feet above the crown of the pipe. Rangers, whalers, and braces must be left in place to support the cut off sheeting.

Movable trench wall supports should not be used below the top of the pipe zone unless approved methods are used for maintaining the integrity of the embedment material; this is true for both rigid and non-rigid materials. Before moving supports, place and compact embedment to sufficient depths to ensure protection of the pipe. As supports are moved, finish placing and compacting the embedment. All voids must be filled immediately upon removal of these supports.

When excavating while depressing the groundwater level, the installer must make sure that the temporary surface of the water is at least 5.0 feet below the bottom of the cut at all times to prevent washout from behind the sheeting or sloughing of the exposed trench walls. Control of the water level below the bottom of the cut should be maintained before, during, and after pipe installation, and until the embedment is installed and sufficient backfill has been placed to prevent flotation of the pipe. To preclude loss of soil support from the native materials' original measured values, the dewatering methodology must employ techniques that minimize the removal of fines and the creation of voids in the in-situ materials.

The following Table 2 summarizes the degree of compaction which can be obtained for the soil classes defined in Table 1 using the various tools available. Table 3, in turn, gives the Engineer of Record an estimate of the M_{sb} that can be expected when using the various soil classes as an embedment material.

Table 2. Degree of Compaction obtainable by class of material by level of effort applied

Class of Embedment	I	II	III	IV
Material Description	Manufactured Granular Materials	Sand & Gravel Soils - Clean	Mixed – Grain Soils	Fine-Grain Soils
Optimum moisture content range		9 - 12	9 – 18	6 - 30
Soil Consolidation Method	% of Standard Proctor (or Relative) Density Range			
Compact by power tamper or rammer	95-100 (75-100)	95-100 (80-100)	95-100	90-100
Densification by portable vibrators	80-95 (60-75)	80-95 (60-80)	80-95	75-90
Consolidate by saturation		80-95 (60-80)		
Hand placing	60-80 (40-60)	60-80 (40-60)		
Hand tamping		60-80 (50-60)	60-80	60-75
Dumping	90-95 (85-90)	60-80 (50-60)	60-80	60-75

Table 3. Approximate values of M_{sb} at various vertical stress levels (cover depths)

Soil Class	Vertical Stress Level psi (ft)	Compaction, % maximum Standard Proctor Density				
		Dumped psi	100 psi	95 psi	90 psi	85 psi
I	1 (1.2)	2000	2350	2000		
I	5 (6)	2600	3450	2600		
I	10 (12)	3000	4200	3000		
I	20 (24)	3450	5500	3450		
II	1 (1.2)		2350	2000	1275 (1085)	470 (330)
II	5 (6)		3450	2600	1500 (1275)	520 (365)
II	10 (12)		4200	3000	1625 (1380)	570 (400)
II	20 (24)		5500	3450	1800 (1530)	650 (455)
III	1 (1.2)			1415 (708)	670 (335)	360 (180)
III	5 (6)			1670 (835)	740 (370)	390 (195)
III	10 (12)			1770 (885)	750 (375)	400 (200)
III	20 (24)			1880 (940)	790 (395)	430 (215)
IV	1 (1.2)			530 (159)	255 (77)	130 (39)
IV	5 (6)			625 (188)	320 (96)	175 (53)
IV	10 (12)			690 (207)	355 (107)	200 (60)
IV	20 (24)			740 (222)	395 (119)	230 (69)

(Burial depths, or vertical stress levels, are for a soil density of 120pcf. Reduced M_{sb} values below groundwater table in parenthesis)

In 2000, AASHTO adopted new values for soil stiffness for backfill materials used for thermoplastic pipe. The modifications included changing the soil design parameter from the modulus of soil reaction, E', to the constrained soil modulus, M_s. This change, based on the work of McGrath (1998), resulted in the above presented (Table 3) design values of the constrained modulus which shows that M_s increases with the depth of fill which reflects the increased confining pressure. This is a well-known soil behavior. At moderate depths of fill the values of M_s are close to the E' values proposed earlier by Amster Howard (1997, 1996).

Table 4. Approximate values of M_{sn} for native granular and cohesive soils

Granular Soils		Cohesive Soils		Modulus
Blow count	Description	q_u tons/ft^2	Description	M_{sn} (psi)
> 15	Compact	> 2.0	Very stiff	5000
8 - 15	Slightly compact	1.0 – 2.0	Stiff	3000
4 - 8	Loose	0.5 – 1.0	Medium	1500
2 - 4	Loose	0.25 – 0.50	Soft	700
1 - 2	Very loose	0.125 – 0.25	Very soft	200
0 - 1	Very very loose	0 – 0.125	Very very soft	50

Blow counts per standard penetration test (ASTM D1586)

Table 4 above summarizes the approximate values for the constrained soil modulus of the native soil or M_{sn}. Geotechnical sampling or in place resistance testing is used to measure the stiffness of the existing soils.

3.3 Thermoset Plastic Fiberglass Composite Pipe Types

Although less commonly specified than other sewer pipe materials, fiberglass composite pipe is particularly useful where corrosion protection is a factor. In recent years, it has also become more common to be used in standard trenchless and open trench installations. These materials are almost universally specified in larger diameters, 36-inches and greater, in the south central parts of the U.S.

Fiberglass pipe segments are joined by a number of different gasket-sealed joints. Lay lengths are available from 5 to 40 feet with a typical length of 20 feet. These shorter lengths make them particularly well suited for deeper bury applications where trench boxes or sheeting must be employed. These pipes are available in standard sizes of 12-inches to 96-inches and in stiffness classes of 18, 36, 46, and 72pii. Fiberglass composite pipe is not deleteriously affected by soil conditions or sanitary sewer flow, therefore, coatings or lining are not required although a highly inert resin layer is usually specified for the inner most surface. Each pipe design can be custom configured for a specific application; thus this pipe material alternative offers significant versatility and flexibility in various non-pressurized sewer applications.

Fiberglass pipe material is applicable for both trenched and trenchless installations. HOBAS® and Flowtite® are the two most common manufacturers. They are discussed in the sections below.

3.3.1 HOBAS®

HOBAS® is centrifugally cast fiberglass reinforced polymer mortar (CCFRM) pipe commonly used for installations where long duration, corrosion resistance, high strength, and easy installation are required. Pipe is manufactured in a centrifugal process that allows for highly dense, layered design in a controlled temperature and curing environment. It is offered in various wall stiffness classes and as a direct jack tunnel product. Open cut pipe is joined using a proprietary female coupling. The stated diameter range is from 18-inches to 132-inches and standard lengths are 20 ft. The pipe is manufactured in various stiffness classes that allow it to be used in direct bury, sliplining, pipe bursting, jacking and microtunneling applications.

3.3.2 Flowtite®

Flowtite pipe systems are glass-reinforced plastic (GRP) pipe typically built-up using resin, fiberglass and silica sand in a continuously wound manufacturing process. These pipes are manufactured using a continuous advancing mandrel process, which creates a dense laminate that maximizes the contribution of the three component materials. A dual resin system can be used to provide internal corrosion resistance and less costly outer structural resin. The result is a core surrounded by internal and outer structural layers. Some of the primary benefits of this material alternative include superior corrosion resistance and high hydraulic efficiency. The pipe lengths can range from 10 feet to 40 feet and standard diameters range from 12-inch to 96-inch; custom pipe diameters up to 156-inch are also available on a project basis.

3.4 Composite Materials Pipe Installation Requirements

All fiberglass pipe installations follow the installation guidance given in ASTM D3839-02 *Standard Guide for Underground Installation of Fiberglass Pipe*. While both Flowtite and Hobas pipes are much stiffer than the thermoplastic pipe materials, their semi-rigid performance still demands proper attention to the trench detail so that a supportive embedment condition is delivered. These materials are strain sensitive and the initially installed deflection must be less than 3.0% to produce the desired long-term performance. The referenced ASTM D3839 is very similar to the previously referenced standard for plastic pipes, D2321. Thus, the preceding discussion on the thermoplastic pipe materials installation requirements should also govern composite pipe materials installations.

Figure 2 shows the four standard installation trench embedment conditions found in the manufacturers' literature. As with the thermoplastic pipe installations, the minimum trench width is governed by the constrained soil modulus of the native material being equal to or greater than the shown embedment zone's constrained soil modulus, or M_{sb}. The minimum trench width starts with the minimum working room required for the placement of the backfill materials to the design compaction amount with particular attention given to getting the materials into the haunch areas of the pipe; and goes up to the 3 times the pipe's O.D. for weak native soils. Of significant importance in the design trench for these composite type pipes is the availability of multiple pipe stiffness numbers (SN) or classes that can be used by the design engineer to tailor the trench requirements to the in situ soil conditions. As defined earlier, the pipe stiffness, or stiffness class, represents the pounds of loading per linear inch of pipe to produce a vertical inch of deflection when tested unsupported between parallel plates (ASTM D2412). Table 5 graphically represents how this works.

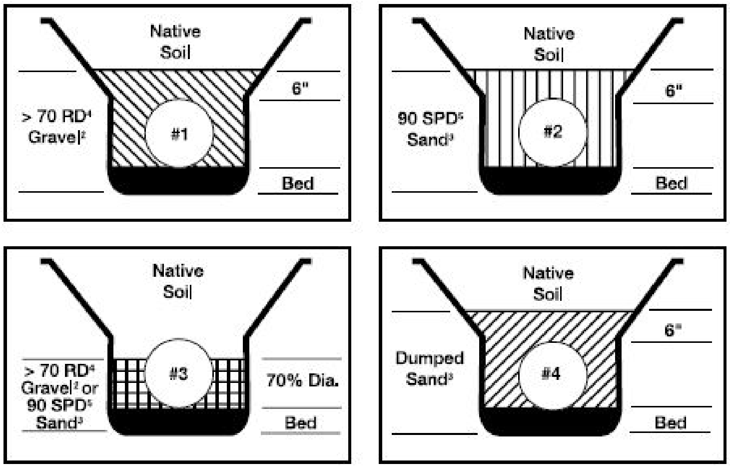


Figure 2 - Trench Embedment Conditions for Composite Materials

Table 5. Fiberglass Composite Pipe – Maximum Cover Depth versus Stiffness Class of the Pipe

Native Soil	Cover Depth (ft.)	Embedment Condition 1	2	3	4
Rock Stiff to V. Hard Cohesive Compact to V. Dense Granular (Blows/ft. >8)	10 & <				SN 72
	10 to 15		SN 36		
	15 to 20			SN 46	
	20 to 25		SN 46		
	25 to 30	SN 46	SN 72		
	30 to 40				ALTERNATE INSTALLATION
	40 to 50				
Medium Cohesive Loose Granular (Blows/ft. 4 to 8)	10 & <		SN 36		SN 72
	10 to 15		SN 46		
	15 to 20	SN 46	SN 72		
	20 to 25				ALTERNATE INSTALLATION
	25 to 30				
Soft Cohesive Very loose Granular (Blows/ft. 2 to 4)	10 & <	SN 36 to 46		SN 72	
	10 to 15	SN 72			
	15 to 20				ALTERNATE INSTALLATION
	Over 20				

Alternative installations include utilization of cement stabilized embedment, wide trenching, permanent sheeting, geotextiles, or combinations of these systems. Installation design for these situations should be engineered to satisfy the site-specific conditions and circumstances present.

4.0 Rigid Pipe Materials

Rigid pipes, while deriving a substantial part of their ultimate load carrying capacity from the structural strength inherent in the rigid pipe wall, still must use the design of the trench to achieve a proper balance between the actual load that will come onto the pipe and the in situ strength of the rigid pipe and its designed embedment system.

4.1 Rigid Pipe Types

The two most common rigid materials for sanitary sewers are vitrified clay pipe (VCP) and reinforced concrete pipe (RCP). Un-reinforced cast in place concrete and brick pipe structures are examples of other rigid materials that are commonly used; however, this document focuses on the precast shape pipes only.

4.1.1 Vitrified Clay

Historically, vitrified clay pipe (VCP) has been one of the most commonly used materials for sewer installations in the U.S. and it has been extensively used in the western U.S. In past years, however, it has become somewhat less popular as new materials have been developed that essentially satisfy its lauded corrosion resistance while offering easier and more forgiving handling during installation and backfill operations. VCP comes in standard laying lengths of 1, 2, and 6 feet in sizes 8-inch through 36-inches; and 1, 2, and 5.5 foot laying lengths in sizes 39 and 42-inches. VCP is manufactured in what are designated as standard, extra-strength, and high-strength classifications on the west coast of the U.S.

VCP is known for having a long life-cycle which is attributed to its highly inert nature after curing. It is also generally considered by contractors as one of the most difficult pipe materials to install correctly; especially in the larger sizes. This is due to the need for digging holes for the bell ends so that a uniform support condition may be established along its length, its weight, joining the pipe without cracking the ends, and the balancing act required to keep the installed trench condition consistent with the pipe's in situ strength performance.

VCP has been fabricated and used as a trenchless replacement pipe material in recent years in installations where the methodology of replacement was static pipe-bursting, pilot-tube micro-tunneling, and slurry micro-tunneling. VCP's robust compressive strength and re-designed coupling system for these type installations have allowed it to compete well with the HDPE pipe materials.

4.1.2 Reinforced Concrete

Reinforced concrete pipe (RCP) is well suited for installations where high strength is required during jacking or for heavy external loads or embankment fill applications. Both circular pipes and box culvert sections can be used depending on the particular application's needs. Pipe segments of this material for sanitary sewer applications are typically delivered with a standard bell and spigot joining construction which utilizes a compressed rubber gasket to make the joint water-tight. Diameters range from 12-inch to 96-inch in this configuration. Today's version of RCP can be manufactured to any reasonable strength requirement by varying the wall thickness, concrete strength, and quantity and configuration of reinforcing steel. The most common standard utilized for RCP in non-pressurized sewer applications is ASTM C-76, but it can also be specified and manufactured under a number of other standards as required.

Because concrete is highly susceptible to damage from hydrogen sulfide (H_2S) attack which is common in sanitary sewers, it is has not been used as often over more cost competitive, corrosion resistant pipe materials that have become available in the larger diameters where it had previously been the only alternative. If it is specified today, a corrosion resistant liner system is recommended to be installed on the interior of the pipe 360 degrees; or, at a minimum, the upper 270 degrees of its circumference. One common lining is T-Lock®, which is a PVC sheeting that mechanically connects to the interior wall of concrete sewer pipe providing a corrosion barrier. The lining system overlaps at the pipe joints and requires post installation welding and testing to minimize future corrosion problems at the joints. However, this PVC overlapping joint can be unstable, difficult to install and historically has had numerous failures and is not recommended for long-term resistance to corrosion prevention of RCP.

4.2 Rigid Pipe Installation Requirements

Vitrified clay and concrete pipes are rigid materials and as such take the load from the surrounding soils first rather than shedding the load to the embedment material right away as do the flexible pipes. This phenomenon of rigid pipes requires that the embedment zone must be firm enough to support the bottom half of the pipe creating a loading condition which multiplies its Three Edge Bearing (TEB) or D-load strength enough to resist the in situ trench loading without reaching its breaking point.

Because rigid pipe theory was developed in the earlier part of the 20th century, the trench design has historically been broken into several configurations for which the multipliers have been determined through extensive experimentation; hence, the four classes of the clay pipe design methodology (Class A through D) and the four types of the concrete pipe design methodology (Types 1 through 4). With that statement, however, comes the realization that there still is the implied requirement for the design engineer to assess the existing soil conditions and detail the embedment zone according to the particular loading that will be present on the pipe and the resistance to that loading that can be developed in that specific native soil condition by the installer's actions.

4.2.1 Vitrified Clay Pipe

The factors influencing the supporting strength of vitrified clay pipe are:

1. The physical properties of the vitrified clay pipe

2. Foundation

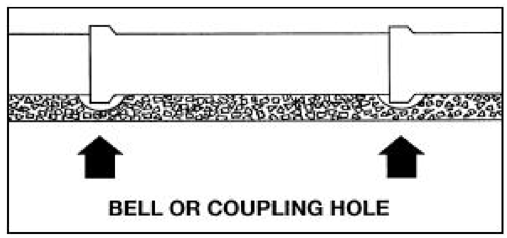
3. Proper bedding to develop the design supporting strength

4. Bedding materials

5. Load factors

Tests to determine the bearing strength of vitrified clay pipe are performed per the ASTM Standard C301. The load test verifies the minimum bearing in terms of pounds per linear foot of pipe. The foundation upon which the pipe will be installed is critical to the performance of the entire pipe installation. It supports the bedding, pipe, and pipe embedment. The foundation must be firm and unyielding.

To obtain the installed supporting strength in accordance with the class of bedding used, the pipe barrel must be uniformly supported by direct contact with firm bedding. Firm bedding means the pipe barrel must rest on undisturbed native or imported material. The native material must be capable of excavation to a uniform undisturbed flat bottom in the case of Class D. If the trench is over-excavated, the trench bottom should be brought back to grade with the required bedding material for class trench needed for the installation. Bell or coupling holes should be carefully excavated so that no part of the load is supported by the bells or couplings. The pipe barrel is designed to support the trench load. *Consolidation of material around and under the bell and couplings during bedding and backfilling should be avoided because it may create a concentrated load resulting in a decreased field supporting strength.* Uniform and continuous support of the pipe barrel between the bell or coupling holes is required for all classes of bedding shown herein.



The National Clay Pipe Institute (NCPI) has conducted extensive laboratory and field research on bedding materials, load factors, and trench load development. Subsequent field experience has confirmed that pipe movement is the leading cause of structural problems. Consequently, the objective of a quality installation must be to develop a stable pipe bedding system which will minimize pipe movement. It is known that not all bedding materials provide the same longitudinal and circumferential pipe support.

Many native materials taken from the trench will provide suitable support for clay pipe and are typically the most cost efficient for the installation. The engineer, during the design phase, should consider if the native materials can achieve the required load factor for his or her particular application. The ideal bedding material is defined as one that: (a) provides uniform support over the greatest area of the pipe barrel, (b) does not develop a point load, (c) does not migrate under the trench conditions present, and (d) is easily placed with little or no compaction required.

The design of the trench detail is governed by the load which a clay pipe must support in an application which is a function of the class of bedding that is specified. The trench details shown below depict the recommended classes of bedding and the resultant bedding factors per the NCPI's referenced testing.

The following figures taken from the NCPI Clay Pipe Engineering Manual illustrate the trench classes and the bedding, or load factor, that should be used.

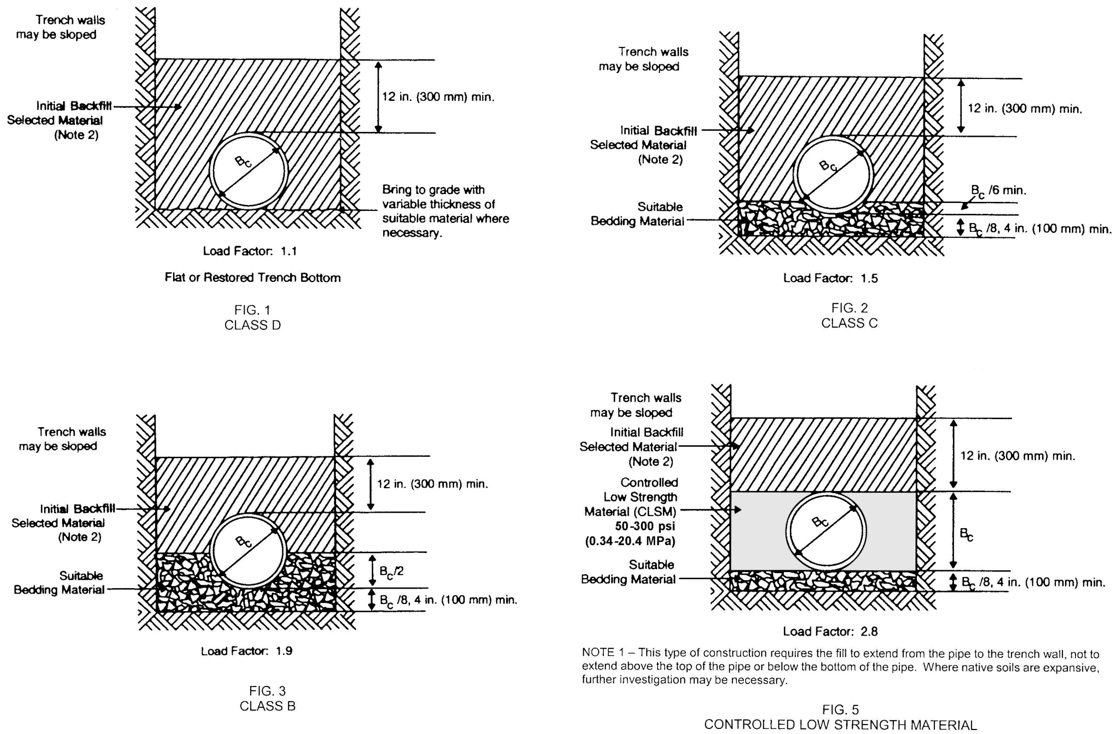


Figure 3 - Trench Bedding and Load Factors for Clay Pipe

4.2.2 Concrete Pipe

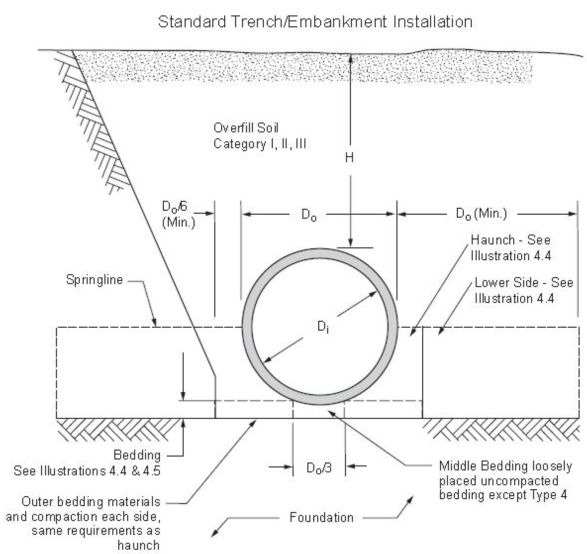
The installation design for concrete pipes has evolved as the understanding of the trench loads for rigid pipes became better defined by research undertaken by the Transportation Research Board (TRB) and the ability to assess the tensile reinforcement needs of the pipe in the current four standard trench installations; which is referred to as the Standard Installation Direct Design (SIDD) method. The four SIDD installations replaced the earlier bedding factor designs similar to those presented above for clay pipe.

The selection of a Standard Installation for a pipe project using RCP should be based on an evaluation of the quality of construction (quality assurance testing) and inspection (construction observation) anticipated. A Type 1 Standard Installation requires the highest construction quality and degree of construction observation. Required construction quality is reduced for a Type 2 Standard Installation, and reduced further for a Type 3 Standard Installation. A Type 4 Standard Installation requires minimal quality assurance testing and/or construction observation. Consequently, a Type 4 Standard Installation will require a higher strength pipe, and a Type 1 Standard Installation will require a lower strength pipe for the same depth of installation.

With the Standard Installations, the additional load that is imposed by the settlement of the soil alongside the pipe is accounted for by using a Vertical Arching Factor (VAF). This factor is multiplied by the soil prism load (weight of the soil column directly above the pipe) to give the total load on the pipe. The minimum VAF by the Standard Installation type are as shown below.

Standard Installation	Minimum Bedding Factor B_{lo}
Type 1	1.35
Type 2	1.40
Type 3	1.40
Type 4	1.45

The details for the SIDD are as follows:



Standard Installations Soil and Minimum Compaction Requirements

Installation Type	Bedding Thickness	Haunch and Outer Bedding	Lower Side
Type 1	D_o/24 minimum, not less than 75 mm (3"). If rock foundation, use D_o/12 minimum, not less than 150 mm (6").	95% Category I	90% Category I, 95% Category II, or 100% Category III
Type 2	D_o/24 minimum, not less than 75 mm (3"). If rock foundation, use D_o/12 minimum, not less than 150 mm (6").	90% Category I or 95% Category II	85% Category I, 90% Category II, or 95% Category III
Type 3	D_o/24 minimum, not less than 75 mm (3"). If rock foundation, use D_o/12 minimum, not less than 150 mm (6") .	85% Category I, 90% Category II, or 95% Category III	85% Category I, 90% Category II, or 95% Category III
Type 4	No bedding required, except if rock foundation, use D_o/12 minimum, not less than 150 mm (6").	No compaction required, except if Category III, use 85% Category III	No compaction required, except if Category III, use 85% Category III

Figure 5a - Standard Installation Direct Design for Concrete Pipe

Equivalent USCS and AASHTO Soil Classifications for SIDD Soil Designations

	Representative Soil Types		Percent Compaction	
SIDD Soil	USCS,	Standard AASHTO	Standard Proctor	Modified Proctor
Gravelly Sand (Category 1)	SW, SP, GW, GP	A1,A3	100 95 90 85 80 61	95 90 85 80 75 59
Sandy Silt (Category II)	GM, SM, ML, Also GC, SC with less than 20% passing #200 sieve	A2, A4	100 95 90 85 80 49	95 90 85 80 75 46
Silty Clay (Category III)	CL, MH, GC, SC	A5, A6	100 95 90 85 80 45	90 85 80 75 70 40

Figure 5b - Standard Installation Direct Design for Concrete Pipe

4.3 Pipe Soil Interaction

Whether a pipe is rigid or flexible has profound effect on the way in which it interacts with the surrounding soil. The interaction between pipe and soil influences the magnitude of loads exerted on the pipe and the manner in which the pipe transfers these loads to the surrounding soils. Calculation of loads exerted on underground pipelines can be traced back to the studies conducted by Anson Marston during the early part of the twentieth century. The results were later expanded by M. G. Spangler and R. K. Watkins and are still in use today (Moser and Folkman, 2008).

Figure 6 provides an illustration of the soil load distribution on rigid and flexible pipes. In the case of rigid pipes, the theory proposes that the soil in the side prism tends to settle relative to the central prism. This causes the pipe to assume full load of the central prism and a portion of the load from the side prisms. In contrast, a flexible pipe tends to deflect, which result in a lowering of the pressure from the central prism.

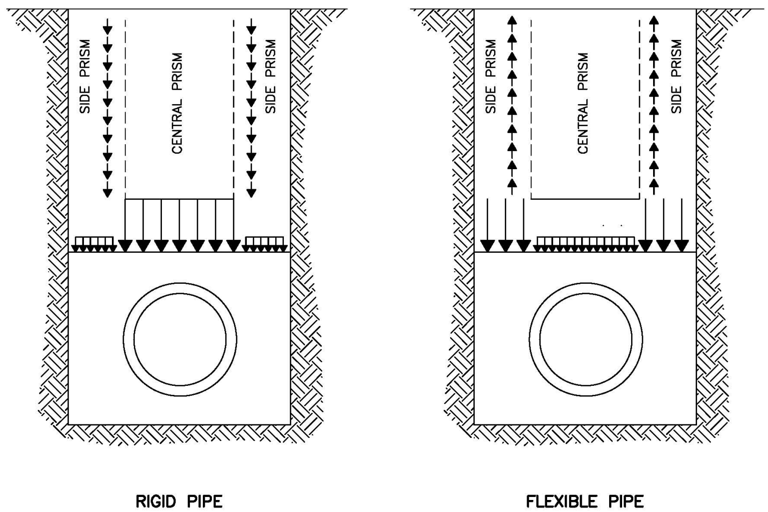


Figure 6 – Trench Load Comparison for Rigid and Flexible Pipes

Soils Arching Effect

Marston's theory (Spangler, 1982) proposes that the load due to the weight of the soil prism above an underground pipeline is modified by an arching action that occurs within the trench walls. According to this theory, part of the soil weight is transferred between side prisms and the central prism, resulting in either an increase or decrease in the effective weight of soil above the pipe. Arching effects could be classified as either positive or negative. Positive arching effects decrease the vertical pressure exerted on the pipeline whereas negative arching effects produce an increase in the vertical pressure acting on the pipe.

For pipelines installed in a trench, insufficiently compacted backfill and embedment material are more compressible than the adjacent native soil that has become well-compacted through natural consolidation. The more compressible backfill and embedment material has a tendency to consolidate and settle more than the native soils. As a result, some of the vertical soil load is transferred through shearing stresses between the side prisms and the central prism and creates positive arching. The degree of transfer depends upon the type of backfill material and how well it is compacted. This arching action can be used advantageously for both rigid and flexible pipes by making the bedding immediately underneath the pipe more compressible than the adjacent bedding. For rigid piping this nestling in further assures uniform support. However, care must be taken in order to avoid differential settlement of the pipe, especially for rigid pipes.

Assuming well-compacted soils in bedding and backfill, positive arching effect occur in the case of flexible pipes that deflect owing to the their lower stiffness. This phenomenon is expected to naturally occur in trenchless installation of pipelines. The relative downward movement of the central prism within the trench mobilizes upward shearing stresses along the sides and creates an arching action that partially supports the soil column weight above the structure (see Fig. 7). In addition to this action, passive resistance of the soils adjacent to the pipe is mobilized and aids in transfer of loads. In contrast and again assuming well-compacted soils in bedding and backfill, negative arching occurs in the case of rigid pipes that do not deflect owing to their high stiffness. Owing to the relatively low stiffness of soils on the sides, shearing forces are transferred from the side prisms to the central prism increasing the effective vertical soil load on the pipe (see Fig. 7).

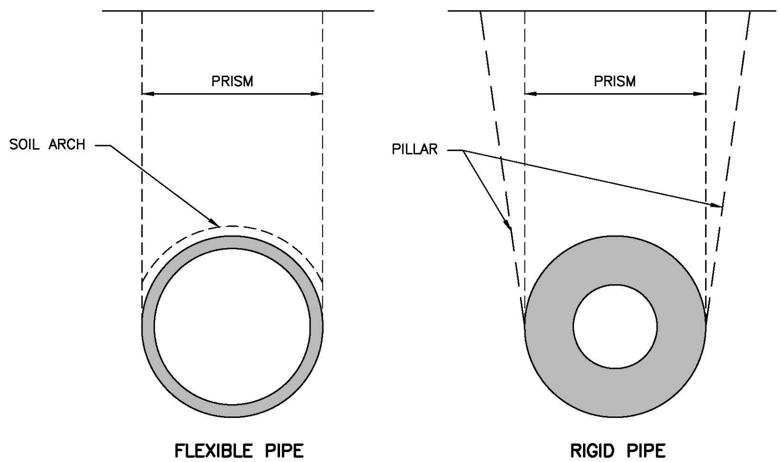


Figure 7 – Arching Effects for Flexible and Rigid Pipes (Gabriel, 2006)

Installation conditions can have a significant effect on the soil loads acting on underground pipelines. In a long-term behavior study in Norway (Vaslestad et al., 1994), a 5.25 feet (1.6 m) diameter circular concrete pipe was constructed with imperfect trench condition (the compressible material was expanded polystyrene foam) with 46 feet (14 m) embankment height. Vertical earth pressure directly above the pipe was only 25 percent of the soil prism weight. Horizontal earth pressure at the mid elevation of the pipe, however, was 73 percent of the soil column weight above that elevation. In the same research, the vertical pressure above a box culvert with 32.8 feet (10 m) backfill height but with 1.7 feet (0.5 m) of expanded polystyrene foam placed immediately above the culvert was 50 percent of the pressure due to the weight of the soil prism above. However, the vertical pressure above an identical box culvert under the same embankment height without the foam, and with normally compacted backfill, was about 120 percent of the soil prism weight. These examples indicate that installation methods and pipe or culvert shape can strongly influence the magnitude and distribution of earth pressures on rigid pipes and culverts.

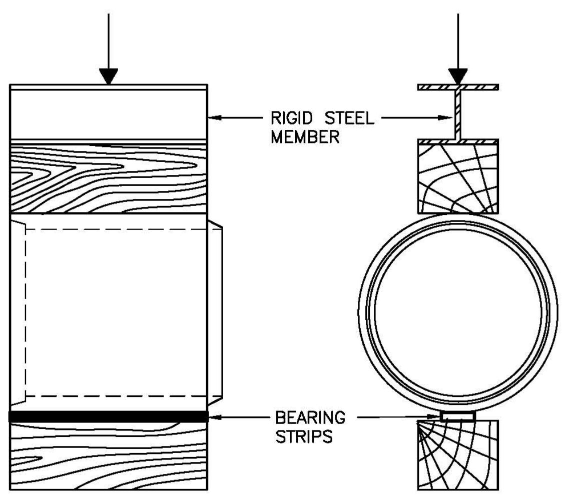
The magnitudes of the loads exerted on pipes depend on arching effects, which are the result of relative deformation of the backfill in a certain zone above the pipes or culverts. This deformation is related to both the soil and the structural stiffness. In the case of flexible pipes, pipe deformation results in arching effects, which reduce the vertical loading regardless of the installation method. Typically, the vertical earth pressure on flexible pipes is less than that due to the weight of the prism of soil above the pipe. For rigid pipe installation, arching effects can also be achieved by introducing a compressible material into the backfill above the pipe. The compressible material provides the “give” necessary to induce the positive arching condition in the trench. Thus, according to Marston’s theory, the vertical earth pressures on pipes are a function of the installation method, the soil and structural stiffness, the geometry of the structure, and the boundary condition with the natural ground. It is worth noting that, even for flexible pipes, a load reduction is achieved as differential settlements transfer loads to the surrounding soil adjacent to the structure.

4.3.1 Behavior of Rigid Pipes

As noted earlier, rigid pipes are designed to transmit loads through their material strength. Since rigid pipes do not deflect appreciably, their design does not consider the horizontal passive resistance of the side soils. Therefore, the allowable load on rigid pipes depends only on the strength of the pipe and the strength of the soil below the pipe. This is usually represented by the following relationship (Howard, 1996):

$$\text{Load on the pipe} = \frac{\text{Pipe Strength x soil strength}}{\text{Safety factor}}$$

Typically, the strength of the material of a rigid pipe is determined in the laboratory by the three-edge bearing test (Fig. 8). The three-edge bearing strength is load per unit length required to cause



either crushing or critical cracking of the pipe (Moser and Folkman, 2008).

Figure 8 – Three-edge Bearing Tests

Strength of soil refers to the amount of support on the bottom half of the pipe and depends on the properties of soil and the contact area. Figure 9 illustrates two extremes of contact area available for pressure distribution below a rigid pipe (Howard, 1996). The point load is the worst possible support case, which in essence is the same as the three-edge bearing strength condition of the lab.

For the distributed load case, the strength of the pipe is enhanced due to uniform distribution, of stress as shown in Fig. 9. Research has shown that the load required to cause failure in installation conditions is typically greater than the three-edge bearing strength owing to the distribution of the supporting forces (Moser and Folkman, 2008).To provide appropriate distribution of the forces it is vitally important to achieve the embedment material's design densities in the haunch area of the pipe.

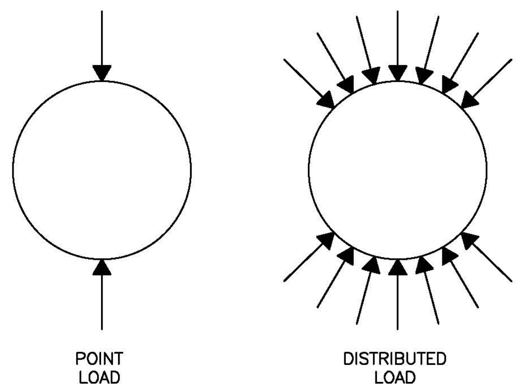


Figure 9 – Load Distribution on Rigid Pipes

The ratio of the field strength of a rigid pipe in a defined trench embedment condition to its three-edge bearing strength is termed the bedding factor and is given by

$$\text{Bedding Factor} = \frac{\text{Actual field Strength}}{\text{three-edge bearing strength}}$$

Bedding factors are empirically derived and specified by different manufacturers for the various types of pipes based on the placement methods and materials used in their testing. These bedding factors have an implied assumption that the native soil's undisturbed strength is equal to or greater than that of the embedment material(s) that generated the published bedding factor. If this is not the case, alternative methods must be employed to insure that the embedment material will be fully supported (i.e., stay in place shoring, etc.)

4.3.2 Behavior of Flexible Pipe

Unlike rigid pipes, flexible pipes are designed to receive the majority of their in place strength from the soil. The embedment material(s) used must be sufficiently strong enough to support the reaction that the pipe will have to the soil load above it. As the load on the pipe increases during and just after its installation, the vertical diameter of the pipe decreases and the horizontal diameter increases accordingly. The increase in horizontal diameter mobilizes the lateral resistance of the native soil(s) as shown in Figure 10. Change in vertical or horizontal dimension of a pipe is usually represented as a percent change and is given by

$$\text{Percent deflection} = \frac{\text{change in diameter}}{\text{original diameter}} \times 100$$

Consider a flexible steel pipe, which is a perfect circle when it is laid on top of the bedding and no soil load has been placed. Steel is a linearly elastic (not viscoelastic) material. After backfilling, though, the steel pipe will most assuredly deflect some amount. When this deflection takes place, two things happen. First, the movement of the pipe vertically induces soil arching which, in turn, reduces the soil load on the steel pipe. So the load the pipe is resisting has decreased; that is, provided that the embedment material is strong enough to support this reaction without too much vertical movement of the top of the pipe. Second, the material in the haunch zone will be strengthened (further compacted) by the expansion of the horizontal diameter movement of the pipe. Again, this performance of the embedment material(s) is counting on the implied assumption that the native soil(s) is equal to or greater in strength than what is required to take the load being transferred to it. In the pipe deflection equation shown below, the amount of deflection that will occur during the installation of the flexible pipe is shown to be a function of the load on the pipe divided by the support resisting that load which is a combination of the pipe's stiffness and the soil's stiffness. Given that the pipe stiffness is very small compared to the soil stiffness one can see just how beneficial the positive soil arching and the increase of the soil's stiffness due to compaction from the pipe's horizontal expansion controls the finished deflection of the flexible pipe.

$$\text{Pipe deflection} = \frac{\text{Load on the pipe}}{\text{pipe stiffness + soil stiffness}}$$

Nevertheless, the load on the pipe has not been reduced sufficiently yet and the pipe further deforms to the shape given by the second deflection in Figure 10. The load on the pipe reduces further due to further soil arching. Soil stiffness again increases because of greater densification of the embedment material in the haunch zone. This secondary increase in the deflection is termed the long-term deflection which continues until the resistance provided by the pipe stiffness and the soil's stiffness is great enough to prevent further deflection taking place. At this point the soil-structure interaction system is said to be stabilized.

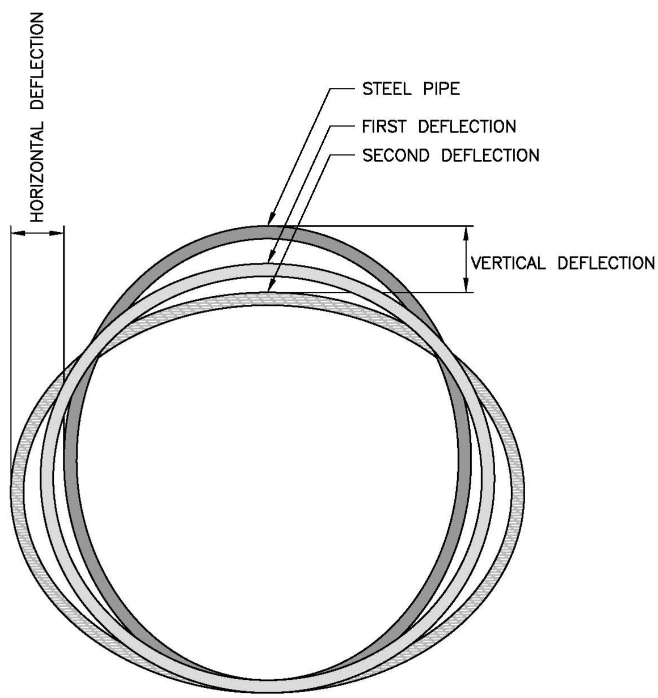


Figure 10 – Load Distribution on Flexible Pipes

Now, the resistance of the combination of the pipe's stiffness and the soil's stiffness is great enough to prevent further deflection. That is how the pipe-soil system stabilizes.

5.0 CVWD Specific Guidelines for Design

It is the intent of this section of the document to review and provide general design guidance to the design engineering community on the currently available non-pressure pipe materials within normal shipping distances of CVWD. Each project undertaken in the CVWD service area poses different challenges and no one document can be expected to prescribe a pipe type without an independent and thorough engineering evaluation of site specific conditions which must be satisfied.

5.1 Pipe Material Selection

The Engineer of Record shall follow a materials selection approach that considers the anticipated project's site specific conditions and utilize the material(s) that are best suited for those conditions. Selection between flexible or rigid pipes, or different type materials within these two categories, depends on a multitude of factors. Flexible pipes may provide certain advantages when the pipe is subjected to ground movement due to soft soil conditions or due to potential seismic hazards such as liquefaction. Conversely, certain more rigid materials may provide advantages in terms of resistance to corrosive environments or other factors. Also, the pipe materials technology is in an ever-improving state with new materials being introduced which may change the landscape of available alternatives over time.

Table 6, below, has been developed to provide a general idea of how the currently available pipe materials compare against each other given size, native soil class, and proposed depth of bury. Alternative trench designs can extend the range of applicability, but require a specialist engineer trained is soil-structure interaction to design the proper trench configuration.

Table 6. Pipe Selection – Maximum Cover Depth versus Soil Stiffness Class

Material	Size Range inches	Max Depth	Native Soil Conditions			
			Class II	Class III	Class IV	Class V
VCP	8 to 36	30	30	20	Alt. Design	Alt. Design
RCP	39 to 96	30	30	20	Alt. Design	Alt. Design
PVC – SDR 35	8 to 24	20	20	15	Alt. Design	Alt. Design
PVC – SDR 26	8 to 15	25	25	20	Alt. Design	Alt. Design
PVC – Profile-wall	18 to 36	35	35	20	Alt. Design	Alt. Design
HDPE – Solid-wall	18 to 36	20	20	15	Alt. Design	Alt. Design
HDPE – Profile-wall	72 to 96	35	35	20	Alt. Design	Alt. Design
CFFRM	18 to 96	50	50	20	Alt. Design	Alt. Design
GRP	12 to 96	50	50	20	Alt. Design	Alt. Design

5.2 Factor of Safety (FS)

The design of the installation trench detail is governed by the load which a pipe must support in a specific application which is a function of the class of bedding that is specified, the native materials stiffness, and the inherent strength of the chosen pipe material(s). For rigid pipes the bedding, or load, factor is the ratio of the supporting strength of the pipe in the trench to its three-edge bearing test strength in the plant. It does not include a design factor of safety (FS). The Engineer of Record shall use the actual loading on the pipe divided by the field supporting strength of the rigid pipe in the installation trench (T.E.B. strength times the bedding factor). For flexible pipes the Engineer of Record inserts the FS directly into the equations used for estimating the in situ deflection and strain performance of the selected material(s). It is the Engineer of Record's responsibility to set an appropriate FS based on the design parameters used in his/her design calculations and the construction difficulties anticipated in the field associated with those choices. CVWD recommends that in no case should the designer produce an installation detail that provides a FS of less than 2.5

Factor of Safety (FS)

The assignment of a factor of safety is done by accounting for:

- the magnitude of damages related to any potential loss of life or property damage,
- the relative cost of increasing or decreasing the FS,
- relative change in the probability of a failure by changing the FS,
- the reliability of the soil data,
- construction tolerances,
- changes in the soil properties due to the anticipated construction operations, and
- the accuracy (or approximations used) in developing the design/analysis methods.

CVWD's minimum recommended factor of safety is 2.5 for $H/D \geq 2$, or 3.0 for $H/D < 2$

(Where H is the height in feet of the fill over the pipe and D is the O.D. of the pipe in feet)

5.3 Flexible Pipe Deflection

All flexible pipe materials are subject to some deflection during the pipe's installation and the subsequent consolidation of the embedment zone material(s) in the first six to nine months. The trench design for these pipe materials will need to take into account the potential for this and the need to keep the deflection below the pipe geometry's known performance limits. The Engineer of Record's calculations should clearly demonstrate that this design limit state will be preserved with the proposed design trench detail given the level of effort that has been used to determine the conditions present on the project site.

It is CVWD's recommendation that the maximum allowable deflection for CCFRM and GRP materials be 3% and the maximum allowable deflection for PVC, HDPE, Polypropylene, and other thermoplastics be 5%. The Engineer of Record's calculations should demonstrate this limit state will be achieved with the design trench detail given the conditions present on the project site. Further, for CCFRM and GRP materials the design shall be checked to confirm that the material's strain limit will be within the known performance limit, as well.

5.4 Pipe Embedment Material

The pipe embedment material is selected by the Engineer of Record to properly support the proposed type of pipe material according to its needs in the native soils found to be present on the project site. It is very important to assess constructability and CVWD's minimum recommended factor of safety, which is 2.5 for $H/D \geq 2$, or 3.0 for $H/D < 2$ (with "H" being the height of the fill over the pipe and "D" being the O.D. of the pipe; both these variables are in feet).

While side support is very necessary for flexible pipes, rigid pipes can also benefit from a material selection that limits settlement of the soil column. The vertical loads on a flexible pipe and the resultant horizontal movement develops a passive soil resistance that varies depending on the soil type and the degree of compaction of the pipe zone backfill material. The historical parameter used to characterize the soil's stiffness (resistance) in the design of flexible pipe is the modulus of soil reaction, or E'. In 2000, AASHTO adopted new soil stiffness values for the backfill materials around flexible pipe reflecting how the soil's resistance increases with the depth of fill due to the increasing confining pressure (e.g. effective vertical pressure on the soil plane at the top of the pipe). This new soil term was designated as M_s, or the constrained soil modulus. To determine M_s for a buried pipe, separate M_s values for the native soil (M_{sn}) and the pipe backfill surround (M_{sb}) must be determined using either the information gathered from a site soils survey, or Tables 2 and 3 contained in section 3.2; and then combined using the soil support combining factor as shown below in Table 7 ($M_s = S_c \times M_{sb}$).

Table 7. Values for the soil support combining factor Sc

M_{sn}/M_{sb}	B_d/D = 1.25	B_d/D = 1.50	B_d/D = 1.75	B_d/D = 2.0	B_d/D = 2.5	B_d/D = 3.0	B_d/D = 4.0	B_d/D = 5.0
0.005	0.02	0.05	0.08	0.12	0.23	0.43	0.72	1.00
0.01	0.03	0.07	0.11	0.15	0.27	0.47	0.74	1.00
0.02	0.05	0.10	0.15	0.20	0.32	0.52	0.77	1.00
0.05	0.10	0.15	0.20	0.27	0.38	0.58	0.80	1.00
0.1	0.15	0.20	0.27	0.35	0.46	0.65	0.84	1.00
0.2	0.25	0.30	0.38	0.47	0.58	0.75	0.88	1.00
0.4	0.45	0.50	0.56	0.64	0.75	0.85	0.93	1.00
0.6	0.65	0.70	0.75	0.81	0.87	0.94	0.98	1.00
0.8	0.84	0.87	0.90	0.93	0.96	0.98	1.00	1.00
1.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.5	1.40	1.30	1.20	1.12	1.06	1.03	1.00	1.00
2	1.70	1.50	1.40	1.30	1.20	1.10	1.05	1.00
3	2.20	1.80	1.65	1.50	1.35	1.20	1.10	1.00
≥5	3.00	2.20	1.90	1.70	1.50	1.30	1.15	1.00

B_d is the trench width; D is the nominal diameter of the pipe.

Initial Backfill placement is designed to protect the new pipe during the backfilling process and to insure that no rocks larger than 6-inches in size will come into contact with the pipe. The level of compaction required is to be commensurate with the material being used and the need to evenly distribute the vertical loading onto the soil plane at the top of the pipe.

The following guidelines can be used by the Engineer of Record as a basis for judgment in determining the suitability of a soil for the embedment material on a particular site. These guidelines, however, are by no means applicable to every field condition that may be encountered.

- Well-graded, angular bedding materials are more stable, allow less movement, and are more resistant to migration when flooded than rounded bedding materials of equal gradation.
- The stability of a bedding material increases as its particle size increases. However, gradations containing particles greater than 1.0 inch become increasingly more difficult to place into the pipe haunch area and may result in uneven support.
- Fine materials are subject to more movement than those of a larger sieve size.
- Sand is suitable as a bedding material in a total sand environment. However, where high or rapidly changing water tables are present in the pipe zone, consideration should be given to the use of an angular bedding material with a geo-fabric material for support. Sand is not an appropriate material for bedding or haunching in a trench cut by blasting or in trenches through hard clay soil.
- Controlled Low Strength Material (50-300 psi) has been shown to be an economic alternative to other bedding materials and classes. It assists in utilizing the inherent strength of the pipe, completely fills the haunch area, and reduces the trench load on a rigid pipe.

5.5 Trench Width Requirements

The minimum and the maximum trench widths should be clearly stated on the project's installation detail. The minimum trench width is necessary to insure that there is adequate room for the selected embedment zone material(s) to be properly placed around the pipe (e.g. under the haunches of the pipe). For flexible pipe materials the minimum width is also important to insure that the selected embedment material(s) will develop the resistance stiffness required to support the pipe. For rigid pipe materials it is important to indicate the maximum width the trench can be opened to during the installation process which is a part of the design engineer's calculations in determining the potential vertical soil loading coming onto the buried rigid pipe.

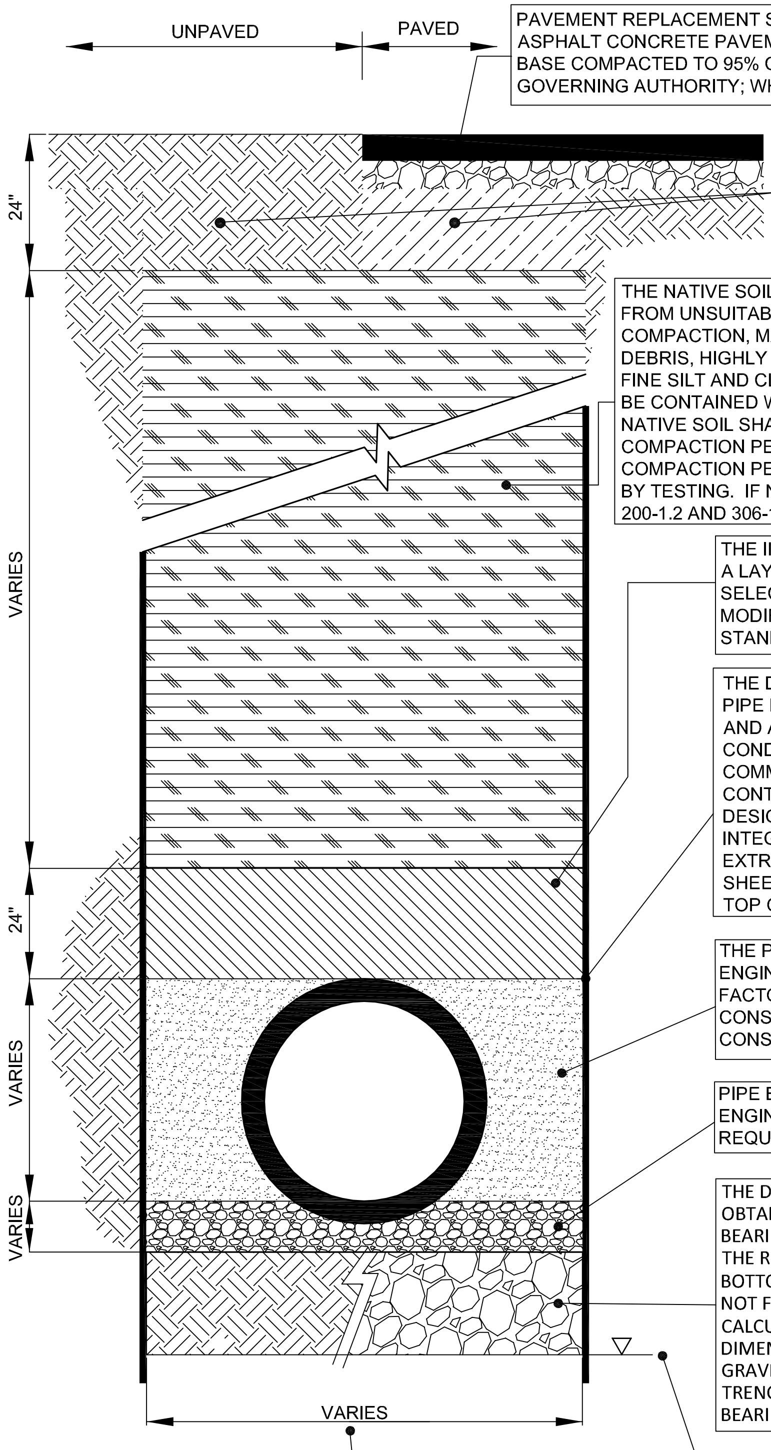
5.6 Trench Bottom's Bearing Capacity

All pipe manufacturers call for the bottom of the excavated trench to be a "firm and unyielding surface". This means that the design of the installation trench needs to support the vertical loading that the Engineer of Record's calculations indicate is going be borne by the pipe. If the strength of the soil at the bottom of the trench is estimated to be, or found during the installation of the pipe, to be less than this loading, the trench must be excavated an additional depth to find this strength in the soil or to reduce the loading on the soil at the bottom of the trench to agree with the native soil's in situ capabilities. This is typically accomplished by placing a coarse rock or other suitable foundation material between this elevation and the bottom of the pipe bedding layer to provide the firm and unyielding surface for the pipe's bedding.

The bottom of the trench shall be shown to be accurately graded to provide uniform bearing and support for each section of pipe at every point along its entire length excluding the bell area. For purposes of quantifying what this minimum level of support is, a handheld penetrometer or other suitable tool shall be utilized to measure the amount of resistance in the soil at that depth. A reading of between 1.0 and 2.0 tons/sf (tsf) will be considered as passing this requirement. Where the bottom of the trench reads less than 1.0 tsf, the Contractor should be directed to excavate the trench in additional 6-inch increments until this minimum bearing capacity is obtained. The maximum additional excavation in any one area shall be limited to 18 inches when the minimum bearing capacity at this depth measures at least 0.5 tsf. If this does not occur, the Contractor shall request input from the Project's Design Engineer as to how to proceed. The foundation material shall consist of 1-½" inch minus rock of a gradation to prevent migration of the native materials into its matrix (e.g. Caltrans Class 2 aggregate base, 1-1/2" size).

5.7 Trench Detail Guideline

The trench detail shown in the following page has been developed to serve as a guide to CVWD's minimum expectations of the design engineering community as to what is required to produce a proper installation detail for projects undertaken within their jurisdiction. This is NOT a standard detail. The components are presented in an informational format to communicate with the Engineer of Record where and how the controlling elements of his or her design analysis are to be communicated to the pipeline installation contractor.



PAVEMENT REPLACEMENT SHALL BE A MINIMUM OF 4" OF HOT-MIX ASPHALT CONCRETE PAVEMENT OVER 8" OF CLASS II AGGREGATE ROAD BASE COMPACTED TO 95% COMPACTION, OR AS PER THE LOCAL GOVERNING AUTHORITY; WHICHEVER IS GREATER.

THE NATIVE SOIL OR SELECT MATERIAL SHALL BE PLACED IN 8" LIFTS (LOOSE) AND COMPACTED TO AT LEAST 95% COMPACTION PER ASTM D1557. COMPACTION SHALL BE VERIFIED BY TESTING .

THE NATIVE SOIL MATERIAL MAY BE USED IN THE TRENCH BACKFILL PROVIDED IT'S FREE FROM UNSUITABLE MATERIAL INCLUDING MATERIAL THAT CANNOT BE STABILIZED BY COMPACTION, MATERIAL GREATER THAN 6" IN SIZE, VEGETATION, TRASH, CONSTRUCTION DEBRIS, HIGHLY EXPANSIVE CLAYS, HIGHLY ORGANIC SOILS AND CONTAMINATED SOILS. THE FINE SILT AND CLAYEY MATERIALS MAY BE USED PROVIDED THEIR MOISTURE CONTENT CAN BE CONTAINED WITHIN THE RANGE THAT ALLOWS FOR THEIR PROPER COMPACTION. THE NATIVE SOIL SHALL BE PLACED IN 8" LIFTS (LOOSE) AND COMPACTED TO AT LEAST 90% COMPACTION PER ASTM D1557, MODIFIED PROCTOR TEST (APPROXIMATELY 95% COMPACTION PER ASTM D698, STANDARD PROCTOR TEST). COMPACTION SHALL BE VERIFIED BY TESTING. IF NATIVE SOIL IS DEEMED NOT SUITABLE, USE BACKFILL PER SSPWC SECTIONS 200-1.2 AND 306-1.3 AND/OR AS SPECIFIED BY THE GEOTECHNICAL ENGINEER.

THE INITIAL BACKFILL ON TOP OF THE PIPE EMBEDMENT ZONE SHALL CONSIST OF A LAYER OF SELECT MATERIAL PLACED TO A DEPTH OF 24" BY 8" LIFTS. THE SELECT MATERIAL SHALL BE COMPACTED TO 90% COMPACTION PER ASTM D1557, MODIFIED PROCTOR TEST (APPROXIMATELY 95% COMPACTION PER ASTM D698, STANDARD PROCTOR TEST). COMPACTION SHALL BE VERIFIED BY TESTING.

THE DESIGN ENGINEER-OF-RECORD MUST CONSIDER THE NEEDS OF THE PIPE MATERIAL THAT PRODUCED THE DESIGNED TRENCH CONFIGURATION AND ANY POTENTIAL CONSTRUCTABILITY ISSUES FOR THE SITE-SPECIFIC CONDITIONS OF THE PROJECT AND MUST CLEARLY COMMUNICATE/DESCRIBE THE CRITICAL PARTS OF THE DESIGN IN THE CONTRACT DOCUMENTS SO THAT THE CONTRACTOR IS ABLE TO PROPERLY DESIGN SHEETING AND SHORING AND UNDERSTANDS ITS IMPACTS ON THE INTEGRITY OF THE PIPE EMBEDMENT WHEN THE SHEETING/SHORING IS EXTRACTED. IN SOME CASES, IT MAY BE NECESSARY TO LEAVE THE SHEETING/SHORING IN PLACE FROM THE BOTTOM OF THE TRENCH TO THE TOP OF THE PIPE (AT A MINIMUM).

THE PIPE EMBEDMENT ZONE IS TO BE DESIGNED BY THE DESIGN ENGINEER-OF-RECORD TO TAKE INTO CONSIDERATION AN APPROPRIATE FACTOR OF SAFETY (2.5 MINIMUM). THE DESIGN NEEDS TO TAKE INTO CONSIDERATION THE NEEDS OF THE PIPE MATERIAL AND ANY CONSTRUCTABILITY ISSUES FOR THE SITE SPECIFIC CONDITIONS.

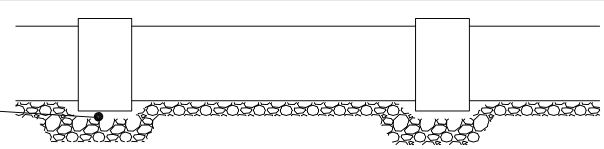
PIPE BEDDING MATERIAL TO BE DESIGNED BY THE DESIGN ENGINEER-OF-RECORD MUST TAKE INTO CONSIDERATION THE DESIGN REQUIREMENTS FOR THE SELECTED PIPE MATERIAL(S).

THE DESIGN ENGINEER-OF-RECORD, BASED ON GEOTECHNICAL INFORMATION OBTAINED FOR THE PROJECT, SHALL EVALUATE AND CONFIRM THE PREDICTED BEARING CAPACITY OF THE NATIVE SOIL AT THE BOTTOM OF THE TRENCH MEETS THE REQUIRED PIPE BEARING CAPACITY OF THE DESIGN TRENCH. WHEN THE BOTTOM OF THE TRENCH DOES NOT MEET THE REQUIRED BEARING CAPACITY (IS NOT FIRM ENOUGH TO SUPPORT THE PIPE BEDDING FOR THE DESIGN LOADING CALCULATED), THE DESIGN ENGINEER-OF-RECORD SHALL DETERMINE THE DIMENSIONS OF A GRAVEL FOUNDATION THAT IS REQUIRED AND THE TYPE OF GRAVEL AND IT'S GRADATION TO BE USED TO ACHIEVE THIS REQUIREMENT. THE TRENCH FOUNDATION SHALL BE ACCURATELY GRADED TO PROVIDE UNIFORM BEARING SUPPORT FOR EACH SECTION OF PIPE AT EVERY POINT ALONG ITS LENGTH.

WHEN A PIPE IS TO BE INSTALLED BELOW THE GROUND WATER TABLE, THE GROUND WATER SHALL BE LOWERED TO AT LEAST 5 FEET BELOW THE LOWEST EXCAVATED TRENCH ELEVATION. THE TRENCH FOUNDATION SHALL BE STABLE WITH NO PONDED WATER, MUD OR MUCK AND SHALL MEET THE REQUIREMENTS NOTED ABOVE.

A MINIMUM AND MAXIMUM TRENCH WIDTH (MEASURED AT THE TOP OF THE PIPE), SHALL BE SPECIFIED. THESE TWO PARAMETERS DEFINE THE WORKING ROOM REQUIRED FOR THE PIPE EMBEDMENT MATERIAL PLACEMENT AND SOIL LOADING USED IN THE PIPELINE INSTALLATION DESIGN OF THE TRENCH.

BELL HOLES SHALL BE PROVIDED AT EACH JOINT WITH A MINIMUM CLEARANCE OF 1" FROM THE BEDDING MATERIAL.



COACHELLA VALLEY WATER DISTRICT

NON-PRESSURIZED PIPELINE TRENCH DETAIL DESIGN GUIDELINES

DATE: OCTOBER 2014

Attachments:

1. ASTM D2321 – 11 Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Application
2. ASTM D3839-02 Standard Guide for Underground Installation of Fiberglass Pipe
3. Hobas® Engineering Brochure
4. Flowtite® Installation Guide

Designation: D2321 – 11

An American National Standard

Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications[1]

This standard is issued under the fixed designation D2321; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This practice provides recommendations for the installation of buried thermoplastic pipe used in sewers and other gravity-flow applications. These recommendations are intended to ensure a stable underground environment for thermoplastic pipe under a wide range of service conditions. However, because of the numerous flexible plastic pipe products available and the inherent variability of natural ground conditions, achieving satisfactory performance of any one product may require modification to provisions contained herein to meet specific project requirements.

1.2 The scope of this practice necessarily excludes product performance criteria such as minimum pipe stiffness, maximum service deflection, or long term strength. Thus, it is incumbent upon the product manufacturer, specifier, or project engineer to verify and assure that the pipe specified for an intended application, when installed according to procedures outlined in this practice, will provide a long term, satisfactory performance according to criteria established for that application. A commentary on factors important in achieving a satisfactory installation is included in Appendix X1.

NOTE 1—Specific paragraphs in the appendix are referenced in the body of this practice for informational purposes.

NOTE 2—The following ASTM standards may be found useful in connection with this practice: Practice D420, Test Method D1556, Method D2216, Specification D2235, Test Method D2412, Specification D2564, Practice D2657, Practice D2855, Test Methods D2922, Test Method D3017, Practice F402, Specification F477, Specification F545, and Specification F913.

NOTE 3—Most Plumbing Codes and some Building Codes have provisions for the installation of underground "building drains and building sewers." See them for plumbing piping applications.

1.3 *Units*—The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D8 Terminology Relating to Materials for Roads and Pavements[3]

D420 Guide to Site Characterization for Engineering Design and Construction Purposes

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3(600 kN-m/m^3))

D1556 Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method

D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D2235 Specification for Solvent Cement for Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe and Fittings

D2412 Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading

D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

D2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)

D2564 Specification for Solvent Cements for Poly(Vinyl Chloride) (PVC) Plastic Piping Systems

D2657 Practice for Heat Fusion Joining of Polyolefin Pipe and Fittings

D2855 Practice for Making Solvent-Cemented Joints with Poly(Vinyl Chloride) (PVC) Pipe and Fittings

[1] This practice is under the jurisdiction of ASTM Committee F17 on Plastic Piping Systems and is the direct responsibility of Subcommittee F17.62 on Sewer.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Withdrawn. The last approved version of this historical standard is referenced on www.astm.org.

***A Summary of Changes section appears at the end of this standard.**

D2922 Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)[3]
D3017 Test Method for Water Content of Soil and Rock in Place by Nuclear Methods (Shallow Depth)
D3839 Guide for Underground Installation of "Fiberglass" (Glass-FiberReinforced Thermosetting-Resin) Pipe
D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
F402 Practice for Safe Handling of Solvent Cements, Primers, and Cleaners Used for Joining Thermoplastic Pipe and Fittings
F412 Terminology Relating to Plastic Piping Systems
F477 Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe
F545 Specification for PVC and ABS Injected Solvent Cemented Plastic Pipe Joints[3]
F913 Specification for Thermoplastic Elastomeric Seals (Gaskets) for Joining Plastic Pipe
F1668 Guide for Construction Procedures for Buried Plastic Pipe

2.2 *AASHTO Standard:*[4]
AASHTO M145 Classification of Soils and Soil Aggregate Mixtures

3. Terminology

3.1 *General—Definitions used in this practice are in accordance with Terminologies F412 and D8 and Terminology D653 unless otherwise indicated.*

3.1.1 Terminology D653 definitions used in this standard:

3.1.2 *compaction curve (Proctor curve) (moisture-density curve)*—the curve showing the relationship between the dry unit weight (density) and the water content of a soil for a given compactive effort.

3.1.3 *optimum water content* —the water content at which a soil can be compacted to a maximum dry unit weight by a given compactive effort.

3.1.4 *percent compaction*—the ratio, expressed as a percentage, of: *(1)* dry unit weight of a soil, to *(2)* maximum unit weight obtained in a laboratory compaction test.

3.1.5 *maximum unit weight*—the dry unit weight defined by the peak of a compaction curve.

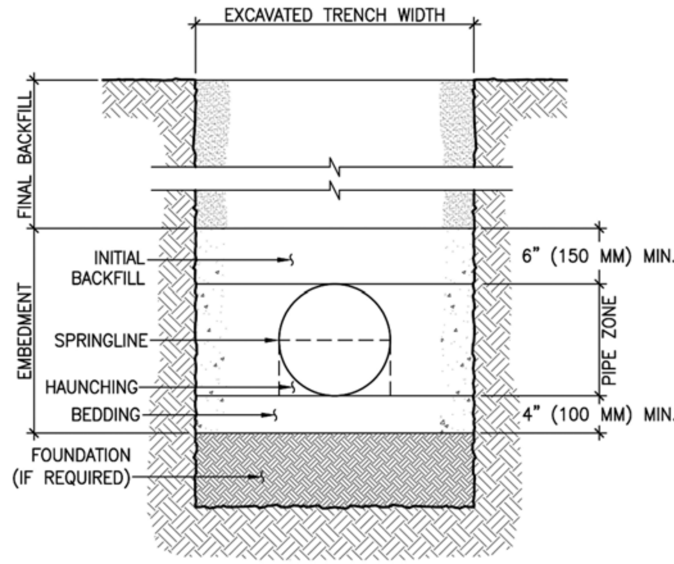
3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *foundation, bedding, haunching, initial backfill, final backfill, pipe zone, excavated trench width*—See Fig. 1 for meaning and limits, and trench terminology.

3.2.2 *aggregate*—a granular material of mineral composition such as sand, gravel, shell, slag or crushed stone (see Terminology D8).

3.2.3 *deflection*—any change in the inside diameter of the pipe resulting from installation and imposed loads. Deflection may be either vertical or horizontal and is usually reported as a percentage of the base (undeflected) inside pipe diameter.

3.2.4 *engineer*—the engineer in responsible charge of the work or his duly recognized or authorized representative.



* See 7.6 Minimum Cover

FIG. 1 Trench Cross Section

3.2.5 *manufactured aggregates*—aggregates such as slag that are products or byproducts of a manufacturing process, or natural aggregates that are reduced to their final form by a manufacturing process such as crushing.

3.2.6 *modulus of soil reaction (E')*—an empirical value used in the Iowa deflection formula that defines the stiffness of the soil embedment around a buried pipe

3.2.7 *open-graded aggregate*—an aggregate that has a particle size distribution such that, when it is compacted, the voids between the aggregate particles, expressed as a percentage of the total space occupied by the material, are relatively large.

3.2.8 *processed aggregates*—aggregates that are screened, washed, mixed, or blended to produce a specific particle size distribution.

3.2.9 *secant constrained soil modulus (M_s)*—- a value for soil stiffness determined as the secant slope of the stress-strain curve of a one-dimensional compression test; M_s can be used in place of *E'* in the Iowa deflection formula.

3.2.10 *standard proctor density*—the maximum dry unit weight of soil compacted at optimum moisture content, as obtained by laboratory test in accordance with Test Methods D698.

4. Significance and Use

4.1 This practice is for use by designers and specifiers, installation contractors, regulatory agencies, owners, and inspection organizations who are involved in the construction of sewers and other gravity-flow applications that utilize flexible thermoplastic pipe. As with any standard practice, modifications may be required for specific job conditions or for special local or regional conditions. Recommendations for inclusion of this practice in contract documents for a specific project are given in Appendix X2.

5. Materials

5.1 *Classification*—Soil types used or encountered in burying pipes include those classified in Table 1 and natural,

[4] Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001, http://www.transportation.org.

TABLE 1 Soil Classification Chart (see Classification D2487)

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests[A]					Soil Classification	
					Group Symbol	Group Name[B]
Coarse-Grained Soils	gravels	clean gravels	C ≥ 4 and 1 ≤ Cc ≤ 3[C]		GW	well-graded gravel[D]
More than 50% retained on No. 200 sieve	more than 50% of coarse fraction retained on No. 4 sieve	less than 5% of fines[E]	Cu < 4 and/or 1> Cc> 3[C]		GP	poorly graded gravel[D]
		gravels with more than 12 % fines[E]	Fines classify as ML or MH		GM	silty gravel[DFG]
			Fines classify as CL or CH		GC	clayey gravel[DFG]
	sands	clean sands	Cu ≥ 6 and 1 ≤ Cc ≤ 3[C]		SW	well-graded sand[H]
	50% or more of coarse fraction passes on No. 4 sieve	less than 5% fines[I]	Cu < 6 and/or 1 > Cc > 3[C]		SP	poorly graded sand[H]
		sand with fines	Fines cLassify as ML or MH		SM	silty sand[FGH]
		more than 12 % fines[I]	Fines classify as CL or CH		SC	clayey sand[FGH]
Fine-Grained Soils	silts and clays	inorganic	PI > 7 and plots on or above "A" line[J]		CL	lean clay[KLM]
50% or more passes the No. 200 sieve	liquid limit less than 50		PI < 4 and plots below "A" line[J]		ML	silt[KLM]
		organic	Liquid Limit-Oven dried	<0.75	OL	organic clay[KLMN]
			Liquid Limit-Not dried			organic silt[KLMO]
	silts and clays	inorganic	PI plots on or above "A" line		CH	fat clay[KLM]
	liquid limit 50 or more		Plots below "A" line		MH	elastic silt[KLM]
		organic	Liquid Limit-Oven Dried	<0.75	OH	organic clay[KLMP]
			Liquid Limit-Not Dried			organic silt[KLMQ]
Highly organic soils	primarily organic matter, dark in color, and organic odor				PT	peat

[A] Based on the material passing the 3-in. (75-mm) sieve.
[B] If field sample contained cobbles or boulders, or both, add "with cobbles or boulders, or both" to group name.
[C] $Cu = D_{60}/D_{10}$

$$Cc = \frac{(D_{30})^2}{D_{10} \times D_{60}}$$

[D] If soil contains ≥15 % sand, add "with sand" to group name.
[E] Gravels with 5 to 12 % fines require dual symbols:
GW-GM well-graded gravel with silt:
GW-GC well-graded gravel with clay
GP-GM poorly graded gravel with silt
GP-GC poorly graded gravel with clay
[F] If fines classify as CL-ML, use dual symbol GC-GM, or SC-SM.
[G] If fines are organic, add "with organic fines" to group name.
[H] If soil contains ≥15 % gravel, add "with gravel" to group name.
[I] Sands with 5 to 12 % fines require dual symbols:
SW-SM well-graded sand with silt
SW-SC well-graded sand with clay
SP-SM poorly graded sand with silt
SP-SC poorly graded sand with clay
[J] If Atterberg limits plot in hatched area, soil is a CL-ML, silty clay (see Test Method D4318).
[K] If soil contains 15 to 29 % plus No. 200, add "with sand" or "with gravel," whichever is predominant.
[L] If soil contains ≥ 30 % plus No. 200, predominantly sand, add "sandy" to group name.
[M] If soil contains ≥ 30 % plus No. 200, predominantly gravel, add "gravelly" to group name.
[N] PI ≥ 4 and plots on or above "A" line.
[O] PI < 4 or plots below "A" line.
[P] PI plots on or above "A" line.
[Q] PI plots below "A" line.

manufactured, and processed aggregates. The soil classifications are grouped into soil classifications in Table 2 based on the typical soil stiffness when compacted. Class I indicates a soil that generally provides the highest soil stiffness at any given percent compaction, and provides a given soil stiffness with the least compactive effort. Each higher-number soil class provides successively less soil stiffness at a given percent compaction and requires greater compactive effort to provide a given level of soil stiffness

NOTE 4—See Practices D2487 and D2488 for laboratory and field visual-manual procedures for identification of soils.

NOTE 5—Processed materials produced for highway construction, including coarse aggregate, base, subbase, and surface coarse materials, when used for foundation, embedment, and backfill, should be categorized in accordance with this section and Table 1 in accordance with particle size and gradation.

5.2 *Installation and Use*—Table 3 provides recommendations on installation and use based on soil classification and location in the trench. Soil Classes I to IV should be used as recommended in Table 3. Soil Class V, including clays and silts with liquid limits greater than 50, organic soils, and frozen soils, shall be excluded from the pipe-zone embedment.

5.2.1 *Class I*— Class I materials provide maximum stability and pipe support for a given percent compaction due to the low content of sand and fines. With minimum effort these materials can be installed at relatively high-soil stiffnesses over a wide range of moisture contents. In addition, the high permeability of Class I materials may aid in the control of water, and these materials are often desirable for embedment in rock cuts where water is frequently encountered. However, when ground-water flow is anticipated, consideration should be given to the potential for migration of fines from adjacent materials into the open-graded Class I materials. (See X1.8.)

5.2.2 *Class II*—Class II materials, when compacted, provide a relatively high level of pipe support; however, open-graded groups may allow migration and the sizes should be checked for compatibility with adjacent material. (See X1.8.)

5.2.3 *Class III*— Class III materials provide less support for a given percent compaction than Class I or Class II materials. Higher levels of compactive effort are required and moisture content must be near optimum to minimize compactive effort and achieve the required percent compaction. These materials provide reasonable levels of pipe support once proper percent compaction is achieved.

5.2.4 *Class IV*—Class IV materials require a geotechnical evaluation prior to use. Moisture content must be near optimum to minimize compactive effort and achieve the required percent compaction. Properly placed and compacted, Class IV materials can provide reasonable levels of pipe support;

TABLE 2 Soil Classes

Soil Group[A,B]	Soil Class	American Association of State Highway and Transportation Officials (AASHTO) Soil Groups[C]
Crushed rock, angular[D]: 100% passing 1-1/2in. sieve, </=15 % passing #4 sieve, </= 25 % passing 3/8in. sieve and </= 12 % passing #200 sieve	Class I	...
Clean, coarse grained soils: SW, SP, GW, GP or any soil beginning with one of these symbols with </=12 % passing #200 sieve[E,F]	Class II	A1,A3
Coarse grained soils with fines: GM, GC, SM, SC, or any soil beginning with one of these symbols, containing > 12 % passing #200 sieve; Sandy or gravelly fine-grained soils: CL, ML, or any soil beginning with one of these symbols, with >/= 30 % retained on #200 sieve	Class III	A-2-4, A-2-5, A-2-6, or A-4 or A-6 soils with more than 30% retained on #200 sieve
Fine-grained soils: CL, ML, or any soil beginning with one of these symbols, with <30 % retained on #200 sieve	Class IV	A-2-7, or A-4, or A-6 soils with 30% or less retained on #200 sieve
MH, CH, OL, OH, PT	Class V Not for use as embedment	A5, A7

[A] See Classification D2487, Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System).

[B] Limits may be imposed on the soil group to meet project or local requirements if the specified soil remains within the group. For example, some project applications require a Class I material with minimal fines to address specific structural or hydraulic conditions and the specification may read "Use Class I soil with a maximum of 5% passing the #200 sieve."

[C] AASHTO M145, Classification of Soils and Soil Aggregate Mixtures.

[D] All particle faces shall be fractured.

[E] Materials such as broken coral, shells, and recycled concrete, with ≤ =12% passing a No. 200 sieve, are considered to be Class II materials. These materials should only be used when evaluated and approved by the Engineer

[F] Uniform fine sands (SP) with more than 50% passing a No. 100 sieve (0.006 in., 0.15 mm) are very sensitive to moisture and should not be used as backfill unless specifically allowed in the contract documents. If use of these materials is allowed, compaction and handling procedures should follow the guidelines for Class III materials.

TABLE 3 Recommendations for Installation and Use of Soils and Aggregates for Foundation and Pipe-Zone Embedment

Soil Class[A]	Class I[B]	Class II	Class III	Class IV
General Recommendations and Restrictions	Acceptable and common where no migration is probable or when combined with a geotextile filter media. Suitable for use as a drainage blanket and under drain where adjacent material is suitably graded or when used with a geotextile filter fabric (see X1.8).	Where hydraulic gradient exists check gradation to minimize migration. Clean groups are suitable for use as a drainage blanket and underdrain (see Table 2). Uniform fine sands (SP) with more than 50 % passing a #100 sieve (0.006 in., 0.15 mm) behave like silts and should be treated as Class IV soils.	Do not use where water conditions in trench prevent proper placement and compaction. Not recommended for use with pipes with stiffness of 9 psi or less	Difficult to achieve high-soil stiffness. Do not use where water conditions in trench prevent proper placement and compaction. Not recommended for use with pipes with stiffness of 9 psi or less
Foundation	Suitable as foundation and for replacing over-excavated and unstable trench bottom as restricted above.	Suitable as foundation and for replacing over-excavated and unstable trench bottom as restricted above. Install and compact in 12 in. (300 mm) maximum layers	Suitable for replacing over-excavated trench bottom as restricted above. Install and compact in 6 in. (150 mm) maximum layers	Suitable for replacing over-excavated trench bottom as restricted above. Install and compact in 6-in (150 mm) maximum layers
Pipe Embedment	Suitable as restricted above. Work material under pipe to provide uniform haunch support.	Suitable as restricted above. Work material under pipe to provide uniform haunch support.	Suitable as restricted above. Difficult to place and compact in the haunch zone.	Suitable as restricted above. Difficult to place and compact in the haunch zone.
Embedment Compaction: Min Recommended Percent Compaction, SPD[D]	See Note[C]	85 % (SW and SP soils) For GW and GP soils see Note[E]	90 %	95 %
Relative Compactive Effort Required to Achieve Minimum Percent Compaction	low	moderate	high	very high
Compaction Methods	vibration or impact	vibration or impact	impact	impact
Required Moisture Control	none	none	Maintain near optimum to minimize compactive effort	Maintain near optimum to minimize compactive effort

[A] Class V materials are unsuitable as embedment. They may be used as final backfill as permitted by the engineer.
[B] Class I materials have higher stiffness than Class II materials, but data on specific soil stiffness of placed, uncompacted Class I materials can be taken equivalent to Class II materials compacted to 95% of maximum standard Proctor density (SPD95), and the soil stiffness of compacted Class I materials can be taken equivalent to Class II materials compacted to 100% of maximum standard Proctor density (SPD100). Even if placed uncompacted (that is, dumped), Class I materials should always be worked into the haunch zone to assure complete placement.
[C] Suitable compaction typically achieved by dumped placement (that is, uncompacted but worked into haunch zone to ensure complete placement).
[D] SPD is standard Proctor density as determined by Test Method D698.
[E] Place and compact GW and GP soils with at least two passes of compaction equipment.

however, these materials may not be suitable under high fills, surface-applied wheel loads, or under high-energy-level vibratory compactors and tampers. Do not use where water conditions in the trench may prevent proper placement and compaction.

NOTE 6—The term "high energy level vibratory compactors and tampers" refers to compaction equipment that might deflect or distort the pipe more than permitted by the specifications or the manufacturer.

5.2.5 *Class V*—Class V materials should be excluded from pipe-zone embedment.

5.3 *Moisture Content of Embedment Materials*—The moisture content of embedment materials must be controlled to permit placement and compaction to required levels. For soils with low permeability (that is, Class III and Class IV and some borderline Class II soils), moisture content is normally controlled to ± 3 % of optimum (see Test Method D698). The practicality of obtaining and maintaining the required limits on moisture content is an important criterion for selecting materials, since failure to achieve required percent compaction, especially in the pipe zone embedment, may result in excessive deflection.

5.4 *Maximum Particle Size*—Maximum particle size for embedment is limited to material passing a 1½-in. (37.5-mm) sieve (see Table 2). To enhance placement around small diameter pipe and to prevent damage to the pipe wall, a smaller maximum size may be required (see X1.9). When final backfill contains rocks, cobbles, etc., the engineer may require greater initial backfill cover levels (see Fig. 1).

6. Trench Excavation

6.1 *General*—Procedures for trench excavation that are especially important in flexible thermoplastic pipe installations are given herein.

6.1.1 *Excavation*—Excavate trenches to ensure that sides will be stable under all working conditions. Slope trench walls or provide supports in conformance with all local and national standards for safety. Open only as much trench as can be safely maintained by available equipment. Backfill all trenches as soon as practicable, but not later than the end of each working day.

6.2 *Water Control*—Do not lay or embed pipe in standing or running water. At all times prevent runoff and surface water from entering the trench.

6.2.1 *Ground Water*—When groundwater is present in the work area, dewater to maintain stability of in-situ and imported materials. Maintain water level below pipe bedding and foundation to provide a stable trench bottom. Use, as appropriate, sump pumps, well points, deep wells, geofabrics, perforated underdrains, or stone blankets of sufficient thickness to remove and control water in the trench. When excavating while depressing ground water, ensure the ground water is below the bottom of cut at all times to prevent washout from behind sheeting or sloughing of exposed trench walls. Maintain control of water in the trench before, during, and after pipe installation, and until embedment is installed and sufficient backfill has been placed to prevent flotation of the pipe. To preclude loss of soil support, employ dewatering methods that minimize removal of fines and the creation of voids in in-situ materials.

6.2.2 *Running Water*—Control running water emanating from drainage of surface or ground water to preclude undermining of the trench bottom or walls, the foundation, or other zones of embedment. Provide dams, cutoffs or other barriers periodically along the installation to preclude transport of water along the trench bottom. Backfill all trenches after the pipe is installed to prevent disturbance of pipe and embedment.

6.2.3 *Materials for Water Control*—Use suitably graded materials in foundation or bedding layers or as drainage blankets for transport of running water to sump pits or other drains. Use well graded materials, along with perforated underdrains, to enhance transport of running water, as required. Select the gradation of the drainage materials to minimize migration of fines from surrounding materials (see X1.8).

6.3 *Minimum Trench Width*—Where trench walls are stable or supported, provide a width sufficient, but no greater than necessary, to ensure working room to properly and safely place and compact haunching and other embedment materials. The space between the pipe and trench wall must be wider than the compaction equipment used in the pipe zone. Minimum width shall be not less than the greater of either the pipe outside diameter plus 16 in. (400 mm) or the pipe outside diameter times 1.25, plus 12 in. (300 mm). In addition to safety considerations, trench width in unsupported, unstable soils will depend on the size and stiffness of the pipe, stiffness of the embedment and in-situ soil, and depth of cover (see X1.10). Specially designed equipment may enable the satisfactory installation and embedment of pipe in trenches narrower than specified above. If it is determined that the use of such equipment provides an installation consistent with the requirements of this standard, minimum trench widths may be reduced, as approved by the engineer.

6.4 *Support of Trench Walls*—When supports such as trench sheeting, trench jacks, trench shields or boxes are used, ensure that support of the pipe and its embedment is maintained throughout installation. Ensure that sheeting is sufficiently tight to prevent washing out of the trench wall from behind the sheeting. Provide tight support of trench walls below viaducts, existing utilities, or other obstructions that restrict driving of sheeting.

6.4.1 *Supports Left in Place*—Unless otherwise directed by the engineer, sheeting driven into or below the pipe zone should be left in place to preclude loss of support of foundation and embedment materials. When top of sheeting is to be cut off, make cut 1.5 ft (0.5 m) or more above the crown of the pipe. Leave rangers, whalers, and braces in place as required to support cutoff sheeting and the trench wall in the vicinity of the pipe zone. Timber sheeting to be left in place is considered a permanent structural member and should be treated against biological degradation (for example, attack by insects or other biological forms) as necessary, and against decay if above ground water.

NOTE 7—Certain preservative and protective compounds may react adversely with some types of thermoplastics, and their use should be avoided in proximity of the pipe material.

6.4.2 *Movable Trench Wall Supports*—Do not disturb the installed pipe and its embedment when using movable trench boxes and shields. Movable supports should not be used below the top of the pipe zone unless approved methods are used for maintaining the integrity of embedment material. Before moving supports, place and compact embedment to sufficient depths to ensure protection of the pipe. As supports are moved, finish placing and compacting embedment.

6.4.3 *Removal of Trench Wall Support*—If the engineer permits the use of sheeting or other trench wall supports below the pipe zone, ensure that pipe and foundation and embedment materials are not disturbed by support removal. Fill voids left on removal of supports and compact all material as required.

6.5 *Rock or Unyielding Materials in Trench Bottom*—If ledge rock, hard pan, shale, or other unyielding material, cobbles, rubble or debris, boulders, or stones larger than 1.5 in. (40 mm) are encountered in the trench bottom, excavate a minimum depth of 6 in. (150 mm) below the pipe bottom and replace with proper embedment material (see 7.2.1).

7. Installation

7.1 *General*—Recommendations for use of the various types of materials classified in Section 5 and Table 2 for foundation, bedding, haunching and backfills, are given in Table 3.

NOTE 8—Installation of pipe in areas where significant settlement may be anticipated, such as in backfill adjacent to building foundations, and in sanitary landfills, or in other highly unstable soils, require special engineering and are outside the scope of this practice.

7.2 *Trench Bottom*—Install foundation and bedding as required by the engineer according to conditions in the trench bottom. Provide a firm, stable, and uniform bedding for the pipe barrel and any protruding features of its joint. Provide a minimum of 4 in. (100 mm) of bedding unless otherwise specified.

7.2.1 *Rock and Unyielding Materials*—When rock or unyielding material is present in the trench bottom, install a cushion of bedding, of 6 in. (150 mm) minimum thickness, below the bottom of the pipe.

7.2.2 *Unstable Trench Bottom*—Where the trench bottom is unstable or shows a "quick'' tendency, excavate to a depth as required by the engineer and replace with a foundation of Class I or Class II material. Use a suitably graded material where conditions may cause migration of fines and loss of pipe support (see X1.8). Place and compact foundation material in accordance with Table 3. For severe conditions, the engineer may require a special foundation such as piles or sheeting capped with a concrete mat. Control of quick and unstable trench bottom conditions may be accomplished with the use of appropriate geofabrics.

7.2.3 *Localized Loadings*—Minimize localized loadings and differential settlement wherever the pipe crosses other utilities or subsurface structures, or whenever there are special foundations such as concrete capped piles or sheeting. Provide a cushion of bedding between the pipe and any such point of localized loading.

7.2.4 *Over-Excavation*—If the trench bottom is over-excavated below intended grade, fill the over-excavation with compatible foundation or bedding material and compact as recommended in Table 3.

7.2.5 *Sloughing*—If trench sidewalls slough off during any part of excavating or installing the pipe, remove all sloughed and loose material from the trench.

7.3 *Location and Alignment*—Place pipe and fittings in the trench with the invert conforming to the required elevations, slopes, and alignment. Provide bell holes in pipe bedding, no larger than necessary, in order to ensure uniform pipe support. Fill all voids under the bell by working in bedding material. In special cases where the pipe is to be installed to a curved alignment, maintain angular "joint deflection'' (axial alignment) or pipe bending radius, or both, within acceptable design limits.

7.4 *Jointing*—Comply with manufacturer's recommendations for assembly of joint components, lubrication, and making of joints. When pipe laying is interrupted, secure piping against movement and seal open ends to prevent the entrance of water, mud, or foreign material.

7.4.1 *Elastomeric Seal Joints*—Protect gaskets from harmful substances such as dust and grit, solvents, and petroleum-based greases and oils. Do not store gaskets close to electrical equipment that produces ozone. Some gaskets may need to be protected from sunlight (consult the manufacturer). Mark, or verify that pipe ends are marked, to indicate insertion stop position, and ensure that pipe is inserted into pipe or fitting bells to this mark. Push spigot into bell using methods recommended by the manufacturer, keeping pipe true to line and grade. Protect the end of the pipe while inserting the spigot into the bell and do not use excessive force that may result in over-assembled joints or dislodged gaskets. If full entry to the specified insertion depth is not achieved, disassemble and clean the joint and reassemble. Use only lubricant supplied or recommended for use by the pipe manufacturer. Do not exceed manufacturer's recommendations for angular "joint deflection'' (axial alignment).

7.4.2 *Solvent Cement Joints*—When making solvent cement joints, follow recommendations of both the pipe and solvent cement manufacturer. If full entry is not achieved, disassemble or remove and replace the joint. Allow freshly made joints to set for the recommended time before moving, burying, or otherwise disturbing the pipe.

7.4.3 *Heat Fusion Joints*—Make heat fusion joints in conformance with the recommendations of the pipe manufacturer. Pipe may be joined at ground surface and then lowered into position, provided it is supported and handled in a manner that precludes damage.

7.5 *Placing and Compacting Pipe Embedment*—Place embedment materials by methods that will not disturb or damage the pipe. Work in and tamp the haunching material in the area between the bedding and the underside of the pipe before placing and compacting the remainder of the embedment in the pipe zone. Follow recommendations for compaction given in Table 2. Do not permit compaction equipment to contact and damage the pipe. Use compaction equipment and techniques that are compatible with materials used and location in the trench (see X1.7). Before using heavy compaction or construction equipment directly over the pipe, place sufficient backfill to prevent damage, excessive deflections, or other disturbance of the pipe. See 7.6 for minimum cover.

7.5.1 *Percent Compaction of Embedment* —The Soil Class (from Table 2) and the required percent compaction of the embedment should be established by the engineer based on an evaluation of specific project conditions (see X1.6.2). The information in Table 3 will provide satisfactory embedment stiffness and is based on achieving an average modulus of soil reaction, E', of 1000 psi (or an appropriate equivalent constrained modulus, M_s).

7.5.2 *Consolidation by Watering*—Consolidation of cohesionless material by using water (jetting or puddling) should only be used under controlled conditions when approved by the engineer. At all times conform to the lift thicknesses and the compaction requirements given in Table 3.

7.6 *Minimum Cover*—To preclude damage to the pipe and disturbance to pipe embedment, a minimum depth of backfill above the pipe should be maintained before allowing vehicles or heavy construction equipment to traverse the pipe trench. The minimum depth of cover should be established by the engineer based on an evaluation of specific project conditions. In the absence of an engineering evaluation, the following minimum cover requirements should be used. For embedment materials installed in accordance with Table 3, provide cover (that is, depth of backfill above top of pipe) of at least 24 in. (0.6 m) or one pipe diameter (whichever is larger) for Class I embedment, and a cover of at least 36 in. (0.9 m) or one pipe diameter (whichever is larger) for Class II, III, and IV embedment, before allowing vehicles or construction equipment to traffic the trench surface, and at least 48 in. (1.2 m) of cover before using a hydrohammer for compaction. Do not use hydrohammer-type compactors unless approved by the engineer. Where construction loads may be excessive (for example, cranes, earth moving equipment, etc.), minimum cover shall be increased as determined by the engineer.

7.7 *Vertical Risers*—Provide support for vertical risers as commonly found at service connections, cleanouts, and drop manholes to preclude vertical or lateral movement. Prevent the direct transfer of thrust due to surface loads and settlement, and ensure adequate support at points of connection to main lines.

7.8 *Exposing Pipe for Making Service Line Connections*—When excavating for a service line connection, excavate material from above the top of the existing pipe before removing material from the sides of the pipe. Materials and percent compaction of service line embedment should conform to the specifications for the existing line, or with this practice, whichever is more stringent.

NOTE 9—Special construction techniques and considerations are required when more than one pipe is installed in the same or adjacent trenches, to ensure that the integrity of the embedment is maintained.

7.9 *Pipe Caps and Plugs*—Secure caps and plugs to the pipe to prevent movement and resulting leakage under test and service pressures.

7.10 *Manhole Connections*—Use flexible water stops, resilient connectors, or other flexible systems approved by the engineer to make watertight connections to manholes and other structures.

7.11 *Field Monitoring*—Compliance with contract documents with respect to pipe installation, including trench depth, grade, water conditions, foundation, embedment and backfill materials, joints, density of materials in place, and safety, should be monitored by the engineer at a frequency appropriate to project requirements. Leakage testing specifications, while not within the scope of this practice, should be made part of the specifications for plastic pipe installations, when applicable.

8. Inspection, Handling, and Storage

8.1 *Inspection*—Upon receipt, inspect each shipment of pipe and fittings for conformance to product specifications and contract documents, and check for damage. Reject nonconforming or damaged pipe, and remove from the job. If not returned to supplier, dispose of legally.

8.2 *Handling and Storage*—Handle and store pipe and fittings in accordance with recommendations of the manufacturer.

9. Keywords

9.1 backfill; bedding; compaction; embedment; haunching; migration; sewer pipe; soil stiffness; thermoplastic; underground installation

APPENDIXES

(Nonmandatory Information)

X1. COMMENTARY

X1.1 Those concerned with the service performance of a buried flexible pipe should understand factors that can affect this performance. Accordingly, key considerations in the design and execution of a satisfactory installation of buried flexible thermoplastic pipe that provided a basis for the development of this practice are given in this Appendix.

X1.2 *General*—Sub-surface conditions should be adequately investigated prior to construction, in accordance with Practice D420, as a basis for establishing requirements for foundation, embedment and backfill materials and construction methods. The type of pipe selected should be suited for the job conditions.

X1.3 *Load/Deflection Performance*—The thermoplastic pipes considered in this practice are classified as flexible conduits since in carrying load they deform (deflect) to develop support from the surrounding embedment. This interaction of pipe and soil provides a pipe-soil structure capable of supporting earth fills and surface live loads of considerable magnitude. The design, specification and construction of the buried flexible pipe system should recognize that embedment materials must be selected, placed and compacted so that pipe and soil act in concert to carry the applied loads without excessive strains from deflections or localized pipe wall distortions.

X1.4 *Pipe Deflection*—Pipe deflection is the diametral change in the pipe-soil system resulting from the process of installing the pipe (construction deflection), static and live loads applied to the pipe (load-induced deflection), and time dependent soil response (deflection lag). Construction and load induced deflections together constitute initial pipe deflection. Additional time dependent deflections are attributed primarily to changes in embedment and in-situ soils, and trench settlement. The sum of initial and time dependent deflections constitutes total deflection.

X1.4.1 *Construction Deflection*

Construction deflections are induced during the process of installing and embedding flexible pipe, even before significant earth and surface loads are applied. The magnitude of construction deflections depends on such factors as the method and extent of compaction of the embedment materials, type of embedment, water conditions in the trench, pipe stiffness, uniformity of embedment support, pipe out-of-roundness, and installation workmanship in general. These deflections may exceed the subsequent load-induced deflections. Compaction of the side fill may result in negative vertical deflections (that is, increases in pipe vertical diameter and decreases in horizontal diameter).

X1.4.2 *Load-Induced Deflection*

Load-induced deflections result from backfill loads and other superimposed loads that are applied after the pipe is embedded. Traditionally, typical soil-structure interaction equations such as the "Iowa Formula'', attributed to Spangler, or other methods have been used to calculate deflections resulting from these loads.

X1.4.3 *Initial Deflection*

Initial deflection is the deflection in the installed and backfilled pipe. It is the total of construction deflections and load-induced deflections.

X1.4.4 *Time Dependent Factors*

Time dependent factors include changes in soil stiffness in the pipe embedment zone and native trench soils, as well as loading changes due to trench settlement over time. These changes typically add to initial deflections; the time involved varies from a few days to several years depending on soil types, their placement, and initial compaction. Time dependent factors are traditionally accounted for by adjusting load-induced deflections by a deflection lag factor. Selection of a deflection lag factor is considered in design guides for buried flexible pipe.

X1.4.5 *Final Deflection*

Final deflection is the total long term deflection of the pipe. It consists of initial deflection adjusted for time dependent factors.

X1.5 *Deflection Criteria*—Deflection criteria are often set as limits for the design and acceptance of buried flexible pipe installation. Deflection limits for specific pipe systems may be derived from both structural and practical considerations. Structural considerations include pipe cracking, yielding, strength, strain, and local distortion. Practical considerations include such factors as flow requirements, clearance for inspection and cleaning, and maintenance of joint seals. Initial and final deflection limits should be based on available structural properties with suitable factors of safety applied.

NOTE X1.1—Some ASTM standard specifications for thermoplastic pipe, such as Specifications D3034, F679, F714, and F949, provide recommended limits for installed deflections.

NOTE X1.2—Deflections may not be indicative of strain levels arising from local distortions caused by non-uniform embedment stiffness or localized loadings. When local distortions may be significant, the engineer needs to establish methods for controlling and monitoring distortion levels.

X1.6 *Deflection Control*—Embedment materials should be selected, placed, and compacted so as to minimize total deflections and, in any event, to maintain installed deflections within specific limits. Methods of placement, compaction, and moisture control should be selected based on soil types given in Table 1 and Table 2 and on recommendations given in Table 3. The amount of load-induced deflection is primarily a function of the stiffness of the pipe and soil embedment system. Other factors that are important in obtaining deflection control are outlined below.

X1.6.1 *Embedment at Pipe Haunches*

Lack of adequate compaction of embedment material in the haunch zone can result in excessive deflection, since it is this material that supports the vertical loads applied to the pipe. A key objective during installation of flexible thermoplastic pipe (or any pipe) is to work in and compact embedment material under pipe haunches, to ensure complete contact with the pipe bottom, and to fill voids below the pipe.

X1.6.2 *Embedment Compaction*

Embedment compaction requirements should be determined by the engineer based on deflection limits established for the pipe, pipe stiffness, and installation quality control, as well as the characteristics of the in-situ soil and compactibility characteristics of the embedment materials used. The compaction requirements given in Table 3 are based on attaining an average modulus of soil reaction (E′) of 1000 psi[5] (or an appropriate equivalent constrained modulus, M_s), which relates soil stiffness to soil type and degree of compaction. For particular installations, the project engineer should verify that the percent compaction specified meets performance requirements.

X1.7 *Compaction Methods*—Achieving desired compaction for specific types of materials depends on the methods used to impart compactive energy. Coarse-grained, clean materials such as crushed stone, gravels, and sand are more readily compacted using vibratory equipment, whereas fine materials with high plasticity require kneading and impact force along with controlled water content to achieve acceptable compaction (see 5.3). In pipe trenches, small, hand-held or walk-behind compactors are required, not only to preclude damage to the pipe, but to ensure thorough compaction in the confined areas around the pipe and along the trench wall. As examples, vibratory plate tampers work well for coarse grained materials of Class I and Class II, whereas hand tampers or air driven hand-held impact rammers are suitable for the fine-grained, plastic groups of Class III and IV. Gas or diesel powered jumping jacks or small, walk-behind vibratory rollers impart both vibratory and kneading or impact force, and hence are suitable for most classes of embedment and backfill material.

X1.8 *Migration*—When coarse and open-graded material is placed adjacent to a finer material, fines may migrate into the coarser material under the action of hydraulic gradient from ground water flow. Significant hydraulic gradients may arise in the pipeline trench during construction when water levels are being controlled by various pumping or well-pointing methods, or after construction when permeable underdrain or embedment materials act as a "french'' drain under high ground water levels. Field experience shows that migration can result in significant loss of pipe support and continuing deflections that may exceed design limits. The gradation and relative size of the embedment and adjacent materials must be compatible in order to minimize migration (see X1.8.1 below). In general, where significant ground water flow is anticipated, avoid placing coarse, open-graded Class I materials above, below, or adjacent to finer materials, unless methods are employed to impede

[5] Howard, Amster, "Modulus of Soil Reaction Values for Buried Flexible Pipe," *Journal of Geotechnical Engineering*, ASCE, Vol. 103, No. GT1, 1977.

migration such as the use of an appropriate stone filter or filter fabric along the boundary of the incompatible materials. To guard against loss of pipe support from lateral migration of fines from the trench wall into open-graded embedment materials, it is sufficient to follow the minimum embedment width guidelines in X1.10.

X1.8.1 The following filter gradation criteria may be used to restrict migration of fines into the voids of coarser material under a hydraulic gradient:

X1.8.1.1 $D_{15} / d_{85} < 5$ where D_{15} is the sieve opening size passing 15 % by weight of the coarser material and d_{85} is the sieve opening size passing 85 % by weight of the finer material, and

X1.8.1.2 $D_{50}/d_{50} < 25$ where D_{50} is the sieve opening size passing 50 % by weight of the coarser material and d_{50} is the sieve opening size passing 50 % by weight of the finer material. This criterion need not apply if the coarser material is well-graded (see Test Method D2487).

X1.8.1.3 If the finer material is a fine-grained soil (CL, CH, ML, or MH), then the following criterion may be used in lieu of X1.8.1.1: $D_{15} < 0.02$ in. (0.5 mm) where D_{15} is the sieve opening size passing 15 % by weight of the coarser material.

NOTE X1.3—Materials selected for use based on filter gradation criteria, such as in X1.8.1, should be handled and placed in a manner that will minimize segregation.

X1.9 *Maximum Particle Size*—Limiting particle size to ¾ in. (20 mm) or less enhances placement of embedment material for nominal pipe sizes 8 in. (200 mm) through 15 in. (380 mm). For smaller pipe, a particle size of about 10 % of the nominal pipe diameter is recommended.

X1.10 *Embedment Width for Adequate Support*—In certain conditions, a minimum width of embedment material is required to ensure that adequate embedment stiffness is developed to support the pipe. These conditions arise where in-situ lateral soil resistance is negligible, such as in very poor native soils or along highway embankments. Examples of poor native soils include poorly compacted soils with blow counts of five or less, peat, muck, or highly expansive soils. Under these conditions, if the native soil is able to sustain a vertical cut, the minimum embedment width shall be 0.5 pipe diameters on either side of the pipe as shown in Fig. X1.1. Under these conditions, if the native soil cannot sustain a vertical cut or if it is an embankment situation, the minimum embedment width shall be one pipe diameter on either side of the pipe as shown in Fig. X1.2. In either case, the embedment material shall be a Class II granular material or a Class I crushed rock as specified in Section 5 of this standard. If other embedment materials are used, the engineer should establish the minimum embedment width based on an evaluation of parameters such as pipe stiffness, embedment stiffness, nature of in-situ soil, and magnitude of construction and service loads. Regardless of the trench width required for adequate support, the trench must be of sufficient width to allow the proper placement of embedment in accordance with 6.3.

NOTE X1.4—Installation in very poor soil conditions may require additional treatment, for example, soil stabilization or permanent sheeting.

NOTE X1.5—The embedment over the top of the pipe shown in Fig. X1.1 and Fig. X1.2 represent minimum cover for impact protection, not for pipe support. Regardless of the minimum cover shown, the requirements of 7.6 must be met.

NOTE X1.6—Refer to X1.6 for backfill material and compaction requirements to control deflection.

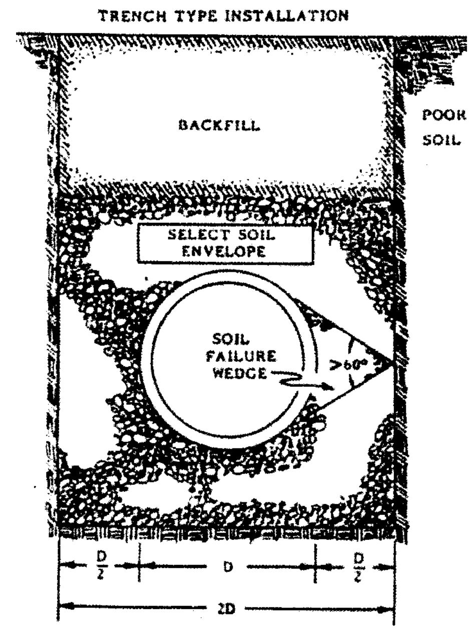


FIG. X1.1 Minimum Embedment Width When Trench and Native Soil Can Sustain a Vertical Cut

X1.11 *Lumps, Clods and Boulders*—Backfill materials should be free of lumps, clods, boulders, frozen matter, and debris. The presence of such material in the embedment may preclude uniform compaction and result in excessive localized deflections.

X1.12 *Other Design and Construction Criteria* —The design and construction of the pipe system should recognize conditions that may induce excessive shear, longitudinal bending, or compression loading in the pipe. Live loads applied by construction and service traffic may result in large, cumulative pipe deflections if the pipe is installed with a low density embedment and shallow cover. Other sources of loads on buried pipes are: freezing and thawing of the ground in the vicinity of the pipe, rising and falling of the ground water table, hydrostatic pressure due to ground water, and localized differential settlement loads occurring next to structures such as manholes and foundations. Where external loads are deemed to be excessive, the pipe should be installed in casing pipe or other load limiting structures.

X1.13 *Deflection Testing*—To ensure specified deflection limits are not exceeded, the engineer may require deflection testing of the pipe using specified measuring devices. To allow for stabilization of the pipe soil system, deflection tests should be performed at least 30 days after installation. However, as a quality control measure, periodic checks of deflection may be made during installation.

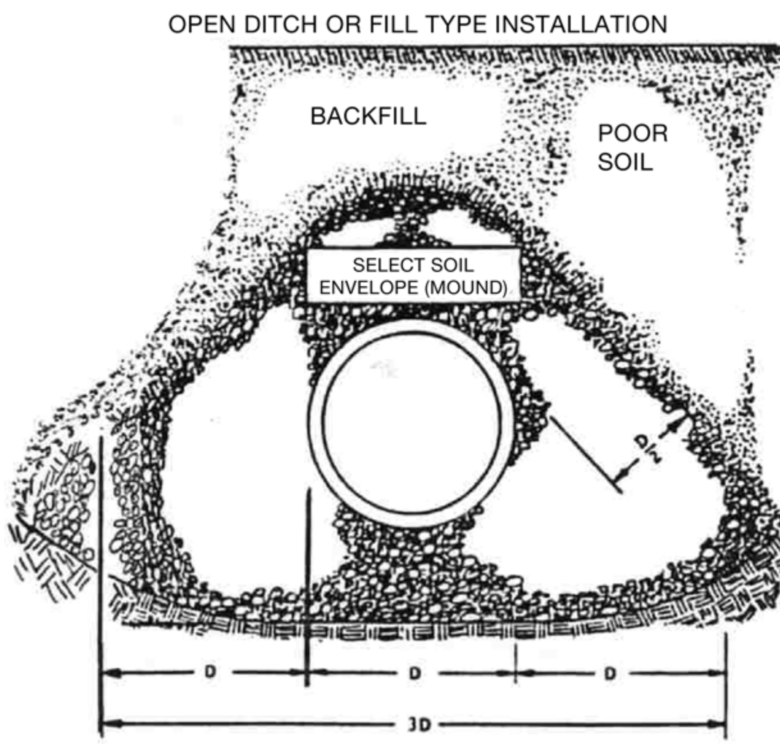


FIG. X1.2 Minimum Embedment Width When Native Soil Can Not Sustain a Vertical Cut or When Installed in the Embankment Condition

X1.13.1 Optional devices for deflection testing include electronic deflectometers, calibrated television or video cameras, or a properly sized "go, no-go'' mandrel. Deflection measurements can be made directly with extension rulers or tape measures in lines that permit safe entry. To ensure accurate measurements, clean the lines before testing.

X1.14 *Additional Installation Information*–Supplemental information useful for buried pipe installation can be found in Practice F1668.

X2. RECOMMENDATIONS FOR INCORPORATION IN CONTRACT DOCUMENTS

X2.1 This practice may be incorporated, by referral, into contract documents for a specific project to cover requirements for installation of flexible thermoplastic pipe in sewers and other gravity-flow applications. Application to a particular project should be made by means of a list of supplemental requirements. Suggested modifications to specific sections are listed below (the list is keyed to applicable section numbers of this practice):

X2.2 *Sections 5.1, 5.2, and Table 3* —Further restrictions on use of Classes of embedment and backfill materials.

X2.3 *Section 5*—Specific gradations of embedment materials for resistance to migration.

X2.4 *Section 5.5*—Maximum particle size, if different from Table 2.

X2.5 *Section 6.2*—Restrictions on mode of dewatering; design of underdrains.

X2.6 *Section 6.3*—Requirements on minimum trench width.

X2.7 *Section 6.4*—Restrictions or details for support of trench walls.

X2.8 *Section 7.5*—Specific restrictions on methods of compaction.

X2.9 *Section 7.5.1 and Table 3* —Minimum embedment percent compaction if different from these recommendations; specific compaction requirements for backfill (for example, for pavement subgrade).

X2.10 *Section 7.6*—Minimum cover requirements if different from this paragraph.

X2.11 *Section 7.7*—Detailed requirements for support of vertical risers, standpipes, and stacks to accommodate anticipated relative movements between pipe and such appurtenances. Detailing to accommodate thermal movements, particularly at risers.

X2.12 *Section 7.10*—Detailed requirements for manhole connections.

X2.13 *Section 7.11*—Requirements on methods of testing compaction and leakage.

X2.14 *Section X1.13*—Requirements on deflection and deflection measurements, including method and time of testing.

SUMMARY OF CHANGES

Committee F17 has identified the location of selected changes to this standard since the last issue (D2321–09) that may impact the use of this standard. (Approved Feb. 1, 2011.)

(*1*) 7.4.1 was revised to add gasket precautions and to eliminate "homing".

Committee F17 has identified the location of selected changes to this standard since the last issue (D2321–08) that may impact the use of this standard. (Approved Dec. 15, 2009)

(*1*) 2.1 and X1.14 – Added reference to Specification F1668.
(*2*) Section 3 – Added and deleted definitions consistent with other changes, including terms from Terminology D653.
(*3*) 7.5.1 – Revised wording in terms of "percent compaction;" added reference to constrained modulus, M_s.
(*4*) Fig. 1 - Changed height of initial backfill over pipe to "minimum 6 in (150 mm);" re-defined haunching zone.
(*5*) Table 2 – Corrected percent of fines for Class III and Class IV soils; added Note F.
(*6*) Table 3 – Modified "General Recommendations and Restrictions" for Class II fine sands (SP); modified "Embedment Compaction" requirements for GW and GP soils; modified "Foundation" requirements for Class IV soils.
(*7*) X1.4.1 – Removed reference to D3839 regarding construction deflection allowances.
(*8*) X1.4.4 – Removed incorrect definition of deflection lag factor.
(*9*) X1.6.2 – Added reference to constrained modulus, M_s.
(*10*) X1.8.1 – Clarified that both X1.8.1.1 and X1.8.1.2 are necessary migration criteria.
(*11*) X1.8.1.3 – Expanded the soil groups that fall within this alternate criterion for migration.
(*12*) Note X1.4 – Changed "hydraulic or under consolidated soils" to "very poor soil conditions."
(*13*) Entire standard – Revised wording for "density" and "Proctor" to "percent compaction."

Standard Guide for Underground Installation of "Fiberglass" (Glass-FiberReinforced Thermosetting-Resin) Pipe[1]

This standard is issued under the fixed designation D 3839; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

ϵ[1] NOTE—Table 3 was editorially revised in November 2003.

1. Scope

1.1 This practice establishes procedures for the burial of pressure and nonpressure "fiberglass" (glass-fiber-reinforced thermosetting-resin) pipe in many typically encountered soil conditions. Included are recommendations for trenching, placing pipe, joining pipe, placing and compacting backfill, and monitoring deflection levels. Guidance for installation of fiberglass pipe in subaqueous conditions is not included.

1.2 Product standards for fiberglass pipe encompass a wide range of product variables. Diameters range from 1 in. to 12 ft (25 mm to 3600 mm) and pipe stiffness range from 9 to over 72 psi (60 to 500 kPa) with internal pressure ratings up to several thousand pound-force per square inch. This standard does not purport to consider all of the possible combinations of pipe, soil types, and natural ground conditions that may occur. The recommendations in this practice may need to be modified or expanded to meet the needs of some installation conditions. In particular, fiberglass pipe with diameters of a few inches are generally so stiff that they are frequently installed in accordance with different guidelines. Consult with the pipe manufacturer for guidance on which practices are applicable to these particular pipes.

1.3 The scope of this practice excludes product-performance criteria such as a minimum pipe stiffness, maximum service deflection, or long-term strength. Such parameters may be contained in product standards or design specifications, or both, for fiberglass pipe. It is incumbent upon the specified product manufacturer or project engineer to verify and ensure that the pipe specified for an intended application, when installed in accordance with procedures outlined in this practice, will provide a long-term, satisfactory performance in accordance with criteria established for that application.

NOTE 1—There is no similar or equivalent ISO standard.

NOTE 2—A discussion of the importance of deflection and a presentation of a simplified method to approximate field deflections are given in AWWA Manual of Practice M45 Fiberglass Pipe Design.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 8 Terminology Relating to Materials for Roads and Pavements[2]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[3]

D 698 Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft (600 kN-m/m))[3]

D 883 Terminology Relating to Plastics[4]

D 1556 Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method[3]

D 1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (56 000 ft-lbf/ft (2 700 kN-m/m))[3]

D 2167 Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method[3]

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock[3]

D 2321 Practice for Underground Installation of Flexible Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications[5]

D 2487 Classification of Soils for Engineering Purposes[5]

D 2488 Practice for Description of Soils (Visual-Manual Procedure)[3]

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[1] This practice is under the jurisdiction of ASTM Committee D20 on Plastics and is the direct responsibility of Subcommittee D20.23 on Reinforced Plastic Piping Systems and Chemical Equipment.

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[2] *Annual Book of ASTM Standards*, Vol 04.03.

[3] *Annual Book of ASTM Standards*, Vol 04.08.

[4] *Annual Book of ASTM Standards*, Vol 08.01.

[5] *Annual Book of ASTM Standards*, Vol 08.04.

D 2922 Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)[3]

D 3017 Test Method for Moisture Content of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)[3]

D 4253 Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table[3]

D 4254 Test Method for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density[3]

D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils[3]

D 4564 Test Method for Density of Soil in Place by the Sleeve Method[3]

D 4643 Method for Determination of Water (Moisture) Content of Soil by the Microwave Oven Method[3]

D 4914 Test Method for Density of Soil and Rock in Place by the Sand Replacement Method in a Test Pit[3]

D 4944 Test Method for Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester Method[6]

D 4959 Test Method for Determination of Water (Moisture) Content of Soil by Direct Heating Method[6]

D 5030 Test Methods for Density and Unit Weight of Soil and Rock in Place by the Water Replacement Method in a Test Pit[6]

D 5080 Test Method for Rapid Determination of Percent Compaction[6]

F 412 Terminology Relating to Plastic Piping Systems[5]

2.2 *Other Standards:*

AASHTO LRFD Bridge Design Specifications, 2nd Edition, American Association of State Highway and Transportation Officials[7]

AAHSTO M145 Classification of Soils and Soil Aggregate Mixtures[7]

AWWA C 950 American Water Works Association Standard Specification for Fiberglass Pressure Pipe[8]

AWWA Manual of Practice M45 Fiberglass Pipe Design Manual[8]

3. Terminology

3.1 *Definitions:*

3.1.1 *General*—Unless otherwise indicated, definitions are in accordance with Terminologies D 8, D 653, D 883, and F 412.

3.2 *Definitions of Terms Specific to This Standard:* Descriptions of Terms Specific to This Standard:

3.2.1 *bedding*—backfill material placed in the bottom of the trench or on the foundation to provide a uniform material on which to lay the pipe.

3.2.2 *deflection*—any change in the inside diameter of the pipe resulting from installation or imposed loads, or both; deflection may be either vertical or horizontal and is usually reported as a percentage of the nominal inside pipe diameter.

3.2.3 *engineer*—the engineer in responsible charge of the work or his duly recognized or authorized representative.

3.2.4 *fiberglass pipe*—a tubular product containing glass-fiber reinforcements embedded in or surrounded by cured thermosetting resin; the composite structure may contain aggregate, granular, or platelet fillers, thixotropic agents, pigments, or dyes; thermoplastic or thermosetting liners or coatings may be included.

3.2.5 *final backfill*—backfill material placed from the top of the initial backfill to the ground surface.

3.2.6 *fines*—soil particles that pass a No. 200 seive.

3.2.7 *foundation*—in situ soil or, in the case of unsuitable ground conditions compacted backfill material, in the bottom of the trench the supports the bedding and the pipe (see Fig. 1).

3.2.8 *geotextile*—any permeable textile material used with foundation, soil, earth, rock, or any other geotechnical engineering related material, as an integral part of a man-made product, structure, or system.

3.2.9 *haunching*—backfill material placed on top of the bedding and under the springline of the pipe; the term haunching only pertains to soil directly beneath the pipe (see Fig. 1).

3.2.10 *initial backfill*—backfill material placed at the sides of the pipe and up to 6 to 12 in. (150 to 300 mm) over the top of the pipe, including the haunching.

3.2.11 *manufactured aggregates*—aggregates that are products or by-products of a manufacturing process, or natural aggregates that are reduced to their final form by a manufacturing process such as crushing.

3.2.12 *maximum standard Proctor density*—the maximum dry unit weight of soil compacted at optimum moisture content, as obtained by laboratory test in accordance with Test Method D 698.

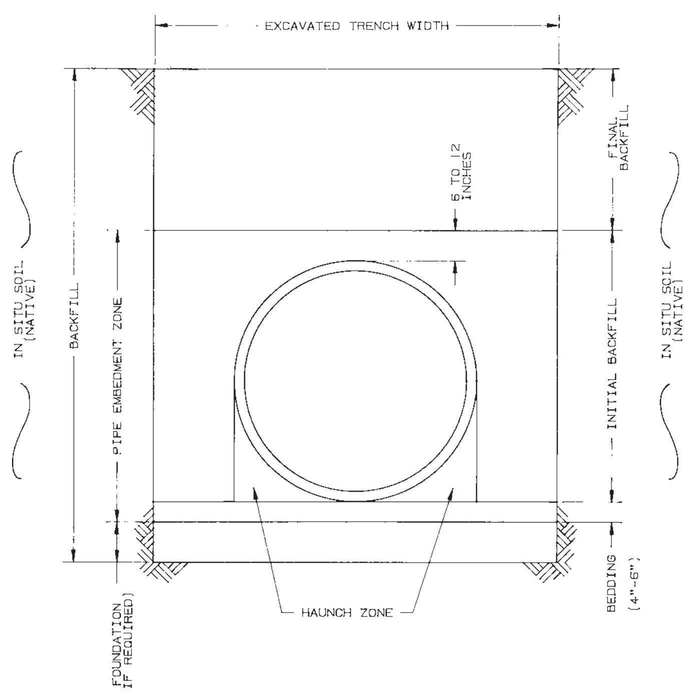

FIG. 1 Trench Cross-Section Terminology

[6] *Annual Book of ASTM Standards*, Vol 04.09.

[7] Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001.

[8] Available from American Water Works Association (AWWA), 6666 West Quincy Ave., Denver CO 80235.

3.2.13 *native (in situ) soil*—natural soil in which a trench is excavated for pipe installation or on which a pipe and embankment are placed.

3.2.14 *open-graded aggregate*—an aggregate that has a particle-size distribution such that, when compacted, the resulting voids between the aggregate particles, expressed as a percentage of the total space occupied by the material, are relatively large.

3.2.15 *optimum moisture content*—the moisture content of soil at which its maximum density is obtained. (See Test Method D 698.)

3.2.16 *pipe zone embedment*—all backfill around the pipe; this includes the bedding, haunching, and initial backfill.

3.2.17 *processed aggregates*—aggregates which are screened or washed or mixed or blended to produce a specific particle-size distribution.

3.2.18 *relative density*—a measure of the density of a granular soil based on the actual density of the soil "relative" to the soil in its loosest state and the soil in its densest state (see Terminology D 653 for a precise definition) as obtained by laboratory testing in accordance with Test Methods D 4253 and D 4254.

3.2.19 *soil stiffness*—a property of soil, generally represented numerically by a modulus of deformation that indicates the relative amount of deformation that will occur under a given load.

3.2.20 *split installation*—an installation in which the initial backfill consists of two different materials; the first material extends from the top of the bedding to a depth of at least 0.6 times the diameter and the second material extends to the top of the initial backfill.

4. Significance and Use

4.1 This practice is for use by designers and specifiers, manufacturers, installation contractors, regulatory agencies, owners, and inspection organizations involved in the construction of buried fiberglass pipelines. As with any practice, modifications may be required for specific job conditions, or for special local or regional conditions. Recommendations for inclusion of this practice in contract documents for a specific project are given in Appendix X1.

5. Materials

5.1 *Classification*—Soil types used or encountered in burying pipes include those classified in Table 1 and natural, manufactured, and processed aggregates. The soil classifications are grouped into soil-stiffness categories (SC#) in Table 2 based on the typical soil stiffness when compacted. Category SC1 indicates a soil that generally provides the highest soil stiffness at any given percentage of maximum Proctor density, and a soil that provides a given soil stiffness with the least compactive effort. Each higher-number soil-stiffness category provides successively less soil stiffness at a given percentage of maximum Proctor density and requires greater compactive effort to provide a given level of soil stiffness.

NOTE 3—See Practices D 2487 and D 2488 for laboratory and field visual-manual procedures for identification of soils.

NOTE 4—Processed materials produced for highway construction, including coarse aggregate, base, subbase, and surface coarse materials, when used for foundation, embedment, and backfill, should be categorized in accordance with this section and Table 1 in accordance with particle size and gradation.

5.2 *Installation and Use*—Table 3 provides recommendations on installation and use based on soil-stiffness category and location in the trench. Categories SC1 to SC4 should be used as recommended in Table 3. Soil-stiffness Category 5, including clays and silts with liquid limits greater than 50, organic soils, and frozen soils, shall be excluded from the pipe-zone embedment.

5.2.1 *Soil-Stiffness Category 1 (SC1)*—SC1 materials provide maximum stability and pipe support for a given percent compaction due to the low content of sand and fines. With minimum effort these materials can be installed at relatively high-soil stiffnesses over a wide range of moisture contents. In addition, the high permeability of SC1 materials may aid in the control of water, and these materials are often desirable for embedment in rock cuts where water is frequently encountered. However, when ground-water flow is anticipated, consideration should be given to the potential for migration of fines from adjacent materials into the open-graded SC1 materials. (See 5.5.)

5.2.2 *Soil-Stiffness Category 2 (SC2)*—SC2 materials, when compacted, provide a relatively high level of pipe support; however, open-graded groups may allow migration and the sizes should be checked for compatibility with adjacent material; see 6.5.

5.2.3 *Soil-Stiffness Category 3 (SC3)*—SC3 materials provide less support for a given density than SC1 or SC2 materials. Higher levels of compactive effort are required and moisture content must be near optimum to minimize compactive effort and achieve the required density. These materials provide reasonable levels of pipe support once proper density is achieved.

5.2.4 *Soil-Stiffness Category 4 (SC4)*—SC4 materials require a geotechnical evaluation prior to use. Moisture content must be near optimum to minimize compactive effort and achieve the required density. Properly placed and compacted, SC4 materials can provide reasonable levels of pipe support; however, these materials may not be suitable under high fills, surface-applied wheel loads, or under high-energy-level vibratory compactors and tampers. Do not use where water conditions in the trench may prevent proper placement and compaction.

NOTE 5—The term "high energy level vibratory compactors and tampers" refers to compaction equipment that might deflect or distort the pipe more than permitted by the specifications or the manufacturer.

5.2.5 *Soil-Stiffness Category 5 (SC5)*— SC5 materials should be excluded from pipe-zone embedment.

5.3 *Moisture Content of Embedment Materials*—The moisture content of embedment materials must be controlled to permit placement and compaction to required levels. For non-free draining soils (that is, SC3 and SC4 and some borderline SC2 soils), moisture content is normally controlled to ±3 % of optimum (see Test Method D 698). The practicality of obtaining and maintaining the required limits on moisture content is an important criterion for selecting materials, since

TABLE 1 Soil Classification Chart (see Classification D 2487)

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests[A]				Soil Classification	
				Group Symbol	Group Name[B]
Coarse-Grained Soils More than 50 % retained on No. 200 sieve	gravels more than 50 % of coarse fraction retained on No. 4 sieve	clean gravels less than 5 % fines[E]	Cu ≥ 4 and 1 ≤ Cc ≤ 3[C]	GW	well-graded gravel[D]
			Cu < 4 and/or 1 > Cc > 3[C]	GP	poorly graded gravel[D]
		gravels with fines more than 12 % fines[E]	Fines classify as ML or MH	GM	silty gravel[D,F,G]
			Fines classify as CL or CH	GC	clayey gravel[D,F,G]
	sands 50 % or more of coarse fraction passes No. 4 sieve	clean sands less than 5 % fines[I]	Cu ≥ 6 and 1 ≤ Cc ≤ 3[C]	SW	well-graded sand[H]
			Cu < 6 and/or 1 > Cc > 3[C]	SP	poorly graded sand[H]
		sands with fines more than 12 % fines[I]	Fines classify as ML or MH	SM	silty sand[F,G,H]
			Fines classify as CL or CH	SC	clayey sand[F,G,H]
Fine-Grained Soils 50 % or more passes the No. 200 sieve	silts and clays liquid limit less than 50	inorganic	PI > 7 and plots on or above "A" line[J]	CL	lean clay[K,L,M]
			PI < 4 or plots below "A" line[J]	ML	silt[K,L,M]
		organic	$\frac{\text{liquid limit} - \text{oven dried}}{\text{liquid limit} - \text{not dried}} < 0.75$	OL	organic clay[K,L,M,N] / organic silt[K,L,M,O]
	silts and clays liquid limit 50 or more	inorganic	PI plots on or above "A" line	CH	fat clay[K,L,M]
			PI plots below "A" line	MH	elastic silt[K,L,M]
		organic	$\frac{\text{liquid limit} - \text{oven dried}}{\text{liquid limit} - \text{not dried}} < 0.75$	OH	organic clay[K,L,M,P] / organic silt[K,L,M,Q]
Highly organic soils	primarily organic matter, dark in color, and organic odor			PT	peat

[A] Based on the material passing the 3-in. (75-mm) sieve.
[B] If field sample contained cobbles or boulders, or both, add "with cobbles or boulders, or both" to group name.
[C] $Cu = D_{60}/D_{10}$ $Cc = \frac{(D_{30})^2}{D_{10} \times D_{60}}$
[D] If soil contains ≥15 % sand, add "with sand" to group name.
[E] Gravels with 5 to 12 % fines require dual symbols:
GW-GM well-graded gravel with silt
GW-GC well-graded gravel with clay
GP-GM poorly graded gravel with silt
GP-GC poorly graded gravel with clay
[F] If fines classify as CL-ML, use dual symbol GC-GM, or SC-SM.
[G] If fines are organic, add "with organic fines" to group name.
[H] If soil contains ≥15 % gravel, add "with gravel" to group name.
[I] Sands with 5 to 12 % fines require dual symbols:
SW-SM well-graded sand with silt
SW-SC well-graded sand with clay
SP-SM poorly graded sand with silt
SP-SC poorly graded sand with clay
[J] If Atterberg limits plot in hatched area, soil is a CL-ML, silty clay (see Test Method D 4318).
[K] If soil contains 15 to 29 % plus No. 200, add "with sand" or "with gravel," whichever is predominant.
[L] If soil contains ≥30 % plus No. 200, predominantly sand, add "sandy" to group name.
[M] If soil contains ≥30 % plus No. 200, predominantly gravel, add "gravelly" to group name.
[N] PI ≥ 4 and plots on or above "A" line.
[O] PI < 4 or plots below "A" line.
[P] PI plots on or above "A" line.
[Q] PI plots below "A" line.

failure to achieve required density, especially in the pipe zone embedment, may result in excessive deflection.

5.4 *Maximum Particle Size*—Maximum particle size for pipe-zone embedment is limited based on pipe diameter as listed in Table 4. For final backfill, the maximum particle size allowed should not exceed 75 % of the lift thickness. When final backfill contains cobbles, boulders, etc., the initial bedding should be extended above the top of the pipe at least 12 in. (300 mm). Backfill containing particles larger than 8 in. (200 mm) shall not be dropped on the backfill or rolled down a sloping trench wall from a height greater than 6 ft (1.8 m) until the depth of fill over the top of the pipe is greater than 24 in. (600 mm).

NOTE 6—The limits of 200 mm (8 in.) particles and a drop height of 6 ft (1.8 m) are somewhat arbitrary, but serve to establish the principle that dropping boulders onto the backfill can damage the pipe even though some backfill has already been placed on the pipe.

5.5 *Migration*—When open-graded material is placed adjacent to a finer material, fines may migrate into the coarser material under the action of hydraulic gradient from ground water flow. Significant hydraulic gradients may arise in the pipeline trench during construction, when water levels are being controlled by various pumping or well-pointing methods, or after construction, when permeable underdrain or embedment materials act as a "french" drain under high ground water levels. Field experience shows that migration can result in significant loss of pipe support and increasing deflections that may eventually exceed design limits. The gradation and relative size of the embedment and adjacent materials must be compatible in order to minimize migration. In general, where significant ground water is anticipated, avoid placing coarse, open-graded materials, such as SC1, above, below, or adjacent

TABLE 2 Soil-Stiffness Categories

NOTE 1—Soil stiffness categories group types together as a function of the relative level of soil stiffness developed when compacted to a given level. At any given level of compaction, SC1 soils provide the highest stiffness and SC5 soils the lowest.

NOTE 2—The soil-stiffness categories are similar but not identical to the soil classes in Practice D 2321.

Soil Group	Soil Stiffness Category
Crushed rock: 15 % sand, maximum 25 % passing the ⅜ in. sieve and maximum 5 % passing a #200 sieve	SC1
Clean, coarse grained soils: SW, SP, GW, GP or any soil beginning with one of these symbols with 12 % or less passing a #200 sieve	SC2
Coarse grained soils with fines: GM, GC, SM, SC, or any soil beginning with one of these symbols, containing more than 12 % passing a #200 sieve; Sandy or gravelly fine-grained soils: CL, ML, (or CL-ML, CL/ML. ML/CL) with more than 30 % retained on a #200 sieve	SC3
Fine-grained soils: CL, ML, (or CL-ML, CL/ML. ML/CL) with 30 % or less retained on a #200 sieve	SC4
MH, CH, OL, OH, PT	SC5 Not for use as embedment

to finer materials, unless methods are employed to impede migration such as the use of an appropriate soil filter or a geotextile filter fabric along the boundary of the incompatible materials.

5.5.1 The following filter gradation criteria may be used to restrict migration of fines into the voids of coarser material under a hydraulic gradient:

$$D_{15}/d_{85} < 5 \quad (1)$$

where:

D_{15} = sieve opening size passing 15 % by weight of the coarser material, and

d_{85} = sieve opening size passing 85 % by weight of the finer material.

$$D_{50}/d_{50} < 25 \quad (2)$$

where:

D_{50} = sieve opening size passing 50 % by weight of the coarser material, and

d_{50} = sieve opening size passing 50 % by weight of the finer material. This criterion need not apply if the coarser material is well-graded (see Classification D 2487).

5.5.2 If the finer material is a medium to highly plastic clay without sand particles (CL or CH), then the following criterion may be used instead of 6.5.1:

$$D_{15} < 0.02\ in.\ (0.5\ mm) \quad (3)$$

where:

D_{15} = sieve-opening size passing 15 % by weight of the coarser material.

NOTE 7—Materials selected for use based on filter-gradation criteria such as in 6.5 should be handled and placed in a manner that will minimize segregation.

5.6 *Cementitious Backfill Materials*—Backfill materials supplemented with cement to improve long-term strength and/or stiffness (soil cement, cement stabilized backfill) or to improve flowability (flowable fill, controlled low strength material) have been shown to be effective backfill materials in terms of ease of placement and quality of support to pipe. While not specifically addressed by this standard, use of these materials is beneficial under many circumstances.

6. Trench Excavation

6.1 *Excavation*—Excavate trenches to ensure that sides will be stable under all working conditions. Slope trench walls or provide supports in conformance with all local and national standards for safety. Place excavated material away from the edge of the trench. Open only enough trench that can be safely maintained by available equipment. Place and compact backfill in trenches as soon as practicable, preferably no later than the end of each working day.

6.2 *Water Control*—It is always good practice to remove water from a trench before laying and backfilling pipe. While circumstances occasionally require pipe installation in standing or running water conditions, such practice is outside the scope of this practice. At all times prevent run-off and surface water from entering the trench.

6.2.1 *Ground Water*—When ground water is present in the work area, dewater to maintain stability of in situ and imported materials. Maintain the water level below pipe bedding. Use, as appropriate, sump pumps, well points, deep wells, geotextiles, perforated underdrains or stone blankets of sufficient thickness to remove and control water in the trench. When excavating while lowering the ground water level, ensure that the ground water is below the bottom of cut at all times to prevent washout from behind sheeting or sloughing of exposed trench walls. Maintain control of water in the trench before, during, and after pipe installation, and until embedment is installed and sufficient backfill has been placed to prevent flotation of the pipe. To preclude loss of soil support, employ dewatering methods that minimize removal of fines and the creation of voids in in situ materials.

6.2.2 *Running Water*—Control running water emanating from surface drainage or ground water to preclude undermining of the trench bottom or walls, the foundation, or other zones of embedment. Provide dams, cutoffs, or other barriers periodically along the installation to preclude transport of water along the trench bottom. Backfill all trenches as soon as practical after the pipe is installed to prevent disturbance of pipe and embedment.

6.2.3 *Materials for Water Control*—Use suitably graded materials in the foundation as drainage blankets for transport of running water to sump pits or other drains. Use properly graded materials or perforated underdrains, or both, to enhance transport of running water. Select the gradation of the drainage materials to minimize migration of fines from surrounding materials. (See 5.5.)

6.3 *Minimum Trench Width*—Where trench walls are stable or supported, provide a width sufficient, but no greater than necessary, to ensure working room to properly and safely place

TABLE 3 Recommendations for Installation and Use of Soils and Aggregates for Foundation and Pipe-Zone Embedment

Soil Stiffness Category[A]	SC1	SC2	SC3	SC4
General Recommendations and Restrictions	Acceptable and common where no migration is probable or when combined with a geotextile filter media. Suitable for use as a drainage blanket and under drain where adjacent material is suitably graded or when used with a geotextile filter fabric (see 6.5).	Where hydraulic gradient exists check gradation to minimize migration. Clean groups are suitable for use as a drainage blanket and underdrain (see Table 2). Uniform fine sands (SP) with more than 50 % passing a #100 sieve (0.006 in., 0.15 mm) behave like silts and should be treated as SC3 soils.	Do not use where water conditions in trench prevent proper placement and compaction. Not recommended for use with pipes with stiffness of 9 psi or less	Difficult to achieve high-soil stiffness. Do not use where water conditions in trench prevent proper placement and compaction. Not recommended for use with pipes with stiffness of 9 psi or less
Foundation	Suitable as foundation and for replacing over-excavated and unstable trench bottom as restricted above.	Suitable as foundation and for replacing over-excavated and unstable trench bottom as restricted above. Install and compact in 12 in. (300 mm) maximum layers	Suitable for replacing over-excavated trench bottom as restricted above. Install and compact in 6 in. (150 mm) maximum layers	Not suitable.
Pipe Zone Embedment	Suitable as restricted above. Work material under pipe to provide uniform haunch support.	Suitable as restricted above. Work material under pipe to provide uniform haunch support.	Suitable as restricted above. Difficult to place and compact in the haunch zone.	Suitable as restricted above. Difficult to place and compact in the haunch zone.
Embedment Compaction:				
Min Recommended Density, SPD[B]	[C]	85 %	90 %	95 %
Relative Compactive Effort Required to Achieve Minimum Density	low	moderate	high	very high
Compaction Methods	vibration or impact	vibration or impact	impact	impact
Required Moisture Control	none	none	maintain near optimum to minimize compactive effort	maintain near optimum to minimize compactive effort

[A] SC5 materials are unsuitable as embedment. They may be used as final backfill as permitted by the engineer.
[B] SPD is standard Proctor density as determined by Test Method D 698.
[C] Minimum density typically achieved by dumped placement.

TABLE 4 Maximum Particle Size for Pipe Embedment

Nominal Diameter (D_i)) Range, in. (mm)	Maximum Particle Size, in., (mm)
D_i= 18 (D_i= 450)	0.50, (13)
18< D_i= 24 (450< D_i= 600)	0.75 (19)
24< D_i= 36 (600< D_i= 900)	1.00 (25)
36< D_i= 48 (900< D_i= 1200)	1.25 (32)
48< D_i(1200< D_i)	1.50 (38)

and compact haunching and other embedment materials. The space between the pipe and trench wall must be wider than the compaction equipment used in this region. For a single pipe in a trench, the minimum trench width should be 1.25 times the outside diameter of the pipe plus 12 in. (300 mm). For multiple pipes in the same trench, interior spaces between pipes must be at least the average of the radii of the two adjacent pipe for depths greater than 12 ft (3.5 m), and ⅔ of the average of the radii of the two adjacent pipe for depths less than 12 ft (3.5 m); the distance from the outside pipe to the trench wall must not be less than if that pipe were installed as a single pipe in a trench. If mechanical compaction equipment is used, the minimum space between pipe and trench wall, or between adjacent pipe shall not be less than the width of the widest piece of equipment plus 6 in. (150 mm). In addition to safety considerations, trench width in unsupported, unstable soils will depend on the size and stiffness of the pipe, stiffness of the embedment and in situ soil, and depth of cover. Specially designed equipment may facilitate the satisfactory installation and embedment of pipe in trenches narrower than specified above. If it is determined that the use of such equipment provides an installation consistent with the requirements of this practice, minimum trench widths may be reduced if approved by the engineer.

6.4 *Support of Trench Walls*—When supports such as trench sheeting, trench jacks, trench shields, or boxes are used, ensure that support of the pipe and the embedment is maintained throughout the installation process. Ensure that sheeting is sufficiently tight to prevent washing out of the trench wall from behind the sheeting. Provide tight support of trench walls below viaducts, existing utilities, or other obstructions that restrict driving of sheeting.

6.4.1 *Support Left in Place*—Unless otherwise directed by the engineer, sheeting driven below the top of the pipe should be left in place to preclude loss of support of foundation and embedment materials. When the top of the sheeting is to be cut off, make the cut 1.5 ft (0.5 m) or more above the crown of the pipe. Leave rangers, walers, and bracers in place as required to support cutoff sheeting and the trench wall in the vicinity of the pipe. Timber sheeting to be left in place is considered a permanent structural member, and should be treated against biological degradation (for example, attack by insects or other biological forms), as necessary, and against decay if above ground water.

NOTE 8—Certain preservative and protective compounds may pose environmental hazards. Determination of acceptable compounds is outside the scope of this practice.

6.4.2 *Movable Trench-Wall Supports*—Do not disturb the installed pipe and its embedment when using movable trench boxes and shields. Movable supports should not be used below the top of the pipe embedment zone, unless approved methods are used for maintaining the integrity of embedment material. Before moving supports, place and compact embedment to sufficient depths to ensure protection of the pipe. As supports are moved, finish placing and compacting embedment, and ensure the direct compaction of embedment materials against the undisturbed native soil.

6.4.3 *Removal of Trench-Wall Support*— If the engineer permits the use of sheeting or other trench-wall supports that extend below the top of the pipe, ensure that neither pipe, foundation, nor embedment materials is disturbed by support removal. Fill voids left on removal of supports and compact all material to required densities.

6.5 *Trench-Bottom*—Excavate trenches to a minimum depth of 4 in. (100 mm) below the pipe. See Section 7 for guidance on installing foundation and bedding.

6.5.1 When ledge, rock, hardpan or other unyielding material, cobbles, rubble or debris, boulders, or stones larger than 1.5 in. (38 mm) are encountered in the trench bottom, excavate a minimum depth of 6 in. (150 mm) below the pipe bottom, or as directed by the engineer.

6.5.2 If the trench bottom is unstable or shows a "quick" tendency, overexcavate to depths directed by the engineer.

6.6 *Trenching on Slopes*—The angle at which slopes can become unstable depends on the quality of the soil. The risk of unstable conditions increases dramatically with slope angle. In general, pipes should not be installed on slopes greater than 15 degrees (a slope of 1 to 4) or in areas where slope instability is suspected, unless supporting conditions have been verified by a proper geotechnical investigation. Installing pipes above ground may be a preferred method for steep slopes as above ground structures such as pipe supports are more easily defined and, therefore, the quality of installation is easier to monitor and settlement easier to detect. Pipes may be installed on slopes greater than 15 degrees (a slope of 1 to 4) provided that:

6.6.1 Long term stability of the installation can be ensured with proper geotechnical design.

6.6.2 Pipes are backfilled with coarse-grained material (SC1) with high shear strength or the shear strength of the backfill is assured by other means. The backfill should be compacted to at least 90 % of maximum standard Proctor density (Test Method D 698).

6.6.3 Pipes should be installed in straight alignment (plus or minus 0.2 degrees) with minimum gap between pipe ends.

6.6.4 Absolute long term movement of the backfill in the axial direction of the pipe must be less than 0.75 in. (20 mm) to avoid joint separation.

6.6.5 The installation is properly drained to avoid washout of materials and ensure adequate soil shear strength.

6.6.6 Stability of individual pipes is monitored throughout the construction phase and the first stages of operation.

6.6.7 The manufacturer is consulted to determine if a special pipe design is required.

7. Installation

7.1 *General*—Recommendations for use of the various types of materials classified in Section 5 and Table 1 for the foundation and pipe zone embedment are given in Table 3.

NOTE 9—Installation of pipe in areas where significant settlement may be anticipated, such as in backfill adjacent to building foundations, and in sanitary landfills, or in other highly unstable soils, require special engineering and are outside the scope of this practice.

7.2 *Foundation/Bedding*—Install foundation and bedding as required by the engineer in accordance with conditions in the trench-bottom. Provide a firm, stable, and uniform bedding for the pipe barrel and any protruding features of its joint. Provide a minimum of 4 in. (100 mm) of bedding below the barrel and 3 in. (75 mm) below any other part of the pipe unless otherwise specified.

7.2.1 *Bedding Material*—Often the bedding material will need to be an imported material to provide the proper gradation and pipe support. The bedding material should be the same material as the initial backfill. Native-soil material can be used as a bedding material if it meets the requirements of the initial backfill. This determination must be made as the pipe installation progresses because native-soil conditions vary widely and may change suddenly along the length of a pipeline. It is increasingly common to leave the bedding uncompacted for a width of ⅓ of the pipe diameter centered directly under the pipe. This reduces concentrated loads on the invert of the pipe.

7.2.2 *Rock and Unyielding Materials*— When rock or unyielding material is present in the trench bottom, install a cushion of bedding, 6-in. (150-mm) minimum thickness, below the bottom of the pipe.

7.2.3 *Unstable Trench-Bottom*—Where the trench-bottom is overexcavated because of unstable or "quick" conditions, install a foundation of SC1, SC2, or larger materials. Complete the foundation with a suitably graded material where conditions may cause migration of fines and loss of pipe support. For severe conditions, the engineer may require a special foundation such as piles or sheeting capped with a concrete mat. Control of quick and unstable trench-bottom conditions may be accomplished with the use of geotextiles.

7.2.4 *Localized Loadings*—Minimize localized loadings and differential settlement wherever the pipe crosses other utilities or subsurface structures, or whenever there are special foundations such as concrete-capped piles or sheeting. Provide a 6-in. (150-mm) minimum cushion of bedding between the pipe and any such point of localized loading.

7.2.5 *Over-Excavation*—If the trench bottom is over-excavated below intended grade, fill the over-excavation with compatible foundation or bedding material and compact to a density not less than the minimum densities stated in Table 3.

7.2.6 *Sloughing*—If trench sidewalls slough off during any excavation or installation of pipe-zone embedment, remove all sloughed and loose material from the trench.

7.3 *Location and Alignment*—Place pipe and fittings in the trench with the invert conforming to the required elevations, slopes, and alignment. Provide bell holes in pipe bedding, no larger than necessary, in order to ensure uniform pipe support. Fill all voids under the bell by working in bedding material. In special cases where the pipe is to be installed to a curved alignment, maintain angular "joint deflection" (axial alignment) or pipe-bending radius within acceptable design limits, or both. Pipe should be laid on flat uniform material that is at the appropriate grade. Do not bring pipe to grade by the use of mounds of soil or other material at points along the length of the pipe. When pipe laying is interrupted, secure piping against movement and seal open ends to prevent the entrance of water, mud, or foreign material.

7.4 *Jointing*—Comply with manufacturer's recommendations for assembly of joint components, lubrication, and making of joints.

7.4.1 *Elastomeric Seal Joints*—Mark, or verify that pipe ends are marked, to indicate insertion stop position, and that pipe is inserted into pipe or fitting bells to this mark. Push spigot into bell using methods recommended by the manufacturer, keeping pipe true to line and grade. Protect the end of the pipe during assembly and do not use excessive force that may result in over-assembled joints or dislodged gaskets. If full entry is not achieved, disassemble and clean joint and reassemble. Use only lubricant supplied or recommended for use by the manufacturer. Do not exceed the manufacturer's recommendations for angular "deflection" (axial alignment).

7.4.2 *Adhesive-Bonded or Wrapped Joints, or Both*—When making adhesive-bonded or wrapped joints, or both, follow recommendations of the pipe manufacturer. Allow freshly made joints to set for the recommended time before moving, burying, or otherwise disturbing the pipe.

NOTE 10—Axial restraint of the joined sections may be required during curing to prevent thermal expansion or contraction which could cause damage to the joint.

7.4.3 *Angularly Deflected Joints*—Large radius bends in pipelines may be accomplished by rotating the alignment of adjacent lengths of pipe (that is, "angularly deflecting" the joint). The amount of angular deflection should not exceed the manufacturer's recommendations.

7.5 *Placing and Compacting Backfill Materials*—Place embedment materials by methods which will not disturb or damage the pipe. Work in and compact the haunching material in the area between the bedding and the underside of the pipe before placing and compacting the remainder of the pipe-zone embedment. Follow recommendations for compaction given in Table 3 and this section. Do not permit compaction equipment to contact and damage the pipe. Use compaction equipment and techniques that are compatible with materials used and location in the trench. See 8.6 for requirements for minimum cover.

7.5.1 *Minimum Density*—The minimum embedment density should be established by the engineer based on an evaluation of specific project conditions. Table 3 gives recommendation for minimum densities that are applicable to most typical projects. Higher densities than those recommended in Table 3 may be appropriate and occasionally lower densities than those recommended in Table 3 may be acceptable.

NOTE 11—The traditional measure of soil stiffness has been the modulus of soil reaction, E', that is commonly used to predict flexible pipe deflection. Recently AASHTO has changed this parameter to the constrained soil modulus, M_s. See Appendix X2 for additional details.

7.5.2 *Densification with Water*—Densification of cohesionless material with water (jetting or saturation with vibration) should only be used under controlled conditions when approved by the engineer. Achieving a suitable water content in the soil is crucial and is best determined by trial test areas. Trial test areas may also be useful in determining the size of internal vibrators required and the appropriate spacing of their insertion into the soil.

7.5.3 *Compaction of Soils Containing Few Fines (Soil Stiffness Categories SC1 and SC2 with Less Than 5 % Fines)*—If compaction is required, use surface plate vibrators, vibratory rollers, or internal vibrators. The compacted lift thickness should not exceed 12 in. (300 mm) when compacted with surface plate vibrators or vibratory rollers and should not exceed the length of the internal vibrator. Density determination should normally be in accordance with Test Methods D 4253 and D 4254 (relative density). In some cases, the density of SW or SP soils may be determined by Test Method D 698 (standard proctor) if the test results in a clearly defined compaction curve.

7.5.4 *Compaction of Soils Containing Some Fines (Soil Stiffness Category SC2 with 5 to 12 % Fines)*—These soils may behave as a soil containing few fines (see 7.5.3) or as a soil containing a significant amount of fines (see 7.5.5). The methods of compaction and density determination should be those methods (7.5.3 or 7.5.5) that result in the higher in-place density.

7.5.5 *Compaction of Soils Containing a Significant Amount of Fines (Soil Stiffness Categories SC3, SC4, and SC5 (CH and MH)*—These soils should be compacted with impact tampers or with sheepsfoot rollers. Density determination should be in accordance with Test Method D 698 (standard Proctor). The maximum density occurs at the optimum moisture content. Less effort is required to reach a given density when the moisture content is within two percentage points of the optimum moisture. A rapid method of determining the percent compaction and moisture variation is described in Test Method D 5080. For compaction levels of 90 % standard Proctor and higher, the compacted lift thickness should not exceed 6 in. (150 mm).

7.5.6 *Determination of the In-Place Density of Soils*—The in-place density of any in situ or fill soil may be determined in accordance with Test Method D 1556, D 2167, D 2922, D 4564, D 4914, or D 5030. The applicable test method will depend on the type of soil, moisture content of the soil, and the maximum particle size present in the soil. The moisture content of the soil may be determined in accordance with Test Method D 2216, D 3017, D 4643, D 4944, or D 4959. When using nuclear density-moisture gages (Test Methods D 2922 and D 3017), the gage should be site-calibrated in the proximity of the pipe and in the excavation unless otherwise indicated by the gage manufacturer.

7.6 *Backfill Around Angularly Deflected Pipe Joints*—When pipe joints are angularly rotated to accomplish large radii bends in pipelines that will operate at internal pressures of 15 psig (100 kPa) or greater, the backfill surrounding the joint should be compacted to at least 90 % of maximum standard Proctor density (or appropriate alternate standard for soils with few fines) for SC1 and SC2 materials, and 95 % of maximum standard Proctor density for SC3 and SC4 materials. Consult the manufacturer for minimum depths of burial and additional restraint that may be required when the angular deflection is vertical.

7.7 *Minimum Cover*—To preclude damage to the pipe and disturbance to pipe embedment, a minimum depth of backfill above the pipe should be maintained before allowing vehicles or heavy construction equipment to traverse the pipe trench. The minimum depth of cover for surface loads, should be established by the engineer based on an evaluation of specific project conditions, including the pipe-zone embedment material and density, the native-soil characteristics, pipe stiffness, pipe diameter, surface pavement, surface loads, and final backfill compaction. In the absence of an engineering evaluation, the following minimum cover requirements should be used.

7.7.1 For embedment materials installed to the minimum densities given in Table 3, provide cover (that is, depth of backfill above top of pipe) of at least 24 in. (0.6 m) for SC1 embedment and a cover of at least 36 in. (0.9 m) for SC2, SC3, or SC4 embedment, before allowing vehicles or construction equipment to traffic the trench surface. Provide at least 48 in. (1.2 m) of cover before using a hydrohammer for compaction unless approved by the engineer. Where construction loads may be excessive (for example, cranes, earth-moving equipment, or other vehicles where wheel loads exceed the AASHTO HS-20 loading) minimum cover shall be increased as determined by the engineer. A minimum of one pipe diameter of cover is suggested to prevent flotation of an empty pipe when full soil saturation to the surface exists.

7.8 *Connections and Appurtenant Structures*:

7.8.1 *Connections to Manholes and Rigid Structures*—When differential settlement can be expected, such as at the ends of casing pipe, when the pipe enters a manhole or at anchor block, provide a flexible system capable of accommodating the anticipated settlement. This may be accomplished by placing a joint as close as practically possible to the face of the structure and a second joint within one to two pipe diameters from the face of the structure. The short length of pipe, called a rocker pipe shall be installed in a straight alignment with the short pipe section coming out of the rigid structure. Multiple rocker pipes should not be used. Alternatively, attach the pipe to the rigid structure with a flexible boot capable of accommodating the anticipated differential movement. Extra care and caution must be taken to replace and properly compact backfill adjacent to any rigid structure. Construction of concrete structures will frequently require over-excavation for formwork, etc. This extra-excavated material must be restored to a density level compatible with surroundings to prevent excess deformation and or joint rotation adjacent the structure. In these areas, compact backfill to achieve the same soil density as specified for all pipe backfill, but not less than that required to achieve a soil constrained modulus (M_a) of at least 1000 psi (6.9 MPa). Other methods of accommodating the differential settlements may be acceptable if approved in advance.

NOTE 12—The use of cement stabilized or flowable backfills adjacent to large structures has been found to be effective in preventing excess deformation where diameters are larger than about 60 in. (1,500 mm).

7.8.2 *Vertical Risers*—Provide support for vertical risers as commonly found at service connections, cleanouts, and drop manholes to preclude vertical or lateral movement. Prevent the direct transfer of thrust due to surface loads and settlement, and ensure adequate support at points of connection to main lines.

7.9 *Exposing Pipe for Making Service-Line Connections*—When excavating for a service-line connection, excavate material from above the top of the existing pipe before removing material from the sides of the pipe. Materials and density of service-line embedment should conform to the specifications for the existing line, or with this practice, whichever is more stringent.

7.10 *Pipe Caps and Plugs*—Secure caps and plugs to the pipe to prevent movement and resulting leakage under test and service pressures.

7.11 *Parallel Piping Systems*—Compact the soil between the pipes in the same manner as the soil between the pipe and the trench wall, taking special care to compact the soil in the haunch zone.

8. Monitoring, Inspecting, and Testing

8.1 *Field Monitoring*—Compliance with pipe installation requirements, including trench depth, grade, water conditions, foundation, embedment and backfill materials, joints, density of materials in place, and safety should be monitored to assure conformance with accordance with contract documents.

8.2 *Deflection*—Monitor the deflection level in the pipe throughout the installation process for conformance to the requirements of the contract specifications and the manufacturer's recommendations. Conduct deflection measurements early in a project to verify that construction procedures are adequate. The deflection at the time of installation will be less than the long-term deflection due to time-dependent load increase. If necessary, also consider the effects of vertical ovalling during compaction. Deflection testing should be completed prior to undertaking pressure tests.

8.3 *Pressure Testing*—Most pressure pipelines are tested after installation to detect leaks, installation flaws, damaged pipes or other deficiencies (see Appendix X1). As a general rule, such tests should not be conducted using air pressure, unless special precautions, not within the scope of this practice, are used. Additional recommendations for conducting pressure tests include:

8.3.1 Required thrust restraints are properly installed (and sufficiently cured if applicable).

8.3.2 Backfilling should be completed. Some sections of the line may be left uncovered provided suitable lateral and longitudinal restraint is provided.

8.3.3 Pumps and valves are anchored.

8.3.4 Assure test caps and endplugs are properly installed and restrained as necessary.

8.3.5 Vent the pipeline while filling to allow all air to escape.

8.3.6 Pressurize the line slowly to avoid pressure surges.

8.3.7 In determining the test pressure remember that the lowest point on the line will have the highest pressure. If the test pressure gage is not installed at this location, then the pressure should be determined by calculation.

8.3.8 Assure that the test fluid temperature is stable during the test period (to avoid pressure changes due to thermal expansion or contraction that may be misinterpreted as leaks).

9. Inspection, Handling, and Storage

9.1 *Inspection*—Upon receipt, inspect each shipment of pipe and fittings for conformance to product specifications and contract documents, and check for damage. Reject or repair nonconforming or damaged pipe. Remove rejected pipe from the jobsite.

9.2 *Handling and Storage*—Proper handling and storage of the pipe is important to achieve a successful installation. Consult the manufacturer for recommendations and appropriate procedures.

10. Keywords

10.1 backfill; bedding; fiberglass pipe; haunching; soil stiffness; underground installation

APPENDIXES

(Nonmandatory Information)

X1. RECOMMENDATION FOR INCORPORATION IN CONTRACT DOCUMENTS

This practice may be incorporated by referral in contract documents for a specific project, to cover requirements for installation. Applications to a particular project should be made by means of a list of supplemental requirements. Suggested modifications to specific section numbers are listed as follows. (The list is keyed to applicable section numbers of the practice):

X1.1 *Paragraph 5.4*—Maximum particle size if different from this section.

X1.2 *Sections 5 and 7 and Table 3*—Further restrictions on use of categories of embedment and backfill materials.

X1.3 *Paragraph 5.5*—Specific gradations of embedment materials for resistance to migration.

X1.4 *Paragraph 6.1.1*—State specific restrictions on leaving trenches open.

X1.5 *Paragraph 6.2*—Restrictions on mode of dewatering; design of underdrains.

X1.6 *Paragraph 6.3*—Requirements on minimum trench width.

X1.7 *Paragraph 6.4*—Restrictions or details for support of trench walls.

X1.8 *Paragraph 7.5*—Specific restrictions on methods of compaction.

X1.9 *Paragraph 7.5.1 and Table 3*—Minimum embedment density if different from these recommendations; specific density requirements for backfill (for example, for pavement subgrade).

X1.10 *Paragraph 7.6*—Minimum cover requirements if different from this paragraph.

X1.11 *Paragraph 7.7.1*—Detailed requirements for manhole connections.

X1.12 *Paragraph 7.7.2*—Detailed requirements for support of vertical risers, standpipes, and stacks to accommodate anticipated relative movements between pipe and such appurtenances. Detailing to accommodate thermal movements, particularly at risers.

X1.13 *Paragraph 8.11*—Requirements on methods of testing compaction and leakage.

X1.14 *Paragraph 8.12*—Requirements on deflection and deflection measurements, including method and time of testing.

X2. SOIL STIFFNESS

X2.1 In 2000, AASHTO adopted new values for soil stiffness for backfill materials used for thermoplastic pipe. The modifications include changing the soil design parameter from the modulus of soil reaction, E', to the constrained soil modulus, Ms. This change is based on the work of McGrath (1998).[9] Design values of the constrained modulus are presented in Table X2.1. The table shows that Ms increases with depth of fill which reflects the increased confining pressure. This is a well-known soil behavior. At moderate depths of fill the values of Ms are close to the E' values proposed by Howard (1977, 1996).[10,11] In design for deflection control, Ms may be

[9] McGrath, T. J., "Replacing E' with the Constrained Modulus in Flexible Pipe Design," *Proceedings of the Conference Pipelines in the Constructed Environment*, ASCE, 1998.

[10] Howard, A. K., "Modulus of Soil Reaction Values for Buried Flexible Pipe," *Journal of Geotechnical Engineering*, ASCE, Vol 103, No. GT1, New York, NY, 1977.

[11] Howard, A. K., *Pipeline Installation*, Relativity Publishing, Lakewood, CO, 1996.

TABLE X2.1 Constrained Soil Modulus, M_s Based on Soil Type and Compaction Condition, Stiffness Category and Vertical Stress[A,B,C]

Vertical Stress Level[D] (psi)	SC2-100 (psi)	SC2-95 (psi)	SC2-90 (psi)	SC2-85 (psi)
1	2,350	2,000	1,275	0,470
5	3,450	2,600	1,500	0,520
10	4,200	3,000	1,625	0,570
20	5,500	3,450	1,800	0,650
40	7,500	4,250	2,100	0,825
60	9,300	5,000	2,500	1,000
Vertical Stress Level[D] (psi)		SC3-95 (psi)	SC3-90 (psi)	SC3-85 (psi)
1		1,415	670	360
5		1,670	740	390
10		1,770	750	400
20		1,880	790	430
40		2,090	900	510
60		2,380	1,120	700
Vertical Stress Level[D] (psi)		SC4-95 (psi)	SC4-90 (psi)	SC4-85 (psi)
1		530	255	130
5		625	320	175
10		690	355	200
20		740	395	230
40		815	460	285
60		895	525	345

[A] The soil types are defined by a stiffness category (SC) to indicate the general soil classification (See AWWA Manual M45). Specific soil groups that fall into these categories, based on Classification D 2487 and AASHTO M 145, are listed in Table X2.2.

[B] The numerical suffix to the soil type indicates the compaction level of the soil as a percentage of maximum dry density determined in accordance with Test Method D 698 or AASHTO T-99.

[C] For design, dumped SC1 soils may use the modulus values of SC2–90 and compacted SC1 soils may use the values of SC2–100.

[D] Vertical stress level is the vertical effective soil stress at the springline elevation of the pipe. It is normally computed as the design soil density times the depth of fill to the springline. Buoyant soil density should be used below the groundwater level.

substituted directly for E' in the Iowa formula. Use of the constrained modulus in predicting deflection may be completed by making a direct substitution of Ms for E' in the Iowa formula. The Iowa formula is presented in many publications, in particular, AWWA Manual M45, Fiberglass Pipe Design.

X2.2 Example: Determine the constrained soil modulus at a depth of 10 ft for an SW soil with a unit weight of 120 pcf.

X2.2.1 Determine vertical applied stress:

p = 10 ft (120 pcf) = 1200 psf = 8.3 psi.

X2.2.2 Determine constrained soil modulus for SW soil, which is soil type SC2-100 from Table X2.1, note c:

for p = 5 psi, M_s= 3,450 psi;

for p = 10 psi, M_s= 4,200 psi.

X2.2.3 Interpolating for p = 8.3 psi, $M_s = 3450 + (4200 - 3450) \{(8.3 - 5)/(10 - 5)\} = 3945$ psi.

TABLE X2.2 Equivalent AWWA, ASTM, and AASHTO Soil Classifications

Soil Type[A]	ASTM D 2487	AASHTO M 145
SC1[B]	Crushed rock: 15 % sand, maximum 25 % passing the ⅜ in. sieve and maximum 5 % passing No. 200 seive	
SC2[C] (Gravelly sand, SW)	Clean, coarse grained soils: SW, SP, GW, GP or any soil beginning with one of these symbols, with 12 % or less passing No. 200 seive	A1, A3
SC3[C] (Sandy silt, ML)	Coarse grained soils with fines: GM, GC, SM, SC, or any soil beginning with one of these symbols, containing 12 % or more passing No. 200 seive; Sandy or gravelly fine-grained soils: CL, ML, (or CL-ML, CL/ML. ML/CL) with 30 % or more retained on a #200 sieve	A-2-4, A-2-5, A-2-6; or A-4 or A-6 soils with 30 % or more retained on a No. 200 sieve
SC4[C] (Silty clay, CL)	Fine-grained soils: CL, ML, (or CL-ML, CL/ML. ML/CL) with 30 % or less retained on a #200 sieve	A-2-7; or A-4 or A-6 soils with 30 % or less retained on a No. 200 sieve

[A] The soil classification listed in parentheses is the type that was tested to develop the constrained soil modulus values in Table X2.1. The correlations to other soil types are approximate.

[B] SC1 soils include crushed rock and gravels with limited sand content. For design, dumped SC1 soils may use the modulus values of SC2-90 and compacted SC1 soils may use the modulus values of SC2-100.

[C] Uniform fine sands (SP) with more than 50 % passing a No. 100 sieve (0.006 in., 0.15 mm) shall not be used as backfill for fiberglass pipe unless specifically allowed in the contract documents and special precautions are taken to control moisture content and monitor compaction levels.

NOTE—Soil type SC5, including MH, CH, and organic soils are not recommended for use as pipe backfill under any conditions.

The Complete HOBAS Guide

HOBAS®

The Unique, Centrifugally Cast, Fiberglass-Reinforced, Polymer Mortar Pipe

Facts & Specifications

Why Pick HOBAS?

The HOBAS name on the pipe says you've chosen the leader in pipe technology: first choice for virtually every application and method of installation:

- **Sliplining**
- **Two-Pass Tunneling**
- **Jacking or Microtunneling**
- **Above Ground**

It's the Best Pipe Investment You Can Make:

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What Do You Want in Your Pipeline?

Here's What HOBAS Delivers:

Easy To Specify, Lower Project Cost, Superior Engineering and Customer Support

HOBAS Defined

HOBAS pipes are unique – centrifugally cast, fiberglass reinforced, polymer mortar (CCFRPM). They are strong and light with consistent dimensions, smooth surfaces and high stiffness.

Longest Service Life

HOBAS pipe is inherently corrosion resistant because of the materials that go into it. Design service life is up to 100 years and more.

Every step of the HOBAS manufacturing process is carefully controlled and verified. In the Quality Control lab, samples taken from the production line are checked for adherence to the standards and specifications.

Table of Contents

Introduction

Manufacturing

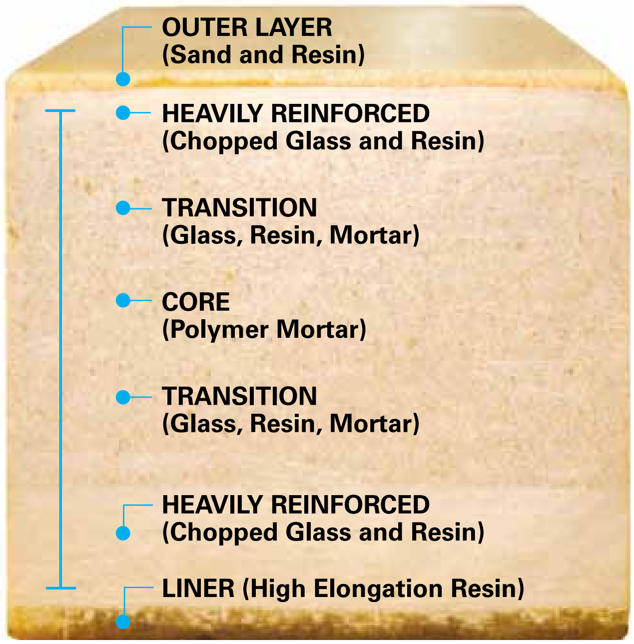
Sophisticated HOBAS manufacturing means you get real value, the lowest life cycle cost in the industry for both new installations and rehabilitation.

ASTM

HOBAS meets or exceeds ASTM standards as measured in sewer pipe accelerated aging tests. Results project that HOBAS pipe will last many thousands of years – unequaled by any other pipe needs.

Wall Construction:

I-Beam Principle



Getting Technical

In the most scientific terms, HOBAS pipe is a glass-fiber-reinforced, aggregate-fortified, thermosetting-resin tubular product manufactured by a centrifugal casting process.

High strength, high stiffness and inherent corrosion resistance make HOBAS pipes ideal for many applications such as this sanitary sewer aerial crossing.

The Product

Consistent Quality and Performance
Most U.S. municipalities have HOBAS pipe in their systems and the use of HOBAS pipe in the USA is expanding faster than ever after more than 25 years of reliable performance. More than 40,000 miles of HOBAS pipe has been installed around the world.

Versatile
HOBAS pipes can be economically designed for non-pressure and pressure service by varying the quantity, placement and orientation of the glass-fiber reinforcements.

Smoother Surfaces, High Flow Capacity
HOBAS Pipe is manufactured with a unique, precise, computer-controlled, centrifugal casting process that no other method can deliver. This produces very consistent, high-density pipe with a mold-smooth exterior surface and a glass-smooth nonporous liner that is resilient and abrasion resistant. In addition to superior hydraulics, thin-wall construction produces an oversized I.D. for the highest flow capacity available.

Leak-Free Joints
Another HOBAS advantage is push-together joints for a leak-free pipeline that preserves the streets above and reduces treatment costs.

Straightforward Installation
Installation is quick and easy with predictable, reliable pipe performance by every method. Push-together joints are simple and fast to assemble. Lightweight pipes are safe and easy to handle, often with the smaller equipment typically on the site.

HOBAS Worldwide

A Little History

In the mid-fifties, a textile manufacturer, seeking a replacement for the traditional wooden rollers, tried to produce cylinders with a smooth surface using polyester resin reinforced with glass fiber.

They tried the widely used filament winding process, but found that it was unsuitable because the outside surface it produced was not smooth enough. The idea of manufacturing the cylinders by centrifugal casting was born. HOBAS pipe is a direct descendant of that invention.

Shortly after, the first piping application appeared. Engineers needed a durable, corrosion resistant pipe with smooth interior surface. Centrifugal casting was adapted to meet the specifications and production quickly expanded. Soon after, pipes were installed in Europe.

Today HOBAS pipe is manufactured and used around the world. From Seattle to Key West, New York to Los Angeles, most U.S. municipalities have HOBAS pipe in their systems. After more than 45 years of reliable service, the use of HOBAS pipe is expanding faster than ever.

Currently, in addition to the USA, HOBAS has factories in Austria, Japan, Germany, China, Thailand, United Arab Emirates, Spain, Poland, Turkey, Uzbekistan, Czech Republic, Kazakhstan, Romania and Egypt. The group of companies has provided more than 40,000 miles of pipe. Over 6.5 million feet have been installed in the USA.

Versatile Solution

84-inch Diameter Hydro-Electric Penstock in New Hampshire

HOBAS centrifugally cast fiberglass reinforced polymer mortar pipes are ideally suited for nearly all large diameter corrosive piping applications. Listed below are the most common environments, installations and services in which the pipe has been used.

Environments

- Gravity sanitary sewers
- Sewer force mains
- Raw water
- Sea water
- Industrial effluents
- Irrigation
- Geo-thermal piping
- Wastewater collection systems
- Storm water and sewer water segregation systems
- Odor control piping
- WWTP piping
- Potable water
- Contaminated water
- Cooling water
- Foul air

Installation and Service Operation

Installation	Service Operation Non-Pressure	Service Operation Pressure
Direct Bury	•	•
Relining (Sliplining)	•	•
Jacking & Microtunneling	•	•
Above Ground	•	•
Tunnel Waterway Carrier	•	•
Pipe Bursting	•	•

Note: Products available for sustained temperatures over 150 ° F. See Corrosion Resistance Guide in Appendix F.

Direct bury installation at DFW Airport

84-inch Diameter jacking pipe for the City of Los Angeles

Sanitary sewer vent line - 30-inch diameter.

60-inch CMP Storm culvert rehabilitation with 54-inch HOBAS.

60-inch Diameter, 100 psi sewer force main in a two-pass system.

Better by Design

HOBAS centrifugally cast fiberglass reinforced polymer mortar pipes have many outstanding features that provide numerous cost saving benefits. Listed below are some of the key features and resulting benefits.

Features	Benefits
Inherent corrosion resistance	• Long, maintenance-free service life.
	• No costly add-on linings or coatings to damage, repair, inspect or maintain.
	• No need for expensive cathodic protection or polybags to install and monitor.
	• Ideal pipe for economical relining of corroded pipelines.
	• Hydraulic characteristics are virtually unchanged with time.
High stiffness design	• Easy to bury using methods routinely specified for traditional pipes.
	• Performance is predictable and reliable.
	• Deep covers handled with ease.
	• Pipes are rugged and durable.
	• Easy to grout annulus on sliplining and tunnel lining applications.

Inherent corrosion resistance of HOBAS pipes is proven by testing in acid under high stress.

Features	Benefits
Smooth interior surface & oversize ID's	• Deliver more fluid than any corrosion resistant pipe.
	• Permits greatest recovery of flow in rehabilitated pipelines.
	• Significant energy savings in pumped systems.
Bottle-tight joints	• Zero infiltration/exfiltration.
	• No extra treatment costs.
	• No pollution of ground waters.
	• Full delivery of pumped fluids.
	• No wasted time & expense trying to find and seal leaking joints to pass acceptance tests.
	• No undermining of above structures and infrastructure.

High stiffness pipes perform reliably even at deep covers such as this installation in Baltimore.

Reflection smooth interior surface and oversize ID's of HOBAS pipes provide outstanding long-term flow characteristics.

Features	Benefits
Lightweight/20 ft. sections	• Lighter, less expensive equipment needed for handling.
	• Fewer joints to assemble.
Push-on coupling joints with angular rotation capability	• "Fool-proof," fast assembly.
	• Requires no secondary treatments, diapers, bonding agents or other chemicals in the field.
	• Lower joining costs.
	• Radius curves possible without the need for fittings.
Smooth Constant OD	• Pipe may be cut anywhere along its entire length and assembled with gasketed joints with only end chamfering needed.
	• Lower forces required to insert pipe into casings or deteriorated pipelines for rehabilitation.
	• Allows longer distance bored tunnels with lower jacking loads, thereby reducing shaft requirements and increasing safety margins.

Lightweight HOBAS pipes handle easier and lay faster with less expensive equipment.

Smooth, constant O.D. of HOBAS pipes permits cutting and joining anywhere along its entire length.

HOBAS push-on FWC coupling joints assemble easily and provide leak-free service.

Features	Benefits
Resilient inner liner	• Excellent abrasion resistance. • High crack resistance.
Computer controlled manufacturing process	• Consistent, reproducible high quality pipes.
Standardized designs & dimensions	• Multiple pressure & stiffness classes to meet most project requirements. • OD's compatible with standard ductile iron fittings.
45 year history of successful applications	• Service tested and time proven performance record.

As you can see, HOBAS fiberglass reinforced polymer mortar pipes save you money during installation and in operation. These initial and daily savings compounded with the elimination of expense for repairs, rehabilitation or premature replacement, make our fiberglass pipes YOUR BEST VALUE IN CORROSION RESISTANT PIPING.

Computer controlled and monitored production results in consistent, high quality HOBAS pipes.

Standard section length is 20 ft. although shorter pipes are available.

Nominal Diameters

18"	20"	24"	27"	28"	30"	33"	36"	41"	42"
44"	45"	48"	51"	54"	57"	60"	63"	66"	69"
72"	78"	84"	85"	90"	96"	104"	110"	120"	

Note: Actual dimensions are given in Appendix B. Other nominal diameters may be available. Please inquire.

Stiffness Classes (SN)

Installation	SN 18	SN 36	SN 46	SN 72	SN >72
Direct Bury	Very Unusual	Infrequent	Standard	Standard	Infrequent
Sliplining Non Pressure	Infrequent	Standard	Standard	Infrequent	Very Unusual
Sliplining Pressure	Very Unusual	Standard	Standard	Infrequent	Very Unusual
Pipe Bursting, Jacking & Microtunneling	Very Unusual	Very Unusual	Very Unusual	Very Unusual	Standard
Tunnel Carrier Pipe	Very Unusual	Standard	Standard	Standard	Infrequent
Aboveground	**See page 17, 46 & 47**				Infrequent

- **Standard**
- **Infrequent**
- **Very Unusual**

SN is minimum pipe stiffness in psi.

Lengths

Standard 20 foot sections (Special lengths and even divisions of 20 ft. are available.)

Diameter range is 18" to 120".

Riser pipes are available for both new construction and rehabilitation.

Fittings

Fiberglass reinforced polymer flanges, elbows, reducers, tees, manholes, wyes & laterals, constructed by contact molding or from mitered sections of fiberglass reinforced polymer mortar pipe joined by glass-fiber-reinforced overlays, are available for all non-pressure and many pressure applications. Protected ductile iron, fusion-bonded epoxy- coated steel or stainless steel fittings are typically compatible and may be used with all HOBAS pressure classes. Fitting details may be found in Section 9 and Appendix E.

Pressure Classes

Dia. (in.)	PN (psi)					
	25	50	100	150	200	250
18						
20						
24						
27						
28						
30						
33						
36						
41						
42						
44						
45						
48						
51						
54						
57						
60						
63						
66					Non-Standard	
69						
72						
78						
84						
85						
90						
96						
104						
110						
120						

A variety of manhole fittings and options are available to suit your needs.

Pipe Stiffness Selection

Direct Bury Applications

Appropriate pipe stiffness is a function of native soil characteristics, trench construction, cover depth, embedment conditions, and haunching. Figure 1 (See below) relates these parameters assuming a minimum width trench as defined in figure 11 (pg. 39). (Under certain circumstances, pipe stiffness less than 36 psi may be suitable.)

For pipes with vacuum operating conditions, see Allowable Negative Pressure in Section 6 (pg. 19) for appropriate pipe stiffness for various installations and negative pressures.

For shallow buried pipes with surface loads, see Traffic Loads in Section 6 (pg. 20) for appropriate pipe stiffness for various installations and cover depths.

High stiffness HOBAS pipes may be buried safely at depths exceeding 50 ft.

NATIVE SOIL [2,5]	COVER DEPTH[1] (ft.)	EMBEDMENT CONDITION[3] 1	2	3	4
	10 & <				SN[6]72
Rock	10 to 15	SN[6] 36			
Stiff to V. Hard Cohesive	15 to 20			SN[6] 46	
Compact to V. Dense Granular	20 to 25		SN[6] 46		
(Blows/ft.[4] > 8)	25 to 30	SN[6] 46			
	30 to 40		SN[6] 72	ALTERNATE INSTALLATION[7]	
	40 to 50				
	10 & <	SN[6] 36			SN[6] 72
Medium Cohesive	10 to 15		SN[6] 46	SN[6] 46	
Loose Granular	15 to 20	SN[6] 46			
(Blows/ft.[4] 4 to 8)	20 to 25		SN[6] 72	ALTERNATE INSTALLATION[7]	
	25 to 30				
Soft Cohesive	10 & <	SN[6] 36 to 46		SN[6] 72	
Very Loose Granular	10 to 15	SN[6] 72			
(Blows/ft.[4] 2 to 4)	15 to 20				
	over 20			ALTERNATE INSTALLATION[7]	

[1] Assuming minimum trench width per Figure 11 page 39.
[2] Blow counts should be representative of weakest condition
[3] Defined in Figure 13 page 40. If a cement stabilized sand pipe zone surround is utilized, use column 1 in the highest soils category.
[4] Standard penetration test per ASTM D1586
[5] For v. soft or v.v. loose soils with blow counts less than 2 use alternate installation per section 14, ¶ A8.
[6] SN is nominal stiffness in psi.
[7] Alternate installation per section 14, ¶ A8.

FIGURE 1 - Pipe Stiffness Selection for Standard Installations[1]

HOBAS pipes easily withstand a full vacuum service condition due to the high stiffness design.

Sliplining Applications

Appropriate pipe stiffness is a function of the insertion compressive load, grouting pressure, grouting deformation loads and external hydrostatic head.

- The table below lists safe (F of S ≈ 3) compressive loads for pushing "straight" for various pipe stiffness classes and diameters. When pushing around curves, allowable safe loads will be reduced depending on the curve radius and pipe section length.
- For safe compressive loads when pushing "straight" on pipe with the flush bell-spigot joint, see the table in the "Tunnel Carrier Pipe Applications" portion of this section on page 18.
- Maximum safe (F of S ≈ 2.0) grouting pressure (psi) without support bracing or counter pressurization is shown in Chart A.
- Net uplift forces (displaced grout weight minus pipe and flow weight) must be coordinated with pipe stiffness to control pipe deformation to within acceptable limits.
- Safe (F of S ≈ 1.5) long-term external hydrostatic head (ft.) for an ungrouted installation is shown in Chart B.

Low-Profile Bell-Spigot Joint Allowable Compressive Load

Nom. Dia. (in.)	O.D. (in.) Pipe Wall	O.D. (in.) Bell	Safe Compressive Load Pushing "Straight" (U.S. Tons) SN 18	SN 36	SN 46
18	19.5	20.4	–	–	25 (SN 62)
20	21.6	22.5	–	–	29
24	25.8	26.8	33 (SN 26)	39	44
27	28.0	29.0	39 (SN 24)	48	54
28	30.0	31.0	45 (SN 22)	56	63
30	32.0	33.0	–	51	58
33	34.0	35.0	–	60	67
36	38.3	39.3	74 (SN 30)	82	92
41	42.9	44.0	92 (SN 26)	108	122
42	44.5	45.6	101 (SN 25)	119	134
44	45.9	47.0	106 (SN 24)	128	143
45	47.7	48.8	116 (SN 23)	141	159
48	50.8	51.9	129 (SN 21)	164	183
51	53.9	55.0	142 (SN19)	188	211
54	57.1	58.2	157	215	239
57	60.0	61.2	178	242	268
60	62.9	64.1	200	271	297
63	66.0	67.2	225	302	333
66	69.2	70.4	231 (SN 19)	305	342
69	72.5	73.8	247	339	378
72	75.4	76.7	273	373	417
78	81.6	82.9	330	448	496
84	87.0	88.4	385	520	575
85	88.6	90.0	403	544	601
90	94.3	95.7	464	625	690
96	99.5	101.0	527	702	776
104	108.0	109.5	636	844	930
110	114.0	115.5	720	950	1050
120	126.0	127.5	905	1190	1300

Max. Safe Grouting Pressure (psi)		
Fluid Flow Level / Dia. Difference	None or low	over 1/2 to full
≤ 5%	SN÷4	SN÷3
≤ 10%	SN÷5	SN÷4
≤ 20%	SN÷6	SN÷5
> 20%	SN÷7	SN÷6

Chart A

Max. Safe Long-term External Head (ft.) for an Ungrouted Installation	
Fluid Flow Level / Dia. Difference	All Flow levels
≤ 5%	SN÷2
≤ 10%	SN÷2.5
≤ 20%	SN÷3
> 20%	SN÷4

Chart B

Notes:

Diameter Difference =

$$\left(\frac{\text{ID Host Pipe - OD Liner Pipe}}{\text{OD Liner Pipe}}\right) \times 100$$

SN is nominal pipe stiffness in psi

Jacking Applications

Non-Pressure

Appropriate pipe stiffness is a function of the jacking compressive load and installation conditions. The jacking contractor must control the jacking loads within the safe limits for the pipe. The adjacent table shows allowable safe jacking loads (pushing "straight") for the typical design. However, the ultimate pipe load capacity is the choice and responsibility of the purchaser and can be affected by a number of factors including the anticipated loads, the amount of steering, the amount of over-cut, the amount of lubrication, the pipe section length, the distance of the jacking operation and any point loading.

Pressure

Details of pressure service jacking pipes are available on a custom design basis depending on jacking loads, operating parameters, and installation conditions.

Jacking Bell-Spigot Joint Allowable Compressive Load

Nom. Dia. (in.)	O.D. (in.)	Nom. Inside Dia. (in.)	Min. Pipe Wall Thickness (in.)	Min. Pipe Wall Thickness @ Gasket Groove (in.)	Allowable Safe Jacking Load Pushing "Straight" (U.S. Tons)		Weight (lb/ft)
					F of S = 3.0	F of S = 2.5	
24	25.8	22.7	1.40	0.99	125	150	107
27	28.0	24.8	1.47	1.06	145	175	120
28	30.0	26.6	1.53	1.12	166	200	137
30	32.0	28.3	1.71	1.21	191	230	159
33	34.0	30.1	1.80	1.29	216	260	179
36	38.3	34.3	1.85	1.31	250	300	208
41	42.9	38.7	1.91	1.32	283	340	245
42	44.5	40.3	1.93	1.33	295	355	255
44	45.9	41.7	1.95	1.34	308	370	263
45	47.7	43.4	1.98	1.35	325	390	280
48	50.8	46.4	2.03	1.37	350	420	306
51	53.9	49.4	2.07	1.38	375	450	333
54	57.1	52.5	2.10	1.39	400	480	361
57	60.0	55.4	2.13	1.40	425	510	380
60	62.9	58.2	2.16	1.41	450	540	408
63	66.0	61.2	2.20	1.42	475	570	438
66	69.2	64.2	2.31	1.43	500	600	478
69	72.5	67.4	2.38	1.47	541	650	512
72	75.4	70.1	2.46	1.52	583	700	553
78	81.6	76.0	2.58	1.60	667	800	634
84	87.0	81.2	2.70	1.68	750	900	701
85	88.6	82.8	2.73	1.69	770	925	727
90 *	94.3	88.2	2.85	1.76	854	1025	800
96 *	99.5	93.1	3.00	1.87	958	1150	886
104 *	108.0	101.3	3.13	1.94	1083	1300	1009
110 *	114.0	106.9	3.29	2.05	1208	1450	1129
120 *	126.0	118.4	3.58	2.25	1470	1765	1350

Note: Alternate pipe designs are available upon request.

** Lead times may be lengthy, please inquire.*

48" aerial interceptor at a WWTP in Odessa, TX withstands high temperatures.

HOBAS jacking pipes have the lowest drive loads.

Aboveground Applications

Appropriate pipe stiffness is a function of the pipe support scheme, pipe diameter, imposed loads and the level of negative operating pressure, if any. Section 14D on above-ground installation provides guidance on pipe support requirements for various pipe classes and diameters. Maximum negative pressure is as given in the adjacent table.

Aboveground Allowable Negative Pressure

Pipe Stiffness (psi)	Allowable Negative Pressure* (% of full vacuum)
18	25
36	50
46	60
72	100

** at 75° F.*

Tunnel Carrier Pipe Applications

Lightweight HOBAS pipes transport easily into the tunnel.

Appropriate pipe stiffness is a function of the external loads and conditions, insertion compressive loads (multiple pipe pushing), grouting pressure, grouting deformation loads, and the blocking scheme. Typically, SN 36 pipes have sufficient performance capability to safely withstand most controlled installations and are used most often. However, because the conditions and installation for tunnel projects tend to be unique, all criteria should be checked for each application to verify the proper pipe stiffness.

The table below lists the dimensions for the typical minimum wall pipes on which the flush bell-spigot joint is available and the safe (F of S ≈ 3) compressive loads when pushing "straight". These flush joint pipe designs may be used in tunnel carrier or in tight fit sliplining installations.

Flush Relining Bell-Spigot Joint Allowable Compressive Load

Nom. Dia. (in.)	O.D. (in.)	Min. Pipe Wall Thickness. (in.)	Nom. Pipe Stiffness (psi.)	Min. Pipe Thickness @ Gasket Groove (in.)	Safe Compressive Load Pushing "Straight" (U.S. Tons)	Weight (lb/ft)
18	19.5	0.75	426	0.34	30	43
20	21.6	0.75	310	0.34	34	48
24	25.8	0.76	187	0.35	42	62
27	28.0	0.76	145	0.35	46	68
28	30.0	0.76	117	0.35	49	73
30	32.0	0.86	143	0.36	54	87
33	34.0	0.87	123	0.37	59	94
36	38.3	0.90	95	0.40	73	110
41	42.9	0.96	83	0.44	91	131
42	44.5	0.99	82	0.46	99	140
44	45.9	1.02	82	0.47	105	148
45	47.7	1.05	80	0.49	114	158
48	50.8	1.09	74	0.51	127	175
51	53.9	1.13	69	0.53	141	192
54	57.1	1.17	65	0.55	155	210
57	60.0	1.21	62	0.58	173	225
60	62.9	1.27	62	0.61	191	251
63	66.0	1.33	62	0.64	211	276
66	69.2	1.45	71	0.66	228	315
69	72.5	1.47	64	0.67	243	335
72	75.4	1.49	59	0.68	257	352
78	81.6	1.53	51	0.71	292	393
84	87.0	1.57	45	0.75	330	430
85	88.6	1.58	43	0.76	342	440
90	94.3	1.66	42	0.82	394	491
96	99.5	1.75	42	0.88	448	547
104	108.0	1.85	39	0.94	521	628
110	114.0	1.94	38	0.99	580	695
120	126.0	2.10	36	1.09	710	829

Hydrostatic Pressure

Pressure Class (PN)	Maximum Sustained Operating Pressure[1] (psi)	Maximum Transient Pressure[1] (psi)	Maximum Field Test Pressure[1] (psi)	Maximum Factory Test Pressure (psi)	Minimum Initial Burst Pressure (psi)
25	25	35	40	50	120
50	50	70	75	100	200
100	100	140	150	200	400
150	150	210	225	300	600
200	200	280	300	400	800
250	250	350	375	500	1000

[1] Maximum pressure may be reduced for buried pipes.

Buried Allowable Negative Pressure

Embedment Condition[2]	Allowable Negative Pressure (% of full vacuum)[4, 5]		
	SN 18	SN 36 or 46	SN 72
1	50	100	100
2	50	100	100
3	—	50	100
4[3]	—	—	100

[2] See Figure 13 in Section 14.
[3] Pipe zone backfill foot tamped.
[4] At the corresponding maximum cover depth shown on figure 1 in section 5.
[5] Allowable negative pressure may be reduced for burials in native soils with qu < 1 Tsf or SPT blows / ft. < 8.

Allowable Cover Depth

See Figure 1 in section 5.

Burst pressure is regularly verified at our factory.

Traffic Loads

Embedment Condition[1]	Minimum Cover (ft) for AASHTO HS-20 Load[2] SN 18	SN 36 or 46	SN 72
1	4	3	2
2	5	4	3
3	–	5	4
4	–	–	5

[1] See Figure 13 in Section 14.
[2] Installation in poor soils or at shallower cover depths is possible with improved pipe support such as cement stabilized sand or concrete encasement.

Flotation

A minimum of 1/2 to one diameter of cover is typically needed to prevent an empty submerged pipe from floating (depending on the density of the cover material) when full saturation to the surface exists. Other options may be acceptable to restrain the pipe against flotation.

Abrasion Resistance

Through comparative tests conducted on several types of pipe using sand, stones and water, HOBAS pipes exhibited superior abrasion resistance to all other materials tested. The abrasion resistance (as measured in this rocking test) for all of the plastic products including the HOBAS pipe was 3 to 10 times better than for cementitious materials such as RCP, CSC, asbestos-cement, and cement lined ductile iron or steel.

Pipe Design

Design calculations to compute the performance of HOBAS Pipe USA fiberglass reinforced polymer mortar pipes in various conditions can be generated using the principles and equations of flexible conduit theory. These include Spangler's deflection equation, Molin's bending equation and constrained buckling analysis. Through extensive research conducted on fiberglass pipes in the 1980's, these equations and others have been refined and combined into a complete design analysis procedure. This information was first printed in Appendix A of the 1988 revision to AWWA Standard C950. It is now contained in the AWWA Fiberglass Pipe Design Manual, M45.

HOBAS Pipe USA can provide design calculations to demonstrate the performance of our pipes in specific conditions on individual projects. This service is available upon request when the pipeline operating conditions are known.

High strength HOBAS pipes withstand high pressure and heavy loads.

Buried HOBAS pipes safely withstand surface loads.

General

The centrifugal casting manufacturing process used to produce HOBAS pipes results in a glass smooth interior surface which will not deteriorate due to chemical attack because of its high corrosion resistance. Research has shown that smooth wall pipes maintain superior flow characteristics over time due to less build-ups and shorter slime lengths (sewers).

Hydraulic Characteristics

Gravity Flow

Users have reported Manning's "n" flow coefficients for HOBAS pipes of 0.0090 new and 0.0105 after several years of sanitary sewer service.

Pressure

Tests conducted on an aged HOBAS pressure pipe system (approximately 100 psi) yielded an average Hazen-Williams "C" value of 155.

The glass smooth interior surface results in higher flow capacity in gravity lines and significant energy savings in pumped systems.

Flow Capacity

Gravity System

For equal flow volumes on the same slope, HOBAS pipes may be 13% smaller than pipes with an "n" value of 0.013. Depending on the condition of an existing (host) pipe, sliplining with HOBAS pipe will frequently improve the renewed line's flow capacity. See the comparison table on the next page for various combinations of criteria. A ratio on the table greater than 1.000 indicates an improved flow volume after lining, while a value less than 1.000 means a reduced flow capacity will result from the diameter change. For example, a 1.150 ratio is a 15% increase in capacity and a ratio of 0.950 is a 5% decrease. The table may also be used to compare diameters for new construction.

Pressure

For equal head loss, HOBAS pipes may be slightly smaller than pipes with worse flow characteristics. However, it is normally more advantageous to maintain the same diameter and enjoy the benefit of 30% to 50% lower head loss versus traditional pipes. The reduced head loss translates into significant energy savings and lower pump horsepower requirements. The projected figures depend on the system operating conditions. If these parameters are known, we would be pleased to compute the future savings possible with HOBAS pipes on your project. Please contact us.

QHOBAS / QExisting

HOBAS Relining Pipe Flow Coefficients, n		Host Pipe Existing Flow Coefficient, n								
		0.013	0.014	0.015	0.016	0.017	0.018	0.020	0.022	0.024
18	0.009	0.722	0.777	0.833	0.888	0.944	0.999	1.110	1.221	1.332
into	0.010	0.649	0.699	0.749	0.799	0.849	0.899	0.999	1.099	1.199
24	0.011	0.590	0.636	0.681	0.727	0.772	0.817	0.908	0.999	1.090
20	0.009	0.961	1.035	1.109	1.183	1.257	1.331	1.479	1.627	1.774
into	0.010	0.865	0.932	0.998	1.065	1.131	1.198	1.331	1.464	1.597
24	0.011	0.786	0.847	0.907	0.968	1.028	1.089	1.210	1.331	1.452
24	0.009	0.860	0.926	0.992	1.059	1.125	1.191	1.323	1.456	1.588
into	0.010	0.774	0.834	0.893	0.953	1.012	1.072	1.191	1.310	1.429
30	0.011	0.704	0.758	0.812	0.866	0.920	0.974	1.083	1.191	1.299
30	0.009	0.945	1.017	1.090	1.163	1.235	1.308	1.453	1.599	1.744
into	0.010	0.850	0.916	0.981	1.046	1.112	1.177	1.308	1.439	1.570
36	0.011	0.773	0.832	0.892	0.951	1.011	1.070	1.189	1.308	1.427
36	0.009	1.008	1.086	1.163	1.241	1.318	1.396	1.551	1.706	1.861
into	0.010	0.907	0.977	1.047	1.117	1.186	1.256	1.396	1.535	1.675
42	0.011	0.825	0.888	0.952	1.015	1.079	1.142	1.269	1.396	1.523
42	0.009	1.057	1.139	1.220	1.301	1.383	1.464	1.627	1.789	1.952
into	0.010	0.952	1.025	1.098	1.171	1.244	1.318	1.464	1.610	1.757
48	0.011	0.865	0.932	0.998	1.065	1.131	1.198	1.331	1.464	1.597
48	0.009	1.103	1.187	1.272	1.357	1.442	1.527	1.696	1.866	2.036
into	0.010	0.992	1.069	1.145	1.221	1.298	1.374	1.527	1.679	1.832
54	0.011	0.902	0.972	1.041	1.110	1.180	1.249	1.388	1.527	1.666
54	0.009	1.140	1.227	1.315	1.403	1.490	1.578	1.754	1.929	2.104
into	0.010	1.026	1.105	1.184	1.263	1.341	1.420	1.578	1.736	1.894
60	0.011	0.933	1.004	1.076	1.148	1.219	1.291	1.435	1.578	1.722
60	0.009	1.145	1.233	1.322	1.410	1.498	1.586	1.762	1.938	2.114
into	0.010	1.031	1.110	1.189	1.269	1.348	1.427	1.586	1.744	1.903
66	0.011	0.937	1.009	1.081	1.153	1.225	1.298	1.442	1.586	1.730
66	0.009	1.173	1.264	1.354	1.444	1.534	1.625	1.805	1.986	2.166
into	0.010	1.056	1.137	1.218	1.300	1.381	1.462	1.625	1.787	1.949
72	0.011	0.960	1.034	1.108	1.182	1.255	1.329	1.477	1.625	1.772
72	0.009	1.193	1.285	1.376	1.468	1.560	1.652	1.835	2.019	2.202
into	0.010	1.074	1.156	1.239	1.321	1.404	1.487	1.652	1.817	1.982
78	0.011	0.976	1.051	1.126	1.201	1.276	1.351	1.502	1.652	1.802
78	0.009	1.210	1.303	1.396	1.489	1.582	1.675	1.861	2.048	2.234
into	0.010	1.089	1.173	1.256	1.340	1.424	1.508	1.675	1.843	2.010
84	0.011	0.990	1.066	1.142	1.218	1.295	1.371	1.523	1.675	1.828
84	0.009	1.194	1.286	1.378	1.470	1.562	1.653	1.837	2.021	2.204
into	0.010	1.075	1.157	1.240	1.323	1.405	1.488	1.653	1.819	1.984
90	0.011	0.977	1.052	1.127	1.202	1.278	1.353	1.503	1.653	1.804
85	0.009	1.054	1.135	1.216	1.297	1.378	1.459	1.622	1.784	1.946
into	0.010	0.949	1.022	1.095	1.168	1.240	1.313	1.459	1.605	1.751
96	0.011	0.862	0.929	0.995	1.061	1.128	1.194	1.327	1.459	1.592
96	0.009	1.225	1.320	1.414	1.508	1.602	1.697	1.885	2.074	2.262
into	0.010	1.103	1.188	1.273	1.357	1.442	1.527	1.697	1.866	2.036
102	0.011	1.003	1.080	1.157	1.234	1.311	1.388	1.542	1.697	1.851
96	0.009	1.052	1.133	1.214	1.295	1.376	1.457	1.619	1.781	1.942
into	0.010	0.947	1.020	1.093	1.165	1.238	1.311	1.457	1.603	1.748
108	0.011	0.861	0.927	0.993	1.060	1.126	1.192	1.324	1.457	1.589
104	0.009	1.134	1.221	1.308	1.395	1.483	1.570	1.744	1.919	2.093
into	0.010	1.020	1.099	1.177	1.256	1.334	1.413	1.570	1.727	1.884
114	0.011	0.928	0.999	1.070	1.142	1.213	1.284	1.427	1.570	1.712
110	0.009	1.143	1.230	1.318	1.406	1.494	1.582	1.758	1.934	2.109
into	0.010	1.028	1.107	1.187	1.266	1.345	1.424	1.582	1.740	1.898
120	0.011	0.935	1.007	1.079	1.151	1.222	1.294	1.438	1.582	1.726
120	0.009	1.152	1.240	1.329	1.417	1.506	1.595	1.772	1.949	1.126
into	0.010	1.036	1.116	1.196	1.276	1.355	1.435	1.596	1.754	1.914
132	0.011	0.942	1.015	1.087	1.160	1.232	1.305	1.450	1.595	1.740

* HOBAS diameters are nominal for 36psi stiffness   ** Existing sewer assumed full size. Nominal Diameter = I.D.

Joint Designs

Several joint designs are available to meet the requirements of many different applications. The FWC coupling is normally utilized for direct bury, aboveground, and some other installations. For sliplining, jacking, and tunnel installations, special joints are available. Closure couplings are available for tie-ins. Joint dimensions are given in Appendix C.

Joining Forces for HOBAS Couplings

Approximate average straight alignment (pounds)		
Nominal Pipe Size	FWC	Flush and LPB
18	1500	750
20	1700	850
24	2000	1000
27	2150	1075
28	2300	1150
30	2500	1250
33	2700	1350
36	3000	1500
41	3400	1700
42	3500	1750
44	3600	1800
45	3750	1875
48	4000	2000
51	4250	2125
54	4500	2250
57	4750	2375
60	5000	2500
63	5250	2625
66	5500	2750
69	5750	2875
72	6000	3000
78	6500	3250
84	6800	3400
85	7000	3500
90	7500	3750
96	8000	4000
104	9000	4500
110	9500	4750
120	10500	5250

Joint Selection

Installation	Service	
	Non-Pressure	Pressure
Direct Bury	FWC Coupling	FWC Coupling
Sliplining	Low Profile Bell-Spigot*	Pressure Relining
Jacking	Flush Bell-Spigot	Flush FWC Coupling
Aboveground	FWC Coupling	FWC Coupling
Tunnel Carrier Pipe	Flush Bell-Spigot**	Pressure Relining
Tie-ins	Closure Coupling	Steel Mechanical Coupling

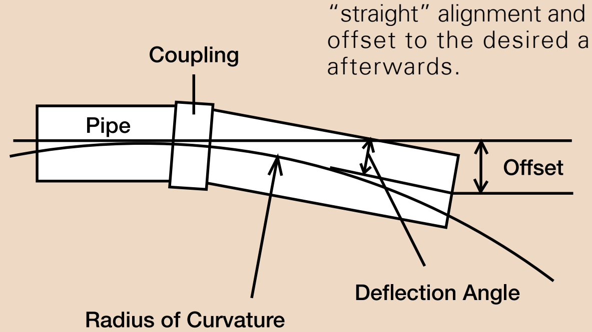
* May use flush bell-spigot joint in very tight fit situations.
** May use FWC coupling in some situations.

Minimum Radius of Curvature for Various Deflected Joints

Max Deflected Angle in Degrees	Max Offset (inches)			Min Radius of Curvature (feet)		
	Section Length (feet)			Section Length (feet)		
	5	10	20	5	10	20
3	3	6	12	95	191	382
2	2	4	8	143	286	573
1.75	1.75	3.5	7	164	327	655
1.5	1.5	3	6	191	382	764
1.25	1.25	2.5	5	229	458	917
1	1	2	4	286	573	1146
0.75	0.75	1.5	3	383	764	1528
0.5	0.5	1	2	573	1146	2292

* See specific joints for capability

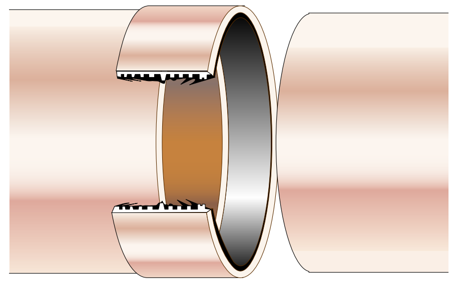
Note: Always join pipes in "straight" alignment and then offset to the desired angle afterwards.



FWC Joint Gap & Angular Deflection

Diameter (inches)	Coupling Width (inches) *	Joint Gap (inches)	Max Deflection Angle, (degrees)
18-20	8	1	3
24-33	10	1	2
36-42	10	1	1.5
44-54	10	1	1
57-60	11.5	1	1
63-78	11.5	1	0.75
84-120	11.5	1	0.5

*Couplings may be wider for some pressure pipes.



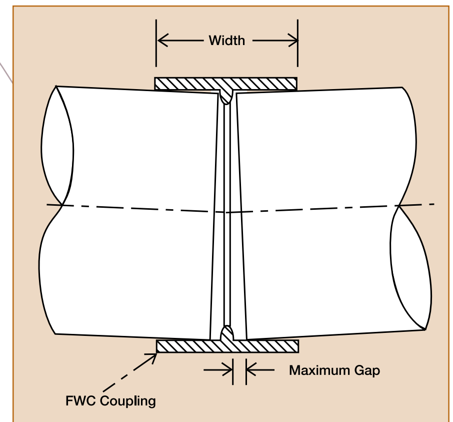
FWC coupling.

FWC Coupling

Description & Capability

The FWC coupling is a structural filament wound sleeve overwrapped and mechanically locked to an internal full-face elastomeric membrane. The sealing design includes both lip and compression elements so the joint is suitable for both non-pressure and for pressure service up to 250 psi. The coupling is factory assembled to one end of each pipe for ease of use in the field.

Per the performance requirements of ASTM D4161, the FWC joint will remain leak-free from twice the rated class pressure to a -0.8 atmosphere vacuum under pressure even when angularly turned and vertically deflected. HOBAS pipes, because of their constant O.D. and their centrifugally cast mold smooth exterior surface, may be joined with the FWC coupling at any place along their entire length with no preparation or machining other than chamfering of the pipe ends.



HOBAS FWC coupling.

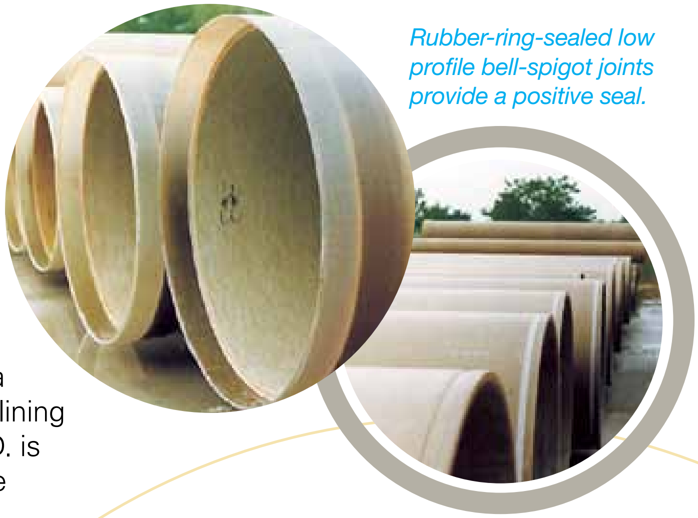
HOBAS FWC couplings are tested internally and externally (shown) to prove leak-free capability.

Pushing home HOBAS FWC coupling with a backhoe bucket makes assembly fast & easy.

Low Profile Bell-Spigot

Description & Capability

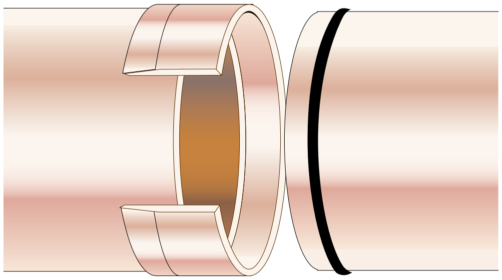
The low profile bell-spigot joint consists of an integral straight bell fixed to one pipe end that seals to the spigot end of another pipe by compressing an elastomeric gasket contained in a groove on the spigot. This joint is intended for sliplining applications for non-pressure service. The bell O.D. is smaller than the O.D. of the FWC coupling. See Appendix C for dimension details. Joining force is substantially less than the FWC coupling joint.



Rubber-ring-sealed low profile bell-spigot joints provide a positive seal.

Minimum Joint Angular Deflection Capability

Diameter (in)	Max Angle
18 to 30	2º
33 to 45	1.5º
48 to 120	1º



Low profile bell-spigot (LPB).

Pressure Relining

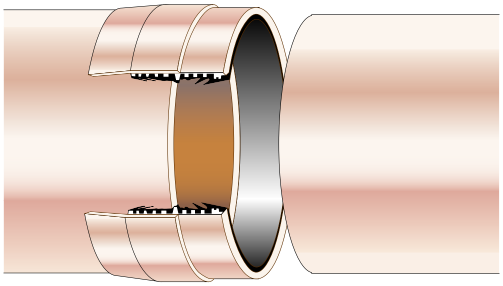
Description & Capability

The pressure relining joint consists of a structural filament wound sleeve overwrapped and mechanically locked to an internal full-face elastomeric membrane. Like the FWC coupling, the sealing design includes both lip and compression elements, so the joint is suitable for both non-pressure and for pressure service up to 250 psi for sliplining installations.

The coupling is fixed permanently at the factory to one end of each pipe and is protected from sliding abrasion by an overwrap. Each mating spigot is chamfered at the pipe end to aid assembly.

The joint O.D. is slightly greater than the FWC coupling O.D. See Appendix C for dimension details.

Joint angular deflection limits and joining force are similar to the FWC coupling.

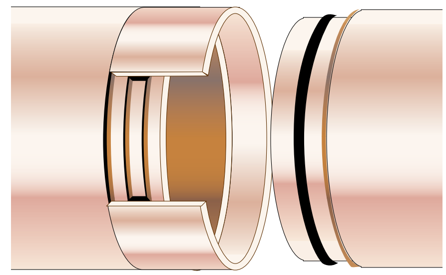


Pressure relining.

Flush Bell-Spigot

Description & Capability

The flush bell-spigot joint consists of an integral straight bell fixed to one pipe end that seals to the spigot end of another pipe by compressing an elastomeric gasket contained in a groove on the spigot. The joint has approximately the same O.D. as the pipe, so when assembled, the joint is essentially flush with the pipe outside surface. It is designed for nonpressure service in jacking and tunnel carrier installations, although it may be used in nonpressure relining applications. Typical allowable joint angular deflection is between 1 and 2 degrees depending on the spacer thickness and joint configuration. Joining force is substantially less than the FWC coupling joint.



Flush bell-spigot.

Flush Joint Gap*

Nominal Diameter (in)	Gap (in)
18 to 28	0.60
30 to 42	0.70
45 to 63	1.36
66 to 120	2.00

* The corresponding angle for each allowable joint gap may be calculated by using the formula: deflection angle in degrees = arctan (gap in inches/O.D.in inches).

* This joint gap is provided for sealing purposes only and does not address installation loads. See Section 14 for installation specific information.

Jacking pipes have rubber-ring-sealed flush bell-spigot joints for quick assembly.

8 | Joints

Closure Couplings

Gravity Flow

Closures are Stainless Steel Couplings which are straight, loose collars with internal gasket systems. The joints seal by compressing the gaskets between the natural O.D. of any HOBAS pipe and the inside of the collar. The typical assembly sequence is shown in Figure 2. Easiest assembly is accomplished with the pipes and coupling in "straight" alignment with an adequate bevel (chamfer) on the outside edge of the pipes to be joined.

Stainless Steel Coupling

This consists of a casing, gasket and a lockpart. The purpose of the casing is to house the gasket and to press it onto the pipe surface when the lockpart is closed. The lockpart is designed to pull the two ends of the casing together circumferentially around the pipe. In order to achieve this, the coupling is labeled with a torque to ensure the gasket is compressed sufficiently against the pipe surface.

Couplings are sold individually, however, a pair are typically utilized at each closure location.

Pressure Systems

To effect closures in force mains, utilize mechanical couplings (with appropriate corrosion protection) such as manufactured by Dresser or Viking-Johnson.

Flush FWC Coupling

The flush FWC coupling joint consists of a reduced diameter FWC coupling fixed to one pipe end (in a recess) that seals to the spigot (recessed) end of another pipe by compressing the elastomeric gasket contained on the inside of the coupling. The joint has approximately the same O.D. as the pipe, so when assembled, the joint is essentially flush with the pipe outside surface. It is designed for pressure service in jacking installations. Allowable angular deflection limits and joining force are similar to the FWC coupling.

Stainless steel closure coupling.

Note: When using mechanical joints, torque bolts to the minimum needed for sealing - maximum 25 ft-lbs.

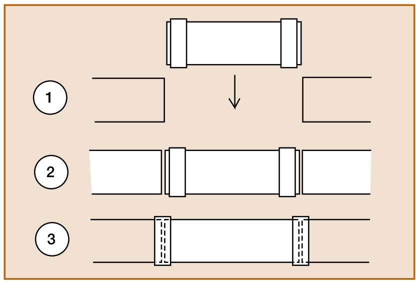
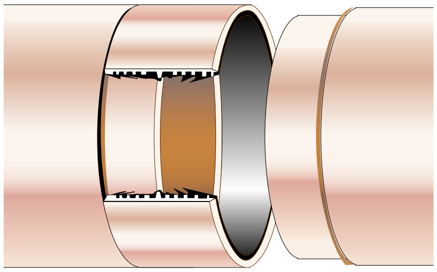


FIGURE 2 - Closure coupling installation & assembly.



Flush FWC Coupling.

Pressure jacking pipes' leak-free, flush joints.

Connections to Other Pipe Material Systems

Connections to other pipe material systems may be accomplished by several methods. Because of compatible OD's, HOBAS pipes, 18" to 48", may be joined directly with ductile iron pipes using either our couplings or ductile iron gasketed joints. In some diameters and applications, Fernco couplings may be suitable. Additionally, HOBAS Pipe USA can frequently custom fabricate the mating bell or spigot for other gasket-sealed systems when the proper dimensions are known. Further, custom fabricated mechanical couplings capable of connecting pipes of different OD's maybe utilized. Although typically the most expensive method, flanges built to ANSI or other drilling specs may also be used. Contact us regarding suitability of or experience with other procedures.

Note: When using mechanical joints, torque bolts to the minimum needed for sealing - maximum 25 ft.-lbs.

Fiberglass bell fabricated to mate to RCP spigot.

Special spigot end to join with RCP bell.

Joining HOBAS pipes (left) to ductile iron with a HOBAS FWC coupling.

HOBAS pipes' O.D. is compatible with DI joints from 18" to 48".

General

Figure 3 shows the general configuration of standard HOBAS Pipe USA fittings, although almost any mitered fitting can be constructed. These fittings are available for all non-pressure and for many pressure applications. Pressure applications will require thrust restraints and may require full encasement in reinforced concrete to resist deformation. Contact HOBAS Pipe USA for assistance to determine details and requirements for your specific situation. Dimensions for standard fittings are given in Appendix E. Details for diameter combinations and angles not shown or for other fitting configurations are available upon request.

Almost any fitting configuration and angle can be constructed with HOBAS fiberglass reinforced polymer mortar pipe.

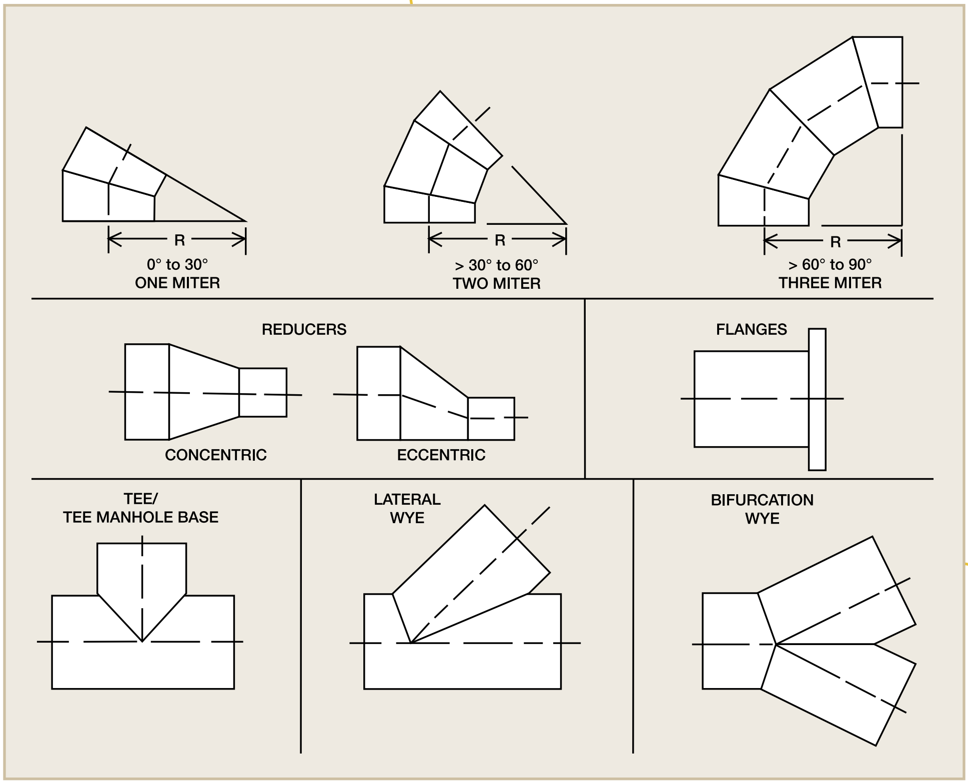


FIGURE 3 - Fittings

HOBAS pipe fittings may be field connected with any of our coupling or flange options.

Quality flange connections are routine.

Compatibility

HOBAS Pipe USA pipes are dimensionally compatible with standard ductile iron fittings (18″ to 48″). Corrosion protection consistent with project conditions should be provided for these parts, if used. Stainless steel or fusion bonded epoxy-coated steel fittings may also be suitable.

Installation

HOBAS Pipe USA fiberglass fittings are designed to join our pipe using our standard FWC coupling or one of our other gasket-sealed joints (section 8). Adequate thrust restraint(s) should be provided in pressure systems.

HOBAS pipes can be used with a wide variety of commercially available manholes including:

- HOBAS tee base system
- Precast concrete
- Cast-in-place concrete

Others may be adaptable. Please consult us for assistance.

HOBAS Tee Base System

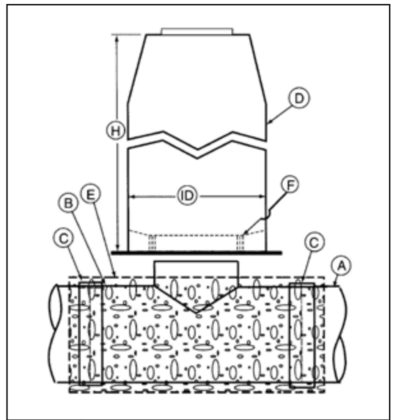
Description & Versatility

The HOBAS tee base manhole system consists of a HOBAS tee base and a one-piece fiberglass riser (2 options available - Figures 4 & 5). As shown, the manhole in Figure 5 is not suitable for traffic loading, although options for that condition are available. The tee base is available with mitered angles for alignment changes. The HOBAS tee base may also be used with RCP riser sections.

Assembly & Installation

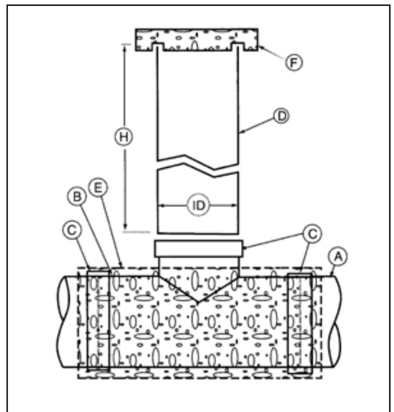
The tee base is assembled to both the mainline sewer pipe and the fiberglass riser section with HOBAS push-on, gasket-sealed FWC couplings (see section 8). Fully concrete encase the tee base so only the indicated length of the riser neck remains exposed. In most cases, the concrete encasement must be designed to support all riser loads and extend past the nearest couplings. More detailed instructions are available. Place the riser sections after the concrete cures.

HOBAS tee base manholes are available in any size and angle.



Item	Description
A	HOBAS Line Pipe
B	HOBAS Tee Base
C	HOBAS FWC Coupling
D	Fiberglass Riser with Cone
E	Concrete Encasement
F	HOBAS FWC Coupling and Riser Invert
H	Riser Height (2 to 40)
ID	Riser ID (48", 60", 72")

FIGURE 4 – HOBAS Tee Base Manhole System with Riser & Cone



Item	Description
A	HOBAS Line Pipe
B	HOBAS Tee Base
C	HOBAS FWC Coupling
D	HOBAS Riser Pipe
E	Concrete Encasement
F	Concrete Flat Top
H	Riser Height (2 to 20)
ID	Riser ID (Equal to neck Dia.≤ line Dia.)

FIGURE 5 – HOBAS Tee Base Manhole System with Riser & Flat Top

Pre-Cast or Cast-in-place Manholes

HOBAS pipes can be easily connected by traditional methods to many pre-cast or cast-in-place concrete manholes as shown in Figures 6, 7, 8 and 9. Other methods may be suitable. Contact us for assistance.

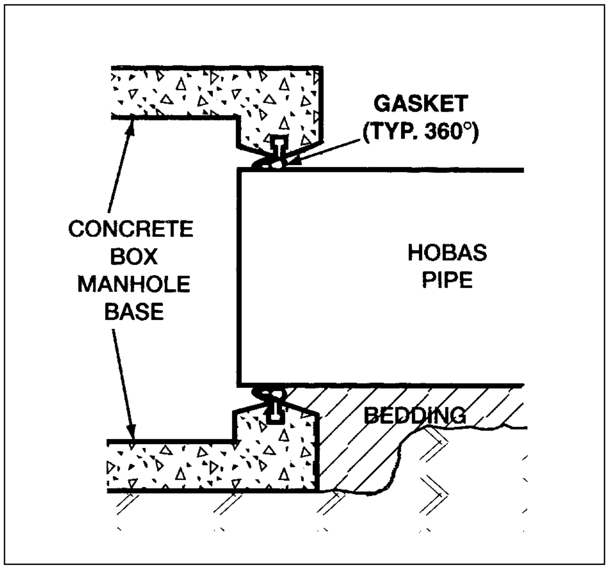


FIGURE 6 – Cast-In Gasket Connection

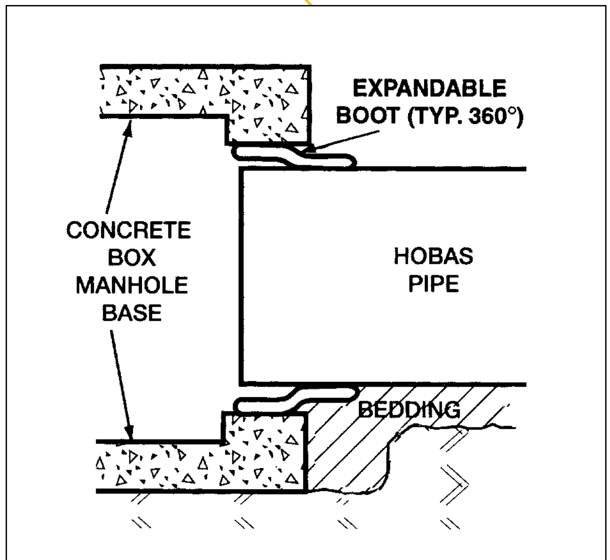


FIGURE 7 – Expandable Boot Seal Connection

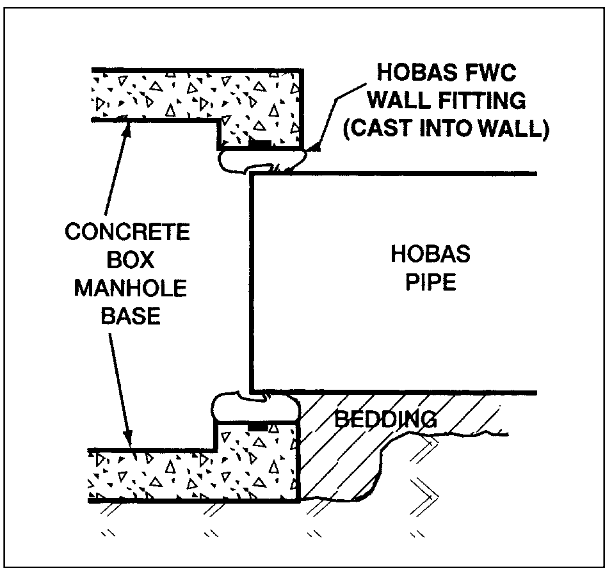


FIGURE 8 - HOBAS FWC Wall Fitting Connection

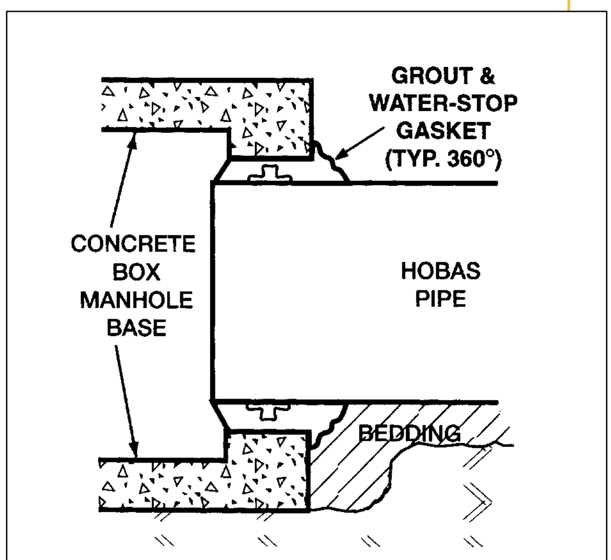


FIGURE 9 – Grout with Water-Stop Connection

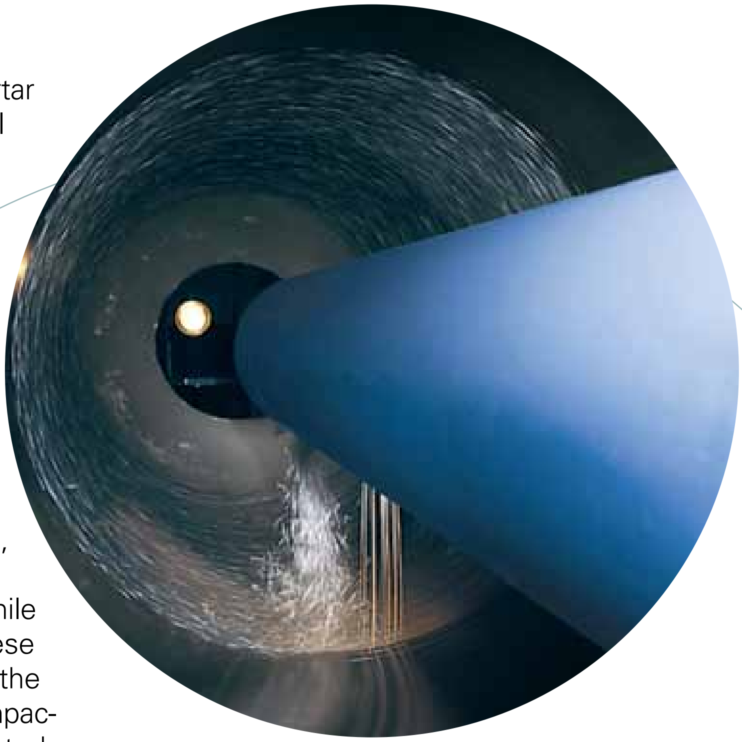
* Such as A-Lok or Press-Seal Econoseal

** Such as Kor-N-Seal or Press-Seal PSX

*** In large diameters it may be best to utilize a rigid encasement adjacent to the structure.

Centrifugal Casting Process

HOBAS fiberglass reinforced polymer mortar pipes are produced by a unique centrifugal casting process. The sophisticated pipe wall structure is built up from the outside surface to the interior surface within an external rotating mold. While the mold is revolving at a relatively slow speed, the pipe raw materials of thermosetting resin, reinforcing glass fibers and aggregates are precisely distributed in specific layers at computer controlled rates. The resin is specially formulated to not polymerize during the filling process. When all the material has been positioned, the mold rotational speed is increased to produce centrifugal forces of up to 75g while the polymerization of the resin begins. These forces compress the composition against the mold causing total deaeration and full compaction. In a short time thereafter, the completed, cured pipe is removed from the mold.



Sophisticated materials feeding process for HOBAS centrifugally cast pipe production.

The centrifugal casting process produces a superior, high density fiberglass reinforced polymer mortar pipe product. Because the process is fully computer controlled, all pipes of each size, stiffness and pressure class have very consistent, high quality. All pipes also have a mold smooth exterior surface and an equally smooth, centrifugally cast interior surface.

Because the pipe materials are placed in many layers, the wall structure can be varied to produce the desired and most economical characteristics for most applications, pressure or non-pressure. Typically, the reinforcing glass-fiber layers are predominantly positioned near the two pipe surfaces, on both sides of the bending neutral axis. The intermediate space is comprised primarily of a glass-fiber fortified aggregate and resin mixture. By virtue of this "sandwich" construction, the pipe wall reacts to bending like an I-beam (Figure 10).

The centrifugal casting process and sophisticated pipe wall structure combine to make HOBAS pipes the most technically advanced fiberglass pipes available today.

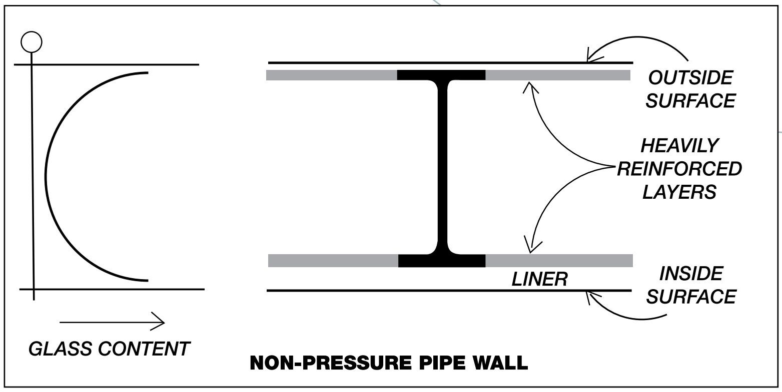


FIGURE 10 - I-Beam Effect In Pipe Wall Bending

Pipe materials feeders are computer controlled. This helps assure consistent high quality. Multiple facilities around the world manufacture CCFRPM pipe using HOBAS technology.

Fabrication of HOBAS FWC high strength coupling.

Reinforcing fibers are distributed in specific layers at computer controlled rates that are monitored continuously.

The constituent raw materials and the pipe production are routinely sampled and tested according to ASTM and AWWA standards to confirm that the desired characteristics and design performance are consistently maintained.

Raw Materials

Resin
All resin shipments have certified test results from the manufacturer for over 10 critical characteristics. Our laboratory randomly verifies these parameters.

Glass Fibers
The lots are checked for moisture, yield and sizing/binder content.

Aggregate
Shipments are monitored for gradation, moisture content and impurities.

The quality of each of the raw materials components is routinely verified.

Raw material properties are checked to ensure suitability.

Process Control

- All process settings are predetermined for each size, type and class of pipe by a multiparameter computer program.
- Process operation, including materials placement and feed rates, is computer controlled to eliminate human errors.
- Actual quantities of materials fed for each pipe are measured automatically and are compared to design minimums to assure proper strengths and other characteristics are achieved.

Pipe materials feed rates and placement are computer controlled for performance consistency.

Pipe stiffness is tested frequently to assure high performance.

Finished Pipe

- Verification for all pipes includes pipe wall thickness, liner thickness, degree of cure, component materials' weights, length and visual inspection of both surfaces for imperfections or other defects.
- Pipe production is periodically sampled per ASTM requirements at a rate of no less than 1 percent and tested for stiffness, deflection characteristics and mechanical properties.

All pipes and couplings are completely inspected.

Product Standards

HOBAS Pipe USA manufactures pipes according to the applicable U.S. product standards as follows:

Application	Standard
Non-pressure Sanitary Sewers	**ASTM D3262**
Sewer Force Mains Industrial Effluents (Pressure)	**ASTM D3754**
Pressure Water Systems	**AWWA C950**
Fiberglass Pipe Design	**AWWA M45**

All of these standards include quality control requirements for:

- Workmanship
- Dimensions
- Pipe Stiffness
- Ring Deflection without Cracking
- Ring Deflection without Failure
- Hoop Tensile Strength
- Axial Tensile Strength

Routine Testing

Routine testing on HOBAS Pipe USA production is conducted to assure full compliance is maintained.

Long-Term Performance & Durability

Long-term performance and durability is measured by extended pressure and ring bending tests that continue for a minimum of 10,000 hours. Test results are extrapolated by regression analysis per ASTM standards to determine the 50 year performance value. Safe operating limits are established by applying design factors as given in the AWWA Fiberglass Pipe Design Manual, M45.

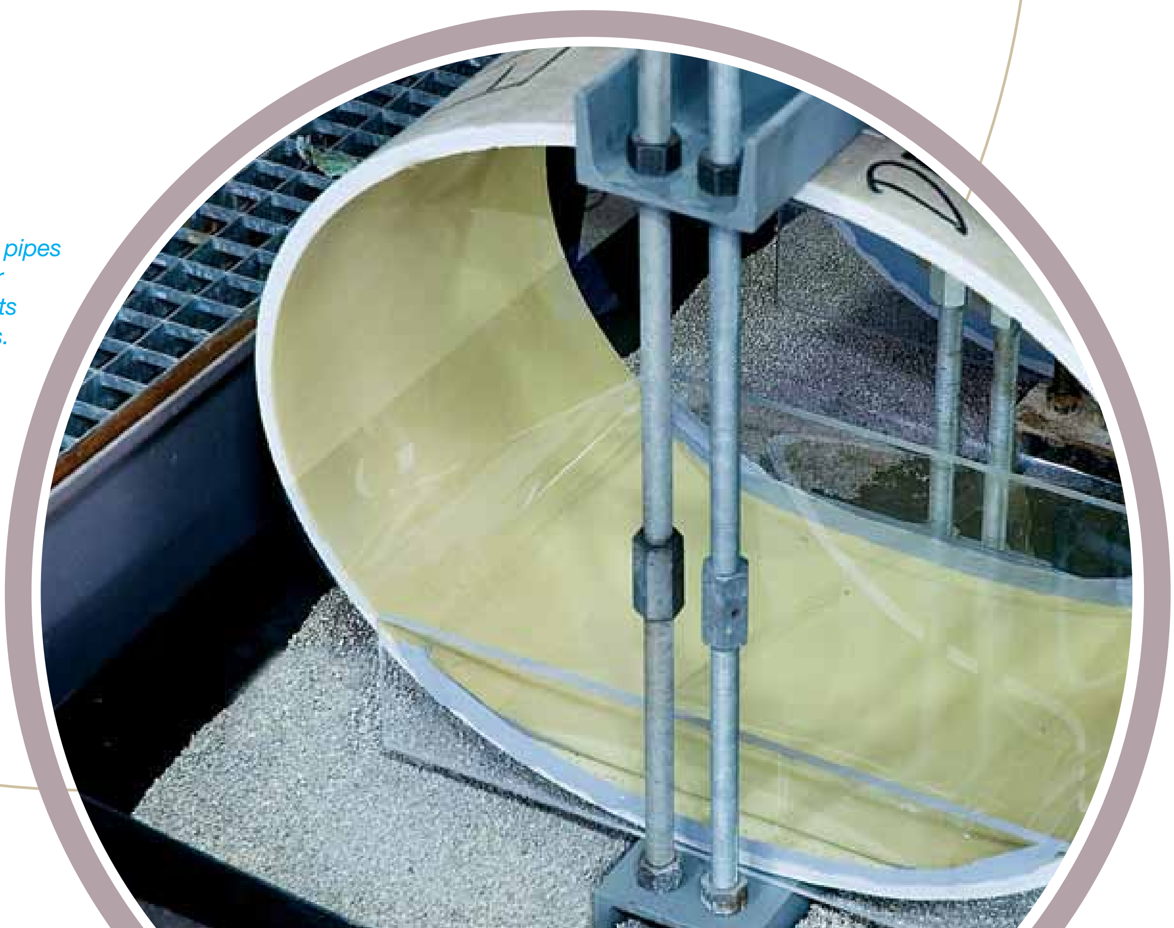
ASTM and AWWA standards define requirements for HOBAS pipes for most applications.

Test Methods

The listed test methods are used to measure the pipe performance and characteristics:

Test Designation	Purpose
ASTM D638	Tensile Properties by Coupon
ASTM D790	Flexural Properties by Coupon
ASTM D1599	Quick Burst
ASTM D2290	Tensile Strength by Split Disk
ASTM D2412	Pipe Stiffness
ASTM D2583	Barcol Hardness (cure)
ASTM D2584	Composition by Loss on Ignition
ASTM D2992	HDB Procedure
ASTM D3567	Dimensions
ASTM D3681	Chemical Resistance - Deflected

HOBAS Pipe USA pipes are acid tested per ASTM requirements for sanitary sewers.



A Direct Bury

A1 Trench Construction

A1.1 Trench width

The minimum trench width shall provide sufficient working room at the sides of the pipe to permit accurate placement and adequate compaction of the pipe zone backfill material. Suggested minimum trench dimensions are given in Figure 11.

A1.1.1 Wide trenches

There is no maximum limit on trench width, however, it is required that the pipe zone backfill material be placed and compacted as specified for the full width of the trench or a distance of 2 diameters on each side of the pipe, whichever is less.

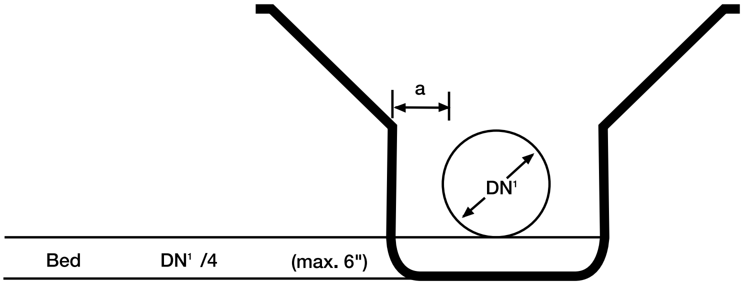
A1.2 Supported trench

When a permanent or temporary trench shoring is used, minimum trench width shall be as per paragraph A1.1 and Figure 11. When using movable trench supports, care should be exercised not to disturb the pipe location, jointing or its embedment. Removal of any trench protection below the top of the pipe and within 2 pipe diameters is not recommended after the pipe embedment has been compacted unless all voids created by sheeting removal are filled with properly densified embedment material and any loose soils at pipe zone elevation are properly compacted prior to loading the pipe with overburden. When possible, use movable trench supports on a shelf above the pipe with the pipe installed in a narrow, vertical wall subditch.

A1.3 Dewatering

Where conditions are such that running or standing water occurs in the trench bottom or the soil in the trench bottom displays a "quick" tendency, the water should be removed by pumps and suitable means such as well points or underdrain bedding. This system should be maintained in operation until the backfill has been placed to a sufficient height to prevent pipe flotation. Care should be taken that any underdrain is of proper gradation and thickness to prevent migration of material between the underdrain, pipe embedment and native soils in the trench, below and at the sides of the pipe.

DN (in.)	Typical Min. a (in.)	
	SPT[2] ≤ 8	SPT[2] > 8
18 to 20	6	4
24 to 33	9	6
36 to 48	12	8
51 to 72	18	12
78 to 120	24	16



[1] DN is nominal diameter

[2] Standard Penetration Test Blows/ft.per ASTM D1586

FIGURE 11 - Standard Trench Dimensions

A1.4 Preparation of Trench Bottom

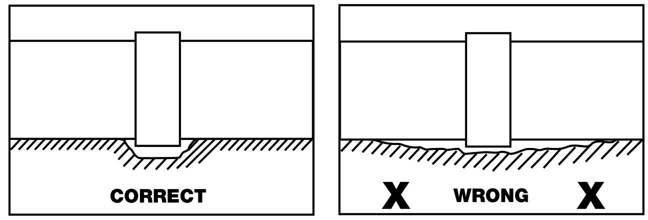
The trench bottom should be constructed to provide a firm, stable and uniform support for the full length of the pipe. Bell holes (Figure 12) should be provided at each joint to permit proper joint assembly and alignment. Any part of the trench bottom excavated below grade should be backfilled to grade and should be compacted as required to provide firm pipe support. When an unstable subgrade condition is encountered which will provide inadequate pipe support, additional trench depth should be excavated and refilled with suitable foundation material. In severe conditions special foundations may be required such as wood pile or sheeting capped by a concrete mat, wood sheeting with keyed-in plank foundation, or foundation material processed with cement or chemical stabilizers. A cushion of acceptable bedding material should always be provided between any special foundation and the pipe. Large rocks and debris should be removed to provide four inches of soil cushion below the pipe and accessories.

A2 Standard Embedment Conditions

Four standard embedment conditions are given in Figure 13. Others may be acceptable. Please consult us for advice on options.

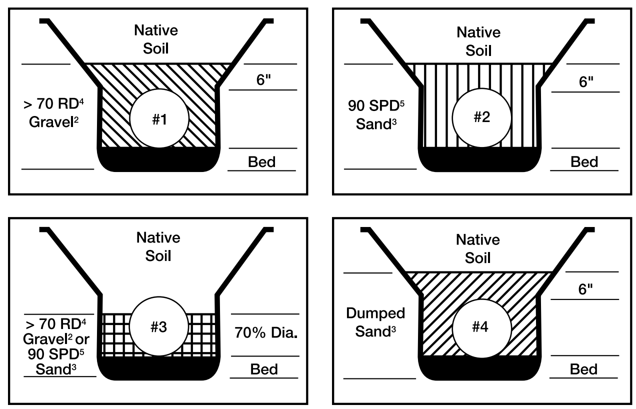
A3 Pipe Zone (Embedment) Backfill Materials

Most coarse grained soils as classified by ASTM D2487, Classification of Soils for Engineering Purposes, are acceptable bedding and pipe zone (embedment) backfill materials as given in the adjacent table.



Note: After joint assembly, fill the bell holes with bedding material and compact as required.

FIGURE 12 - Bell Holes



[2] Gravel is defined in section 14, paragraph A3
[3] Sand is defined in section 14, paragraph A3
[4] RD is relative density per ASTM D4253.
[5] SPD is standard proctor density per ASTM D698.

FIGURE 13 - Standard Embedment Conditions

Specification	Definition	Symbols
Gravel	Gravel or crushed rock	GW, GP GW-GC, GW-GM GP-GC, GP-GM
Sand	Sand or sand-gravel mixtures	SW, SP SW-SC, SW-SM SP-SC, SP-SM

Maximum grain size should typically not exceed 1 to $1^{1}/_{2}$ times the pipe wall thickness or $1^{1}/_{2}$ inches whichever is smaller.

Well graded materials that will minimize voids in the embedment materials should be used in cases where migration of fines in the trench wall material into the embedment can be anticipated. Alternatively, separate the open graded material from the non-cohesive soil with a filter fabric to prevent migration of the smaller grained soil into the open graded material. Such migration is undesirable since it would reduce the soil density near the pipe zone and thereby lessen the pipe support.

Embedment materials should contain no debris, foreign or frozen materials.

A4 Bedding

A firm, uniform bed should be prepared to fully support the pipe along its entire length (Figure 14). Bedding material should be as specified on Figure 13 and in paragraph A3. Bedding minimum depth should be equal to 25% of the nominal diameter or 6 inches, whichever is less (Figure 11).

A firm trench bottom must be provided (see paragraphs A1.3 and A1.4). Initially place and compact bedding to achieve $^{2}/_{3}$ of the total bed thickness (normally four inches). Loosely place the remaining bedding material to achieve a uniform soft cushion in which to seat the pipe invert (bottom).

After joining pipes, assure that all bell holes are filled with the appropriate embedment materials and compacted as specified.

Note: Do not use blocking to adjust pipe grade.

A5 Haunching

A very important factor affecting pipe performance and deflection is the haunching material and its density. Material should be placed and consolidated under the pipe (Figure 15) while avoiding both vertical and lateral displacement of the pipe from proper grade and alignment.

Dumped crushed rock is an ideal pipe zone backfill material for HOBAS pipes.

Buried HOBAS pipes are routinely embedded in compacted sand.

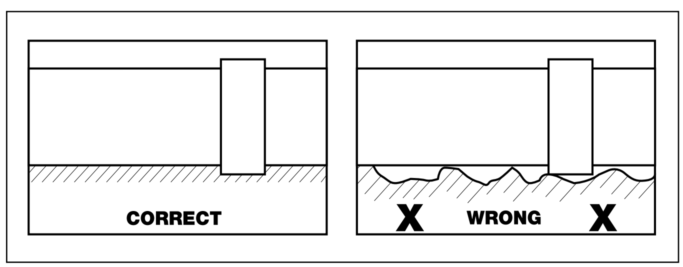


FIGURE 14 - Bedding

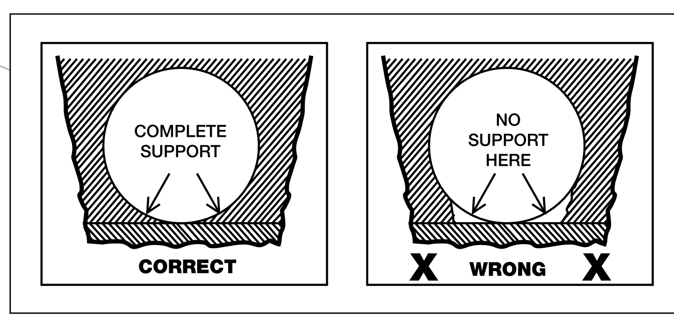


FIGURE 15 - Haunching

A6 Backfilling

Pipe zone (embedment) material shall be as specified on Figure 13 and in paragraph A3. (It must be the same as the bedding material to prevent potential migration.)

Place and compact the embedment material in lifts to achieve the depths and densities specified on Figure 13. Little or no tamping of the initial backfill directly over the top of the pipe should be done to avoid disturbing the embedded pipe.

Remaining backfill may be the native trench material provided clumps and boulders larger than 3 to 4 inches in size are not used until 12 inches of pipe cover has been achieved.

A6.1 Maximum Cover Depth

Maximum recommended cover depth is given in Figure 16.

NATIVE SOIL [2, 5]	COVER DEPTH (ft.)	EMBEDMENT CONDITION[3]			
		1	2	3	4
	10 & <				SN[6]72
Rock	10 to 15		SN[6] 36		
Stiff to V. Hard Cohesive	15 to 20			SN[6] 46	
Compact to V. Dense Granular	20 to 25		SN[6] 46		
(Blows/ft.[4] > 8)	25 to 30	SN[6] 46			
30 to 40			SN[6] 72		ALTERNATE INSTALLATION[7]
40 to 50					
	10 & <		SN[6] 36		SN[6] 72
Medium Cohesive	10 to 15		SN[6] 46	SN[6] 46	
Loose Granular	15 to 20	SN[6] 46	SN[6] 72		
(Blows/ft.[4] 4 to 8)	20 to 25				ALTERNATE INSTALLATION[7]
		25 to 30			
	10 & <	SN[6] 36 to 46		SN[6] 72	
Soft Cohesive	10 to 15	SN[6] 72			
Very Loose Granular	15 to 20				ALTERNATE INSTALLATION[7]
(Blows/ft.[4] 2 to 4)	over 20				

[1] Assuming minimum trench width per Figure 11.
[2] Blow counts should be representative of weakest condition.
[3] Defined in Figure 13. If a cement stabilized sand pipe zone surround is utilized, use column 1 in the highest soils category.
[4] Standard penetration test per ASTM D1586.
[5] For v. soft or v.v. loose soils with blow counts less than 2 use alternate installation per section 14, ¶ A8.
[6] SN is nominal stiffness in psi.
[7] Alternate installation per section 14, ¶ A8.

FIGURE 16 - Maximum Cover Depth[1]

A6.2 Minimum Cover for Traffic Load Application

Minimum recommended cover depth of compacted fill above the pipe crown prior to application of vehicle loads is given in the above chart. Installation in poor soils or at shallower cover depths is possible by using a surface bridging slab or pipe encasement in concrete or similar.

Embedment Condition[1]	Minimum Cover (ft) for HS20 Load[2] SN 18	SN 36 or 46	SN 72
1	4	3	2
2	5	4	3
3	–	5	4
4	–	–	5

[1] See Figure 13.
[2] Installation in poor soils or at shallower cover depths is possible with improved pipe support such as cement stabilized sand or concrete encasement.

A7 Pipe Deflection

Pipe initial vertical cross-section deflection measured within the first 24 hours after completion of all backfilling and removal of dewatering systems, if used, shall not exceed 3% of the original pipe diameter. (See Appendix G for minimum inside diameters.)

Pipe deflection after 30 days should typically not exceed 4% of the original pipe diameter. Maximum long-term pipe deflection is 5% of the original pipe diameter. (See Appendix G for minimum inside diameters.) Maximum long-term deflection for pipes with vinyl ester resin liner is 4%.

For very high stiffness pipes (approx. SN 120 and above), the maximum long-term deflection may be reduced and the 24 hour and 30 day deflection limits also decreased proportionally.

A8 Alternate Installations

Alternate installations, as indicated on figure 16, include cement stabilized embedment, wide trenching, permanent sheeting, geo-fabrics or combinations of these systems. Installation design for these situations should be engineered to satisfy the specific conditions and circumstances that are present.

B Sliplining

B1 Existing Pipe Preparation

The existing sewer may be maintained in operation during the relining process. Obstructions such as roots, large joint off-sets, rocks or other debris, etc. that would prevent passage or damage the liner pipe sections must be removed or repaired prior to installing the new pipe. Prior to starting the liner insertion, verify the existing pipe diameter is sufficient by pulling a mandrel through the line.

It must be determined that the rehabilitated pipeline will be sufficient structurally to carry the overburden loads for the intended design life.

B2 Liner Pipe Insertion

Liner pipes may be pushed or pulled into the existing pipe. The pipes must be inserted spigot end first with the bell end trailing. Sometimes the leading pipe spigot end is protected by a nose piece designed to ride-up and over off-set joints and other minor inconsistencies or debris in the invert. The pushing force must be applied to the pipe wall end inside of the bell as shown in Figure 17. DO NOT apply the pushing load to the end of the bell. Assure that the safe (F of S ≈ 3) jacking loads given in the above table are not exceeded. For pipes with flush bell-spigot joints, see the table on page 48 for typical allowable push loads. Allowable safe jacking loads may be reduced by point loading (i.e. pushing through curves). Maximum allowable joint angular deflection is given on p. 25.

Low-Profile Bell-Spigot Joint Allowable Compressive Load

Nom. Dia. (in.)	O.D. (in.)		Safe Compressive Load Pushing "Straight" (U.S. Tons)		
	Pipe Wall	Bell	SN 18	SN 36	SN 46
18	19.5	20.4	–	–	25 (SN 62)
20	21.6	22.5	–	–	29
24	25.8	26.8	33 (SN 26)	39	44
27	28.0	29.0	39 (SN 24)	48	54
28	30.0	31.0	45 (SN 22)	56	63
30	32.0	33.0	–	51	58
33	34.0	35.0	–	60	67
36	38.3	39.3	74 (SN 30)	82	92
41	42.9	44.0	92 (SN 26)	108	122
42	44.5	45.6	101 (SN 25)	119	134
44	45.9	47.0	106 (SN 24)	128	143
45	47.7	48.8	116 (SN 23)	141	159
48	50.8	51.9	129 (SN 21)	164	183
51	53.9	55.0	142 (SN19)	188	211
54	57.1	58.2	157	215	239
57	60.0	61.2	178	242	268
60	62.9	64.1	200	271	297
63	66.0	67.2	225	302	333
66	69.2	70.4	231 (SN 19)	305	342
69	72.5	73.8	247	339	378
72	75.4	76.7	273	373	417
78	81.6	82.9	330	448	496
84	87.0	88.4	385	520	575
85	88.6	90.0	403	544	601
90	94.3	95.7	464	625	690
96	99.5	101.0	527	702	776
104	108.0	109.5	636	844	930
110	114.0	115.5	720	950	1050
120	126.0	127.5	905	1190	1300

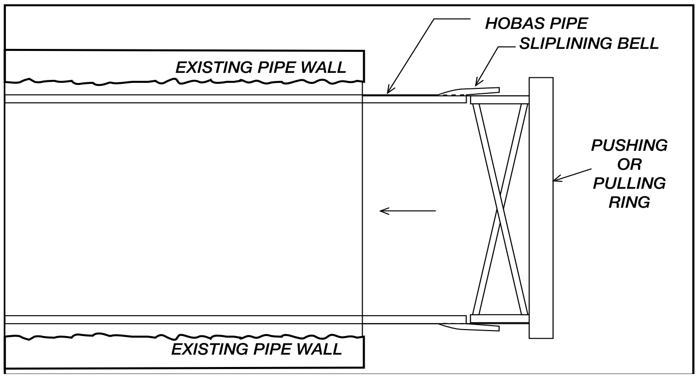


FIGURE 17 - Pipe Insertion

Small access pits needed for sliplining with HOBAS pipes save time, money and surface disruption.

B3 Laterals

Laterals may be typically reconnected to the new liner pipe using "Inserta Tees" or similar accessories.

B4 Grouting

Grout the annular space between the OD of the installed liner pipe and the ID of the existing pipe with a cement or chemical based grout. Minimum compressive strength of the grout shall be as required to assure the structural adequacy of the rehabilitated pipe. During grout placement, assure that the safe (F of S ≈ 2) grouting pressure given in the table below is not exceeded and that the grout density, lift heights and sewage flow depth are coordinated to control the liner pipe flotation and deformation to within allowable limits.

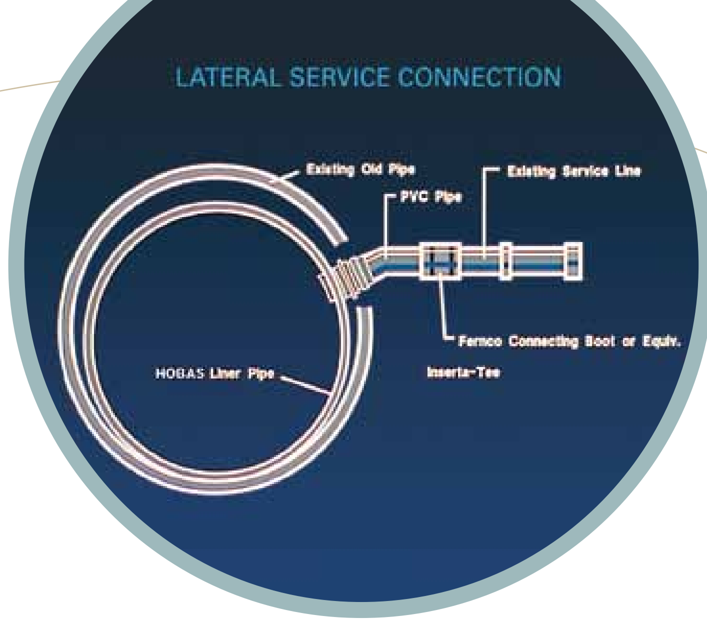
Max. Safe Grouting Pressure (psi)		
	Fluid Flow Level	
Diameter Difference	None or low	Over ½ to full
≤ 5%	SN÷4	SN÷3
≤ 10%	SN÷5	SN÷4
≤ 20%	SN÷6	SN÷5
> 20%	SN÷7	SN÷6

Notes:

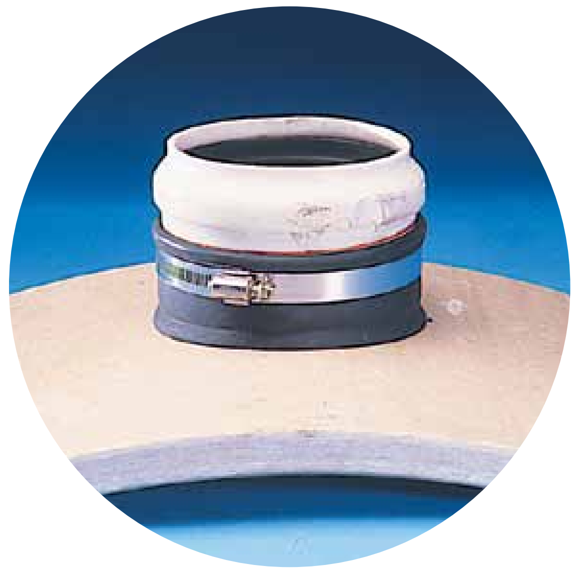
Diameter Difference =

$$\left(\frac{\text{ID Host Pipe - OD Liner Pipe}}{\text{OD Liner Pipe}}\right) \text{X } 100$$

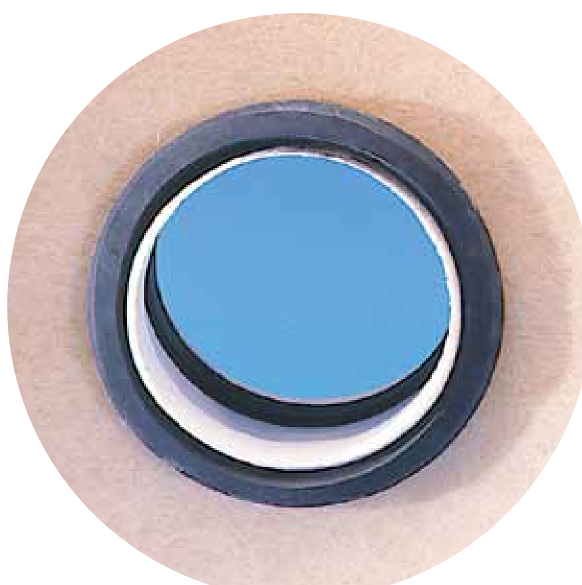
SN is nominal pipe stiffness in psi



Lateral Service reconnection using an "Inserta Tee".



"Inserta Tee" installed in HOBAS Pipe.



Underside (inside) of "Inserta Tee" installation.

C Jacking

C1 General

A boring head begins the tunnel excavation from an access shaft and is pushed along by an hydraulic jacking unit that remains in the pit. The link to the boring head is maintained by adding jacking pipe between the pushing unit and the head. By this procedure, the pipe is installed as the tunnel is bored.

C2 Maximum Allowable Safe Jacking Load

The jacking contractor must control the jacking loads within the safe limits for the pipe. The adjacent table shows allowable safe jacking loads (pushing "straight") for the typical design. However, the ultimate pipe load capacity is the choice and responsibility of the purchaser and can be affected by a number of factors including the anticipated loads, the amount of steering, the amount of over-cut, the amount of lubrication, the pipe section length, the distance of the jacking operation and any point loading. Pipes should be jacked bell-trailing.

Jacking Bell-Spigot Joint Allowable Compressive Load

Nom. Dia. (in.)	O.D. (in.)	Nom. Inside Dia. (in.)	Min. Pipe Wall Thickness (in.)	Min. Pipe Wall Thickness @ Gasket Groove (in.)	Allowable Safe Jacking Load Pushing "Straight" (U.S. Tons)		Weight (lb/ft)
					F of S = 3.0	F of S = 2.5	
24	25.8	22.7	1.40	0.99	125	150	107
27	28.0	24.8	1.47	1.06	145	175	120
28	30.0	26.6	1.53	1.12	166	200	137
30	32.0	28.3	1.71	1.21	191	230	159
33	34.0	30.1	1.80	1.29	216	260	179
36	38.3	34.3	1.85	1.31	250	300	208
41	42.9	38.7	1.91	1.32	283	340	245
42	44.5	40.3	1.93	1.33	295	355	255
44	45.9	41.7	1.95	1.34	308	370	263
45	47.7	43.4	1.98	1.35	325	390	280
48	50.8	46.4	2.03	1.37	350	420	306
51	53.9	49.4	2.07	1.38	375	450	333
54	57.1	52.5	2.10	1.39	400	480	361
57	60.0	55.4	2.13	1.40	425	510	380
60	62.9	58.2	2.16	1.41	450	540	408
63	66.0	61.2	2.20	1.42	475	570	438
66	69.2	64.2	2.31	1.43	500	600	478
69	72.5	67.4	2.38	1.47	541	650	512
72	75.4	70.1	2.46	1.52	583	700	553
78	81.6	76.0	2.58	1.60	667	800	634
84	87.0	81.2	2.70	1.68	750	900	701
85	88.6	82.8	2.73	1.69	770	925	727
90 *	94.3	88.2	2.85	1.76	854	1025	800
96 *	99.5	93.1	3.00	1.87	958	1150	886
104*	108.0	101.3	3.13	1.94	1083	1300	1009
110*	114.0	106.9	3.29	2.05	1208	1450	1129
120*	126.0	118.4	3.58	2.25	1470	1765	1350

Note: Alternate pipe designs are available upon request.
* Lead times may be lengthy, please inquire.

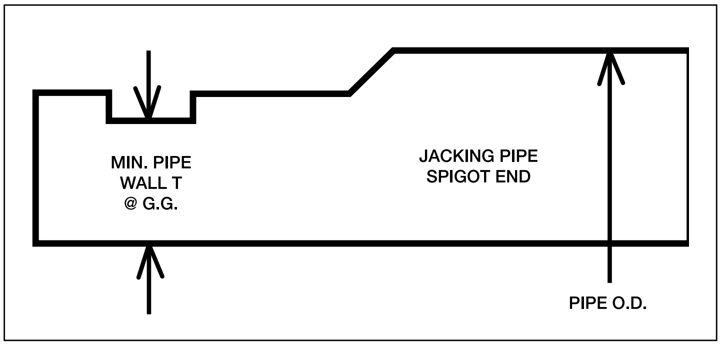


FIGURE 18 - Jacking Pipe Spigot End

C3 Tunnel Diameter

Overcut the tunnel diameter and lubricate the annular space to minimize jacking loads. Take care to control the external pressure to within the safe buckling capacity of the pipe.

C4 Joint & Pipe Deflection

The typical allowable joint angular deflection is between 1 and 2 degrees depending on the spacer thickness and joint configuration. Maximum long-term pipe deflection is typically 3% of the original pipe diameter. For pipes with stiffness exceeding 400 psi, a lower deflection limit normally applies.

HOBAS pipes are the only inherently corrosion resistant, resilient product strong enough to safely withstand the high pushing loads for direct jacking.

D Aboveground

D1 Support Configuration

Recommended pipe support configuration for ambient temperatures is shown on Figures 19 & 20. Pipe diameters and classes shown acceptable (Figure 19) for support scheme A (Figure 20) require only one support location per 20 ft. section. This is best accomplished by a single cradle support on each FWC coupling. These pipes may also be supported as shown in scheme B (Figure 20) with cradles on the pipe wall immediately adjacent to both sides of each coupling, however the mid-point support is not required.

Pipe diameters and classes shown acceptable (Figure 19) for support scheme B (Figure 20) require supports on 10 ft. centers. This must include a double pipe wall cradle bridging each FWC coupling and a mid-span pipe wall cradle support.

Special pipe designs are available for elevated temperature applications or longer support spans.

Protection from long-term exposure to ultraviolet rays is typically required to prevent surface degradation to joints and fittings.

Pipe Support Configurations*

PN**	25 & 50			100	150	200	250
DIA. (In.) / SN+	18	36/46	≥72	≥18	≥36	≥36	≥72
18 & 20	Scheme B	Scheme B	Scheme B	Scheme B	Scheme B	Scheme B	Scheme A
24 to 28	Scheme B	Scheme B	Scheme B	Scheme B	Scheme B	Scheme A	Scheme A
30 to 36	Scheme B	Scheme B	Scheme B	Scheme B	Scheme A	Scheme A	Scheme A
41 to 45	Scheme B	Scheme B	Scheme B	Scheme A	Scheme A	Scheme A	Non-Standard
48 & 51	Scheme B	Scheme B	Scheme A	Scheme A	Scheme A	Scheme A	Non-Standard
54 & 57	Scheme B	Scheme B	Scheme A	Scheme A	Scheme A	Scheme A	Non-Standard
60 & 63	Scheme B	Scheme B	Scheme A	Scheme A	Scheme A	Non-Standard	Non-Standard
66 to 72	Scheme B	Scheme A	Scheme A	Scheme A	Scheme A	Non-Standard	Non-Standard
78 to 120	Scheme A	Scheme A	Scheme A	Scheme A	Non-Standard	Non-Standard	Non-Standard

(SCHEME B FIGURE 20; SCHEME A FIGURE 20; NON-STANDARD)

FIGURE 19 - Pipe Support Configurations

* At ambient temperature
**PN is pipe pressure class in psi
+ SN is pipe stiffness class in psi

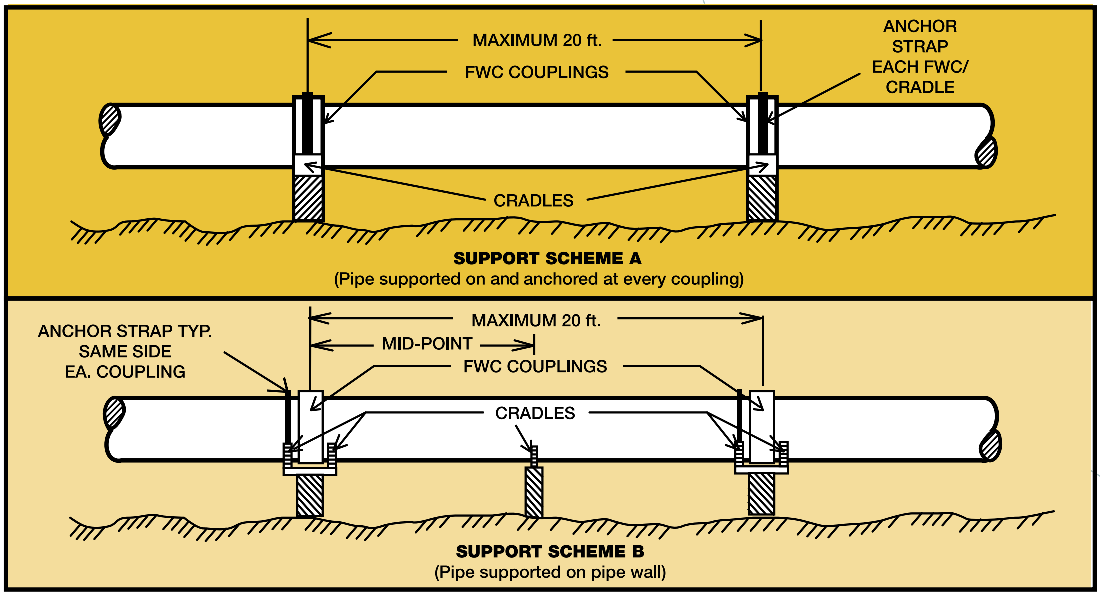


FIGURE 20 - Pipe Support Spacing and Scheme

D2 Cradles

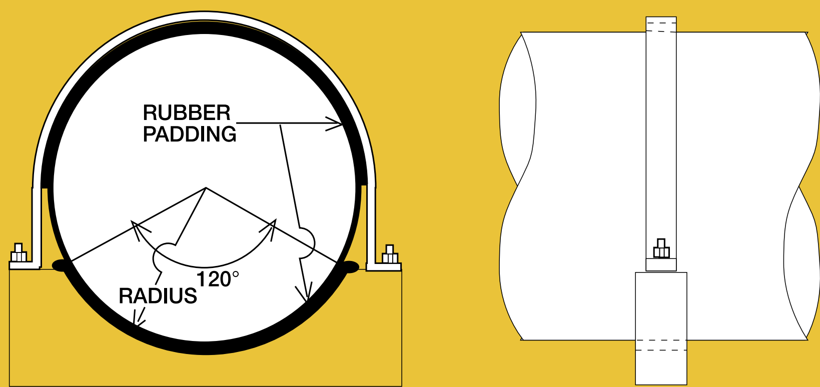
Cradles shall have a minimum 120° support arc and be dimensioned as shown on Figure 21. All cradles shall be faced with a 1/4" thick rubber padding (approx. 50 to 60 durometer).

D3 Anchors

Both support schemes require one anchored cradle (Figure 21) for each pipe section. The anchor strap over the pipe or coupling shall be padded with rubber to create maximum friction resistance to pipe movement. In support scheme A, all cradle positions (support on FWC coupling) must be anchored. In support scheme B, one pipe wall cradle (near the FWC coupling) per section should be anchored as shown on Figure 20. At the other cradle locations the pipe may be restrained loosely to prevent lateral or vertical movement, but should not be so fixed as to restrict axial sliding.

D4 Pipe Restraint

The pipe support and restraint system must be designed to withstand any unbalanced thrust forces at angularly deflected joints or at fittings that may be developed due to pipe pressurization. Other loads caused by wind, temperature changes, fluid momentum, etc. must also be considered.



SUPPORT LOCATION	CRADLE RADIUS TO RUBBER FACE	MIN. CRADLE WIDTH
ON PIPE WALL (SCHEME B)	PIPE O.D.*/2	18" to 24" dia. = 3" 27" to 44" dia. = 4" 45" to 78" dia. = 6" 84" to 120" dia. = 8"
ON FWC COUPLING (SCHEME A)	FWC O.D.**/2	WIDTH OF FWC COUPLING (8", 10" or 11 $^1/_2$")

**See Appendix B for Pipe O.D. Dimensions*
*** See Appendix C for FWC O.D. Dimensions*

FIGURE 21 - Single Cradle w/Anchor Detail

Dimensional consistency makes above ground installations with HOBAS pipe easy.

E Tunnel Carrier

E1 Carrier Pipe Insertion

Carrier pipes may be placed in the tunnel one at a time or may be inserted in a continuous push. If the insertion method involves sliding, the HOBAS carrier pipes must be protected from excessive abrasion. Normally, insert the carrier pipes spigot end first with the pushing force, if used, applied to the pipe wall end inside of the bell as shown in Figure 17 on page 43. DO NOT apply the pushing load to the end of the bell. Assure that the allowable safe (F of S ≈ 3) pushing load given in the adjacent table is not exceeded.

E2 Blocking Schemes

The carrier pipes must be blocked within the tunnel to fix line and grade, and to aid in control of deformation of the carrier pipes during grouting. Two typical blocking schemes are shown in Figures 22 and 23. The actual blocking scheme must be designed so the uplift contact pressure of the blocks on the pipe wall does not exceed allowable limits (maximum contact pressure approximately equal to the pipe stiffness).

Flush Relining Bell-Spigot Joint Allowable Compressive Load

Nom. Dia. (in.)	O.D. (in.)	Min. Pipe Wall Thickness. (in.)	Nom. Pipe Stiffness (psi.)	Min. Pipe Thickness @ Gasket Groove(in.)	Safe Compressive Load Pushing "Straight" (U.S. Tons)	Wt. lb./ft.
18	19.5	0.75	426	0.34	30	43
20	21.6	0.75	310	0.34	34	48
24	25.8	0.76	187	0.35	42	62
27	28.0	0.76	145	0.35	46	68
28	30.0	0.76	117	0.35	49	73
30	32.0	0.86	143	0.36	54	87
33	34.0	0.87	123	0.37	59	94
36	38.3	0.90	95	0.40	73	110
41	42.9	0.96	83	0.44	91	131
42	44.5	0.99	82	0.46	99	140
44	45.9	1.02	82	0.47	105	148
45	47.7	1.05	80	0.49	114	158
48	50.8	1.09	74	0.51	127	175
51	53.9	1.13	69	0.53	141	192
54	57.1	1.17	65	0.55	155	210
57	60.0	1.21	62	0.58	173	225
60	62.9	1.27	62	0.61	191	251
63	66.0	1.33	62	0.64	211	276
66	69.2	1.45	71	0.66	228	315
69	72.5	1.47	64	0.67	243	335
72	75.4	1.49	59	0.68	257	352
78	81.6	1.53	51	0.71	292	393
84	87.0	1.57	45	0.75	330	430
85	88.6	1.58	43	0.76	342	440
90	94.3	1.66	42	0.82	394	491
96	99.5	1.75	42	0.88	448	547
104	108.0	1.85	39	0.94	521	628
110	114.0	1.94	38	0.99	580	695
120	126.0	2.10	36	1.09	710	829

E3 Grouting

Grout the annular space between the tunnel I.D. and the carrier pipe O.D. with a cement or chemical based grout. Minimum compressive strength of the grout shall be as required to assure the structural adequacy of the completed installation. During grout placement, assure that both the safe (F of S ≈ 2) grouting pressure of the carrier pipe (pipe stiffness ÷ 5) is not exceeded and that the grout density, lift heights and blocking scheme are coordinated to control the carrier pipe deformation loads to within allowable limits.

HOBAS pipes' constant OD makes blocking simpler.

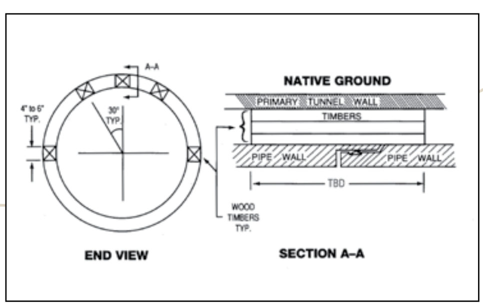


FIGURE 22 - Typical blocking scheme at each flush joint.

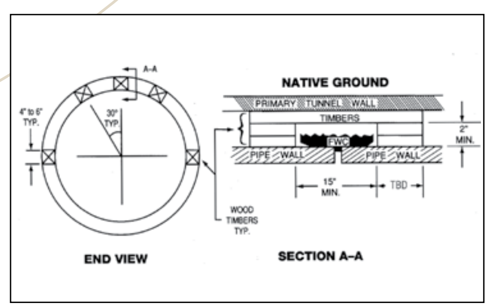


FIGURE 23 - Typical blocking scheme at each FWC coupling joint.

CCFRPM Pipe for Direct Bury Installation - Gravity Service

Part I General

1.01 Section Includes

A. Centrifugally Cast Fiberglass Reinforced Polymer Mortar Pipe. (CCFRPM)

1.02 References

A. ASTM D3262 - Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer Pipe.

B. ASTM D4161 - Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe Joints Using Flexible Elastomeric Seals.

C. ASTM D2412 - Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading.

D. ASTM D3681 – Standard Test Method for Chemical Resistance of "Fiber glass" Pipe in a Deflected Condition.

E. ASTM D638 – Test Method for Tensile Properties of Plastics.

1.03 Specifications

A. The specifications contained herein govern, unless otherwise agreed upon between purchaser and supplier.

Part 2 Products

2.01 Materials

A. Resin Systems: The manufacturer shall use only polyester resin systems with a proven history of performance in this particular application. The historical data shall have been acquired from a composite material of similar construction and composition as the proposed product.

B. Glass Reinforcements: The reinforcing glass fibers used to manufacture the components shall be of highest quality commercial grade E-glass filaments with binder and sizing compatible with impregnating resins.

C. Silica Sand: Sand shall be minimum 98% silica with a maximum moisture content of 0.2%.

D. Additives: Resin additives, such as curing agents, pigments, dyes, fillers, thixotropic agents, etc., when used, shall not detrimentally effect the performance of the product.

E. Elastomeric Gaskets: Gaskets shall meet ASTM F477 and be supplied by qualified gasket manufacturers and be suitable for the service intended.

2.02 Manufacture and Construction

A. Pipes: Manufacture pipe by the centrifugal casting process to result in a dense, nonporous, corrosion-resistant, consistent composite structure. The interior surface of the pipes exposed to sewer flow shall be manufactured using a resin with a 50% elongation (minimum) when tested in accordance with D638. The interior surface shall provide crack resistance and abrasion resistance. The exterior surface of the pipes shall be comprised of a sand and resin layer which provides UV protection to the exterior. Pipes shall be Type 1, Liner 2, Grade 3 per ASTM D3262.

B. Joints: Unless otherwise specified, the pipe shall be field connected with fiberglass sleeve couplings that utilize elastomeric sealing gaskets as the sole means to maintain joint watertightness. The joints must meet the performance requirements of ASTM D4161. Joints at tie-ins, when needed, may utilize gasket-sealed closure couplings.

C. Fittings: Flanges, elbows, reducers, tees, wyes, laterals and other fittings shall be capable of withstanding all operating conditions when installed. They may be contact molded or manufactured from mitered sections of pipe joined by glass-fiber-reinforced overlays. Properly protected standard ductile iron, fusion-bonded epoxy- coated steel and stainless steel fittings may also be used.

D. Acceptable Manufacturer: HOBAS Pipe USA.

2.03 Dimensions

A. Diameters: The actual outside diameter (18" to 48") of the pipes shall be in accordance with ASTM D3262. For other diameters, OD's shall be per manufacturer's literature.

B. Lengths: Pipe shall be supplied in nominal lengths of 20 feet. Actual laying length shall be nominal +1, -4 inches. At least 90% of the total footage of each size and class of pipe, excluding special order lengths, shall be furnished in nominal length sections.

C. Wall Thickness: The minimum wall thickness shall be the stated design thickness.

D. End Squareness: Pipe ends shall be square to the pipe axis with a maximum tolerance of 1/8".

2.04 Testing

A. Pipes: Pipes shall be manufactured and tested in accordance with ASTM D3262.

B. Joints: Coupling joints shall meet the requirements of ASTM D4161.

C. Stiffness: Minimum pipe stiffness when tested in accordance with ASTM D2412 shall normally be 36 psi.

D. Strain Corrosion: The extrapolated 50-year strain corrosion value shall not be less than 0.9% as determined in accordance with ASTM D3681 and ASTM D3262.

2.05 Customer Inspection

A. The Owner or other designated representative shall be entitled to inspect pipes or witness the pipe manufacturing.

B. Manufacturer's Notification to Customer: Should the Owner request to see specific pipes during any phase of the manufacturing process, the manufacturer must provide the Owner with adequate advance notice of when and where the production of those pipes will take place.

2.06 Packaging, Handling, Shipping

A. Packaging, handling, and shipping shall be done in accordance with the manufacturer's instructions.

Part 3 Execution

3.01 Installation

A. Burial: The bedding and burial of pipe and fittings shall be in accordance with the project plans and specifications and the manufacturer's requirements (Section 14 A of the product brochure)

B. Pipe Handling: Use textile slings, other suitable materials or a forklift. Use of chains or cables is not recommended.

C. Jointing:

1. Clean ends of pipe and coupling components.
2. Apply joint lubricant to pipe ends and elastomeric seals of coupling. Use only lubricants approved by the pipe manufacturer.
3. Use suitable equipment and end protection to push or pull the pipes together.
4. Do not exceed forces recommended by the manufacturer for coupling pipe.
5. Join pipes in straight alignment then deflect to required angle. Do not allow the deflection angle to exceed the deflection permitted by the manufacturer.

D. Field Tests:

1. Infiltration / Exfiltration Test: Maximum allowable leakage shall be per local specification requirements.
2. Low Pressure Air Test: Each reach may be tested with air pressure (max 5 psi). The system passes the test if the pressure drop due to leakage through the pipe or pipe joints is less than or equal to the specified amount over the prescribed time period.
3. Individual Joint Testing: For pipes large enough to enter, individual joints may be pressure tested with a portable tester to 5 psi max. with air or water in lieu of line infiltration, exfiltration or air testing.
4. Deflection: Maximum allowable long-term deflection is normally 5% of the initial diameter.

CCFRPM Pipe for Sliplining Installation - Gravity Service

PART 1 General

1.01 Section Includes

A. Centrifugally Cast Fiberglass Reinforced Polymer Mortar Pipe. (CCFRPM)

1.02 References

A. ASTM D3262 - Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer Pipe.

B. ASTM D4161 - Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe Joints Using Flexible Elastomeric Seals.

C. ASTM D2412 - Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading.

D. ASTM D3681 – Standard Test Method for Chemical Resistance of "Fiber glass" Pipe in a Deflected Condition.

E. ASTM D638 – Test Method for Tensile Properties of Plastics.

1.03 Specifications

A. The specifications contained herein govern, unless otherwise agreed upon between purchaser and supplier.

PART 2 Products

2.01 Materials

A. Resin Systems: The manufacturer shall use only polyester resin systems with a proven history of performance in this particular application. The historical data shall have been acquired from a composite material of similar construction and composition as the proposed product.

B. Glass Reinforcements: The reinforcing glass fibers used to manufacture the components shall be of highest quality commercial grade E-glass filaments with binder and sizing compatible with impregnating resins.

C. Silica Sand: Sand shall be minimum 98% silica with a maximum moisture content of 0.2%.

D. Additives: Resin additives, such as curing agents, pigments, dyes, fillers, thixotropic agents, etc., when used, shall not detrimentally effect the performance of the product.

E. Elastomeric Gaskets: Gaskets shall meet ASTM F477 and be supplied by qualified gasket manufacturers and be suitable for the service intended.

2.02 Manufacture and Construction

A. Pipes: Manufacture pipe by the centrifugal casting process to result in a dense, nonporous, corrosion-resistant, consistent composite structure. The interior surface of the pipes exposed to sewer flow shall be manufactured using a resin with a 50% elongation (minimum) when tested in accordance with D638. The interior surface shall provide crack resistance and abrasion resistance. The exterior surface of the pipes shall be comprised of a sand and resin layer which provides UV protection to the exterior. Pipes shall be Type 1, Liner 2, Grade 3 per ASTM D3262.

B. Joints: Unless otherwise specified, the pipe shall be field connected with low-profile, fiberglass bell-spigot joints or flush fiberglass bell-spigot joints, when the fit requires. Either joint shall utilize elastomeric sealing gaskets as the sole means to maintain joint water tightness and shall meet the performance requirements of ASTM D4161. Joints at tie-ins, when needed, may utilize gasket-sealed closure couplings.

C. Fittings: Flanges, elbows, reducers, tees, wyes, laterals and other fittings shall be capable of withstanding all operating conditions when installed. They may be contact molded or manufactured from mitered sections of pipe joined by glass-fiber-reinforced overlays.

D. Acceptable Manufacturer: HOBAS Pipe USA.

2.03 Dimensions

A. Diameters: The actual outside diameter (18" to 48") of the pipe barrel shall be in accordance with ASTM D3262. For other diameters, OD's shall be per manufacturer's literature.

B. Lengths: Pipe shall be supplied in nominal lengths of 20 feet. When required by radius curves, pit size, sewer irregularities, etc., pipe shall be supplied in nominal lengths of 10 feet or other even divisions of 20 feet. Actual laying length shall be nominal +1, -4 inches. At least 90% of the total footage of each size and class of pipe, excluding special order lengths, shall be furnished in nominal length sections.

C. Wall Thickness: The minimum wall thickness shall be the stated design thickness.

D. End Squareness: Pipe ends shall be square to the pipe axis with a maximum tolerance of 1/8".

2.04 Testing

A. Pipes: Pipes shall be manufactured and tested in accordance with ASTM D3262.

B. Joints: Joints shall meet the requirements of ASTM D4161.

C. Stiffness: Minimum pipe stiffness when tested in accordance with ASTM D2412 shall normally be 36 psi (may range from 18 psi to 46 psi and sometimes higher).

D. Strain Corrosion: The extrapolated 50-year strain corrosion value shall not be less than 0.9% as determined in accordance with ASTM D3681 and ASTM D3262.

2.05 Customer Inspection

A. The Owner or other designated representative shall be entitled to inspect pipes or witness the pipe manufacturing.

B. Manufacturer's Notification to Customer: Should the Owner request to see specific pipes during any phase of the manufacturing process, the manufacturer must provide the Owner with adequate advance notice of when and where the production of those pipes will take place.

2.06 Packaging, Handling, and Shipping

A. Packaging, handling, and shipping shall be done in accordance with the manufacturer's instructions.

PART 3 Execution

3.01 Installation

A. Installation: The installation of pipe and fittings shall be in accordance with the project plans and specs and the manufacturer's requirements (Section 14 B of product brochure).

B. Pipe Grouting: Annular space grouting shall not damage the liner and shall conform to the manufacturer's requirements (Section 14 B of product brochure).

C. Pipe Handling: Use textile slings, other suitable materials or a forklift. Use of chains or cables is not recommended.

D. Jointing

1. Clean ends of pipe and joint components.
2. Apply joint lubricant to the bell interior surface and the elastomeric seals. Use only lubricants approved by the pipe manufacturer.
3. Use suitable equipment and end protection to push or pull the pipes together.
4. Do not exceed forces recommended by the manufacturer for joining or pushing pipe .
5. Join pipes in straight alignment then deflect to the required angle. Do not allow the deflection angle to exceed the deflection permitted by the manufacturer.

E. Field Tests

1. Acceptance of the installed liner shall be based on a video taped TV inspection after grouting to assure all joints are properly assembled, no damage exists and that any leakage or deformation is within the allowable limits.

CCFRPM Pipe for Jacking Installation - Gravity Service

Part 1 General

1.01 Section Includes

A. Centrifugally Cast Fiberglass Reinforced Polymer Mortar Pipe. (CCFRPM)

1.02 References

A. ASTM D3262 - Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer Pipe.

B. ASTM D4161 - Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe Joints Using Flexible Elastomeric Seals.

C. ASTM D2412 - Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading.

D. ASTM D3681 – Standard Test Method for Chemical Resistance of "Fiber glass" Pipe in a Deflected Condition.

E. ASTM D638 – Test Method for Tensile Properties of Plastics.

1.03 Specifications

A. The specifications contained herein govern, unless otherwise agreed upon between purchaser and supplier.

Part 2 Products

2.01 Materials

A. Resin Systems: The manufacturer shall use only polyester resin systems with a proven history of performance in this particular application. The historical data shall have been acquired from a composite material of similar construction and composition as the proposed product.

B. Glass Reinforcements: The reinforcing glass fibers used to manufacture the components shall be of highest quality commercial grade E-glass filaments with binder and sizing compatible with impregnating resins.

C. Silica Sand: Sand shall be minimum 98% silica with a maximum moisture content of 0.2%.

D. Additives: Resin additives, such as curing agents, pigments, dyes, fillers, thixotropic agents, etc., when used, shall not detrimentally effect the performance of the product.

E. Elastomeric Gaskets: Gaskets shall meet ASTM F477 and be supplied by qualified gasket manufacturers and be suitable for the service intended.

2.02 Manufacture and Construction

A. Pipes: Manufacture pipe by the centrifugal casting process to result in a dense, nonporous, corrosion-resistant, consistent composite structure. The interior surface of the pipes exposed to sewer flow shall be manufactured using a resin with a 50% elongation (minimum) when tested in accordance with D638. The interior surface shall provide crack resistance and abrasion resistance. The exterior surface of the pipes shall be comprised of a sand and resin layer which provides UV protection to the exterior. Pipes shall be Type 1, Liner 2, Grade 3 per ASTM D3262.

B. Joints: Unless otherwise specified, the pipe shall be field connected with fiberglass sleeve couplings or bell-spigot joints that utilize elastomeric sealing gaskets as the sole means to maintain joint watertightness. The joints must meet the performance requirements of ASTM D4161. The joint shall have approximately the same O.D. as the pipe, so when the pipes are assembled, the joints are essentially flush with the pipe outside surface. Joints at tie-ins, when needed, may utilize gasket-sealed closure couplings.

C. Fittings: Flanges, elbows, reducers, tees, wyes, laterals and other fittings shall be capable of withstanding all operating conditions when installed. They may be contact molded or manufactured from mitered sections of pipe joined by glass-fiber-reinforced overlays. Properly protected standard ductile iron, fusion-bonded epoxy- coated steel and stainless steel fittings may also be used.

D. Acceptable Manufacturer: HOBAS Pipe USA.

2.03 Dimensions

A. Diameters: The actual outside diameter (18" to 48") of the pipes shall be in accordance with ASTM D3262. For other diameters, OD's shall be per manufacturer's literature.

B. Lengths: Pipe shall be supplied in nominal lengths of 10 or 20 feet. Actual laying length shall be nominal +1, -4 inches. At least 90% of the total footage of each size and class of pipe, excluding special order lengths, shall be furnished in nominal length sections.

C. Wall Thickness: The minimum wall thickness, measured at the bottom of the spigot gasket groove where the wall cross-section has been reduced, is determined from the maximum jacking load. Minimum factor of safety against jacking force is 2.5 based on straight alignment.

D. End Squareness: Pipe ends shall be square to the pipe axis with a maximum tolerance of 1/16".

2.04 Testing

A. Pipes: Pipes shall be manufactured and tested in accordance with ASTM D3262.

B. Joints: Joints shall meet the requirements of ASTM D4161.

C. Stiffness: Minimum pipe stiffness when tested in accordance with ASTM D2412 shall normally be 140 psi.

D. Strain Corrosion: The extrapolated 50-year strain corrosion value shall not be less than 0.9% as determined in accordance with ASTM D3681 and ASTM D3262.

2.05 Customer Inspection

A. The Owner or other designated representative shall be entitled to inspect pipes or witness the pipe manufacturing.

B. Manufacturer's Notification to Customer: Should the Owner request to see specific pipes during any phase of the manufacturing process, the manufacturer must provide the Owner with adequate advance notice of when and where the production of those pipes will take place.

2.06 Packaging, Handling, and Shipping

A. Packaging, handling, and shipping shall be done in accordance with the manufacturer's instructions.

Part 3 Execution

3.01 Installation

A. Installation: The installation of pipe and fittings shall be in accordance with the project plans and specifications and the manufacturer's requirements (Section 14 C of product brochure).

B. Pipe Handling: Use textile slings, other suitable materials or a forklift. Use of chains or cables is not recommended.

C. Jointing:

1. Clean ends of pipe and joint components.
2. Apply joint lubricant to the bell interior surface and the elastomeric seals. Use only lubricants approved by the pipe manufacturer.
3. Use suitable equipment and end protection to push the pipes together.
4. Do not exceed forces recommended by the manufacturer for joining or pushing pipe. Jacking direction should be bell-trailing

D. Field Tests:

1. Infiltration / Exfiltration Test: Maximum allowable leakage shall be per local specification requirements.
2. Low Pressure Air Test: Each reach may be tested with air pressure (max 5 psi). The system passes the test if the pressure drop due to leakage through the pipe or pipe joints is less than or equal to the specified amount over the prescribed time period.
3. Individual Joint Testing: For pipes large enough to enter, individual joints may be pressure tested with a portable tester to 5 psi max. with air or water in lieu of line infiltration, exfiltration or air testing.
4. Deflection: Maximum allowable long-term deflection is typically 3% of the initial diameter.

CCFRPM Pipe for Above Ground Installation - Gravity Service

Part 1 General

1.01 Section Includes

A. Centrifugally Cast Fiberglass Reinforced Polymer Mortar Pipe. (CCFRPM)

1.02 References

A. ASTM D3262 - Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer Pipe.

B. ASTM D4161 - Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe Joints Using Flexible Elastomeric Seals.

C. ASTM D2412 - Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading.

D. ASTM D3681 – Standard Test Method for Chemical Resistance of "Fiber glass" Pipe in a Deflected Condition.

E. ASTM D638 – Test Method for Tensile Properties of Plastics.

1.03 Specifications

A. The specifications contained herein govern, unless otherwise agreed upon between the purchaser and supplier.

Part 2 Products

2.01 Materials

A. Resin Systems: The manufacturer shall use only polyester resin systems with a proven history of performance in this particular application. The historical data shall have been acquired from a composite material of similar construction and composition as the proposed product.

B. Glass Reinforcements: The reinforcing glass fibers used to manufacture the components shall be of highest quality commercial grade E-glass filaments with binder and sizing compatible with impregnating resins.

C. Silica Sand: Sand shall be minimum 98% silica with a maximum moisture content of 0.2%.

D. Additives: Resin additives, such as curing agents, pigments, dyes, fillers, thixotropic agents, etc., when used, shall not detrimentally effect the performance of the pipe.

E. Elastomeric Gaskets: Gaskets shall meet ASTM F477 and be supplied by qualified gasket manufacturers and be suitable for the service intended.

2.02 Manufacture and Construction

A. Pipes: Manufacture pipe by the centrifugal casting process to result in a dense, non-porous, corrosion-resistant, consistent composite structure. The interior surface of the pipes exposed to sewer flow shall be manufactured using a resin with a 50% elongation (minimum) when tested in accordance with D638. The interior surface shall provide crack resistance and abrasion resistance. The exterior surface of the pipes shall be comprised of a sand and resin layer which provides UV protection to the exterior. Pipes shall be Type 1, Liner 2, Grade 3 per ASTM D3262.

B. Joints: Unless otherwise specified, the pipe shall be field connected with fiberglass sleeve couplings that utilize elastomeric sealing gaskets as the sole means to maintain joint watertightness. The joints must meet the performance requirements of ASTM D4161. Joints at tie-ins, when needed, may utilize gasket-sealed closure couplings.

C. Fittings: Flanges, elbows, reducers, tees, wyes, laterals and other fittings shall be capable of withstanding all operating conditions when installed. They may be contact molded or manufactured from mitered sections of pipe joined by glass-fiber-reinforced overlays. Properly protected standard ductile iron, fusion-bonded epoxy- coated steel and stainless steel fittings may also be used.

D. Acceptable Manufacturer: HOBAS Pipe USA.

2.03 Dimensions

A. Diameters: The actual outside diameter (18" to 48") of the pipes shall be in accordance with ASTM D 3262. For other diameters, OD's shall be per manufacturer's literature.

B. Lengths: Pipe shall be supplied in nominal lengths of 20 feet. Actual laying length shall be nominal +1, -4 inches. At least 90% of the total footage of each size and class of pipe, excluding special order lengths, shall be furnished in nominal length sections.

C. Wall Thickness: The minimum wall thickness shall be the stated design thickness.

D. End Squareness: Pipe ends shall be square to the pipe axis with a maximum tolerance of 1/8".

2.04 Testing

A. Pipes: Pipes shall be manufactured and tested in accordance with ASTM D3262.

B. Joints: Coupling joints shall meet the requirements of ASTM D4161.

C. Stiffness: Minimum pipe stiffness when tested in accordance with ASTM D2412 shall normally be 18 psi.

D. Strain Corrosion: The extrapolated 50-year strain corrosion value shall not be less than 0.9% as determined in accordance with ASTM D3681 and ASTM D3262

2.05 Customer Inspection

A. The Owner or other designated representative shall be entitled to inspect pipes or witness the pipe manufacturing.

B. Manufacturer's Notification to Customer: Should the Owner request to see specific pipes during any phase of the manufacturing process, the manufacturer must provide the Owner with adequate advance notice of when and where the production of those pipes will take place.

2.06 Packaging, Handling, Shipping

A. Packaging, handling, and shipping shall be done in accordance with the manufacturer's instructions.

Part 3 Execution

3.01 Installation

A. The installation of pipe and fittings shall be in accordance with the project plans and specifications and the manufacturer's requirements (Section 14 D of the product brochure).

B. Pipe Handling: Use textile slings, other suitable materials or a forklift. Use of chains or cables is not recommended.

C. Jointing:

1. Clean ends of pipe and coupling components.
2. Apply joint lubricant to pipe ends and the elastomeric seals of coupling. Use only lubricants approved by the pipe manufacturer.
3. Use suitable equipment and end protection to push or pull the pipes together.
4. Do not exceed forces recommended by the manufacturer for coupling pipe.
5. Join pipes in straight alignment then deflect to required angle. Do not allow the deflection angle to exceed the deflection permitted by the manufacturer.

D. Field Tests:

1. Infiltration / Exfiltration Test: Maximum allowable leakage shall be per local specification requirements.
2. Individual Joint Testing: For pipes large enough to enter, individual joints may be pressure tested with a portable tester to 5 psi max. with air or water in lieu of line infiltration, exfiltration or air testing.

CCFRPM Pipe for Tunnel Carrier Installation - Gravity Service

Part 1 General

1.01 Section Includes

A. Centrifugally Cast Fiberglass Reinforced Polymer Mortar Pipe. (CCFRPM)

1.02 References

A. ASTM D3262 - Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer Pipe.

B. ASTM D4161 - Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe Joints Using Flexible Elastomeric Seals.

C. ASTM D2412 - Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading.

D. ASTM D3681 – Standard Test Method for Chemical Resistance of "Fiber glass" Pipe in a Deflected Condition.

E. ASTM D638 – Test Method for Tensile Properties of Plastics.

1.03 Specifications

A. The specifications contained herein govern, unless otherwise agreed upon between the purchaser and supplier.

Part 2 Products

2.01 Materials

A. Resin Systems: The manufacturer shall use only polyester resin systems with a proven history of performance in this particular application. The historical data shall have been acquired from a composite material of similar construction and composition as the proposed product.

B. Glass Reinforcements: The reinforcing glass fibers used to manufacture the components shall be of highest quality commercial grade E-glass filaments with binder and sizing compatible with impregnating resins.

C. Silica Sand: Sand shall be minimum 98% silica with a maximum moisture content of 0.2%.

D. Additives: Resin additives, such as curing agents, pigments, dyes, fillers, thixotropic agents, etc., when used, shall not detrimentally effect the performance of the product.

E. Elastomeric Gaskets: Gaskets shall meet ASTM F477 and be supplied by qualified gasket manufacturers and be suitable for the service intended.

2.02 Manufacture and Construction

A. Pipes: Manufacture pipe by the centrifugal casting process to result in a dense, nonporous, corrosion-resistant, consistent composite structure. The interior surface of the pipes exposed to sewer flow shall be manufactured using a resin with a 50% elongation (minimum) when tested in accordance with D638. The interior surface shall provide crack resistance and abrasion resistance. The exterior surface of the pipes shall be comprised of a sand and resin layer which provides UV protection to the exterior. Pipes shall be Type 1, Liner 2, Grade 3 per ASTM D3262.

B. Joints: Unless otherwise specified, the pipe shall be field connected with fiberglass sleeve couplings or bell-spigot joints, "flush" or "non-flush", that utilize elastomeric sealing gaskets as the sole means to maintain joint watertightness. The joints must meet the performance requirements of ASTM D4161. Joints at tie-ins, when needed, may utilize gasket-sealed closure couplings.

C. Fittings: Flanges, elbows, reducers, tees, wyes, laterals and other fittings shall be capable of withstanding all operating conditions when installed. They may be contact molded or manufactured from mitered sections of pipe joined by glass-fiber-reinforced overlays. Properly protected standard ductile iron, fusion-bonded epoxy-coated steel and stainless steel fittings may also be used.

D. Acceptable Manufacturer: HOBAS Pipe USA.

2.03 Dimensions

A. Diameters: The actual outside diameter (18" to 48") of the pipes shall be in accordance with ASTM D3262. For other diameters, OD's shall be per manufacturer's literature.

B. Lengths: Pipe shall be supplied in nominal lengths of 20 feet. When required by radius curves, pit size, or other limitations restrict the pipe to shorter lengths, nominal sections of 10 feet or other even divisions of 20 feet shall be used. Actual laying length shall be nominal +1, -4 inches. At least 90% of the total footage of each size and class of pipe, excluding special order lengths, shall be furnished in nominal length sections.

C. Wall Thickness: The minimum wall thickness shall be the stated design thickness.

D. End Squareness: Pipe ends shall be square to the pipe axis with a maximum tolerance of 1/8".

2.04 Testing

A. Pipes: Pipes shall be manufactured and tested in accordance with ASTM D3262.

B. Joints: Joints shall meet the requirements of ASTM D4161.

C. Stiffness: Minimum pipe stiffness when tested in accordance with ASTM D2412 shall normally be 36 psi.

D. Strain Corrosion: The extrapolated 50-year strain corrosion value shall not be less than 0.9% as determined in accordance with ASTM D3681 and ASTM D3262

2.05 Customer Inspection

A. The Owner or other designated representative shall be entitled to inspect pipes or witness the pipe manufacturing.

B. Manufacturer's Notification to Customer: Should the Owner request to see specific pipes during any phase of the manufacturing process, the manufacturer must provide the Owner with adequate advance notice of when and where the production of those pipes will take place.

2.06 Packaging, Handling, Shipping

A. Packaging, handling, and shipping shall be done in accordance with the manufacturer's instructions.

Part 3 Execution

3.01 Installation

A. Installation: The installation of pipe and fittings shall be in accordance with the project plans and specifications and the manufacturer's requirements (Section 14 E of the product brochure).

B. Pipe Grouting: Annular space grouting shall not damage the liner and shall conform to the manufacturer's requirements (Section 14 E of product brochure).

C. Pipe Handling: Use textile slings, other suitable materials or a forklift. Use of chains or cables is not recommended.

D. Jointing:

1. Clean ends of pipe and coupling components.
2. Apply joint lubricant to pipe ends or bell interior surfaces and the elastomeric seals. Use only lubricants approved by the pipe manufacturer.
3. Use suitable equipment and end protection to push or pull the pipes together.
4. Do not exceed forces recommended by the manufacturer for joining or pushing pipe.
5. Join pipes in straight alignment then deflect to required angle. Do not allow the deflection angle to exceed the deflection permitted by the manufacturer.

E. Field Tests

1. Infiltration / Exfiltration Test: Maximum allowable leakage shall be per local specification requirements.
2. Low Pressure Air Test: Each reach may be tested with air pressure (max 5 psi). The system passes the test if the pressure drop due to leakage through the pipe or pipe joints is less than or equal to the specified amount over the prescribed time period.
3. Individual Joint Testing: For pipes large enough to enter, individual joints may be pressure tested with a portable tester to 5 psi max. with air or water in lieu of line infiltration, exfiltration or air testing.
4. Deflection: Maximum allowable long-term deflection is normally 5% of the initial diameter.

CCFRPM Pipe for Pressure Service

Part 1 General

1.01 Section Includes

A. Centrifugally Cast Fiberglass Reinforced Polymer Mortar Pipe. (CCFRPM)

1.02 References

A. ASTM D3754 - Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer and Industrial Pressure Pipe.

B. AWWA C950 - AWWA Standard for Fiberglass Pressure Pipe

C. ASTM D4161 - Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe Joints Using Flexible Elastomeric Seals.

D. ASTM D2412 - Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading.

1.03 Specifications

A. The specifications contained herein govern, unless otherwise agreed upon between purchaser and supplier.

Part 2 Products

2.01 Materials

A. Resin Systems: The manufacturer shall use only polyester resin systems with a proven history of performance in this particular application. The historical data shall have been acquired from a composite material of similar construction and composition as the proposed product.

B. Glass Reinforcements: The reinforcing glass fibers used to manufacture the components shall be of highest quality commercial grade E-glass filaments with binder and sizing compatible with impregnating resins.

C. Silica Sand: Sand shall be minimum 98% silica with a maximum moisture content of 0.2%.

D. Additives: Resin additives, such as curing agents, pigments, dyes, fillers, thixotropic agents, etc., when used, shall not detrimentally effect the performance of the product.

E. Elastomeric Gaskets: Gaskets shall meet ASTM F477 and be supplied by qualified gasket manufacturers and be suitable for the service intended.

2.02 Manufacture and Construction

A. Pipes: Manufacture pipe by the centrifugal casting process to result in a dense, nonporous, corrosion-resistant, consistent composite structure. The pipe nominal pressure class (PN) shall be equal to or greater than the maximum sustained operating pressure of the line. The maximum transient (operating plus surge) pressure of the line shall not exceed the pipe nominal pressure class by more than 40%. Pipes shall be Type 1, Liner 2, Grade 3 per ASTM D3754.

B. Joints: Unless otherwise specified, the pipe shall be field connected with fiberglass sleeve couplings that utilize elastomeric sealing gaskets as the sole means to maintain joint watertightness. The joints must meet the performance requirements of ASTM D4161. Tie-ins, when needed, may utilize gasket-sealed mechanical couplings.

C. Fittings: Flanges, elbows, reducers, tees, wyes, laterals and other fittings shall be capable of withstanding all operating conditions when installed. They may be contact molded or manufactured from mitered sections of pipe joined by glass- fiber-reinforced overlays. Properly protected standard ductile iron, fusion-bonded epoxy- coated steel and stainless steel fittings may also be used. Unbalanced thrust forces shall be restrained with thrust blocks or other suitable methods. Fiberglass tees, wyes, laterals, or other similar fittings shall be fully encased in reinforced concrete designed to withstand the pressure forces.

D. Acceptable Manufacturer: HOBAS Pipe USA.

2.03 Dimensions

A. Diameters: The actual outside diameter (18" to 48") of the pipes shall be in accordance with AWWA C950. For other diameters, OD's shall be per manufacturer's literature.

B. Lengths: Pipe shall be supplied in nominal lengths of 20 feet. Actual laying length shall be nominal +1, -4 inches. At least 90% of the total footage of each size and class of pipe, excluding special order lengths, shall be furnished in nominal length sections.

C. Wall Thickness: The minimum wall thickness shall be the stated design thickness.

D. End Squareness: Pipe ends shall be square to the pipe axis with a maximum tolerance of $^1/_8$".

2.04 Testing

A. Pipes: Pipes shall be manufactured in accordance with the applicable standard.

B. Joints: Coupling joints shall meet the requirements of ASTM D4161.

C. Stiffness: Minimum pipe stiffness when tested in accordance with ASTM D2412 shall normally be 36 psi.

D. Tensile Strength: Pipe hoop tensile strength for pressure pipe shall be verified as specified in applicable standard (ASTM D3754 or AWWA C950) or by random burst testing at the same sampling frequency. All pipes shall be capable of withstanding a test pressure of two (2) times the maximum sustained operating pressure of the line without leaking or cracking. This performance shall be verified as agreed between the buyer and seller.

2.05 Customer Inspection

A. The Owner or other designated representative shall be entitled to inspect pipes or witness the pipe manufacturing.

B. Manufacturer's Notification to Customer: Should the Owner request to see specific pipes during any phase of the manufacturing process, the manufacturer must provide the Owner with adequate advance notice of when and where the production of those pipes will take place.

2.06 Packaging, Handling, and Shipping

A. Packaging, handling, and shipping shall be done in accordance with the manufacturer's instructions.

Part 3 Execution

3.01 Installation

A. Installation: The installation of pipe and fittings shall be in accordance with the project plans and specifications and the manufacturer's requirements (Section 14 of product brochure).

B. Pipe Handling: Use textile slings, other suitable materials or a forklift. Use of chains or cables is not recommended.

C. Jointing:

1. Clean ends of pipe and coupling components.
2. Apply joint lubricant to pipe ends and the elastomeric seals of coupling. Use only lubricants approved by the pipe manufacturer.
3. Use suitable equipment and end protection to push or pull the pipes together.
4. Do not exceed forces recommended by the manufacturer for coupling pipe.
5. Join pipes in straight alignment then deflect to required angle. Do not allow the deflection angle to exceed the deflection permitted by the manufacturer.

D. Field Tests:

1. Pressure Test: Pressure pipes may be field tested after completion of the installation (including required thrust restraints) at a maximum pressure of 1.5 times the system operating pressure not to exceed 1.5 x PN. Prior to testing, assure that all work has been properly completed.

   When filling the line assure that all air is expelled to avoid dangerous build-up of compressed air potential energy. Pressurize the line slowly, so pressure surges exceeding test pressures are not developed. Check for leaks when the test pressure has stabilized.

2. Deflection: Maximum Allowable long-term deflection is normally 5% of the initial diameter.

Class SN 18* (minimum pipe stiffness of 18 psi)

Nominal Pipe Size (in.)	Pipe O.D. (in.)	Class PN**/SN					
		25 /18		50/18		100/18	
		min. wall t (in.)	weight (lb/ft)	min. wall t (in.)	weight (lb/ft)	min. wall t (in.)	weight (lb/ft)
18	19.5	0.30	19	0.29	19	0.29	18
20	21.6	0.32	23	0.32	23	0.32	22
24	25.8	0.38	32	0.37	31	0.37	30
27	28.0	0.41	38	0.40	37	0.40	35
28	30.0	0.43	42	0.43	42	0.42	39
30	32.0	0.46	48	0.45	47	0.45	45
33	34.0	0.48	53	0.48	53	0.47	50
36	38.3	0.54	67	0.53	66	0.52	61
41	42.9	0.60	83	0.59	82	0.58	77
42	44.5	0.62	89	0.61	88	0.60	82
44	45.9	0.64	95	0.63	93	0.62	87
45	47.7	0.66	101	0.65	100	0.64	94
48	50.8	0.70	114	0.69	113	0.68	106
51	53.9	0.74	128	0.73	126	0.72	118
54	57.1	0.78	143	0.77	141	0.76	132
57	60.0	0.82	157	0.81	155	0.80	146
60	62.9	0.86	173	0.84	169	0.83	159
63	66.0	0.90	189	0.88	185	0.87	174
66	69.2	0.94	207	0.92	203	0.91	191
69	72.5	0.98	226	0.97	224	0.95	209
72	75.4	1.02	245	1.00	240	0.99	226
78	81.6	1.10	285	1.08	280	1.07	264
84	87.0	1.17	323	1.15	318	1.13	297
85	88.6	1.19	334	1.17	329	1.15	308
90	94.3	1.26	377	1.24	371	1.22	347
96	99.5	1.33	419	1.31	413	1.29	387
104	108.0	1.44	492	1.42	485	1.40	455
110	114.0	1.52	546	1.51	542		
120	126.0	1.68	659	1.67	655		

* Normally not available for direct bury. ** Maximum nominal working pressure class in psi.

Class SN 36 (minimum pipe stiffness of 36 psi)

Nominal Pipe Size (in.)	Pipe O.D. (in.)	Class PN*/SN									
		25 /36		50/36		100/36		150/36		200/36	
		min. wall t (in.)	weight (lb/ft)	min. wall t (in.)	weight (lb/ft)	min. wall t (in.)	weight (lb/ft)	min. wall t (in.)	weight (lb/ft)	min. wall t (in.)	weight (lb/ft)
18	19.5	0.36	23	0.36	23	0.35	21	0.35	21	0.34	20
20	21.6	0.40	28	0.39	28	0.39	26	0.38	25	0.37	24
24	25.8	0.46	39	0.46	39	0.45	36	0.45	35	0.44	33
27	28.0	0.50	45	0.50	45	0.49	42	0.48	40	0.47	38
28	30.0	0.53	51	0.53	51	0.52	48	0.51	45	0.50	44
30	32.0	0.57	59	0.56	58	0.55	54	0.54	51	0.53	49
33	34.0	0.60	66	0.59	64	0.58	60	0.57	57	0.56	55
36	38.3	0.67	82	0.66	81	0.65	76	0.64	72	0.63	69
41	42.9	0.74	101	0.74	101	0.73	95	0.71	89	0.70	86
42	44.5	0.77	109	0.76	108	0.75	101	0.74	96	0.72	92
44	45.9	0.79	116	0.79	116	0.77	107	0.76	102	0.74	97
45	47.7	0.82	125	0.81	123	0.80	116	0.78	109	0.77	105
48	50.8	0.87	141	0.86	139	0.85	131	0.83	123	0.82	119
51	53.9	0.92	157	0.91	156	0.90	147	0.88	138	0.86	132
54	57.1	0.97	176	0.97	176	0.95	164	0.93	155	0.91	148
57	60.0	1.02	194	1.01	192	1.00	181	0.98	171		
60	62.9	1.07	213	1.06	211	1.04	197	1.02	186		
63	66.0	1.12	234	1.11	232	1.09	217	1.06	203		
66	69.2	1.17	256	1.16	254	1.14	237	1.12	225		
69	72.5	1.22	279	1.21	277	1.20	261	1.17	246		
72	75.4	1.27	302	1.26	300	1.24	281				
78	81.6	1.37	353	1.36	350	1.34	328				
84	87.0	1.46	400	1.45	398	1.43	373				
85	88.6	1.49	416	1.48	413	1.45	385				
90	94.3	1.58	469	1.57	466	1.54	435				
96	99.5	1.66	520	1.65	516	1.62	482				
104	108.0	1.80	611	1.79	608						
110	114.0	1.90	680	1.89	676						
120	126.0	2.10	829	2.08	821						

* Maximum nominal working pressure class in psi.

Class SN 46 (minimum pipe stiffness of 46 psi)

Nominal Pipe Size (in.)	Pipe O.D. (in.)	Class PN*/SN									
		25/46		50/46		100/46		150/46		200/46	
		min. wall t (in.)	weight (lb/ft)	min. wall t (in.)	weight (lb/ft)	min. wall t (in.)	weight (lb/ft)	min. wall t (in.)	weight (lb/ft)	min. wall t (in.)	weight (lb/ft)
18	19.5	0.39	25	0.39	25	0.38	23	0.37	22	0.37	21
20	21.6	0.43	30	0.42	29	0.42	28	0.41	27	0.40	25
24	25.8	0.50	42	0.50	42	0.49	39	0.48	37	0.47	35
27	28.0	0.54	49	0.53	48	0.53	46	0.52	43	0.51	41
28	30.0	0.57	55	0.57	55	0.56	51	0.55	49	0.54	47
30	32.0	0.61	63	0.60	62	0.60	59	0.58	55	0.57	53
33	34.0	0.64	70	0.64	70	0.63	65	0.62	62	0.60	59
36	38.3	0.72	88	0.72	88	0.70	81	0.69	77	0.68	75
41	42.9	0.80	109	0.80	109	0.78	101	0.77	96	0.75	92
42	44.5	0.83	117	0.82	116	0.81	109	0.79	103	0.78	99
44	45.9	0.85	124	0.85	124	0.84	117	0.82	110	0.80	105
45	47.7	0.89	135	0.88	133	0.87	125	0.85	118	0.83	113
48	50.8	0.94	151	0.93	150	0.92	141	0.90	133	0.88	127
51	53.9	1.00	171	0.99	169	0.97	158	0.95	149	0.93	142
54	57.1	1.05	190	1.04	188	1.03	177	1.01	167	0.98	159
57	60.0	1.10	209	1.09	207	1.08	195	1.05	183		
60	62.9	1.15	228	1.15	228	1.13	213	1.10	200		
63	66.0	1.21	252	1.20	250	1.18	234	1.15	220		
66	69.2	1.27	277	1.26	275	1.24	257	1.21	242		
69	72.5	1.32	301	1.31	299	1.29	280	1.26	264		
72	75.4	1.38	328	1.36	323	1.34	303				
78	81.6	1.48	380	1.47	377	1.45	354				
84	87.0	1.58	432	1.57	429	1.54	400				
85	88.6	1.61	448	1.60	445	1.57	416				
90	94.3	1.71	506	1.69	500	1.67	470				
96	99.5	1.80	562	1.79	559	1.76	522				
104	108.0	1.95	660	1.93	654						
110	114.0	2.06	710	2.04	703						
120	126.0	2.27	863	2.25	855						

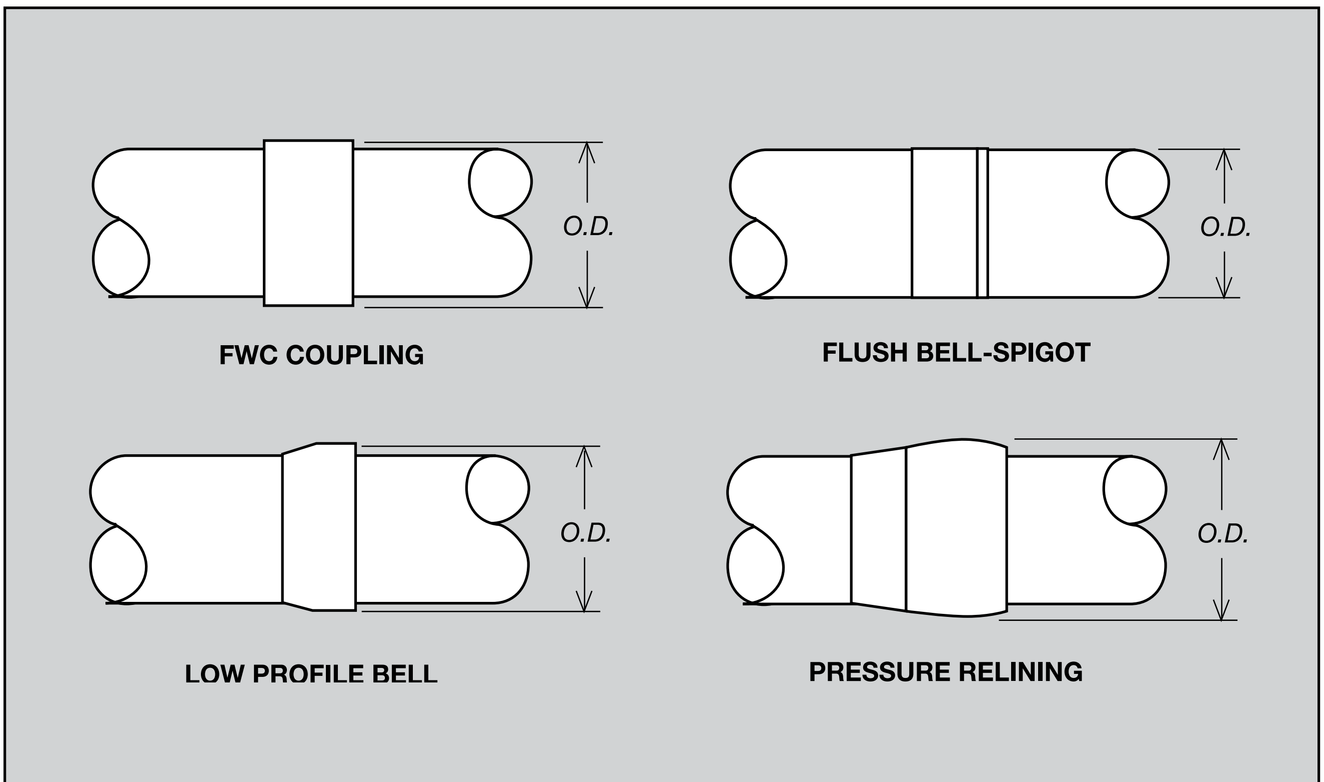
* Maximum nominal working pressure class in psi.

Class SN 72 (minimum pipe stiffness of 72 psi)

Nominal Pipe Size (in.)	Pipe O.D. (in.)	Class PN*/SN									
		25 & 50/72		100/72		150/72		200/72		250/72	
		min. wall t (in.)	weight (lb/ft)	min. wall t (in.)	weight (lb/ft)	min. wall t (in.)	weight (lb/ft)	min. wall t (in.)	weight (lb/ft)	min. wall t (in.)	weight (lb/ft)
18	19.5	0.44	28	0.44	26	0.43	25	0.42	24	0.42	24
20	21.6	0.49	34	0.48	32	0.47	30	0.47	29	0.46	28
24	25.8	0.57	47	0.56	44	0.56	42	0.55	41	0.54	40
27	28.0	0.62	55	0.61	52	0.60	49	0.59	47	0.58	46
28	30.0	0.66	63	0.65	59	0.64	56	0.63	54	0.62	52
30	32.0	0.70	71	0.69	67	0.68	64	0.67	61	0.66	59
33	34.0	0.74	80	0.73	75	0.72	71	0.71	69		
36	38.3	0.83	101	0.81	94	0.80	89	0.79	86		
41	42.9	0.92	125	0.91	117	0.89	111	0.88	107		
42	44.5	0.95	134	0.94	126	0.93	120	0.91	115		
44	45.9	0.98	142	0.97	134	0.95	126	0.94	122		
45	47.7	1.02	153	1.00	143	0.99	137	0.97	131		
48	50.8	1.08	173	1.07	163	1.05	154	1.03	148		
51	53.9	1.15	195	1.13	182	1.11	173	1.10	167		
54	57.1	1.21	217	1.19	203	1.17	193	1.16	187		
57	60.0	1.27	239	1.25	224	1.23	212				
60	62.9	1.33	263	1.31	246	1.29	233				
63	66.0	1.39	288	1.37	270	1.35	256				
66	69.2	1.46	317	1.44	297	1.41	280				
69	72.5	1.53	348	1.50	324	1.48	308				
72	75.4	1.59	375	1.56	350						
78	81.6	1.71	437	1.69	410						
84	87.0	1.82	495	1.79	463						
85	88.6	1.86	515	1.83	482						
90	94.3	1.97	581	1.94	543						
96	99.5	2.08	646	2.05	605						
104	108.0	2.25	758								
110	114.0	2.38	817								
120	126.0	2.62	992								

* Maximum nominal working pressure class in psi.

Nominal Pipe Size (in.)	Nominal Outside Diameter, OD (in.)							
	FWC Coupling					Low Profile Bell	Flush Bell-Spigot	Pressure Relining
	PN 25 PN 50	PN 100	PN 150	PN 200	PN 250			
18	21.3	21.3	21.3	21.3	21.4	20.4	19.5	
20	23.4	23.4	23.4	23.4	23.6	22.5	21.6	
24	27.6	27.6	27.6	27.7	27.9	26.8	25.8	
27	29.8	29.8	29.8	30.0	30.2	29.0	28.0	
28	31.9	31.9	32.0	32.1	32.3	31.0	30.0	
30	33.9	33.9	34.0	34.2	34.4	33.0	32.0	
33	35.9	35.9	36.1	36.3		35.0	34.0	
36	40.2	40.2	40.4	40.6		39.3	38.3	
41	44.9	44.9	45.2	45.5		44.0	42.9	FWC
42	46.5	46.5	46.8	47.2		45.6	44.5	
44	47.9	47.9	48.2	48.6		47.0	45.9	
45	49.7	49.7	50.0	50.4		48.8	47.7	
48	52.8	52.9	53.2	53.6		51.9	50.8	
51	56.0	56.1	56.5	56.8		55.0	53.9	
54	59.2	59.4	59.8	60.1		58.2	57.1	O.D.'s Plus
57	62.2	62.5	62.8			61.2	60.0	
60	65.2	65.5	65.9			64.1	62.9	
63	68.3	68.7	69.1			67.2	66.0	
66	71.6	72.0	72.4			70.4	69.2	
69	74.9	75.4	75.8			73.8	72.5	0.4
72	77.9	78.3				76.7	75.4	
78	84.2	84.7				82.9	81.6	
84	89.6	90.2				88.4	87.0	
85	91.4	92.0				90.0	88.6	
90	97.1	97.8				95.7	94.3	
96	102.5	103.1				101.0	99.5	
104	111.1					109.5	108.0	
110	117.2					115.5	114.0	
120	129.3					127.5	126.0	



Nominal Pipe Size (in.)	FWC Coupling Nominal Weight (lb.)				
	PN 25 PN 50	PN 100	PN 150	PN 200	PN 250
18	20	20	20	20	26
20	22	22	22	28	32
24	34	34	34	37	53
27	37	37	37	42	60
28	40	40	40	47	68
30	42	42	45	53	76
33	45	45	48	59	
36	51	51	57	69	
41	57	57	69	83	
42	59	59	73	111	
44	61	61	77	117	
45	63	63	81	123	
48	67	70	90	135	
51	71	77	120	150	
54	75	83	133	165	
57	80	89	148		
60	112	140	170		
63	118	151	192		
66	124	163	215		
69	133	177	234		
72	142	191			
78	155	205			
84	167	236			
85	172	245			
90	187	274			
96	201	300			
104	223				
110	245				
120	284				

Material properties of HOBAS Pipe USA pipes exceed the requirements of ASTM D3262 for non-pressure applications and of AWWA C950 for pressure service. Actual properties vary depending on pressure and stiffness class. The following range of values covers most pipe constructions. For values specific to individual pipes contact HOBAS Pipe USA.

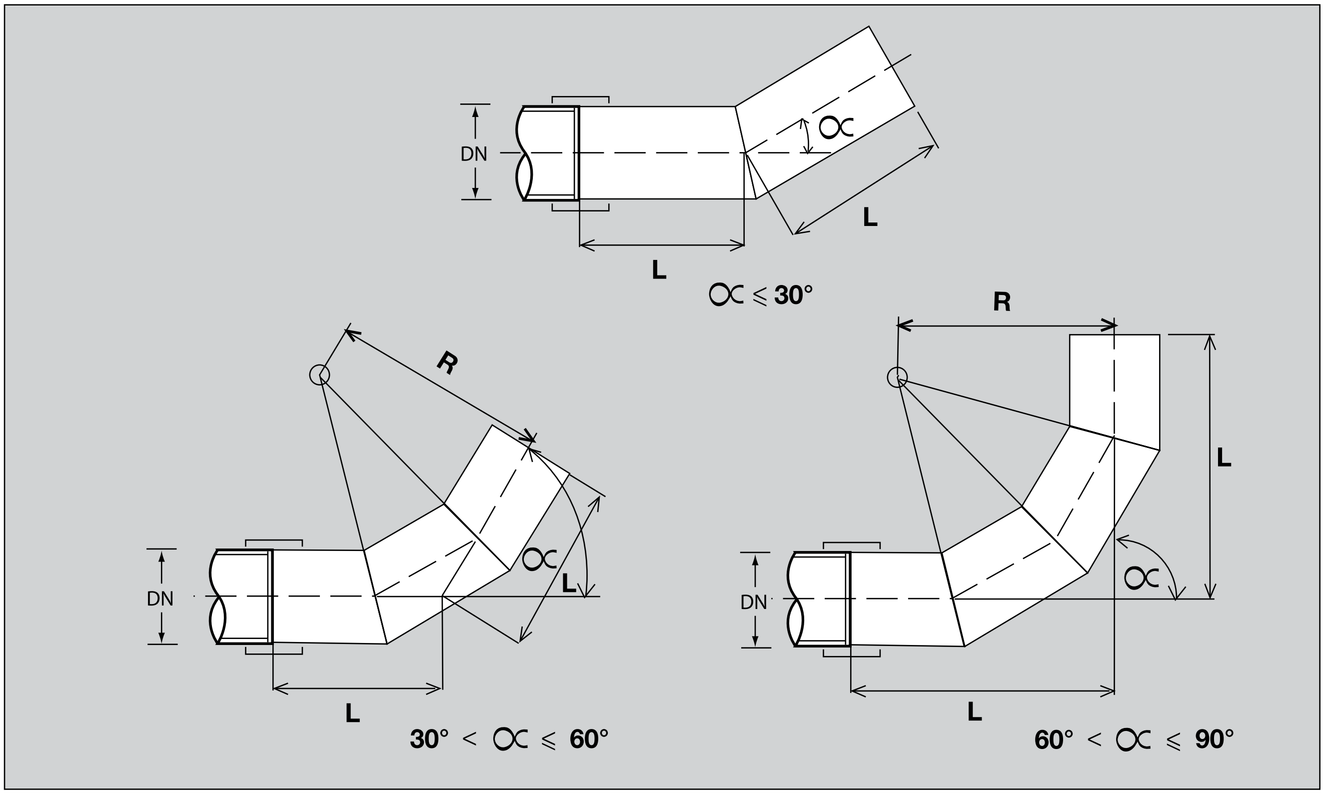
Pipe Property	Range of Values[1]	
E-Modulus[1] (10^6 psi):	**PN 0**	**PN 50 to 250**
* Circumferential Flexural	1.0 to 1.9	1.3 to 2.4
* Circumferential Tensile	–	0.5 to 2.8
* Axial Tensile	0.4 to 0.8	0.4 to 1.7
Strength[1] (10^3 psi):		
* Circumferential Tensile	–	7.0 to 33.0
* Axial Tensile	1.4 to 2.1	1.4 to 6.4
* Compressive	10.5	10.5
Thermal Coefficient of Linear Expansion (axial)	16×10^{-6}	in./in./°F.

Note 1: Values given are for the reinforced wall (i.e. liner is not included).

Flow Factors vary somewhat with pipe diameter and flow rate. The following values have been found to be typically representative long-term and are commonly used.

** Hazen-Williams*	*"C" 155*
** Manning's*	*"n" 0.009*

E1 Fiberglass Elbows



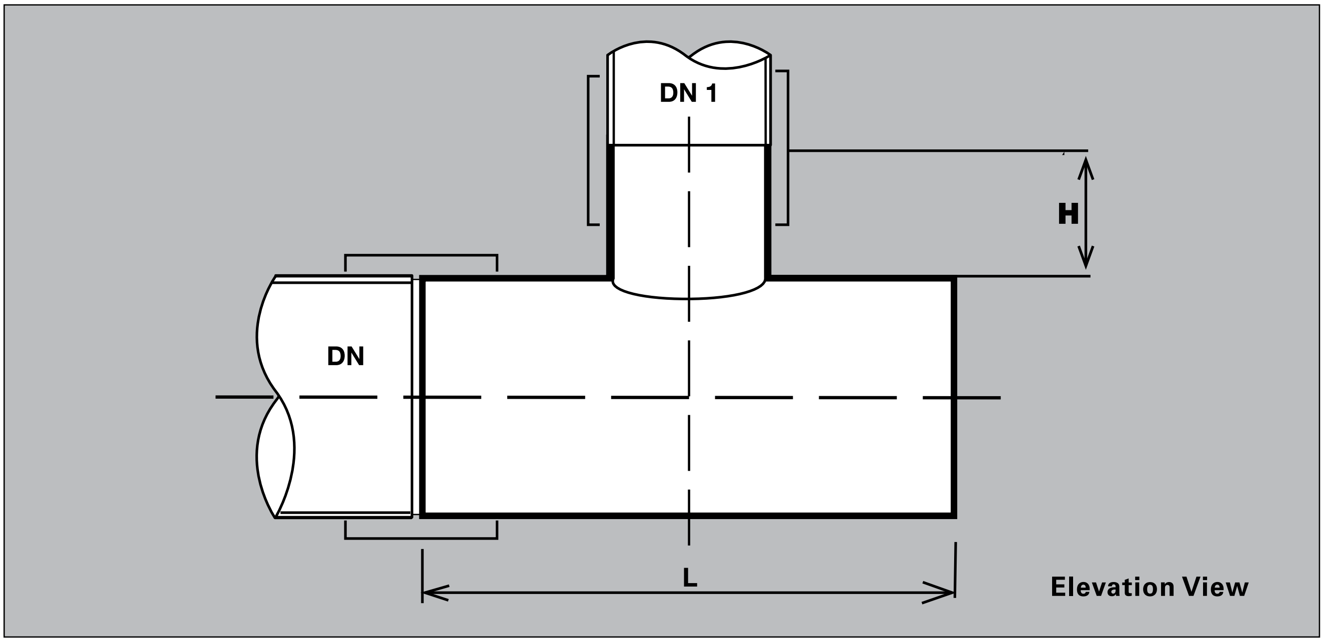
E1 Fiberglass Elbows

DN (in.)	R (in.)	L (in.) for α 11 $^{1}/_{4}$°	22 $^{1}/_{2}$°	30°	45°	60°	90°	P* (psi)
18	27	18	19	20	25	30	40	200
20	30	18	19	20	26	31	42	175
24	36	20	21	22	28	33	48	
27	38	20	21	22	29	34	50	
28	40	20	22	23	30	35	52	150
30	42	20	22	23	31	36	54	
33	44	20	22	24	32	37	56	
36	48	20	22	24	33	39	60	125
41	52	22	23	25	36	42	64	
42	54	23	25	26	37	43	66	
44	55	23	25	26	37	44	67	100
45	57	23	25	27	38	45	69	
48	60	25	25	27	39	46	72	
51	63	27	27	28	40	48	75	
54	66	28	28	28	41	49	78	
57	68	30	30	30	42	50	81	
60	70	31	31	31	43	51	84	
63	73	33	33	33	44	53	87	
66	75	34	34	34	45	54	90	
69	78	36	36	36	47	55	93	75
72	80	38	38	38	48	56	96	
78	84	41	41	41	51	60	102	
84	88	43	43	43	53	63	106	
85	90	44	44	44	54	64	108	
90	95	47	47	47	57	68	114	
96	100	50	50	50	60	72	120	
104	108	54	54	54	63	76	126	
110	112	57	57	57	66	80	132	
120	120	63	63	63	72	88	144	50

Note 1: L may need to be increased if the design pressure exceeds P.

Note 2: Dimensions for other angles or different turning radii are available upon request.

E2-A Fiberglass Manhole Tee Bases

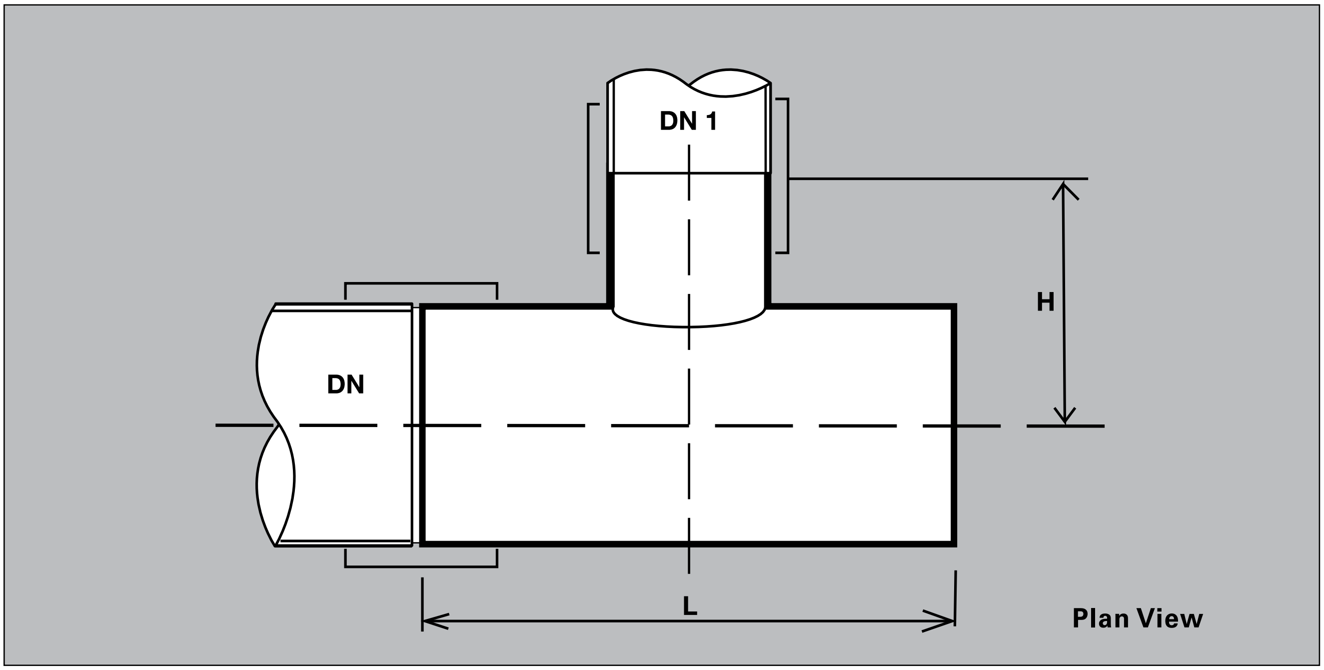


E2-A Fiberglass Manhole Tee Bases

DN (in.)	DN1[1] (in.)	L (in.)	H (in.)	DN1[1] (in.)	L (in.)	H (in.)	DN1[1] (in.)	L (in.)	H (in.)
30	24	54	12	30	60	12	30	60	12
33	24	54	12	30	60	12	30	60	12
36	24	54	12	36	78	12	36	78	12
41	24	54	12	36	78	12	36	78	12
42	24	54	12	36	78	12	36	78	12
44	24	54	12	36	78	12	36	78	12
45	24	54	12	36	78	12	36	78	12
48	24	54	12	36	78	12	48	108	12
51	24	54	12	36	78	12	48	108	12
54	24	54	12	36	78	12	48	108	12
57	24	78	12	36	78	12	48	108	12
60	24	78	12	36	78	12	48	108	12
63	24	78	12	36	78	12	48	108	12
66	24	78	12	36	78	12	48	108	12
69	24	78	12	36	78	12	48	108	12
72	24	78	12	36	78	12	48	108	12
78	24	78	12	36	78	12	48	108	12
84	24	108	12	36	108	12	48	108	12
85	24	108	12	36	108	12	48	108	12
90	24	108	12	36	108	12	48	108	12
96	24	108	12	36	108	12	48	108	12
104	24	108	12	36	108	12	48	108	12
110	24	108	12	36	108	12	48	108	12
120	24	108	12	36	108	12	48	108	12

Notes:
1. Total lay length "L" shown above is typical for (DN1) branch diameter shown. Adjustment to "L" are available.
2. All tee bases to be concrete encased to prevent deformations. Concrete design by others.
3. Complete manhole design by others to include allowance for transfer of surface loads (HS-20) away from branch (DN1).
4. "H" dimension shown is typical, it can be adjusted to allow for specific encasement heights, service laterals, FRP riser connections with FWC couplings, etc.
5. Configurations shown (DN x DN1) can be adjusted to meet specific designs.
6. DN1 can change but must be less than or equal to DN for all tee base configurations.
7. Above dimensions are for straight thru (180 deg.) configurations. Tee bases with angles (PI's) are available, with increased L

E2-B Fiberglass Lateral Tees

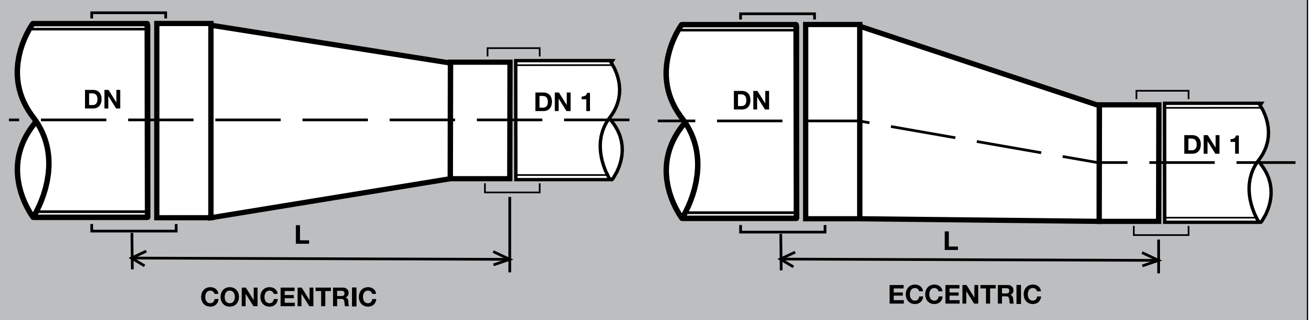


E2-B Fiberglass Lateral Tees

DN (in.)	DN1[1] (in.)	L (in.)	H (in.)	DN1[1] (in.)	L (in.)	H (in.)	DN1[1] (in.)	L (in.)	H (in.)
18	18	57	30	-	-	-	-	-	-
20	20	60	30	18	60	30	-	-	-
24	24	66	33	20	66	33	18	63	33
27	27	68	34	24	67	34	20	64	34
28	28	70	35	24	68	35	20	65	35
30	30	72	36	24	69	36	20	66	36
33	33	75	38	30	72	38	24	66	38
36	36	81	40	30	75	40	24	69	40
41	41	87	44	36	81	44	30	75	44
42	42	90	45	36	84	45	30	78	45
44	44	93	46	42	86	46	36	80	46
45	45	96	47	42	87	47	36	81	47
48	48	99	48	42	90	48	36	84	48
51	51	102	51	48	99	51	42	93	51
54	54	108	54	48	102	54	42	96	54
57	57	111	56	54	105	56	48	99	56
60	60	114	57	54	108	57	48	102	57
63	63	117	59	60	111	59	54	105	59
66	66	120	60	60	114	60	54	108	60
69	69	123	62	66	120	62	60	114	62
72	72	126	63	66	120	63	60	114	63
78	78	138	69	72	132	69	66	126	66
84	84	141	70	78	135	70	72	129	70
85	85	144	72	78	138	72	72	132	72
90	90	150	75	84	144	75	78	138	75
96	96	156	78	90	150	78	84	144	78
104	104	168	84	96	162	84	90	156	84
110	110	180	90	104	174	90	96	168	90
120	120	192	96	110	180	96	104	174	96

Note 1: Dimensions for other combinations of DN and DN 1 are available upon request.

E3 Fiberglass Reducers



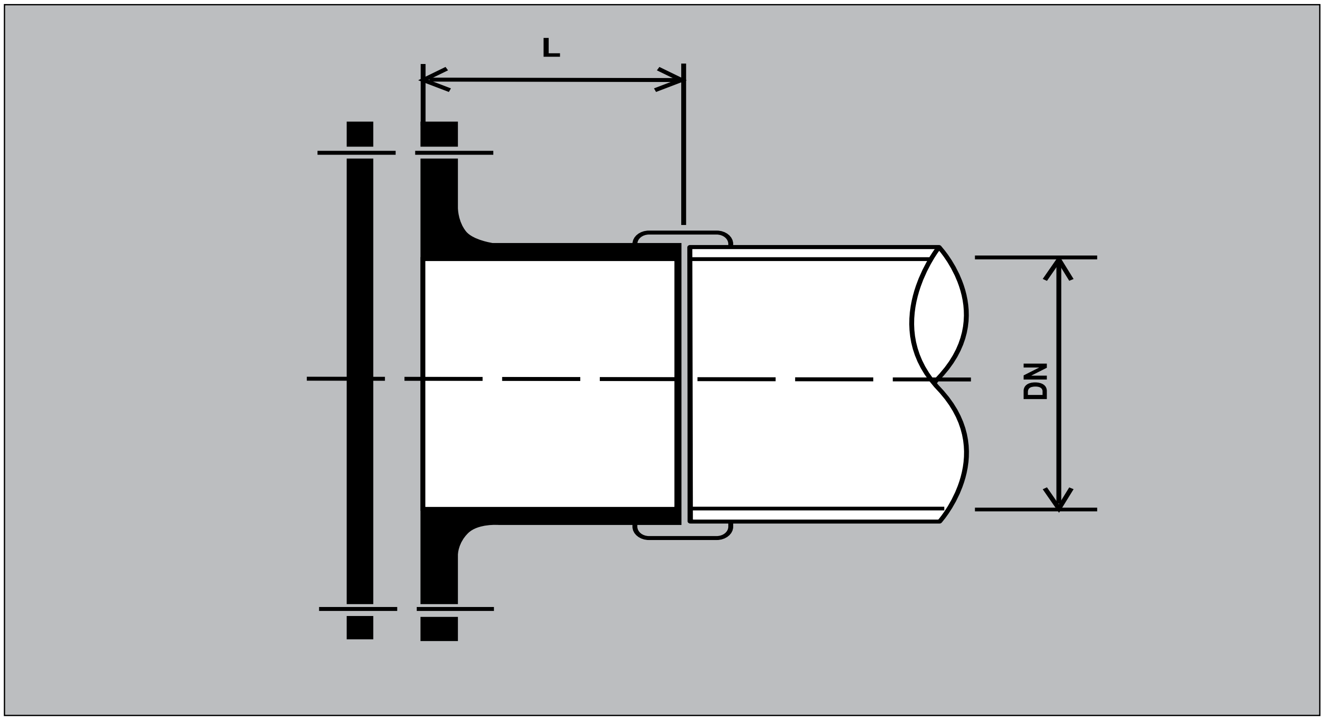
NOTE: Length of tapered portion is 1.5 x (DN - DN 1).

E3 Fiberglass Reducers

DN (in.)	DN1[1] (in.)	L (in.)	DN1[1] (in.)	L (in.)	DN1[1] (in.)	L (in.)	DN1[1] (in.)	L (in.)	P (psi)
	20	18	48	-	-	-	-	-	-
24	20	54	18	57	-	-	-	-	250
27	24	54	20	60	18	63	-	-	
28	24	54	20	60	18	63	-	-	
30	24	57	20	63	18	66	-	-	
33	30	54	24	63	20	69	18	72	200
36	30	57	24	66	20	72	18	75	
41	36	57	30	66	24	75	20	81	
42	36	57	30	66	24	75	20	81	
44	36	60	30	69	24	78	20	84	175
45	42	54	36	63	30	72	24	81	
48	42	57	36	66	30	75	24	84	
51	48	54	42	63	36	72	30	81	150
54	48	57	42	66	36	75	30	84	
57	54	60	48	63	42	72	36	81	
60	54	63	48	66	42	75	36	84	
63	60	66	54	66	48	72	42	81	125
66	60	69	54	69	48	75	42	84	
69	66	72	60	72	54	72	48	81	
72	66	75	60	75	54	75	48	84	
78	72	81	66	81	60	81	54	84	100
84	78	87	72	87	66	87	60	87	
85	78	90	72	90	66	90	60	90	
90	84	96	78	96	72	96	66	96	
96	90	99	84	99	78	99	72	99	75
104	96	108	90	108	84	108	78	108	
110	104	114	96	114	90	114	85	114	
120	110	126	104	126	96	126	90	126	50

Note 1: Dimensions for other combinations of DN and DN 1 are available upon request.
Note 2: L may need to be increased if the design pressure exceeds P.

E4 Fiberglass Flanges



E4 Fiberglass Flanges

DN (in.)	Minimum L (in.)	Minimum O.D. of Flange (in.)	Number 0f Bolts (in.)	Bolt Circle Diameter (in.)	Bolt Diameter (in.)	Minimum Bolt Hole Diam-eter (in.)
18	24	25.00	16	22.75	1.125	1.250
20	30	27.50	20	25.00	1.125	1.250
24	30	32.00	20	29.50	1.250	1.375
27	32	34.25	24	31.75	1.250	1.375
28	34	36.50	28	34.00	1.250	1.375
30	36	38.75	28	36.00	1.250	1.375
36	36	46.00	32	42.75	1.500	1.625
41	40	50.75	36	47.25	1.500	1.625
42	42	53.00	36	49.50	1.500	1.625
48	48	59.50	44	56.00	1.500	1.625
54	48	66.25	44	62.75	1.750	1.875
60	48	73.00	52	69.25	1.750	1.875
66	48	80.00	52	76.00	1.750	1.875
72	48	86.50	60	82.50	1.750	1.875
78	48	93.00	64	89.00	2.000	2.125
84	48	99.75	64	95.50	2.000	2.125
90	48	106.50	68	102.00	2.250	2.375
96	48	113.25	68	108.50	2.250	2.375
104	48	120.00	72	114.50	2.500	2.625
110	48	126.75	72	120.75	2.500	2.625
120	48	140.25	76	132.75	2.75	2.875

Note 1: Flange drilling dimensions are according to AWWA C207 Class D (150 psi) and ANSI B16.1 (125 psi)
Note 2: Fiberglass reinforced polymer flanges are available for non-pressure and some pressure applications. Protected ductile iron, fusion bonded epoxy coated steel or stainless steel flanges may be used at any pressure.

Introduction

The following guide is a compilation of corrosion resistance information obtained from resin manufacturers and actual test results on our pipe. The recommendations are believed to represent acceptable continuous environments for satisfactory long-term pipe performance, however, individual project conditions should be considered when selecting the appropriate product construction. Also, pressure and stiffness ratings may be reduced at elevated temperatures. It is our intention to assist the design engineer as much as possible in making these evaluations.

Chemicals

Chemicals not listed on the following pages have probably not been tested with our pipe materials by the date of this publication. Contact us for new information.

Temperature

The recommended maximum temperature given is not always the absolute maximum acceptable service temperature. It is the highest temperature at which a resin or product has been tested, used or evaluated. A product may be suitable for higher temperature operation, but additional information or testing would be required in order to establish such performance.

Coupling Gaskets

The standard FWC coupling gasket material is an elastomeric compound. It exhibits superior chemical and temperature resistance and it is suitable for a wide variety of environments including sanitary sewage, water, salt water, many acids, bases, salts and other chemicals. Some types of gaskets may be sensitive to some chemicals such as some hydrocarbons and many chlorinated and aromatic solvents.

Alternate gasket materials may be available for these situations. We would be pleased to assist you in the selection of an appropriate gasket material and in the establishment of specific limitations for temperature and concentration based on your individual application.

Abbreviations & Symbols

Std. (Standard) - Std. refers to our standard pipe constructed with thermosetting polyester resins.

VE (Vinyl Ester) - VE refers to HOBAS pipes constructed using thermosetting vinyl ester resins.

NR (Not Recommended) - Product of this construction is not recommended for continuous service in this environment. However, it may be suitable at a lower concentration or for intermittent exposure.

- (Dash) - This symbol indicates no data is currently available.

Chemical	Concentration % By Weight	Maximum Recommended Temperature °F. Std.	VE
A			
Acetaldehyde	All	NR	NR
Acetic Acid	0-25 25-50 50-75	— — —	150 150 —
Acetic Anhydride	All	NR	NR
Acetone	100	NR	NR
Acrylic Acid	25	—	100
Acrylonitrile	All	NR	NR
Alcohol, Butyl	All	NR	—
Alcohol, Ethyl	10 100	80 —	150 —
Alcohol, Isopropyl	10 100	80 NR	150 —
Alcohol, Methyl	10 100	NR NR	— NR
Alcohol, Methyl Isobutyl	10	NR	150
Alcohol, Secondary Butyl	10	NR	150
Allyl Chloride	All	NR	NR
Alum	All	100	180
Aluminum Chloride	All	100	180
Aluminum Fluoride	All	—	80
Aluminum Hydroxide	All	NR	150
Aluminum Nitrate	All	100	150
Aluminum Potassium Sulfate	All	90	180
Ammonia, Aqueous	0-20	NR	140
Ammonia, Gas		NR	100
Ammonia, Liquid		NR	NR
Ammonium Bicarbonate	0-50	NR	150
Ammonium Bisulfite	All	—	150
Ammonium Carbonate	All	NR	150

Chemical	Concentration % By Weight	Maximum Recommended Temperature °F.	
		Std.	VE
Ammonium Chloride	All	90	180
Ammonium Citrate	All	—	150
Ammonium Fluoride	All	—	150
Ammonium Hydroxide	5 10 20 29	NR NR NR NR	150 150 150 100
Ammonium Nitrate	All	90	180
Ammonium Persulfate	All	NR	180
Ammonium Phosphate	65	90	180
Ammonium Sulfate	All	90	180
Amyl Acetate	100	NR	NR
Aniline	All	NR	NR
Aniline Hydrochloride	All	—	150
Aniline Sulfate	All	NR	180
Arsenious Acid	All	—	—

B

Barium Acetate	All	NR	180
Barium Carbonate	All	NR	180
Barium Chloride	All	100	180
Barium Hydroxide	0-10	NR	150
Barium Sulfate	All	90	180
Barium Sulfide	All	NR	180
Beer		80	120
Benzene	100	NR	NR
5% Benzene in Kerosene		—	—
Benzene Sulfonic Acid	All	NR	180
Benzoic Acid	All	—	180
Benzyl Alcohol	100	NR	NR
Benzyl Chloride	100	NR	NR
Black Liquor Recovery, (furnace gasses)		NR	—
Bromine, Liquid		NR	NR
Bromine, Water	5	NR	—
Butyl Acetate	100	NR	NR
Butyric Acid	0-50 100	— NR	— —

C

Cadmium Chloride	All	—	180
Calcium Bisulfite	All	—	180
Calcium Carbonate	All	NR	180
Calcium Chlorate	All	—	180
Calcium Chloride	All	100	180
Calcium Hydroxide	All	NR	180
Calcium Hypochlorite	All	NR	160
Calcium Nitrate	All	100	180
Calcium Sulfate	All	90	180
Calcium Sulfite	All	—	180

Chemical	Concentration % By Weight	Maximum Recommended Temperature °F.	
		Std.	VE
Cane Sugar Liquor	All	—	180
Caprylic Acid	100	—	180
Carbon Dioxide	100	—	180
Carbon Disulfide		NR	NR
Carbon Monoxide (gas)		100	180
Carbon Tetrachloride	100	NR	—
Carbon Acid		—	—
Carbowax	—	—	—
Castor Oil		—	180
Carboxy Methyl Cellulose	10	—	150
Chlorinated Brine Liquors (caustic chlorine cell)		—	—
Chlorinated Wax	All	—	180
Chlorine Dioxide/Air	15	NR	—
Chlorine Dioxide, Wet Gas	Satd.	NR	180
Chlorine, Dry Gas	100	NR	180
Chlorine, Wet Gas	100	NR	180
Chlorine, Liquid		NR	NR
Chlorine Water	All	NR	—
Chloracetic Acid	25 50 Con.	NR NR NR	— — NR
Chlorobenzene	100	NR	NR
Chloroform	100	NR	NR
Chlorosulfonic Acid	100	NR	NR
Chromic Acid	20 30	NR NR	— NR
Chromium Sulfate	All	—	—
Citric Acid	All	100	180
Coconut Oil		—	180
Copper Chloride	All	100	180
Copper Cyanide	All	NR	180
Copper Fluoride	All	NR	180
Copper Nitrate	All	100	180
Copper Sulfate	All	100	180
Corn Oil		—	180
Corn Starch	Slurry	—	180
Corn Sugar	All	—	180
Cottonseed Oil		—	180
Cresylic Acid	100	NR	NR
Crude Oil, Sour	100	80	180
Crude Oil, Sweet	100	80	180
Cyclohexane	100	NR	—
Cyclohexanone	100	NR	—

Chemical	Concentration % By Weight	Maximum Recommended Temperature °F.	
		Std.	VE
D			
Detergents, Sulfonated	All	—	—
Dialfyl Phthalate	All	—	—
Di-Ammonium Phosphate	65	—	180
Dibromophenol	100	NR	NR
Dibutyl Ether	100	—	—
Dichloro Benzene	100	NR	NR
Dichloroethylene	100	NR	NR
Dichloromonomethane	100	NR	NR
Dichloropropane	100	NR	NR
Dichloropropene	100	NR	NR
Diesel Fuel	100	90	180
Diethanol Amine	100	—	—
Diethyl Amine	100	NR	NR
Diethyl Benzene	100	NR	
Diethyl Carbonate	100	NR	NR
Diethylene Glycol	100	—	—
Diethylhexyl Phosphoric Acid (in Kerosene)	20	—	120
Diethyl Sulfate	100	NR	NR
Diisopropanol Amine	100	—	—
Dimethyl Formamide	100	NR	NR
Dimethyl Morpholine	100	NR	NR
Dimethyl Phthalate	100	NR	—
Dioctyl Phthalate	100	NR	—
Dipropylene Glycol	100	—	—
E			
Electrosol	5	—	150
Epichlorohydrin	100	NR	NR
Epoxidized Soybean Oil	100	—	150
Ethyl Acetate	100	NR	NR
Ethyl Acrylate	100	NR	NR
Ethyl Benzene	100	NR	NR
Ethyl Bromide	100	NR	NR
Ethyl Chloride	100	NR	NR
Ethyl Ether	100	NR	NR
Ethylene Glycol	All	90	180
Ethyl Sulfate	100	—	—
F			
Fatty Acids	All	—	180
Ferric Chloride	All	100	180
Ferric Nitrate	All	100	180
Ferric Sulfate	All	100	180
Ferrous Chloride	All	100	180
Ferrous Nitrate	All	100	180

Chemical	Concentration % By Weight	Maximum Recommended Temperature °F.	
		Std.	VE
Ferrous Sulfate	All	100	180
Flue Gas		—	—
Fluoboric Acid	All	80	180
Fluosilisic Acid	10 20	80 —	180 160
Formaldehyde	All	—	—
Formic Acid	10 All	70 NR	180 100
Freon II		—	—
Fuel Oil	100	90	180
Furfural	5 10 100	— — NR	— — NR
G			
Gas, Natural		—	180
Gluconic Acid	50	—	180
Glucose	All	100	180
Glycerine	All	90	180
Gold Plating Solution: 63% Potassium Ferrocyanide .2% Potassium Gold Cyanide .8% Sodium Cyanide		—	180
H			
Heptane		—	150
Hexane		—	150
Hexylene Glycol		—	150
Hydraulic Fluid		—	180
Hydrazine		NR	NR
Hydrochloric Acid	0-20 20-37	NR NR	180 160
Hydrochloric Acid saturated with Chlorine gas	30	NR	—
Hydrocyanic Acid	All	—	180
Hydrofluoric Acid	10 20	NR NR	150 100
Hydrofluosilicic Acid	10	—	180
Hydrogen Bromide Wet Gas	100	—	180
Hydrogen Chloride Dry Gas	100	—	180
Hydrogen Chloride Wet Gas	100	—	180
Hydrogen Peroxide	0-30	NR	150
Hydrogen Sulfide, Dry	All	100	180
Hydrogen Sulfide, Aqueous	All	100	180
Hydrogen Fluoride, Vapor		—	180

Chemical	Concentration % By Weight	Maximum Recommended Temperature °F. Std.	VE
Hydrosulfite Bleach		—	180
Hypochlorous Acid	10 20	— NR	180 150
I			
Isopropyl Amine	All	—	100
Isopropyl Palmitate	100	—	180
K			
Kerosene		—	180
L			
Lactic Acid	All	—	180
Lasso* (50% Chlorobenzene)		NR	NR
Latex	All	—	—
Laurel Chloride	100	—	180
Lauric Acid	All	—	180
Lead Acetate	All	—	180
Lead Nitrate	All	—	180
Levulinic Acid	All	—	180
Linseed Oil		—	180
Lithium Bromide	All	—	180
Lithium Sulfate	All	—	180
M			
Magnesium Bisulfite	All	—	180
Magnesium Carbonate	All	—	180
Magnesium Chloride	All	100	180
Magnesium Hydroxide	All	NR	180
Magnesium Sulfate	All	100	180
Maleic Acid	All	—	180
Mercuric Chloride	All	100	180
Mercurous Chloride	All	80	180
Methylene Chloride	100	NR	NR
Methyl Ethyl Ketone	100	NR	NR
Methyl Isobutyl Carbitol	100	NR	NR
Methyl Isobutyl Ketone	100	NR	NR
Methyl Styrene	100	NR	NR
Mineral Oils		80	180
Monochloro Acetic Acid	100	NR	NR
Monoethynolamine	100	NR	NR
Motor Oil	—	—	180
Myristic Acid	100	—	180
N			
Naphtha	100	—	180
Naphthalene	100	—	180
Nickel Chloride	All	100	180

Chemical	Concentration % By Weight	Maximum Recommended Temperature °F. Std.	VE
Nickel Nitrate	All	100	180
Nickel Chloride	All	100	180
Nickel Nitrate	All	100	180
Nickel Plating 8% Lead .8% Fluoboric Acid .4% Boric Acid		—	180
Nickel Plating 11% Nickel Sulfate 2% Nickel Chloride 1% Boric Acid		—	180
Nickel Plating 44% Nickel Sulfate 4% Ammonium Chloride 4% Boric Acid		—	180
Nickel Sulfate	All	100	180
Nitric Acid	5 20 52	NR NR NR	150 120 NR
Nitric Acid Fumes	—	—	160
Nitrobenzene	100	NR	NR
O			
Oakite Rust Stripper		—	180
Octanoic Acid	100	—	180
Oil, Sour Crude	100	80	180
Oil, Sweet Crude	100	80	180
Oleic Acid	All	NR	180
Oleum (Fuming Sulfuric)		NR	NR
Olive Oil	100	—	180
Oxalic Acid	All	—	180
P			
Perchloretylene	100	NR	100
Perchloric Acid	10 30	NR NR	150 100
Peroxide Bleach 2% Sodium Peroxide 96% .025% Epsom Salts, 5% Sodium Silicate, 42° BE 1.4% Sulfuric Acid, 66°BE		NR	180
Phenol	100	NR	NR
Phenol Sulfonic Acid	100	NR	NR
Phosphoric Acid	All	100	180
Phosphoric Acid Fumes		100	180
Phosphorous Pentoxide	0-54	—	180
Phosphorous Trichloride	100	NR	NR
Phthalic Acid	All	—	180

Chemical	Concentration % By Weight	Maximum Recommended Temperature °F. Std.	VE
Pickling Acids Sulfuric and Hydrochloric		NR	180
Picric Acid/ Alcoholic	10	NR	180
Polyvinyl Acetate Latex	All	—	180
Polyvinyl Alcohol	100	NR	120
Polyvinyl Chloride Latex with 35 parts DOP		—	120
Potassium Alum Sulfate	All	90	180
Potassium Bicarbonate	0-50	NR	150
Potassium Bromide	All	90	180
Potassium Carbonate	All	NR	150
Potassium Chloride	All	100	180
Potassium Dichromate	All	—	180
Potassium Ferricyanide	All	—	180
Potassium Ferrocyanide	All	—	180
Potassium Hydroxide	All	NR	150
Potassium Nitrate	All	100	180
Potassium Permanganate	All	NR	180
Potassium Persulfate	All	—	180
Potassium Sulfate	All	100	180
Propionic Acid	20	—	180
	50	—	160
	100	—	NR
Propylene Glycol	All	—	180
Pyridine	100	—	NR

S

Chemical	Concentration % By Weight	Std.	VE
Salicylic Acid	All	—	160
Sebacic Acid	All	—	180
Selenius Acid	All	—	180
Silver Nitrate	All	—	180
Soaps	All	90	180
Sodium Acetate	All	—	180
Sodium Aluminate	All	NR	120
Sodium Alkyl Aryl Sulfonates	All	—	150
Sodium Benzoate	100	—	180
Sodium Bicarbonate	All	NR	180
Sodium Bifluoride	All	—	120
Sodium Bisulfate	All	80	180
Sodium Bisulfite	All	70	180
Sodium Bromate	10	—	—
Sodium Bromide	All	90	180
Sodium Carbonate	0-25	NR	—
	35	NR	—
Sodium Chlorate	All	NR	180
Sodium Chloride	All	100	180
Sodium Chlorite	All	NR	150
Sodium Chromate	50	—	180

Chemical	Concentration % By Weight	Maximum Recommended Temperature °F. Std.	VE
Sodium Cyanide	All	—	180
Sodium Dichromate	All	—	180
Sodium Di-Phosphate	All	—	180
Sodium Ferricyanide	All	—	180
Sodium Ferrocyanide	All	—	180
Sodium Fluoride	All	—	180
Sodium Fluoro Silicate	All	—	150
Sodium Hexametaphosphates	All	—	120
Sodium Hydroxide	5	NR	150
	10	NR	150
	25	NR	120
	50	NR	160
Sodium Hydrosulfide	All	—	180
Sodium Hypochlorite	0-5	70	180
	5-15	NR	150
Sodium Lauryl Sulfate	All	—	180
Sodium Mono-Phosphate	All	100	180
Sodium Nitrate	All	100	180
Sodium Nitrite	All	100	180
Sodium Persulate	20	—	130
Sodium Silicate	All	NR	180
Sodium Sulfate	All	100	180
Sodium Sulfide	All	NR	180
Sodium Sulfite	All	NR	180
Sodium Tetro Borate	All	—	180
Sodium Thiocyanate	57	—	180
Sodium Thiosulfate	All	—	180
Sodium Tripolyphosphate	All	—	180
Sodium Xylene Sulfonate	All	NR	180
Sorbitol Solutions	All	—	150
Sour Crude Oil	100	80	180
Soya Oil	All	—	180
Stannic Chloride	All	—	180
Stannous Chloride	All	—	180
Stearic Acid	All	100	180
Styrene	100	NR	NR
Sugar, Beet and Cane Liquor	All	—	180
Sugar, Sucrose	All	—	180
Sulfamic Acid	0-25	70	180
Sulfanilic Acid	All	—	180
Sulfated Detergents	All	100	180
Sulfur Dioxide, Dry or Wet		NR	—
Sulfur Trioxide/Air	All	NR	180

Chemical	Concentration % By Weight	Maximum Recommended Temperature °F. Std.	VE
Sulfuric Acid	0-5	100	180
	5-70	—	160
	75	NR	—
	Over 75	NR	NR
Sulfurous Acid	All	NR	—
Superphosphoric Acid 105% H_3PO_3 76% P20s		NR	180

T

Chemical	Concentration % By Weight	Std.	VE
Tall Oil	All	—	—
Tannic Acid	All	—	—
Tartaric Acid	All	NR	180
Tetrachloroethylene	100	NR	NR
Thionyl Chloride	100	NR	NR
Toluene	100	NR	NR
Toluene Solfonic Acid	All	—	180
Transformer Oils:			
Mineral Oil Types		—	180
Chloro-Phenyl Types		NR	NR
Trichlor Acetic Acid	50	NR	180
Trichloroethane	100	NR	—
Trichloroethylene	100	NR	NR
Trichlorophenol	100	NR	NR
Tridecylbenzene Sulfonate	All	—	180
Trimethylene Chlorobromide	100	NR	NR

Chemical	Concentration % By Weight	Maximum Recommended Temperature °F. Std.	VE
Trisodium Phosphate	All	NR	180
Turpentine	100	NR	—
Tween Surfactant	All	—	150

V

Chemical	Concentration % By Weight	Std.	VE
Vegetable Oils		100	180
Vinegar		100	180
Vinyl Acetate	100	NR	NR
Vinyl Toluene	100	NR	—

W

Chemical	Concentration % By Weight	Std.	VE
Water			
Deionized		NR	180
Demineralized		100	180
Distilled		100	180
Fresh		100	180
Salt		100	180
Sea		100	180

X

Chemical	Concentration % By Weight	Std.	VE
Xylene	100	NR	NR

Z

Chemical	Concentration % By Weight	Std.	VE
Zinc Chlorate	All	—	180
Zinc Chloride	All	100	180
Zinc Nitrate	All	100	180
Zinc Sulfate	All	100	180

Appendix G

Deflected Pipe Minimum Inside Diameters

Class SN 18

Nominal Pipe Size (in.)	Pipe O.D. (in.)	Class PN/SN					
		25 /18		50/18		100/18	
		Min. Dia (in.)		Min. Dia (in.)		Min. Dia (in.)	
		@ 3% defl.	@ 5% defl.	@ 3% defl.	@ 5% defl.	@ 3% defl.	@ 5% defl.
18	19.5	18.18	17.81	18.20	17.83	18.20	17.83
20	21.6	20.18	19.76	20.18	19.76	20.18	19.76
24	25.8	24.13	23.63	24.15	23.65	24.15	23.65
27	28.0	26.20	25.66	26.22	25.68	26.22	25.68
28	30.0	28.10	27.52	28.10	27.52	28.12	27.54
30	32.0	29.98	29.36	30.00	29.38	30.00	29.38
33	34.0	31.88	31.22	31.88	31.22	31.90	31.24
36	38.3	35.92	35.18	35.94	35.20	35.97	35.22
40	42.9	40.26	39.43	40.28	39.45	40.30	39.47
41	44.5	41.77	40.91	41.79	40.93	41.81	40.95
44	45.9	43.09	42.20	43.11	42.22	43.13	42.24
45	47.7	44.80	43.87	44.82	43.89	44.84	43.91
48	50.8	47.72	46.74	47.74	46.76	47.76	46.78
51	53.9	50.64	49.60	50.67	49.62	50.69	49.64
54	57.1	53.67	52.56	53.69	52.58	53.71	52.60
57	60.0	56.40	55.23	56.42	55.25	56.44	55.27
60	62.9	59.13	57.91	59.17	57.95	59.19	57.97
63	66.0	62.05	60.77	62.09	60.81	62.11	60.83
66	69.2	65.07	63.73	65.12	63.77	65.14	63.79
69	72.5	68.19	66.79	68.21	66.81	68.26	66.85
72	75.4	70.92	69.46	70.97	69.50	70.99	69.52
78	81.6	76.77	75.19	76.81	75.23	76.84	75.25
84	87.0	81.87	80.18	81.91	80.22	81.95	80.26
85	88.6	83.38	81.66	83.42	81.70	83.46	81.74
90	94.3	88.76	86.93	88.80	86.97	88.85	87.01
96	99.5	93.66	91.73	93.70	91.77	93.75	91.81
104	108.0	101.68	99.59	101.72	99.63		
110	114.0	107.34	105.12	107.36	105.14		
120	126.0	118.65	116.20	118.67	116.22		

Class SN 36

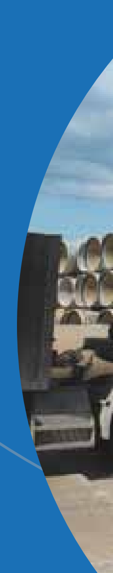
Nominal Pipe Size (in.)	Pipe O.D. (in.)	Class PN/SN									
		25 /36		50/36		100/36		150/36		200/36	
		Min. Dia (in.)		Min. Dia (in.)		Min. Dia (in.)		Min. Dia (in.)		Min. Dia (in.)	
		@ 3% defl.	@ 5% defl.	@ 3% defl.	@ 5% defl.	@ 3% defl.	@ 5% defl.	@ 3% defl.	@ 5% defl.	@ 3% defl.	@5% defl.
18	19.5	18.06	17.69	18.06	17.69	18.08	17.71	18.08	17.71	18.10	17.73
20	21.6	20.01	19.60	20.03	19.62	20.03	19.62	20.05	19.64	20.07	19.66
24	25.8	23.96	23.47	23.96	23.47	23.98	23.49	23.98	23.49	24.00	23.51
27	28.0	26.02	25.48	26.02	25.48	26.04	25.50	26.06	25.52	26.08	25.54
28	30.0	27.89	27.32	27.89	27.32	27.91	27.34	27.93	27.36	27.96	27.38
30	32.0	29.75	29.14	29.77	29.16	29.79	29.18	29.81	29.20	29.83	29.22
33	34.0	31.63	30.98	31.65	31.00	31.67	31.02	31.69	31.04	31.71	31.06
36	38.3	35.66	34.92	35.68	34.94	35.70	34.96	35.72	34.98	35.74	35.00
41	42.9	39.97	39.15	39.97	39.15	40.00	39.17	40.04	39.21	40.06	39.23
42	44.5	41.47	40.61	41.49	40.63	41.51	40.65	41.53	40.67	41.57	40.71
44	45.9	42.78	41.90	42.78	41.90	42.82	41.94	42.84	41.96	42.88	42.00
45	47.7	44.47	43.55	44.49	43.57	44.51	43.59	44.55	43.63	44.57	43.65
48	50.8	47.37	46.39	47.39	46.41	47.41	46.43	47.45	46.47	47.47	46.49
51	53.9	50.27	49.24	50.30	49.26	50.32	49.28	50.36	49.32	50.40	49.36
54	57.1	53.28	52.18	53.28	52.18	53.32	52.22	53.36	52.26	53.40	52.30
57	60.0	55.99	54.83	56.01	54.85	56.03	54.87	56.07	54.91		
60	62.9	58.70	57.49	58.72	57.51	58.76	57.55	58.80	57.59		
63	66.0	61.60	60.33	61.62	60.35	61.66	60.39	61.72	60.45		
66	69.2	64.60	63.27	64.62	63.29	64.66	63.33	64.70	63.37		
69	72.5	67.70	66.30	67.72	66.32	67.74	66.34	67.80	66.40		
72	75.4	70.41	68.96	70.43	68.98	70.47	69.02				
78	81.6	76.22	74.65	76.24	74.67	76.28	74.71				
84	87.0	81.27	79.60	81.29	79.62	81.33	79.66				
85	88.6	82.76	81.06	82.78	81.08	82.84	81.14				
90	94.3	88.11	86.29	88.13	86.31	88.19	86.37				
96	99.5	92.98	91.07	93.01	91.09	93.07	91.15				
104	108.0	100.94	98.86	100.96	98.88						
110	114.0	106.56	104.36	106.58	104.38						
120	126.0	117.79	115.36	117.83	115.40						

Class SN 46

Nominal Pipe Size (in.)	Pipe O.D. (in.)	Class PN/SN									
		25/46 Min. Dia (in.)		50/46 Min. Dia (in.)		100/46 Min. Dia (in.)		150/46 Min. Dia (in.)		200/46 Min. Dia (in.)	
		@ 3% defl.	@ 5% defl.	@ 3% defl.	@ 5% defl.	@ 3% defl.	@ 5% defl.	@ 3% defl.	@ 5% defl.	@ 3% defl.	@ 5% defl.
18	19.5	18.00	17.63	18.00	17.63	18.02	17.65	18.04	17.67	18.04	17.67
20	21.6	19.95	19.54	19.97	19.56	19.97	19.56	19.99	19.58	20.01	19.60
24	25.8	23.88	23.39	23.88	23.39	23.90	23.41	23.92	23.43	23.94	23.45
27	28.0	25.93	25.40	25.95	25.42	25.95	25.42	25.97	25.44	25.99	25.46
28	30.0	27.81	27.24	27.81	27.24	27.83	27.26	27.85	27.28	27.87	27.30
30	32.0	29.67	29.06	29.69	29.08	29.69	29.08	29.73	29.12	29.75	29.14
33	34.0	31.55	30.90	31.55	30.90	31.57	30.92	31.59	30.94	31.63	30.98
36	38.3	35.55	34.82	35.55	34.82	35.60	34.86	35.62	34.88	35.64	34.90
41	42.9	39.85	39.03	39.85	39.03	39.89	39.07	39.91	39.09	39.95	39.13
42	44.5	41.34	40.49	41.36	40.51	41.38	40.53	41.42	40.57	41.44	40.59
44	45.9	42.66	41.78	42.66	41.78	42.68	41.80	42.72	41.84	42.76	41.88
45	47.7	44.32	43.41	44.34	43.43	44.36	43.45	44.40	43.49	44.45	43.53
48	50.8	47.23	46.25	47.25	46.27	47.27	46.29	47.31	46.33	47.35	46.37
51	53.9	50.11	49.08	50.13	49.10	50.17	49.14	50.21	49.18	50.25	49.22
54	57.1	53.11	52.02	53.13	52.04	53.15	52.06	53.19	52.10	53.26	52.16
57	60.0	55.82	54.67	55.84	54.69	55.86	54.71	55.92	54.77		
60	62.9	58.53	57.32	58.53	57.32	58.57	57.37	58.63	57.43		
63	66.0	61.42	60.15	61.44	60.17	61.48	60.21	61.54	60.27		
66	69.2	64.40	63.07	64.42	63.09	64.46	63.13	64.52	63.19		
69	72.5	67.49	66.10	67.51	66.12	67.56	66.16	67.62	66.22		
72	75.4	70.18	68.74	70.22	68.78	70.27	68.82				
78	81.6	75.99	74.43	76.01	74.45	76.05	74.49				
84	87.0	81.02	79.35	81.05	79.37	81.11	79.43				
85	88.6	82.51	80.81	82.54	80.83	82.60	80.89				
90	94.3	87.84	86.03	87.88	86.07	87.92	86.11				
96	99.5	92.70	90.79	92.72	90.81	92.78	90.87				
104	108.0	100.63	98.56	100.67	98.60						
110	114.0	106.23	104.04	106.27	104.08						
120	126.0	117.44	115.01	117.48	115.05						

Class SN 72

Nominal Pipe Size (in.)	Pipe O.D. (in.)	Class PN/SN									
		25/72 & 50/72 Min. Dia (in.)		100/72 Min. Dia (in.)		150/72 Min. Dia (in.)		200/72 Min. Dia (in.)		250/72 Min. Dia (in.)	
		@ 3% defl.	@ 5% defl.	@ 3% defl.	@ 5% defl.	@ 3% defl.	@ 5% defl.	@ 3% defl.	@ 5% defl.	@ 3% defl.	@ 5% defl.
18	19.5	17.89	17.52	17.89	17.52	17.91	17.54	17.93	17.57	17.93	17.57
20	21.6	19.83	19.42	19.85	19.44	19.87	19.46	19.88	19.47	19.89	19.48
24	25.8	23.74	23.25	23.76	23.27	23.76	23.27	23.78	23.29	23.80	23.31
27	28.0	25.77	25.24	25.79	25.26	25.81	25.28	25.83	25.30	25.85	25.32
28	30.0	27.63	27.06	27.65	27.08	27.67	27.10	27.69	27.12	27.71	27.14
30	32.0	29.48	28.88	29.50	28.90	29.53	28.92	29.55	28.94	29.57	28.96
33	34.0	31.34	30.70	31.36	30.72	31.38	30.74	31.40	30.76		
36	38.3	35.33	34.60	35.37	34.64	35.39	34.66	35.41	34.68		
41	42.9	39.60	38.79	39.63	38.81	39.67	38.85	39.69	38.87		
42	44.5	41.10	40.25	41.12	40.27	41.14	40.29	41.18	40.33		
44	45.9	42.39	41.52	42.41	41.54	42.45	41.58	42.47	41.60		
45	47.7	44.06	43.15	44.10	43.19	44.12	43.21	44.16	43.25		
48	50.8	46.94	45.97	46.96	45.99	47.00	46.03	47.04	46.07		
51	53.9	49.80	48.77	49.84	48.82	49.88	48.86	49.90	48.88		
54	57.1	52.78	51.69	52.82	51.73	52.86	51.77	52.89	51.79		
57	60.0	55.47	54.33	55.51	54.37	55.55	54.41				
60	62.9	58.16	56.96	58.20	57.00	58.24	57.04				
63	66.0	61.05	59.79	61.09	59.83	61.13	59.87				
66	69.2	64.01	62.69	64.05	62.73	64.11	62.79				
69	72.5	67.06	65.68	67.12	65.74	67.17	65.78				
72	75.4	69.75	68.31	69.81	68.37						
78	81.6	75.52	73.96	75.56	74.00						
84	87.0	80.53	78.87	80.59	78.93						
85	88.6	82.00	80.31	82.06	80.37						
90	94.3	87.30	85.50	87.37	85.56						
96	99.5	92.12	90.22	92.18	90.28						
104	108.0	100.02	97.95								
110	114.0	105.57	103.39								
120	126.0	116.72	114.31								



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FLOWTITE

Flowtite GRP Pipe Systems

1 Introductory Information

1.1 Foreword

This document is part of the Flowtite documentation for the users of Flowtite products. It is to be used in connection with the Flowtite Product Guide and is intended to assist the installer in understanding the requirements and procedures for the successful handling and buried installation of FLOWTITE®, pipe. The appendices may serve as a helpful source of data for owner's engineers.

This document mainly addresses the usual circumstances that may be encountered in the field; unique situations requiring special considerations are not addressed and should be resolved in cooperation with the supplier.
Installations other than direct bury, such as trenchless, sub-aqueous or above-ground, are not discussed in this manual. Consult the supplier for suggested procedures and limitations in these cases.

Most importantly, this installation guide is not meant to replace common sense, good engineering requirements and judgement, applicapable laws, safety or environmental or other regulations or local ordinances, nor the specifications and instructions of the owner and/or the owner's engineer, who is/are the final authority on each job. Should any conflicting information in this brochure create doubts as to how to proceed properly please consult the supplier and the owner's engineer to obtain assistance.
The installation procedures outlined in this Installation Guide and the suggestions of the Field Technicians, when carefully followed, will help with the thorough execution of a proper, long-lasting installation. Consult the supplier on any questions or when variations from this installation guide are being considered.

! **Note:** These installation instructions are based on the structural design procedures of AWWA M 45.

Conversion from Customary Inch – Lb Units to Metric (SI)

This version of the Installation Guide for Flowtite Pipes is presented using customary inch – lb units. In the text rounded metric units are shown in parenthesis for the convenience of the reader. However, the many tables are presented in inch-lb units only. To show both unit systems would lead to very lengthy and complex tables. For the user who may wish to convert the inch-lb units to metric (SI), the following conversion tables will be helpful.
Throughout the Guide the designation PN, DN and SN are used. These stand for Nominal Pressure, Nominal Diameter and Nominal Stiffness respectively.

A special note is necessary for pipe stiffness (SN). The testing and reporting of pipe stiffness is on a somewhat different basis in the ASTM and AWWA standards and the ISO and CEN standards. Briefly, the ASTM and AWWA standards measure and report stiffness at 5% deflection and on the basis of EI/r^3. The ISO and CEN standards measure stiffness at 3% deflection and report as referenced to zero deflection on the basis of EI/D^3. This can lead to some problems in direct conversion of stiffness from one system to the other. The following listing gives the correct conversion.

PIPE STIFFNESS (psi) (Initial Stiffness)	PIPE STIFFNESS (N/m²) (Initial Stiffness)
18	2500
36	5000
46	6400
72	10000

The following table gives the conversion factors that can be used as necessary to convert inch-lb units to metric (SI).

Inch – lb units	Multiply by to convert	Metric (SI) units
Inch (in)	25.4	Millimetre (mm)
Pound (lb)	2.2	Kilogram (kg)
Foot (ft)	0.305	Metre
Pressure (psi)	6894	N/m^2
Pressure (psi)	0.0690	bar
Ft – lb (torque)	1.356	N - metre
Pound force	4.45	N
Pound per ft^3 (pcf)	0.157	kN/M^3

1.2 Soil-pipe system

The versatility of soil behaviour, along with the strength and flexibility of Flowtite pipes offers a unique potential for soil-structure interaction that allows optimum system performance. The glass fibre reinforcement is placed where needed in the pipe for flexibility and strength, while trench geometry, along with selection, placement and compaction of backfill ensures the integrity of the system.

Broadly there are two sets of loads that the pipe is subject to:

1. external loads resulting from overburden, surface loads and traffic, creating bending stresses in the pipe wall

2. internal pressure creating hoop stresses in the pipe and unbalanced thrust creating axial stresses.

The flexibility of FLOWTITE pipe combined with the natural structural behaviour of soils provide an ideal combination for transferring vertical load. Unlike stiff pipes, which would break under excessive vertical load, the pipe's flexibility combined with its high strength, allow it to bend and redistribute the load to the surrounding soil. The deflection of the pipe serves as an indicator of the stresses generated in the pipe and the quality of the installation.

Hoop stresses are resisted by placing continuous glass fibre reinforcement circumferentially in the pipe wall. The amount of reinforcement is dictated by the pressure level and determines the pressure class of the pipe.

Unbalanced thrust is usually most economically resisted through thrust blocks that transfer the thrust by direct bearing to the native soil. The standard FLOWTITE pipe is therefore not required to transfer axial thrust and the amount of reinforcement in the pipe wall in the axial direction is limited to secondary effects. Consequently the joints are not required to transfer axial load, but allow for movement of the pipe within the joint due to temperature and Poisson's effect.

In some cases thrust-blocks may be undesirable due to their weight, lack of space, or other reasons. In such cases enough reinforcement is placed in the pipe wall in the axial direction to carry the direct thrust. Restraint joints for such systems are designed to carry the full axial thrust, and the thrust is transferred to the surrounding soil through direct bearing and friction.

1.3 Field Technician

The supplier can, at the request of the purchaser and within the terms of the agreement between the purchaser and the supplier, provide a Field Technician.

The Field Technician can advise the purchaser and/or the Installer to help him achieve a satisfactory pipe installation. It is recommended that "on the job" field service should be engaged in the initial stage of installation and may continue periodically throughout the project. The service may range from continuous (essentially full time) to intermittent depending on agreement between purchaser and supplier.

1.4 Safety

Glass-reinforced polyester (GRP) pipe, like virtually all pipe made with petrochemicals, can burn and is therefore not recommended for use in applications which are exposed to intense heat or flames. During installation, care must be taken to avoid exposure of the pipe to welder's sparks, cutting-torch flames or other heat/flame/electrical sources which could ignite the pipe material. This precaution is particularly important when working with volatile chemicals in making layup joints, repairing or modifying the pipe in the field.

Operations in trenches are carried out in potentially hazardous conditions. Where appropriate shore, sheet, brace, slope or otherwise support the trench walls to protect any person in the trench. Take precautions to prevent objects falling into the trench, or its collapse caused by the position or movements of adjacent machinery or equipment, while the trench is occupied. Excavated material should be deposited in a safe distance from the edge of the trench, and the proximity and height of the soil bank should not be allowed to endanger the stability of the excavation.

2 Shipping, Handling and Storage

2.1 Inspecting Pipe

All pipes should be inspected upon receipt at the job site to insure that no damage has occurred in transit.
Depending on length of storage, amount of job site handling and other factors that may influence the pipes condition, it is recommended that the pipe be re-inspected just prior to installation. Inspect the shipment upon delivery, as follows:

1. Make an overall inspection of the load. If the load is intact, ordinary inspection while unloading will normally be sufficient to make sure the pipe has arrived without damage.
2. If the load has shifted or indicates rough treatment, carefully inspect each pipe section for damage. Generally, an exterior inspection will be sufficient to detect any damage. When pipe size permits, an interior inspection of the pipe surface at the location of an exterior scrape may be helpful to determine if the pipe is damaged.
3. Check the quantity of each item against the bill of lading
4. Note on the bill of lading any transit damage or loss and have the carrier representative sign your copy of the receipt. Claims against the carrier should be in accordance with their instructions.
5. If any imperfections or damage is found, segregate the affected pipes and contact the supplier.

Do not use pipe that appears damaged or defective.

2.2 Repairing Pipe

Normally, pipes with minor damage can be repaired quickly and easily at the job site by a qualified individual. If in doubt about the condition of a pipe, do not use it.

The Field Technician can help you determine whether repair is required and whether it is possible and practical. Repair designs can vary greatly due to pipe thickness, wall composition, application, and the type and extent of the damage. Therefore do not attempt to repair a damaged pipe without consulting the supplier first. Repairs must be made by a trained repair technician. Improperly repaired pipes may not perform as intended.

2.3 Unloading and Handling Pipe

Unloading the pipe is the responsibility of the customer. Be sure to maintain control of the pipe during unloading. Guide ropes attached to pipes or packages will enable easy manual control when lifting and handling. Spreader bars may be used when multiple support locations are necessary. Do not drop, impact, or bump the pipe, particularly at pipe ends.

- **Single Pipes**
  When handling single pipes, use pliable straps, slings or rope to lift. Do not use steel cables or chains to lift or transport the pipe. Pipe sections can be lifted with only one support point ***(Figure 2–1)*** although two support points placed as in ***Figure 2–2*** is the preferred method for safety reasons as it makes the pipe easier to control. Do not lift pipes using hooks at pipe ends or by passing a rope, chain or cable through the section end to end. See Appendix H for approximate weights of standard pipes and couplings.

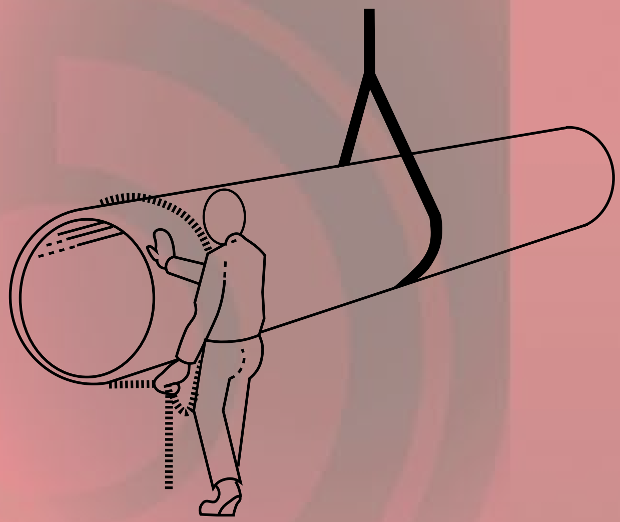

Figure 2–1 Lifting pipe at one support point

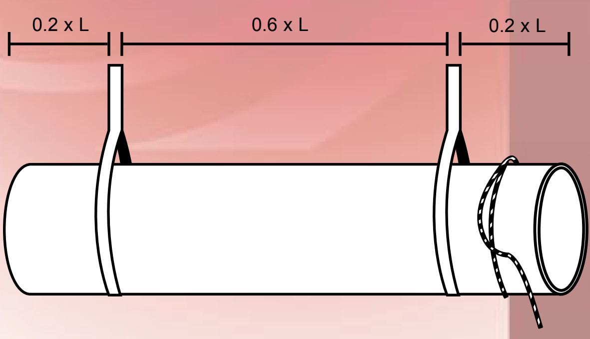

Figure 2–2 Lifting pipe at two support points

Unitized Loads

Unitized loads may be handled using a pair of slings as shown in ***Figure 2–3***. Do not lift a non-unitized stack of pipes as a single bundle.
Non-unitized pipes must be unloaded and handled separately (one at a time).

If at any time during handling or installation of the pipe, any damage such as a gouge, crack or facture occurs, the pipe should be repaired before the section is installed.

Contact the supplier for inspection of damage and for recommendation of repair method or disposal.
See section 2.2 ➔.

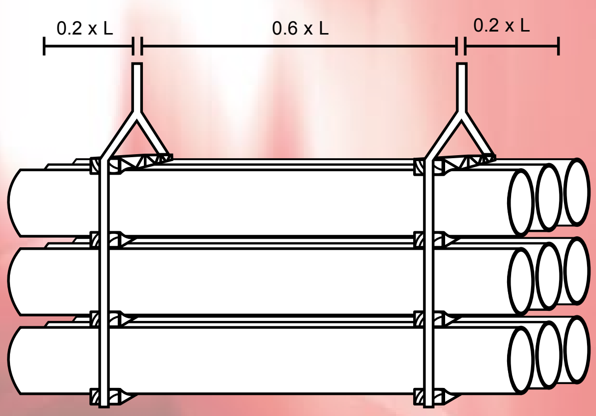

Figure 2–3 Lifting unitized package

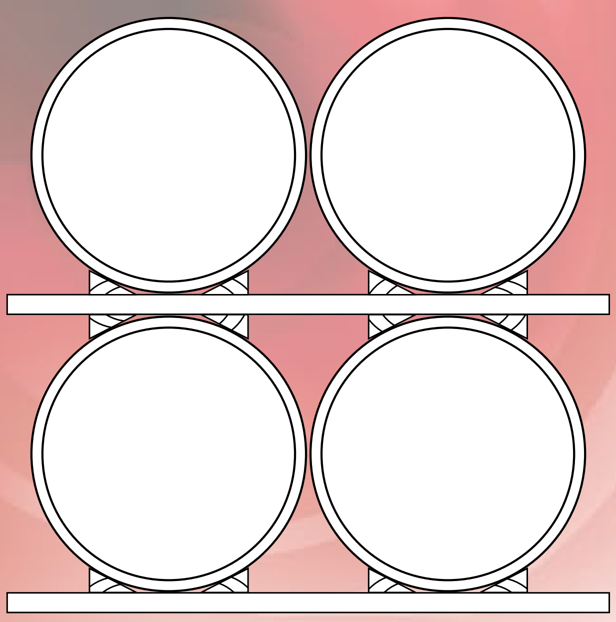

Figure 2–4 Storing pipe

2.4 Site Pipe Storage

It is generally advantageous to store pipe on flat timber supports to facilitate placement and removal of lifting slings around the pipe.

When storing pipe directly on the ground, be sure that the area is relatively flat and free of rocks and other potentially damaging debris. Placing the pipe on mounds of backfill material has been found to be an effective way of site storing the pipe. All pipes should be chocked to prevent rolling in high winds.

If it is necessary to stack pipes, it is best to stack on flat timber supports (minimum width of 3 in [75 mm]) at the quarter points with chocks ***(see Figure 2–4)***. If it is available, use the original shipping dunnage.

Insure the stack will be stable for conditions such as high winds, uneven storage surface or other horizontal loads.
If strong winds are anticipated consider using ropes or slings to tie pipes down.
Maximum stack height is approximately 10 ft (3 m).

Bulges, flat areas or other abrupt changes of pipe curvature are not permitted. Storing of pipes outside of these limitations may result in damage to the pipes.

2.5 Storing Gaskets and Lubricant

Rubber ring gaskets, when shipped separately from the couplings, should be stored in the shade in their original packing and should not be exposed to sunlight except during the pipe joining. Also, the gaskets must be protected from exposure to greases and oils which are petroleum derivatives, and from solvents and other harmful substances.

Gasket lubricant should be carefully stored to prevent damage. Partially used buckets should be resealed to prevent contamination of the lubricant. If temperatures during installation are below 40° F (5° C), gaskets and lubricant should be sheltered until used.

2.6 Transporting Pipe

Support all pipe sections on flat timbers, spaced at maximum 12 ft (4 m), with a maximum overhang of 6 ft (2 m). Chock the pipes to maintain stability and separation. Avoid abrasion.

Maximum stack height is approximately 8 ft (2.5 m). Strap pipe to the vehicle over the support points using pliable straps or rope ***(Figure 2–5)***. Never use steel cables or chains without adequate padding to protect the pipe from abrasion. Bulges, flat areas or other abrupt changes of curvature are not permitted. Transport of pipes outside of these limitations may result in damage to the pipes.

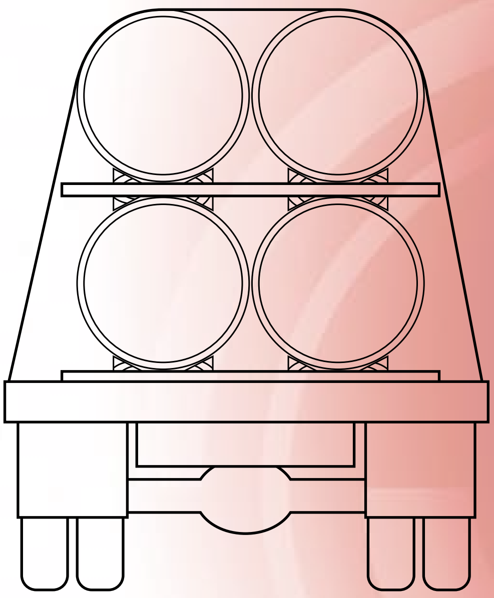

Figure 2–5 Transporting pipe

2.7 Handling Nested Pipes

Pipes may be nested (smaller diameter pipes inside of larger sizes). These pipes generally have special packaging and may require special procedures for unloading, handling, storing and transporting. Special measures, if required, will be carried out by the pipe supplier prior to shipment. However, the following general procedures should always be followed:

1. Always lift the nested bundle using at least two pliable straps ***(Figure 2–6)***. Limitations, if any, for spacing between straps and lifting locations will be specified for each project. Insure that the lifting slings have sufficient capacity for the bundle weight. This may be calculated from the approximate pipe weights given in Appendix H.

2. Nested pipes are usually best stored in the transport packaging. Stacking of these packages is not advised unless otherwise specified.

3. Nested pipe bundles can only be safely transported in the original transport packaging. Special requirements, if any, for support, configuration and/or strapping to the vehicle will be specified for each project.

4. Package removal and de-nesting of the inside pipe(s) is best accomplished at a de-nesting station. Inside pipes, starting with the smallest size may be removed by lifting slightly with an inserted padded boom to suspend the section and carefully move it out of the bundle without damaging the other pipes ***(Figure 2–7)***.
When weight, length and/or equipment limitations preclude the use of this method, procedures for sliding the inside pipe(s) out of the bundle will be ecommended for each project.

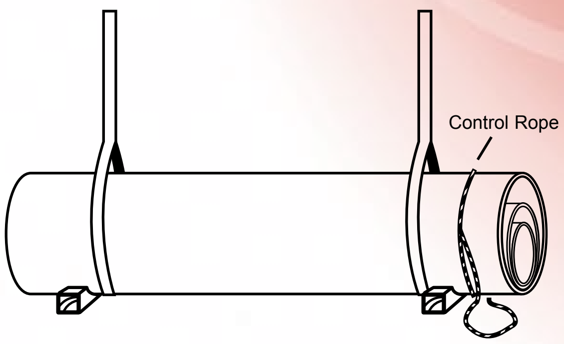

Figure 2–6 Double support point for nested pipes

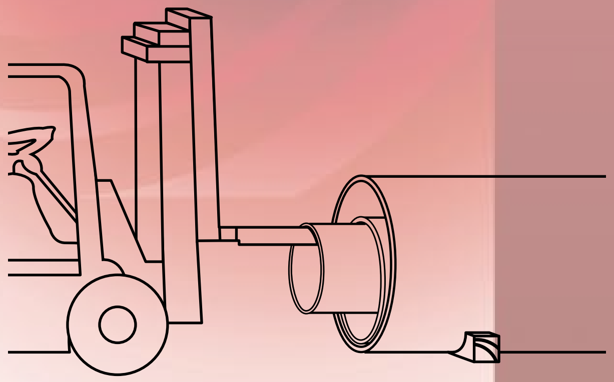

Figure 2–7 De-nesting with padded boom on forklift truck

3 **Pipe Installation Procedure**

The type of installation procedure appropriate for FLOWTITE pipe varies with pipe stiffness, cover depth, trench width, native soil characteristics, surcharge loads and backfill materials.

The native material must adequately confine the pipe zone backfill to achieve proper pipe support. The following installation procedures are intended to assist the installer in achieving a proper pipe installation

3.1 Standard Trench

Figure 3–1 shows typical trench dimensions. Dimension "A" must always be wide enough to allow for adequate space to ensure proper placement and compaction of backfill in the haunch region. Dimension "A" must also be wide enough to safely operate compaction equipment without damaging the pipe. Typically dimension "A" is a minimum of 0.4 DN.

For larger diameter pipes a smaller value for "A" may be adequate depending on the native soil, backfill material and compaction technique. As an example for native soil groups 1, 2 and 3 and backfill materials SC1 and SC2 which require limited compaction effort, a narrower trench could be considered.

! **Note:** Where rock, hard pan, soft, loose, unstable or highly expansive soils are encountered in the trench bottom, it may be necessary to increase the depth of the bedding layer to achieve uniform longitudinal support.

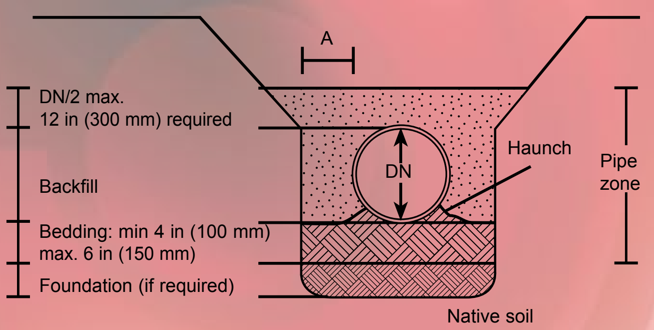

Figure 3–1 Pipe backfill nomenclature

3.2 Pipe Bedding

The bedding should be placed over a firm, stable trench bottom so as to provide proper support. The finished bed must provide a firm, stable and uniform support for the pipe barrel and any protruding feature of its joint.

Provide 4 - 6 in (100 - 150 mm) of bedding below the barrel and 3 in (75 mm) below the coupling. For soft or unstable trench bottom, an additional foundation may be needed to achieve firm support for the bedding, see section 7.3 ➜.

The bedding material may need to be imported to provide proper gradation and pipe support. The recommended materials for bedding are SC1 or SC2. To determine if the native material is acceptable as a bedding material, it should meet all of the requirements of the pipe zone backfill. This determination must be made constantly during the pipe installation process because native soil conditions may vary and change suddenly along the length of a pipeline.

The bed must be over-excavated at each joint location to ensure that the pipe will have a continuous support and does not rest on the couplings. The coupling area must be properly bedded and backfilled after the joint assembly is completed. See ***Figure 3–2*** and ***Figure 3–3*** for proper and improper bedding support.

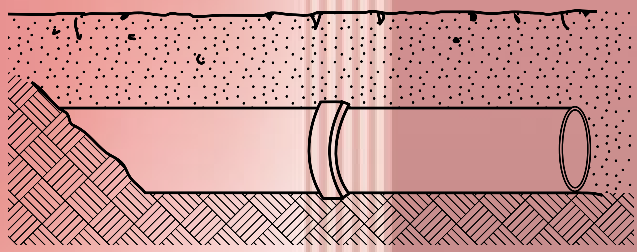

Figure 3–2 Proper bedding support

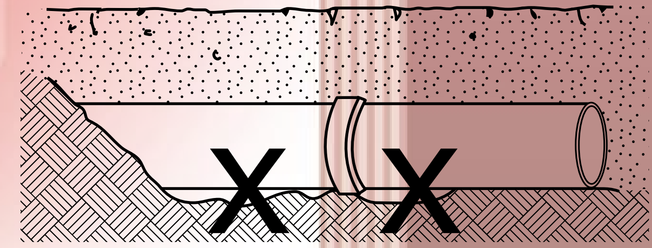

Figure 3–3 Improper bedding support

3.3 Backfill Materials

Table 3–1 groups backfill materials into categories. SC1 and SC2 backfill soils are the easiest to use and require the least compaction effort to achieve a given level of relative compaction.
Regardless of the backfill grouping and whether the backfill soil is imported or not the following general restrictions apply:

1. For the maximum particle size and stone size the limits given in ***Table 3–2*** must be respected.
2. No soil clumps greater than two times the maximum particle size.
3. No frozen material.
4. No organic material.
5. No debris (tires, bottles, metals, etc.)

Backfill Soil Group	Description of Backfill Soils
SC1	Crushed rock with < 15% sand, maximum 25% passing the 3/8 in sieve and maximum 5% fines
SC2	Clean, coarse-grained soils with < 12% fines
SC3	Clean, coarse-grained soils with 12% or more fines Sandy or fine-grained soils with less than 70% fines
SC4	Fine grained soils with more than 70% fines
(See Appendix D for further clarification and Appendix G for definitions)	

Table 3–1 Backfill materials

Maximum particle size in the pipe zone (up to 12 in [300 mm] over the pipe crown):

DN	Max. Size (in)
Up to 18	0.5
> 20 to 24	0.75
> 24 to 36	1.00
> 36 to 48	1.25
48 & greater	1.50

Table 3–2 Maximum Particle Size

The backfill above the pipe zone may be made with excavated material with a maximum particle size of up to 12 in (300 mm) providing there is at least 12 in (300 mm) cover over the pipe. Stones larger than 8 in (200 mm) should not be dropped on the 12 in (300 mm) layer covering the pipe crown from a height greater than 6 ft (2 m).

3.4 Installation types

Two standard backfilling configurations are recommended ***(Figure 3–4 and Figure 3–5)***. The selection of type depends on the native soil characteristics, the backfill materials, required depth of burial, surcharge conditions, pipe stiffness and the pipe operating conditions. The Type 2, "split" configuration is generally more utilized for applications of lower pressure (PN ≤ 150 psi [10 bar]), light duty traffic loading and limited negative pressure (vacuum) requirement.

Installation Type 1

- Construct the pipe bed following the guidelines of section 3.2 ➔ .
- Backfill the pipe zone (to 12 in [300 mm]) over the pipe crown with the specified backfill material compacted to the required compaction level (see Appendix B ➔).

! **Note**: For low pressure (PN ≤ 15 psi [1 bar]) applications without traffic load the requirement to compact the 12 in (300 mm) over the pipe crown may be waived.

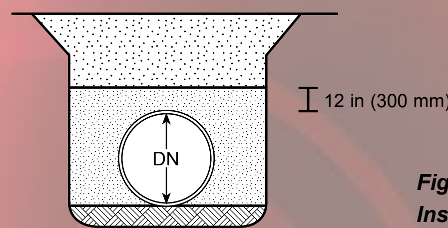

Figure 3–4
Installation Type 1

Installation Type 2

- Construct the pipe bed following the guidelines of section 3.2 ➔. Backfill to a level of 60% of pipe diameter with the specified backfill material compacted to the required compaction level.
- Backfill from 60% of diameter to 12 in (300 mm) over the pipe crown with specified backfill material compacted to the required compaction level.

! **Note:** Backfill Configuration Type 2 is not practical for small diameter pipes.

! **Note:** Backfill Configuration Type 2 is not suitable for heavy traffic loading situations.

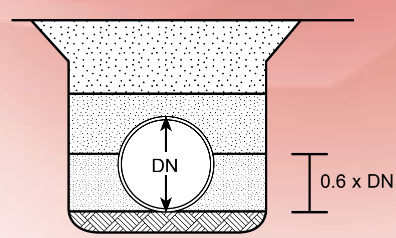

Figure 3–5
Installation Type 2

3.5 Backfilling Pipe

Immediate backfilling after joining is recommended as it will prevent two hazards, i.e. floating of pipe due to heavy rain and thermal movements due to large differences between day and night temperatures. Floating of pipe can damage the pipe and create unnecessary reinstallation costs. Thermal expansion and contraction can cause loss of seal due to movement of several pipe lengths accumulated at one joint.

If sections of pipe are placed into the trench and backfilling is delayed, each pipe should have the centre section backfilled to the crown to help minimize movements at the joint.

Proper selection, placement and compaction of pipe zone backfill are important for controlling the vertical deflection and are critical for pipe performance. Care must be taken so that the backfill material is not contaminated with debris or other foreign materials that could damage the pipe or cause loss of support. The haunching material in the area between the bedding and the underside of the pipe should be worked in and compacted before placing the remainder of the backfill ***(see Figure 3–6 and Figure 3–7)***.

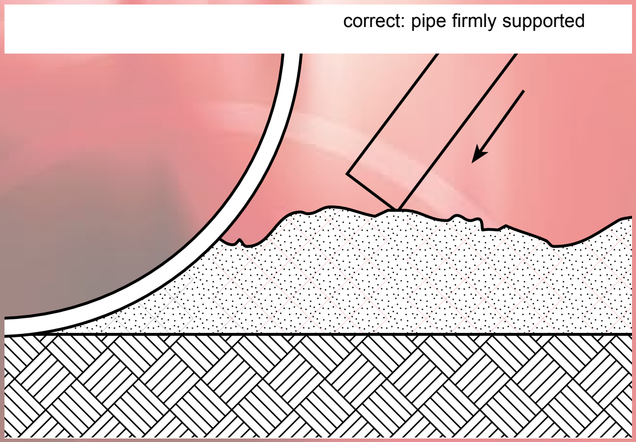

Figure 3–6 Proper haunch backfill

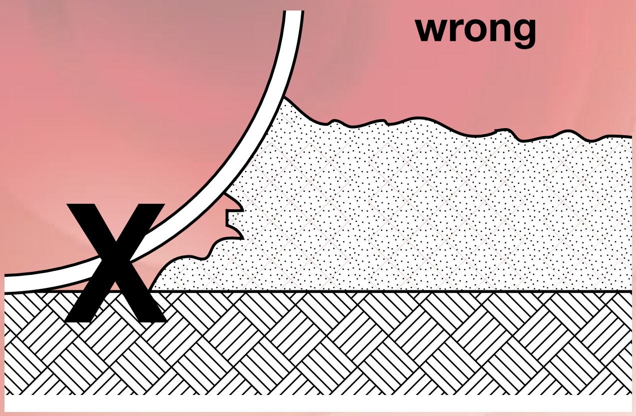

Figure 3–7 Improper haunch backfill

The depth of the layer being compacted must be controlled as well as the energy placed into the compaction method. Proper backfilling is typically done in 4 to 12 in (100 mm to 300 mm) lifts depending on backfill material and compaction method. When gravel or crushed stone is used as backfill material, 12 in (300 mm) lifts will generally be adequate since gravel is relatively easy to compact. Finer grained soils need more compaction effort and the lift height should be limited. Note that it is important to achieve proper compaction of each lift to ensure that the pipe will have adequate support.

Backfill Types SC1 and SC2 are relatively easy to use and very reliable as backfill materials for pipe. These soils have low moisture sensitivity. Backfill can be easily compacted using a plate vibrator compactor in 8 to 12 in (200 to 300 mm) lifts. Occasionally, a filter fabric should be used in combination with gravel soils to preclude fines migration and subsequent loss of pipe support. See Appendix A.8 for criteria.

Backfill Type SC3 soils are acceptable and are often readily available as backfill materials for pipe installations. Many local soils, in which the pipe is installed, are Type SC3 and therefore the excavated soil can be directly reused as pipe-zone backfill. Precaution is to be taken with these soils as they can be moisture sensitive. The characteristics of Type SC3 soil are often dictated by the characteristics of the fines. Moisture control may be required when compacting the soil to achieve the desired density with reasonable compaction energy and easily used compaction equipment. Compaction can be achieved by using impact compactor in 4 to 8 in (100 to 200 mm) lifts.

Backfill type SC4 can only be used as pipe-zone backfill with the following precautions:

- Moisture content must be controlled during placement and compaction.
- Do not use in installations with unstable foundations or with standing water in the trench.
- Compaction techniques may require considerable energy, and practical limitations of relative compaction and resulting soil stiffness must be considered.
- When compacting, use lifts of 4 to 6 in (100 to 150 mm) with an impact compactor such as Whacker or pneumatic rammer (pogo stick).
- Compaction tests should be conducted periodically to assure that proper compaction is achieved. See Appendix F for further information ➔.

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The compaction of finer grain backfill is most easily accomplished when the material is at or near its optimum moisture content. When backfilling reaches pipe spring-line, all compaction should start near the trench sides and proceed towards the pipe.
Pipe zone backfill can be placed and compacted in such a way as to cause the pipe to ovalise slightly in the vertical direction. Initial vertical ovalisation, however, must not exceed 1.5 % of pipe diameter as measured when backfill reaches pipe crown. The amount of initial ovalisation obtained will be related to the energy required to achieve the relative compaction needed. The high energy levels that may be necessary with backfill Types SC3 and SC4 may lead to exceeding the limit. If this occurs consider a higher stiffness pipe or other backfill materials or both.

These recommendations are summarised in ***Table 3–3***.

Backfill Soil Type	Lift Height Hand-operated Impact Compactor	Lift Height Hand-operated Vibrating Plate Compactor	Recommendations
Type SC1		12 in	Two passes should provide good compaction
Type SC2		8 to 10 in	Two to four passes, depending on height and required density
Type SC3	4 to 8 in		Layer height and number of passes are dependent on required density Use at or near optimum moisture content. Check compaction.
Type SC4	4 to 6 in		May require considerable compaction energy. Control moisture content to be at optimum. Verify compaction.

Table 3–3 Summary of recommendations for compaction of pipe-zone backfill

3.6 Compaction above Pipe

Type 1 installation requires the 12 in (300 mm) over the pipe to be compacted. Trench backfill under areas subjected to traffic load is often compacted to minimize road surface settlement. ***Table 3–4*** shows the minimum cover height over the pipe necessary before certain compaction equipment may be used directly above the pipe. Care must be taken to avoid excessive compaction effort above the pipe crown which may cause bulges or flat areas. However, the material in this area must not be left loose and the desired specific density should be achieved.

Equipment Weight lb	Minimum Pipe Cover* (in) Tamped	Vibrated
Less than 110	-	-
110 to 220	10	6
220 to 440	14	8
440 to 1100	18	12
1100 to 2200	28	18
2200 to 4500	36	24
4500 to 9000	48	32
9000 to 18000	60	40
18000 to 26000	72	48
26000 to 40000	86	60

*It may be necessary to begin with higher cover so that, as compaction is achieved, the cover will not be less than the minimum

Table 3–4 Minimum cover for compaction above pipe

3.7 Pipe Deflections

Deflection of the backfilled pipe is a good indicator of the quality of the installation. The expected initial vertical pipe deflection after backfilling to grade level is less than 2% for most installations.

A value exceeding this amount indicates that the desired quality of the installation has not been achieved and should be improved for the next pipes (i.e. increased pipe zone backfill compaction, coarser grained pipe zone backfill materials or wider trench, etc.).

The maximum allowable initial deflection is 3% of diameter. It is recommended to check the pipe deflection as soon as the pipe has been backfilled to grade level in order to get a continuous feedback on installation quality, see section 9.1 ➔
.

4 Joining Pipes

FLOWTITE pipe sections are typically joined using FLOWTITE couplings. Pipe and couplings may be supplied separately or the pipe may be supplied with a coupling installed on one end. If the couplings are not delivered pre-mounted, it is recommended that they be mounted at the storage yard or at the trench side before the pipe is lowered to the trench bed. The couplings may be supplied with or without a rubber centre stop register. If a centre register is not supplied a home-line will be marked on the pipe as an aid for jointing.
Other joining system such as flanges, mechanical couplings and lay-up joints may also be used for joining FLOWTITE pipes.

4.1 FLOWTITE double Bell Couplings

Flowtite Pressure Coupling (FC)

The following steps (1 to 5) are meant for Flowtite Pressure Couplings.

Step 1 Foundation and Bedding
The bed must be over-excavated at each joint location to ensure that the pipe will have continuous support and does not rest on the couplings. The coupling area must be properly bedded and backfilled after the joint assembly is completed.

Step 2 Cleaning Coupling
Thoroughly clean double bell coupling grooves and rubber gasket rings to make sure no dirt or oil is present ***(Figure 4–1)***.

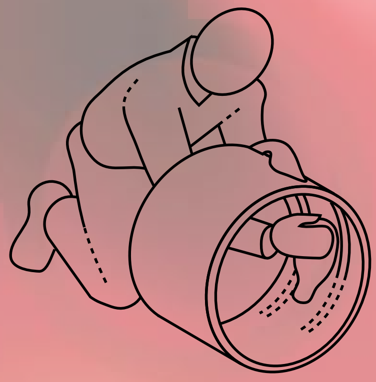

Figure 4–1 Cleaning coupling

Step 3 Install Gaskets
Insert the gasket into the groove leaving loops (typically two to four) of rubber extending out of the groove.
Do not use any lubricant in the groove or on the gasket at this stage of assembly. Water may be used to moisten the gasket and groove to ease positioning and insertion of the gasket

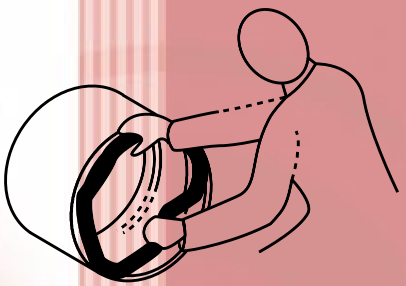

Figure 4–2 Installing gasket

(Figure 4–2).
With uniform pressure, push each loop of the rubber gasket into the gasket groove. When installed, pull carefully in the radial direction around the circumference to distribute compression of the gasket. Check also that both sides of the gasket protrude equally above the top of the groove around the whole circumference. Tapping with a rubber mallet will be helpful to accomplish the above.

Step 4 Lubricate Gaskets
Next, apply a thin layer of lubricant to the rubber gaskets ***(Figure 4–3)***. See Appendix I ➔ for normal amount of lubricant consumed per joint.

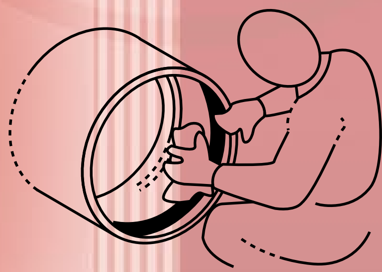

Figure 4–3 Lubricant gaskets

Step 5 Clean and Lubricate Spigots
Thoroughly clean pipe spigots to remove any dirt, grit, grease, etc. Inspect spigot sealing surface for possible damage. Apply a thin layer of lubricant to the spigots from the end of the pipe to the black alignments stripe. After lubricating, take care to keep the coupling and spigots clean ***(Figure 4–4)***. It has been found that placing a cloth or plastic sheet, approximately one metre square, under the jointing area will keep the spigot ends and gasket clean.

! **Caution:** It is very important to use only the correct lubricant. The supplier provides sufficient lubricant with each delivery of couplings. If for some reason you run out, please contact the supplier for additional supply or advice on alternative lubricants. Never use a petroleum based lubricant.

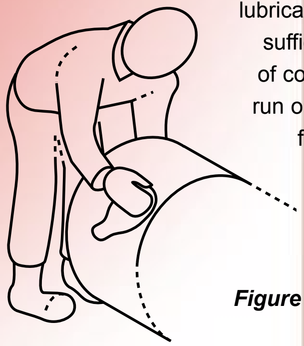

Figure 4–4 Cleaning spigot

Jointing

If the coupling is not pre-mounted it should be mounted on the pipe in a clean, dry place before the pipes are joined. This is accomplished by placing a clamp or a sling around the pipe at a distance of 3 to 6 ft (1 to 2 m) from the spigot on to which the coupling will be mounted. Make sure the pipe spigot is resting at least 4 in (100 mm) above the ground surface to keep away from dirt. Push the coupling on to the pipe spigot end manually and place a 2 x 4 in timber across the coupling. Use two come-along jacks connected between the timber and the clamp and pull the coupling into position i.e. until the coupling is aligned with the “home line” or until the spigot touches the centre register ***(see Figure 4–5)***.
The following steps (6 to 8) apply to joining pipes using clamps or slings and “come-along jacks”. Other techniques may also be used providing the general objectives outlined here are met. In particular, insertion of the spigot ends of the pipe should be limited to the home-line and any damage to the pipe and coupling avoided.

Step 6 **Pipe Placement**

The pipe with the coupling mounted is lowered onto the trench bed. In the location of the joint the trench should be over-excavated to ensure that the pipe will have a continuous support and does not rest on the couplings.

Step 7 **Fixing of Clamps**

Clamp (or sling) A is fixed anywhere on the first pipe or left in position from the previous joint. Fix Clamp (or sling) B on the pipe to be connected in a convenient position ***(Figure 4–6)***.

! **Note:** Clamp contact with the pipe shall be padded or otherwise protected to prevent damage to the pipe and to have high friction resistance with the pipe surface. If clamps are not available, nylon slings or rope may be used as in ***(Figure 4–7)***, but care must be taken in the alignment of the coupling.

Step 8 **Join Coupling**

Come-along jacks are placed one on each side of the pipe and connected to the clamps. The pipe is pulled into position into the coupling until it reaches the home-line or touches the centre register. Clamp A is then moved onto the next pipe to be joined.

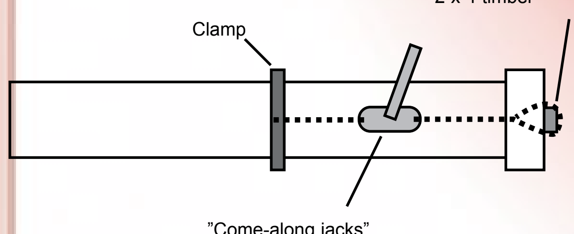

Figure 4–5 Mounting of coupling on pipe

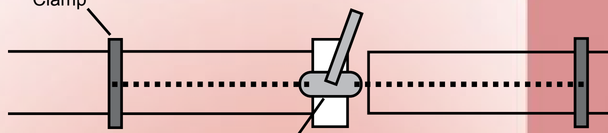

Figure 4–6 Pipe joining using clamps

The pipes can also be mounted by an excavator shovel or a crowbar (up to DN 12 in [300 mm]). The spigot ends are to be protected from any damage. The approximate mounting force can be calculated as follows:
Mounting force in lbs= (DN in inches*100)

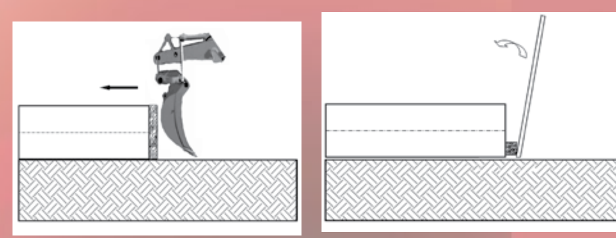

Figure 4–7 Mounting with excavator shovel or crowbar

Angular Deflection of FLOWTITE Couplings

Maximum angular deflection in service at each coupling taking into account combined vertical and horizontal, must not exceed the values given in ***Table 4–1***. This can be utilized to accomodate gradual changes in line direction. The pipes should be then joined in straight alignment and thereafter deflected angularly as required. The maximum offset and

Nom. Pipe Diameter (in)	Max. Angle of Deflection (deg) for pressure (PN) up to 16 bars
DN ≤ 20	3.0
20 < DN ≤ 33	2.0
33 < DN ≤ 60	1.0
DN > 60	0.5

Table 4–1 Angular Deflection at Double Coupling Joint

Angle of Deflection (deg)	Maximum Offset (in) Pipe length			Radius of Curvature (ft) Pipe length		
	10 ft	20 ft	40 ft	10 ft	20 ft	40 ft
3.0	6.28	12.56	25.12	191	382	764
2.0	4.19	8.38	16.76	286	572	1144
1.0	2.09	4.18	8.36	573	1146	2292
0.5	1.05	2.10	4.20	1146	2292	4584

Table 4–2 Offset and Radius of Curvature

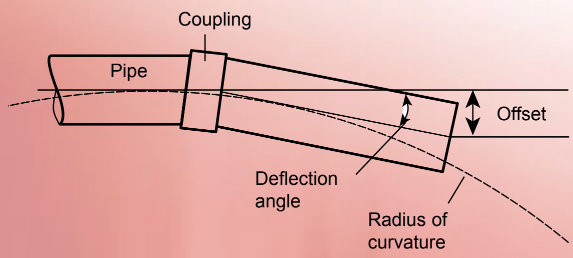

Figure 4–8 Flowtite coupling, angular joint deflection

corresponding radius of curvature are shown in ***Table 4–2*** (See ***Figure 4–8*** for definition of terms).

! **Note:** The above is for information purposes.The minimum allowable length is a function of nominal pressure and backfill type and compaction, but in no case should it be less than 10 ft (3 m).

Angular deflected coupling joints are stabilised by the stiffness of the soil surrounding the pipe and coupling. Pressure pipes PN > 15 psi (1 bar) should have angularly rotated joints backfilled to minimum 90% standard proctor compaction. Coupling joints that are placed with vertical angular rotation, where the direction of the thrust is upward, should be backfilled to a minimum cover depth of 4 ft (1.2 m) for operating pressures of 225 psi (16 bar) and greater.

Flowtite Sewer Coupling (FSC)

A gasket is used for the FSC, which is pre-equipped by the supplier and fixed to the coupling groove. With that the steps, described under 4.1 – cleaning of the grooves and installing of the gasket – can be dropped. All other working instructions and user data are identical with the steps – mentioned under 4.1 – for the Flowtite Pressure Coupling.

Pipe Misalignment

The maximum allowable misalignment of adjacent pipe ends is 0.2 in (5 mm) – ***see Figure 4–9***. It is recommended the misalignment be monitored near thrust blocks, valve chambers and similar structures, and at closure or repair locations.

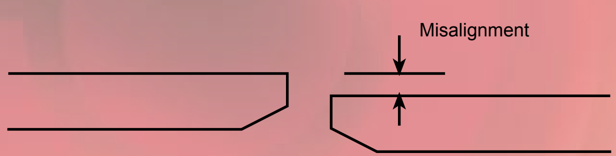

Figure 4–9 Misalignment

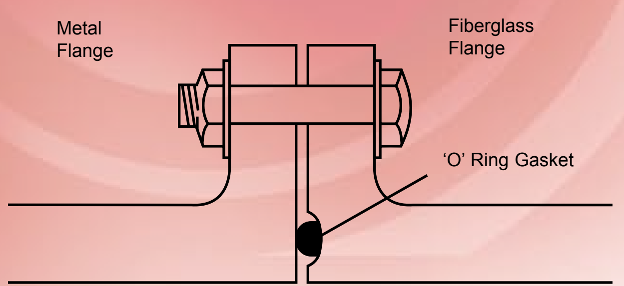

Figure 4–11 Flanged joint

4.2 Locked Joints (FBC)

The FLOWTITE locked joint is a double bell with rubber gaskets and locking rods to transfer axial thrust from one pipe section to another. On each side, the coupling bell has a standard rubber gasket and a rod-groove system, through which the load is transferred via compressive and shear action.
The pipe spigot for locked joints has a matching groove.

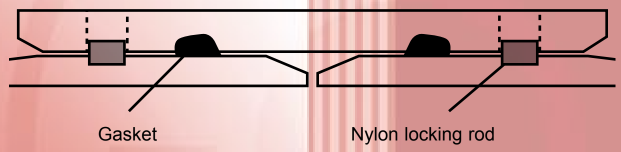

Figure 4–10 FLOWTITE locked joint

The joint is assembled by using a similar procedure as the standard FLOWTITE pressure coupling, except that there is no centre register. Steps 1 through 6 above should be followed. For step 7 the pipe is pulled in position until the groove in the pipe is visible through the opening in the coupling. The locking rod is then pushed into position with a hammer.

4.3 Flanged Joints

Contact Moulded

GRP flanges should be joined according to the following procedure: ***(Figure 4–11)***

1. Thoroughly clean the flange face and the O-ring groove.
2. Ensure the sealing gasket is clean and undamaged.
3. Position sealing gasket in groove.
4. Align flanges to be joined.
5. Insert bolts, washers and nuts. All hardware must be clean and lubricated to avoid incorrect tightening. Washers must be used on all GRP flanges.
6. Using a torque wrench, tighten all bolts to 25 ft-lb (35 Nm) torque, following standard flange bolt tightening sequences.
7. Repeat this procedure, raising the bolt torque to 50 ft-lb (70 Nm), or until the flanges touch at their inside edges. Do not exceed this torque. To do so may cause permanent damage to GRP flanges.
8. Check bolt torques one hour later and adjust if necessary to 50 ft-lb (70 Nm).

Loose Ring Flanges

FLOWTITE pipe can also be supplied with loose ring (van Stone) flanges. The loose ring can be rotated to easily align with the bolt holes in the mating flange.

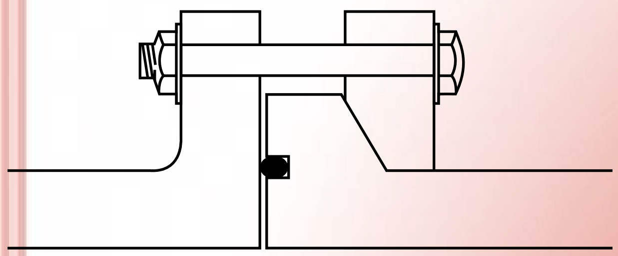

Figure 4–12 Loose ring flange with O-ring gasket

The loose ring flange can be manufactured for two types of gasket sealing using

1. an "O"-ring seal (groove required in flange face, see ***Figure 4–12***) and
2. an "O"-ring profile gasket with steel ring for flat flange surfaces (no groove required) as shown in ***Figure 4–13***.

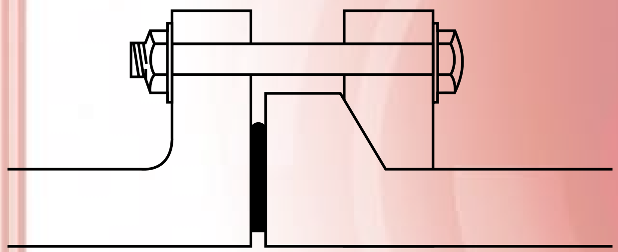

Figure 4–13 Loose ring flange with O-ring profile gasket with steel ring

The joining procedure for both types of loose ring flanges is identical and is described below.

1. Thoroughly clean the flange face to be joined and where applicable the "O"-ring groove.
2. Ensure the gasket to be used is clean and undamaged. Do not use defective gaskets.
3. Position the gasket onto the flange face. For the "O" ring seal, ensure that the gasket is pushed firmly into the "O"-ring groove. It is recommended that the "O"-ring be secured with small strips of tape or adhesive.
4. Align flanges to be jointed.
5. Insert bolts, washers and nuts. All hardware must be clean and lubricated to avoid incorrect tightening. It is important that the mating surface between the bolt head/washers and backing ring plate are well lubricated to avoid excessive torque build up.
6. Use a torque wrench to tighten all bolts to the required torque settings in ***Table 4–3*** following standard flange bolt tightening sequences.
7. Check bolt torques one hour later and adjust if necessary to the set bolt torque.

Type of Gasket	PN	Maximum torque ft-lb*)
"O"-ring	100	11 x Pipe OD (in ft)
"O"-ring	150	22 x Pipe OD (in ft)
"O"-ring	250	45 x Pipe OD (in ft)
"O"-profile with integral ring	100	10 x Pipe OD (in ft)
"O"-profile with integral ring	150	17 x Pipe OD (in ft)
"O"-profile with integral ring	250	20 x Pipe OD (in ft)

*) Based on standard flange dimensions according to ISO 7005

Table 4–3 Torque settings for loose ring flanges

! **Note**: When connecting two GRP flanges made with an "O"-ring gasket, only one flange shall have a gasket groove in the face.

4.4 Layup Joint

This type of joint is made from glass fibre reinforcements impregnated with polyester resin It requires special designs, clean, controlled conditions and skilled, trained personnel. Special instructions will be provided when this type of joint is required (see ***Figure 4–14***).

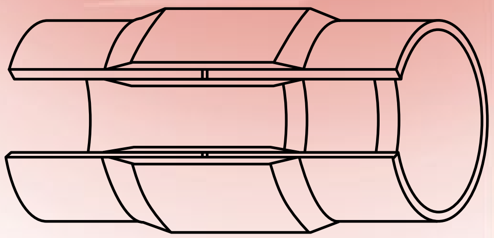

Figure 4–14 Lay-up joint

4.5 Other Joining Methods

Flexible Steel Couplings
(Straub, Tee-Kay, Arpol, etc. – see ***Figure 4–15***)

When connecting FLOWTITE pipe to other pipe materials with different outside diametres, flexible steel couplings are one of the preferred jointing methods. These couplings consist of a steel mantle with an interior rubber sealing sleeve. They may also be used to join FLOWTITE pipe sections together, for example in a repair or for closure.

Three grades are commonly available:

1. Coated steel mantle
2. Stainless steel mantle
3. Hot dip galvanized steel mantle

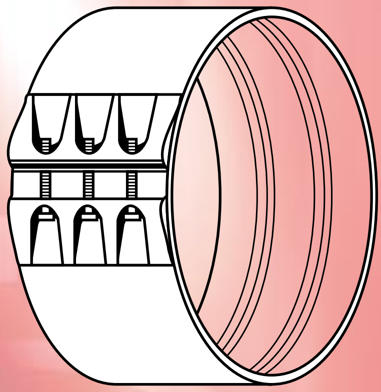

Figure 4–15 Flexible steel coupling

Control of the bolting torque of flexible steel couplings is important. Do not over torque as this may over stress the bolts or the pipe. Follow the coupling manufacturer's recommended assembly instructions, but with the pipe supplier's recommended bolt torque limits.

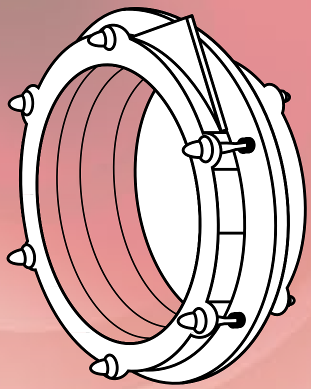

Figure 4–16 Dual bolt mechanical coupling

Mechanical Steel Couplings
(Viking Johnson, Helden, Kamflex, etc. see ***Figure 4–16***)

Mechanical couplings have been used successfully to join pipes of different materials and diametres, and to adapt to flange outlets. There is a wide variation in the design of these couplings, including bolt size, number of bolts and gasket design. Large variations also exist in the diameter tolerance of other materials, which often results in higher bolt torque than necessary in order to achieve a tight seal on the FLOWTITE side.

Consequently, we cannot recommend the general use of mechanical couplings with FLOWTITE pipe. If a mechanical coupling is used to join FLOWTITE to another pipe material then only mechanical couplings with a dual independent bolting system should be used (***Figure 4–16***). This allows for the independent tightening of the FLOWTITE side, which typically requires less torque than recommended by the coupling manufacturer.

It is advised that the local FLOWTITE pipe supplier be consulted when mechanical couplings are contemplated for use on a project. Be prepared to present information on the specific design (brand and model). The pipe supplier can then advise under what conditions, if any, this design might be suitable for use with FLOWTITE.

Corrosion Protection

Regardless of the corrosion protection applied to the steel mantle, the balance of the coupling needs to be corrosion protected as well. Typically this involves the application of a shrink fit polyethylene sleeve over the installed coupling.

GRP Adapters

The FLOWTITE coupling can be used to join FLOWTITE pipe to other materials with the same outside diameter (***Table 6–1***) for non-pressure applications. For higher pressures consult the manufacturer.

Special GRP adaptors or stepped couplings can be made to connect GRP pipe with other materials or different diametres. Consult the manufacturer.

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5 Thrust Restraints, Concrete Encasement and Connections to Rigid Structures

When the pipeline is pressurized, unbalanced thrust forces occur at bends, reducers, tees, wyes, bulkheads and other changes in line direction. These forces must be restrained in some manner to prevent joint separation. Usually this is most economically accomplished by use of thrust blocks or alternatively by direct bearing and friction between pipe and soil.

Direct transfer of thrust through friction and bearing are accomplished by using restraint joints and special pipes that transfer axial thrust. The accompanying fittings is designed for direct bury. A friction factor of 0.5 between Flowtite pipe and cohesionless soils may be considered when determining the required anchor length of the pipe connecting to the fittings.

Determination of need and design, as well as the level of steel reinforcement of concrete structures, is the responsibility of the owner's engineer. Flowtite fittings are designed to withstand the full internal pressure, while the concrete structure shall support its shape and transfer the load. As the expansion of the pressurised fittings is typically greater than the tensile strength of the concrete would carry, steel reinforcement to control crack widths should be considered. The following conditions also apply:

Thrust Blocks

Thrust blocks must limit the displacement of the fitting relative to the adjacent pipe to preserve the leak tightness of the Flowtite coupling joint. The resulting angular deflection shall be less than the values indicated in ***Table 4–1***.
For more details of pipe installation and system layout see clauses 5.1 and 5.2.

For operating pressures above 150 psi (10 bar) the block must completely surround the fitting. For lower pressures special fittings can be supplied that allow for partial embedding. The block should be placed either against undisturbed earth or backfilled with pipe zone materials selected and compacted as appropriate to meet the original native soil's strength and stiffness.

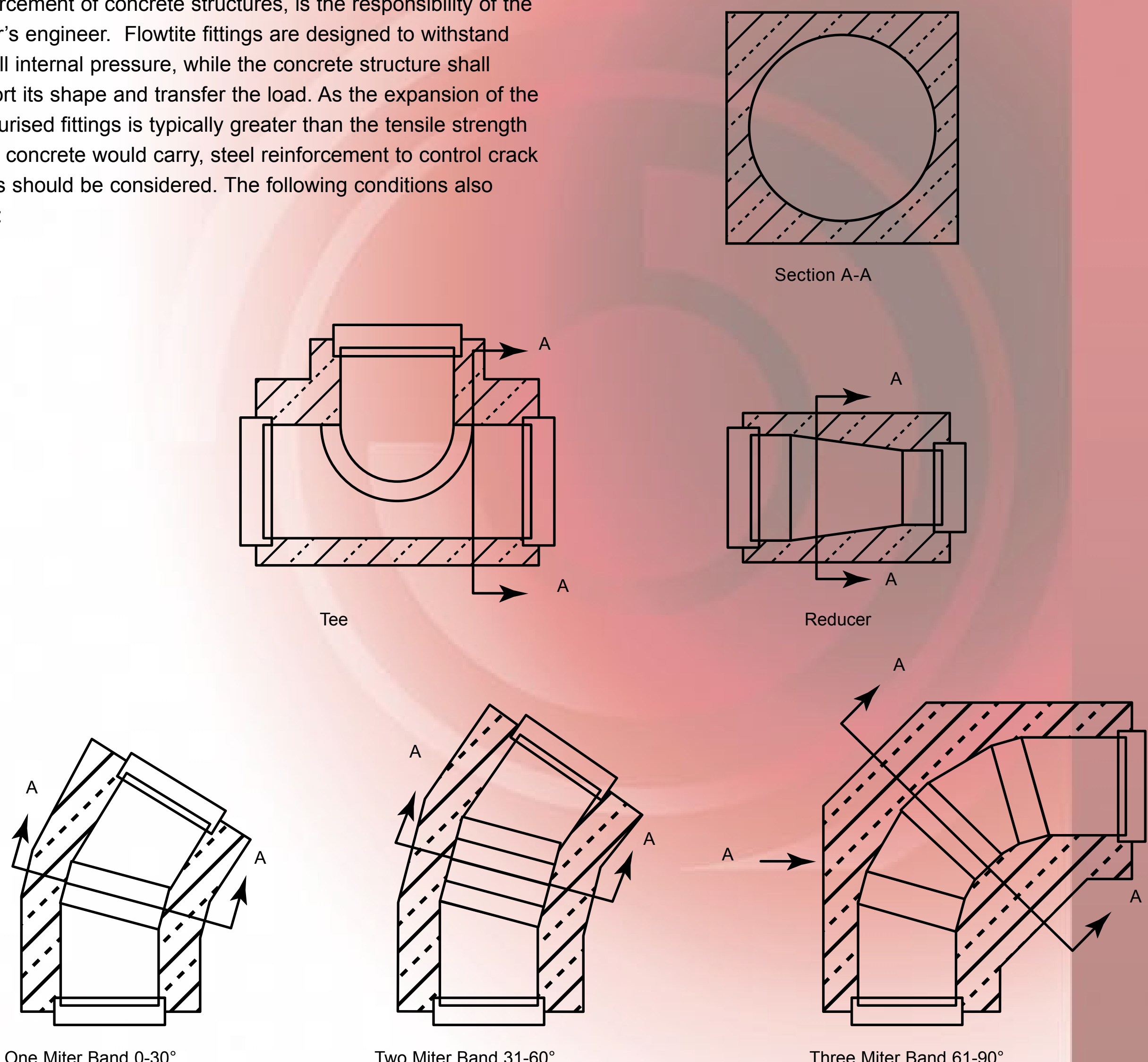

Figure 5–1 Thrust blocks

Thrust blocks are required for the following fittings when the line pressure exceeds 15 psi (1 bar):

1. All bends, reducers, bulkheads and blind flanges.
2. Tees, when the branch pipe is concentric to the header pipe centreline.

Concentric manways (blind flange tees), drains and air vents, which do not generate unbalanced thrust in operation, do not require encasement, but do require thrust resistant branches and fittings.

! **Note**: The thrust block shapes shown are typical for illustration. The exact shape will be dependent on design and project requirement.

Valves

Valves must be sufficiently anchored to absorb the pressure thrust. More details on valves and chambers are provided in section 8.

Nozzles

Nozzles are tee branches meeting all of the following criteria:

1. Nozzle diameter ≤ 12 in (300 mm).
2. Header diameter ≥ 3 times nozzle diameter.

! **Note:** it is not necessary to encase nozzle connections in concrete.

5.1 Concrete Encasement

When pipes (or fittings) must be encased in concrete, such as for thrust blocks, stress blocks, or to carry unusual loads, specific additions to the installation procedures must be observed.

DN	Maximum Spacing (ft)
12 in – 16 in	8
20 in – 24 in	12
30 in – 36 in	16
≥ 42 in	20

Table 5–1 Maximum Strap Spacing

Pipe Anchoring

During the pouring of the concrete, the empty pipe or fitting will experience large uplift (flotation) forces. The pipe must be restrained against movement that could be caused by these loads. This is normally accomplished by strapping over the pipe to a base slab or other anchor(s). Straps should be a flat material of minimum 1 in (25 mm) width, strong enough to withstand flotation uplift forces, with a minimum of two straps per section length and with the maximum spacing between straps as shown in ***Table 5–1***. The straps should be tightened to prevent pipe uplift, but not so tight that additional pipe deflection is caused (see ***Figure 5–2*** ➔).

Pipe Support

The pipe should be supported in such a way that the concrete can easily flow completely around and fully underneath the pipe. Also, the supports should result in an acceptable pipe shape (less than 3% deflection and no bulges or flat areas).

Concrete Pouring

The concrete must be placed in stages allowing sufficient time between layers for the cement to set and no longer exert buoyant forces. The maximum lift heights, as a function of stiffness class, are as shown in ***Table 5–2***.

Maximum lift is the maximum depth of concrete that can be poured at one time for a given nominal stiffness class.

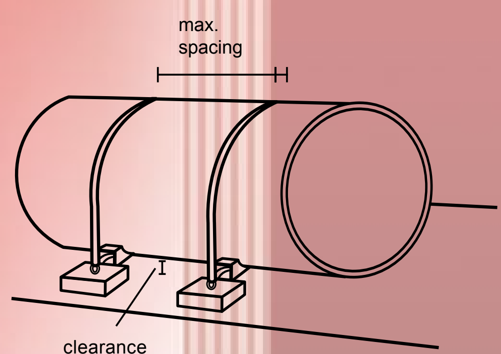

Figure 5–2 Pipe anchoring – Maximum spacing of straps see table Table 5–1

SN	Maximum lift
18	Larger of 1.0 ft or DN/4
36 & 46	Larger of 1.5 ft or DN/3
72	Larger of 2.0 ft or DN/2

Table 5–2 Maximum Concrete Pour Lifts

5.2 Connections to Rigid Structures

Excessive bending and shear stresses can develop in a pipe that moves excessively in relation to a rigid structure. Situations where this may occur are when a pipe passes through a wall (e.g. valve chamber or manhole), is encased in concrete (e.g. thrust block), or is flanged to a pump, valve or other structure.

For all connections to rigid structures action must be taken by the installer to minimize the development of high discontinuity stresses in the pipe. Angular deflection and misalignment at joints close to thrust blocks shall be avoided during installation. Two options are available. The standard (preferred) uses a coupling joint cast into the concrete-pipe interface. The alternate wraps the pipe in rubber to ease the transition.

Standard

Where possible, cast a coupling joint in the concrete at the interface (***Figure 5–3***) so that the first pipe outside the concrete has complete freedom of movement (within the limits of the joint). For PN 225 psi (16 bar) and higher this standard method should be used, and the length of the short section pipe kept at the maximum indicated in ***Figure 5–3***.

! **Caution**: When casting a coupling in concrete be sure to maintain its roundness so later joint assembly may be accomplished easily. Alternatively, make up the joint prior to pouring the concrete.

! **Caution**: Since the coupling cast in concrete is rigid, it is very important to minimize the vertical deflection and deformation of the adjacent pipe.

Alternate

Where the standard method is not possible, wrap (***Figure 5–4***) a band (or bands) of rubber (***Figure 5–5*** and ***Table 5–3***) around the pipe prior to placement of any concrete such that the rubber slightly protrudes 1 in (25 mm) from the concrete. Lay out the pipeline so the first completely exposed coupling joint is located as shown in ***Figure 5–4***. For PN 225 psi (16 bar) and higher this alternate method is not recommended.

Construction Guidelines

1. When the design of the concrete structure is considered, it should be noted that any excessive settlement of the structure relative to the pipe can be the cause of a pipe failure.

2. It has been found that including a short length (rocker pipe) near the rigid connection is a good way to accommodate differential settlement (see ***Figure 5–3*** and ***Figure 5–4***).
The minimum length of the short length should be the larger of one DN or 3 ft (1 m), and the maximum length the larger of two DN or 6 ft (2 m).
This rocker pipe section is used to account for some differential settlements that may occur. The rocker pipe should have straight alignment with the concrete structure at the time of installation to provide maximum flexibility for subsequent movements.
Multiple short lengths or rocker pipes should not be used, as the short spacing between couplings may result in an unstable condition. Misalignment problems should be remedied by re-bedding the full pipe sections leading to the rocker pipe.

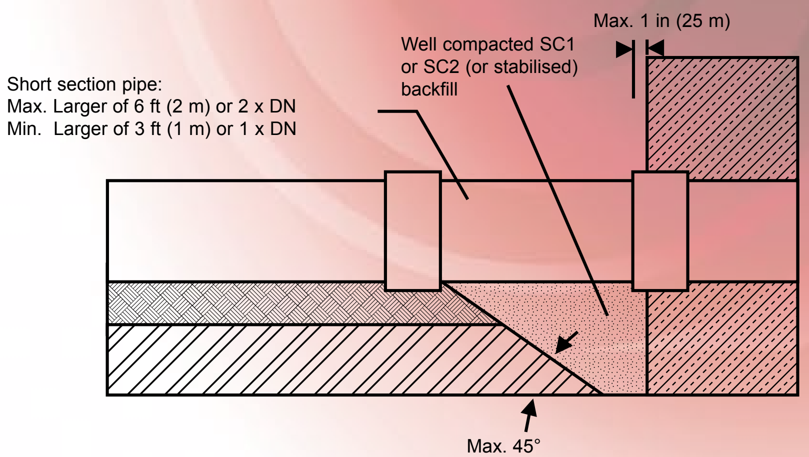

Figure 5–3 Standard connection – Coupling cast in concrete

Diameter (in)	SN 18 Pressure, psi					SN 36 and larger
	50	100	150	200	250	All pressures
12 - 24	A	A	A	A	A	A
30 - 36	C	C	C	C	C	A
42 - 48	C	C	C	C	C	C
54	C	C	C	C	-	C
60 - 63	C	C	C	-	-	C
72 - 78	C	C	-	-	-	C
84 - 96	C	-	-	-	-	C

Table 5–3 Quantity and Configuration of rubber wraps

3 Care must be taken to replace and properly compact backfill adjacent to the concrete structure. Construction of the concrete structure will frequently require over-excavation for formwork, etc. This extra excavated material must be restored to a density level compatible with surroundings to prevent excess deformation, or joint rotation adjacent to the structure. Type SC1 or SC2 backfill compacted to 90% Standard Proctor Density should be brought up to 60% of the pipe's diameter at the interface with the rigid structure (see Figure 5–3 and Figure 5–4) and gradually tapered back. Stabilised backfill (cement) may also be used for this purpose.

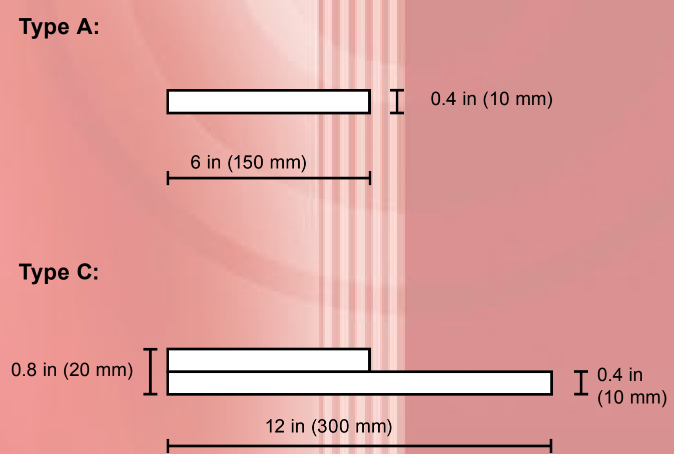

Figure 5–5
Rubber wrap configuration – Rubber shall be 50 Durometer

Rubber Wrap Placement

1 Position as shown in ***Figures 5–4*** and ***5–5***.

2 Tape all seams and edges to assure no cement can get between the rubber and the pipe or between the rubber wraps.

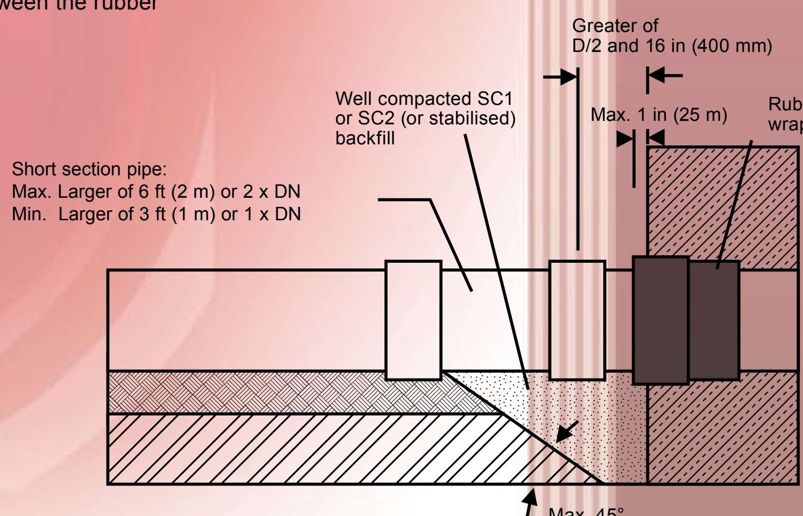

Figure 5–4 Alternate connection – Rubber wrap encased in concrete

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5.3 Casings (Tunnels)

When Flowtite standard pipe (unequal exterior flush) is installed in a casing the following precautions should be observed.

1. Pipes may be placed into the casing by pulling (drawing) or pushing (jacking). Please consult the supplier for the calculation of the maximum insertion length/-force.

2. For an easy insertion and for protection from sliding damage the pipes should be equipped with plastic spacers, steel sleeves or wooden skids (as shown in ***Figure 5-6 and 5-7***). These must provide sufficient height to permit clearance between the coupling joints and the casing wall.

3. Installation into the casing is made considerably easier by using lubricant between the skids and the casing wall. Do not use a petroleum based lubricant as it may cause harm to some gaskets.

4. The annular space between the casing and pipe may be filled with sand, gravel or cement grout. Care must be taken to not overstress or collapse the pipe during this step, particularly when grouting. Maximum grouting pressure is given in ***Table 5–4***

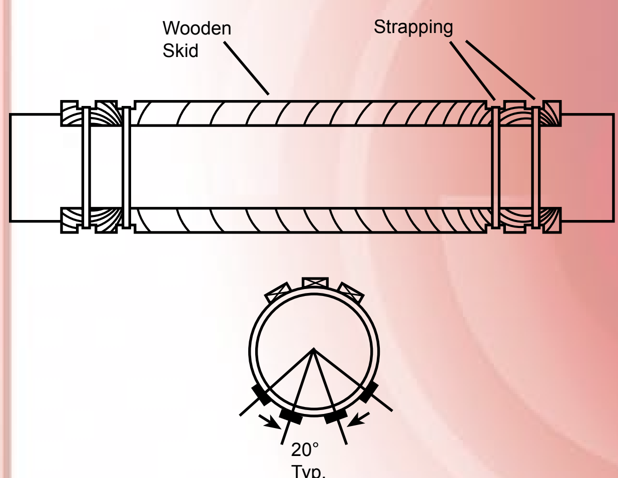

Figure 5–6 Typical skid arrangement

! **Note**: Do not wedge or brace the pipe in a manner that causes concentrated or point loads on the pipe. Consult the supplier prior to this step for advice on suitability of the chosen method.

! **Note**: If the annular space is not grouted and the pipe will be subjected to negative pressure, the pipe stiffness – installation combination must be sufficient to withstand the load. Consult the supplier for advice.

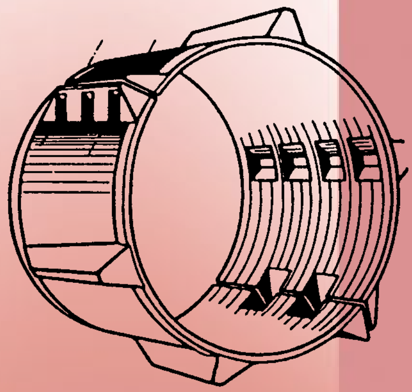

Figure 5–7 Plastic spacer unit

SN	Maximum Grout Pressure (psi)
18	5
36	10
46	12
72	20

Table 5–4 Maximum Grouting Pressure (Pipe Invert) without Internal Supports

At the same time pipe systems with flush joint can be used.

Figure 5–8 Flush joint

5.4 Concrete-wall Connections

When a pipe must pass through a concrete wall special precautions need to be followed to ensure continuous leak tightness of the system.

The connection systems are divided into two categories:

1. Made in situ

2. Precast

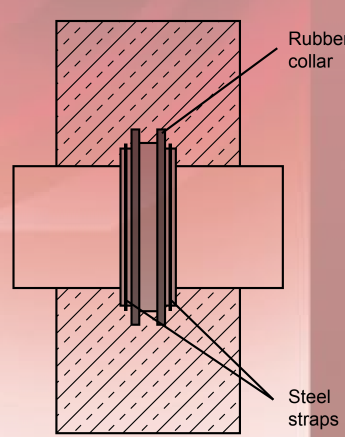

Figure 5–9 Rubber collar

Made in situv

An in situ connection is created when the concrete is poured directly at the site. Sometimes the pipe is completely encapsulated in the concrete base with the crown (top) of the pipe later cut away. No connection is needed in this case. At other times, only the ends of the pipe are inserted in the formwork limiting the concrete's contact to the pipe ends. For either case the market has developed rubber collars that are affixed to the pipe ends before the concrete is poured.

The rubber collar is first attached to the pipe using stainless steel straps. The collar is then embedded in the concrete. Due to its shape, a watertight seal between the concrete and pipe is achieved (***Figure 5–9***).

! **Note:** The water stop collar is not to be considered a load bearing anchor, or what is commonly called a puddle flange.

The recommended installation instructions for this collar are as follows:

1. Mark the end of the FLOWTITE pipe with the location of where the rubber collar will be located, and the extent of the concrete outer wall. The collar should be at the mid-point of the finished concrete wall.
2. Clean the entire outer surface of the pipe that will be in contact with the concrete, especially under the area where the collar is to be located. Any deep gouges should be ground smooth ensuring a better seal for the rubber collar.
3. Slip the rubber collar over the pipe end. Be careful to locate the collar at the expected mid-point of the concrete wall.
4. Install the stainless steel straps to press and fix the collar. To improve the sealing further it is generally recommended to use a fine concrete (i.e. no large aggregates) directly in contact with the collar. These collars can be used either with the pipe or with the Flowtite coupling. If one wants to achieve a flexible connection, it is recommended to use the Flowtite coupling and assemble the collar directly over the Flowtite coupling.

Precast

Precast connections are made off-site and are installed after the concrete has set. The inlet and outlet holes need to be dimensioned by the precast fabricator to fit FLOWTITE pipe at the time of initial production. The issue now becomes creating a water tight seal between FLOWTITE's outer wall and the pre-dimensioned hole in the concrete wall.

Manufacturer produce a special gasket which is designed for connections of a pipe passing through a concrete wall. The product is available for the complete diameter range of FLOWTITE pipe. The gasket is installed in the concrete hole as shown in ***Figure 5–10***.

The hole through the wall can be created in two ways:

1. Using a diamond tipped hole-cutter – only practical for small diametres.
2. Using a cylindrical form, with the requisite outside diameter, during fabrication of the hole.

The gasket is kept in place by compression.
Sealing is through compression/deformation of the lips.

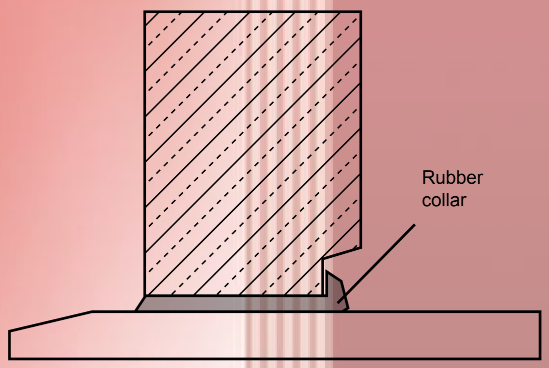

Figure 5–10 Rubber collar in concrete wall

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6 Field Adjustments

6.1 Length Adjustment

A large majority of the pipe supplied by Flowtite producers has the outside diameter of the barrel of the pipe within the tolerance range of the calibrated spigot (***Table 6–1***). These pipes are often marked as Adjustment Pipe or similar. The following procedures will assist in correctly making the length adjustment:

1. Ensure that the pipe diameter is within the spigot tolerance range.
2. Determine the length required and mark a square cut on the selected pipe.
3. Cut the pipe at the appropriate location using a circular saw with a diamond coated blade. Use proper eye, ear and dust protection. Consult the pipe supplier for recommendations.
4. Clean the surface in the jointing area, sand smooth any rough spots and with a grinder bevel grind the pipe end to ease assembly (see ***Figure 6–1***). No further grinding is necessary.

DN (in)	Minimum (in)	Maximum (in)	Spigot width (in)	Bevel Length (L) (in)
12	13.150	13.189	6.199	0.25
16	17.362	17.402	6.340	0.40
18	19.449	19.488	6.413	0.50
20	21.575	21.614	6.489	0.55
24	25.748	25.787	6.638	0.65
30	31.969	32.008	6.772	0.80
36	38.268	38.307	6.772	0.80
42	44.449	44.488	6.772	0.80
48	50.748	50.787	6.772	0.80
54	57.520	57.559	6.772	0.80
60	61.575	61.614	6.772	0.80
63	64.488	64.528	6.772	0.80
72	72.402	72.441	6.772	0.80
78	80.433	80.472	6.772	0.80
84	88.465	88.504	6.772	0.80
96	96.496	96.535	6.772	0.80

Table 6–1 Spigot Dimensions and Tolerances.

! **Note**: Spigot Diameter series based on Cast Iron O.D. Series

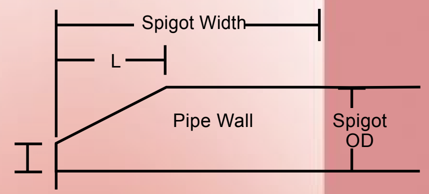

Figure 6–1 Pipe spigot and bevel dimensions definition for coupling joints

! **Note**: For field closure section, double the spigot width.

The design of the pipes does not require any sealing of the spigot ends after field cutting.

! **Note:** In relation to this it is of great importance that the interior edge of an adjustment pipe is chamfered after field cutting.

6.2 Field Closures with FLOWTITE Couplings

FLOWTITE couplings can be used for field closures and repairs. The minimum length of the closure pipe should be 3 ft (1 m). In addition, the closure pipe should not be adjacent to a “rocker” pipe, i.e., the short length meant to provide flexibility adjacent to rigid connections (see ***Figures 5–3 and 5–4*** ➔).

Procedure

Measure the distance between the pipe ends where you want to set in the closure pipe. The closure pipe should be 0.4 to 0.8 in (10 to 20 mm) shorter than the measured length.
The narrower the gap the easier it will be to make the closure.

Figure 6–2 Closure section assembly

Pipe Selection

Choose a pipe which is within the spigot diameter tolerance. These pipes will have the required spigot outside dimension for joining along the entire pipe length. If possible choose a pipe with the outside dimension at the low end of the spigot range (see ***Table 6–1***).

Pipe Preparation

Mark the pipe length required and make a cut perpendicular and square to the pipe axis with a circular saw. Use a grinding tool to make a 20 degree bevel on the pipe end and round-off the corners.
Be careful that the remaining thickness on the pipe spigot end is not less than one half the pipe thickness. It is also important to have a minimum chamfer length, L, for guiding the pipe end without damaging the gasket. Follow the recommended lengths in ***Table 6–1***. After bevelling, use sandpaper to remove any sharp corners on the pipe surface which may have been caused by the cutting. Smooth the spigot of any rough spots.

! **Note**: The spigot width must be at least equal to the coupling width. This will be twice the values shown in ***Table 6–1***.

Please make sure that the surface has no grooves, and that the spigot OD is within the limits shown in ***Table 6–1***.

Installation

1 Select two couplings, remove the centre registers, and leave the gaskets in place. Clean the couplings if necessary. The gasket groove must be free of dirt to allow unrestricted deformation of the gasket.

2 Lubricate carefully, including between the lips.

3 Lubricate also the clean spigot ends of the closure pipes with a thin continuous layer of lubricant. Do not forget the bevelled surfaces.

4 Place one coupling square onto the end of the closure pipe so that the gasket is in contract around its entire circumference. Push or pull the coupling uniformly onto the closure pipe until the entire coupling is resting on the spigot end. It may be necessary to gently help the second ring over the chamfered end of the pipes. Repeat with the second coupling on the other end.

5 Mark home-lines onto the adjacent pipe spigot ends to control the uniform backward movement of the coupling. The home-line's location is calculated as follows:

HL = (Wc-Wg)/2
HL – homeline
Wc – width of the coupling
Wg – width of gap between closure pipe and adjacent pipe (measured).

2 Set the closure pipe in the trench aligned with the adjacent pipes and with equal clearance on either side. Any angle or tilt will complicate the assembling process.

7 Clean the spigot ends of the adjacent pipes and lubricate with an even, thin layer. Install special tools to pull the coupling back to closing position. (consult your supplier for information about the tools). It is recommended that you pull the couplings over both sides simultaneously, keep the closure pipe centred and minimize pipe end contact. Stop pulling when the coupling's edge touches the home-line. For man-entry size pipes, an individual inside the pipe watching the assembly process can be advantageous.

8 The compaction of the backfill around a field closure pipe is very important and should be no less than 90% SPD. Often the closure area is over excavated for ease of access. This is recommended to prevent excessive movement and joint rotations.

! **Note**: After the coupling is in final position, a feeler gauge may be used to assure that gasket lips are properly oriented.

6.3 Field Closures with Non-FLOWTITE Couplings

Follow the general procedures of section 6.2 ➔ except that the closure pipe will not typically need to have the special long machined spigot ends.

The installation procedures for the particular coupling used must be followed (see section 4.5 ➔).

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7 Other Installation Procedures and Considerations

7.1 Multiple Pipes in Same Trench

When two or more pipes are installed parallel in the same trench, clear spacing between the pipes should be as shown in ***Figure 7–1***. Space between pipe and trench wall should be as shown in ***Figure 3–1***.
It is advisable when laying pipes of different diametres in the same trench to lay them with the same invert elevation. When this is not possible, use backfill material type SC1 or SC2 to fill all the space from the trench bottom to the invert of the higher pipe. Proper compaction must be achieved (min 90% SPD).

Depth of cover up to 13 ft (4 m):
$C \geq (D_1 + D_2)/6$

Depth of cover over 13 ft (4 m):
$C \geq (D_1 + D_2)/4$

but not less than 6 in (150 mm) or sufficient room to place and compact backfill

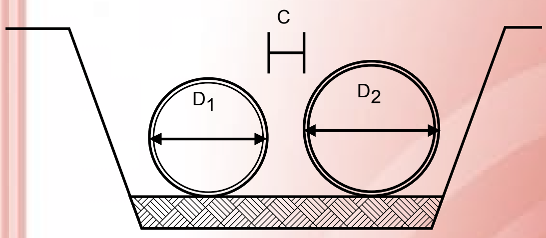

Figure 7–1 Spacing between pipes in the same trench

7.2 Cross-Overs

When two pipes cross, so that one passes over the other, vertical spacing between pipes and installation of the bottom pipe should be as shown in ***Figure 7–2***.
In some cases, it is necessary to lay a pipe under an existing line. Extra care should be taken not to damage the existing pipe. It should be protected by fastening it to a steel beam crossing the trench. It is also advisable to wrap the pipe in order to protect it from impact damage.

Depth of cover up to 13 ft (4 m):
$f \geq \frac{D_1 + D_2}{6}$

Over 13 ft (4 m):
$f \geq \frac{D_1 + D_2}{4}$

but not less than 6 in (150 mm)

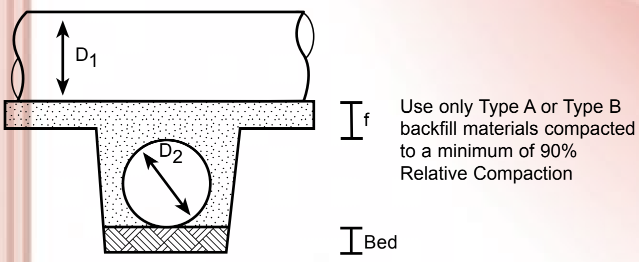

Figure 7–2 Crossing pipes

When the new pipe is laid, backfill material type SC1 or SC2 must be placed back into the trench and compacted to a minimum of 90% SPD completely around both pipes plus 12 in (300 mm) above the crown of the upper pipe. This backfill should extend at least twice the diameter into each trench (see ***Figure 7–3***).

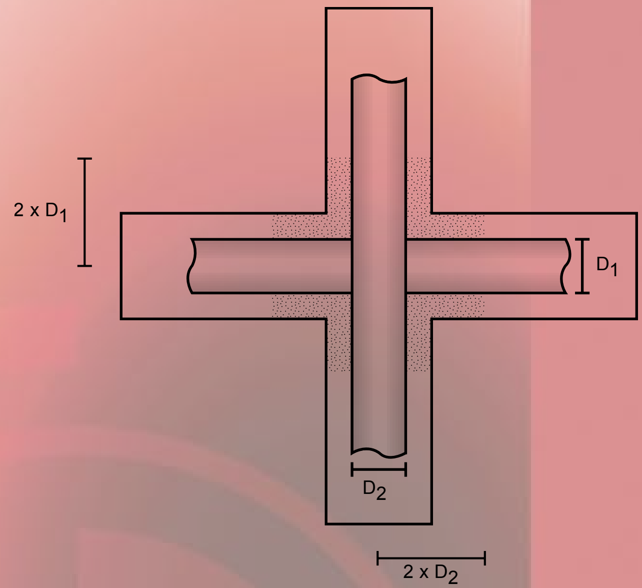

Figure 7–3 Top view of backfill in cross-over.

7.3 Unstable Trench Bottom

Where the trench bottom has soft, loose or highly expansive soils, it is regarded as unstable. An unstable trench bottom must be stabilised before laying pipe or a foundation must be constructed to minimize differential settlement of the trench bottom. A well graded sandy gravel compacted to 90% SPD or crushed stone is recommended for use in foundation layers.

The depth of the sandy gravel or crushed stone material used for foundation depends upon the severity of the trench bottom soil conditions, but should not be less than 6 in (150 mm).

The normal bedding must be placed on top of such foundations. When crushed rock is used the use of filter cloth to completely surround the foundation material will prevent foundation and bedding materials from migrating into one another which could cause loss of pipe bottom support. Filter cloth is not needed if the same material is used for foundation and bed, or if graded sandy gravel is used for the foundation. Additionally, the maximum pipe section length between flexible joints shall be 20 ft (6 m).

7.4 Flooded Trench

When the groundwater table is above the trench bottom, the water level must be lowered to at least the trench bottom (preferably about 8 in (200 mm) below) prior to preparation of the bed. Different techniques may be used depending on the nature of the native material.
For sandy or silty soils, a system of well-points to a header pipe and a pump is recommended. The spacing between individual well-points and the depth at which they will be driven depends on the groundwater table and the permeability of the soil. It is important to use a filter around the suction point (coarse sand or gravel) to prevent clogging of the well-points by fine grained native material.

When the native material consists of clay or bedrock, well-points will not work. Dewatering is more difficult to achieve in this case. The use of sumps and pumps is recommended.
If the water cannot be maintained below the top of the bedding, sub-drains must be provided. The sub-drains should be made using single size aggregate (0.8 to 1.0 in [20-25 mm]) totally embedded in filter cloth. The depth of the sub-drain under the bed depends on the amount of water in the trench. If the groundwater can still not be maintained below the bed, filter cloth should be used to surround the bed (and if necessary the pipe zone area as well) to prevent it from being contaminated by the native material. Gravel or crushed stone should be used for bed and backfill. The following cautions should be noted when dewatering:

- Avoid pumping long distances through the backfill materials or native soils, which could cause loss of support to previously installed pipes due to removal of materials or migration of soil.
- Do not turn off the dewatering system until sufficient cover depth has been reached to prevent pipe flotation.

7.5 Use of Trench Supports

Care must be taken to ensure proper support between native soil and backfill when sheeting is removed. Removing the sheeting in steps and direct compaction of pipe-zone backfill against the trench wall provides the best support to the pipe and fills the voids that frequently occur behind sheet piling. If the sheeting is pulled after the pipe-zone backfill has been placed, the backfill loses support which reduces the support to the pipe, especially when voids form behind the sheeting. To minimize this loss of support the sheeting should be vibrated during removal.
Make sure that there are no voids or lack of backfill between the outside of the sheeting and the native soil up to at least 3 ft (1 m) above the pipe crown. Use only backfill type SC1 or SC2 between the temporary sheeting and the native soil, compacted to at least 90% SPD.

For permanent sheeting, use sheeting of sufficient length to properly distribute the pipes lateral loads at least 12 in (300 mm) above the pipe crown. The quality of the permanent sheeting should be such that it lasts for the design life of the pipe.

Backfill procedures are the same as for standard installations. Permanent sheeting can be assumed to be a group 1 native soil.

7.6 Trench Construction in Rock

Minimum dimensions for pipe installations in a rock trench should be as in 3.1 ➜. Where the rock ends and the pipe passes into a soil trench area (or reverse), flexible joints should be used as shown in ***Figure 7–4***.

Alternatively, use of cement stabilised backfill (see section 5.2) for the foundation and bedding of a pipe just passing through a rock-soil transition would negate the need to locate a flexible joint at this transition. Trench construction should be according to the method applicable for the native soil condition.

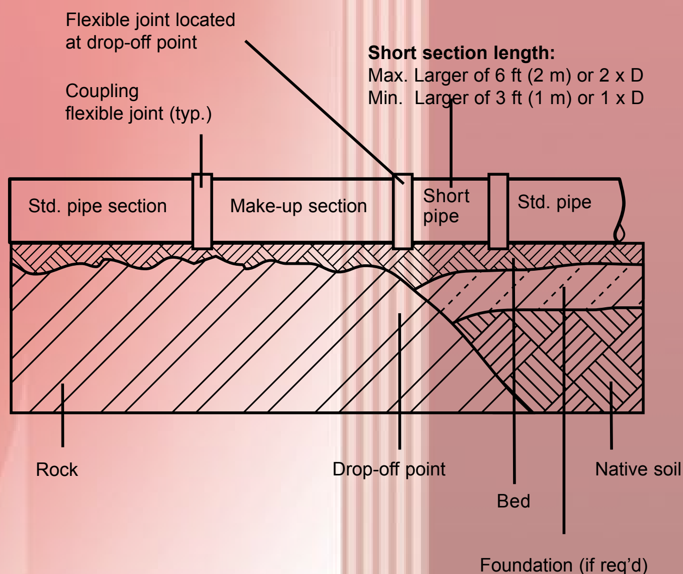

Figure 7–4 Method of trench construction and pipe layout at rock-soil trench transition or at abrupt changes in bedding conditions.

7.7 Inadvertent Over-Excavation

Any inadvertent over-excavation of the trench walls or the trench bottom in the foundation, bed or pipe zone areas should be filled with backfill material compacted to a least 90% relative compaction.

7.8 Installation of Pipes on Slopes (Parallel)

General

- The angle at which slopes can become unstable depends on the quality of the soil. The risk of unstable conditions increases dramatically with slope angle.
- In general, pipes should not be installed on slopes greater then 15 degrees, or in areas where slope instability ts suspected, unless supporting conditions have been verified by a proper geotechnical investigation.

Aboveground Installation

- The preferred method of installing pipes on steep slopes is above ground as above ground structures such as pipe supports are more easily defined, the quality of installation is easier to monitor and settlement easier to detect.
- See above ground installation brochure for more information ➔.

Buried Installation

Before pipes are installed underground on slopes greater then 15 degrees, it is recommended that a geotechnical engineer be consulted. Flowtite pipes may be installed on slopes greater than 15 degrees provided the following minimum conditions are achieved:

- Long-term stability of the installation can be ensured with a proper geo-technical design.
- For slopes over 15 degrees, use either SC1 or cement-stabilised backfill in the pipe zone as backfill material.
- For slopes greater than 15 degrees, use one anchor rib at the centre of each pipe section.
- Installation should always proceed from the low point and progress up the slope. Each pipe should be properly backfilled to grade before the next pipe is placed in the trench.
- The surface over the completed pipe trench must be protected against erosion from flowing water.
- Pipes are installed in straight alignment (plus or minus 0.2 degrees) with a minimum gap between pipe spigots.
- Absolute long-term movement of the backfill in the axial direction of the pipe must be less than 0.8 in (20 mm).
- The installation is properly drained to avoid washout of materials and ensure adequate soil shear strength.
- Stability of individual pipes is monitored throughout the construction phase and the first phases of operation. This can be done by controlling the gap between pipe spigots.
- A special pipe design may be required, consult the pipe supplier.

Perpendicular to the hillside

When pipes are installed perpendicular to the fall line of a steep slope, consultation with a geotechnical engineer is recommended when the slope angle exceeds 15 degrees to assure that the hillside remains stable.

The surface of the completed trench must be configured to eliminate depressions and preclude the formation of puddles water. The collection of water on a slope may reduce the stability of the slope.

8 Accommodating Valves and Chambers

Most pressure pipelines periodically have in-line valves for isolating a portion of the supply or distribution system, air and vacuum relief valves at high points in the pipeline to slowly release accumulated air thereby avoiding blockages or to allow air to enter in order to avoid under-pressure, and clean out (wash out) or drainage chambers. All of these different appurtenances can be accommodated with FLOWTITE pipe. The ultimate responsibility for the design of the piping systems is the professional engineer. However, over the years Flowtite Technology engineers have observed many different methods of incorporating these appurtenances into a pipeline using FLOWTITE pipe. This section is devoted to offering the design engineer or contractor some guidelines on accommodating valves and chambers in a pressure FLOWTITE pipeline.

8.1 Anchoring In-Line Valves

Flowtite pipe is designed to handle nominal axial loads, but is not designed to accommodate thrust and shear loads that may result from the inclusion of valves in the piping system. Loads from valves must be externally restrained as required by AWWA C600-93. Several methods for anchoring valves are described. The best method will be dependent on the specific operating conditions for each system. Generally, the best method is dependent on pipe diameter and operating pressure. There are two basic considerations for in-line valves: are they directly accessible (installed in chambers) or not (direct buried)? Generally, smaller diameter valves are direct buried without the use of concrete chambers for easy access. Consequently, our guidelines are based on these two different situations.

Direct Bury

Type 1 The lowest cost and easiest installation for a small diameter valve is to direct bury it, encapsulated in its own concrete thrust block (See Figure 8–1). This method can be used with larger valves, the only limit being a reasonable thrust block design. The reinforced concrete thrust block must be properly designed to resist thrust from a closed valve with movement limited to the leaktightness of the joint.

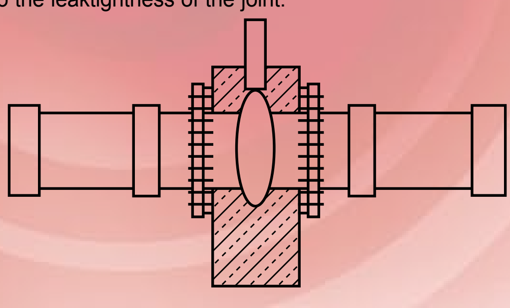

Figure 8–1 Type 1 – Valve encased in thrust block

The following guidelines should be observed in designing the Type 1 arrangement:

1. The size of the concrete thrust block is based on the local soil stiffness, backfill materials and installation conditions. Limit movement to 0.6 in (15 mm).

2. The flanged stubs should be no more than 20 in (500 mm) in length, with a FLOWTITE coupling on the outside leg connecting the stub to a rocker pipe(see ***Figures 5–3 and 5–4*** ➔).

Type 2 The anchoring method here is similar to Type 1 except that the valve body can be accessed (see ***Figure 8–2***). While allowing a relatively simple installation, the valve may be available for servicing. The limit of use is dependent on the strength of the stub of steel or ductile iron pipe and the attached anchoring collar. For small thrust loads, only one side of the valve needs to be anchored.

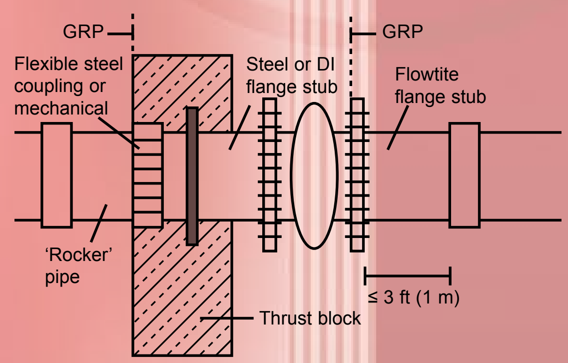

Figure 8–2 Type 2 – Thrust block adjacent to valve

The following guidelines should be observed in designing the Type 2 arrangement:

1. The size of the thrust block is based on the local soil stiffness, backfill material and installation conditions. Limit lateral movement to preserve the leaktightness of the joint.

2. The flanged stubs should be no more than 3 ft (1 m) in length. The stub, with the flange or anchor collar, connects to the FLOWTITE rocker pipe with the standard FLOWTITE coupling.

3. If steel or ductile iron stubs are used, the use of flexible steel couplings or transitions (dual bolting) mechanical couplings is recommended.

Chambers

Type 3 This method can be used for all but the larger, higher pressure valves. The limit of use is dependent on the ability to place the structural support system into the valve chamber. The support system must be designed to accept the total axial thrust without over-stressing the valve flanges or the reinforced concrete valve chamber walls. The valve chamber acts as the thrust block and must be designed as such. The thrust restraint is placed on the compression side of the valve to transfer the thrust directly to the chamber wall. The other end of the pipe system is relatively free to move axially allowing for movement due to temperature change and Poisson effect.

The assumption inherent in ***Figure 8–3*** is that the thrust acts only in one direction. However, consideration must be given to the possibility of back pressure on a closed valve which could create a thrust load in the opposite direction. To accommodate this possibility the structural support system can be designed to handle load in either direction. The details are left up to the design engineer.

The following guidelines should be observed in designing the Type 3 arrangement:

1. Thrust and shear from the valve is to be supported through a steel frame support system. Standard FLOWTITE pipe and flanges can be supplied for this method of use.

2. The standard FLOWTITE pipe is to have either a rubber wrap or sealing gasket at the outward concrete wall penetration to reduce local stresses caused by the constraint of free radial displacement during pressurization.

3. The valve chamber must be designed to accept the full axial thrust and vertical weight of the valve. Local reinforcements of the valve chamber foundation and walls will be required to accept the axial forces at the attachment points.

4. The valve chamber is to be designed as a thrust block to resist axial thrust. The backfill selection, placement and compaction must be sufficient to resist settlement and lateral forces created by the valve closure. Limit lateral movement to preserve the leaktightness of the joint.

5. There must be a rocker pipe placed outside the valve chamber according to standard installation practices.

6. The thrust is taken via compression of the structural support system. No axial load is transmitted to the pipe.

7. Use cement stabilised backfill, or gravel compacted to 90% relative compaction, to fill the void beneath the pipe exiting the valve chamber structure (s. ***Figures 5–3 and 5–4*** ➔).

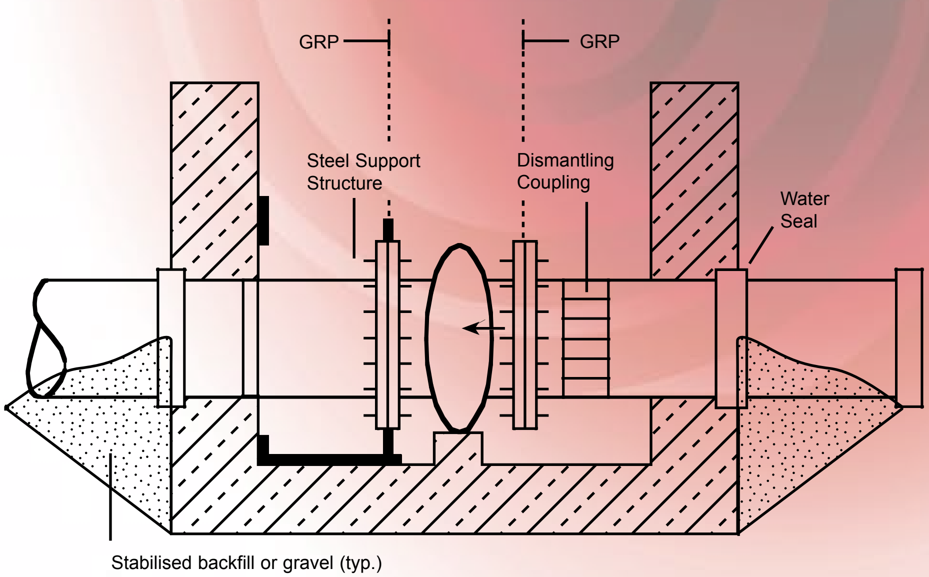

Figure 8–3 Type 3 – Use of structural support system to accommodate thrust forces

Type 4 This method (***Figure 8–4***) can be used for anchoring any valve with pressures up to 225 psi (16 bar). The limitation in use of this method are the practical limits of FLOWTITE pipe reinforcement and puddle flange length. The puddle flange is placed on the compression side of the valve directly loading the chamber wall which acts as a thrust block. The other side of the pipe system in the chamber is relatively free to move axially to allow movement due to temperature change and Poisson effect.

The following guidelines should be observed in designing the Type 4 arrangement:

1. A "special" pipe will have a GRP puddle flange fabricated on the compression-side which is embedded into the valve chamber wall acting as an anchor.

2. The other pipe leg is free to move axially through a sealing gasket in the valve chamber wall.

3. The weight of the valve is to be supported from the base of the valve chamber, and the valve chamber must be designed to accept the full axial thrust of the valve. A concentration of reinforcement bars will be required to accept the axial forces from the embedded puddle flange.

4. The valve chamber is to be designed as a thrust block to resist axial thrust. The backfill selection, placement and compaction must be sufficient to resist settlement and lateral forces created by the valve closure. Lateral movement limited to 0.6 in (15 mm).

5. The "special" pipe will incorporate a coupling embedded in the valve chamber wall. The "special" pipe within the valve chamber will be reinforced to accept the axial loads and local stresses at the interior face of the concrete chamber. Please advise the Flowtite supplier of maximum anticipated thrust loads so that the proper reinforcement for the "special" pipe can be designed.

6. There must be a rocker pipe placed outside the valve chamber according to standard installation practices (see ***section 5–2*** ➔).

7. Use cement stabilised backfill, or gravel compacted to 90% relative compaction, to fill the voids under the pipe outside the valve chamber structure (see ***Figures 5–3 and 5–4*** ➔).

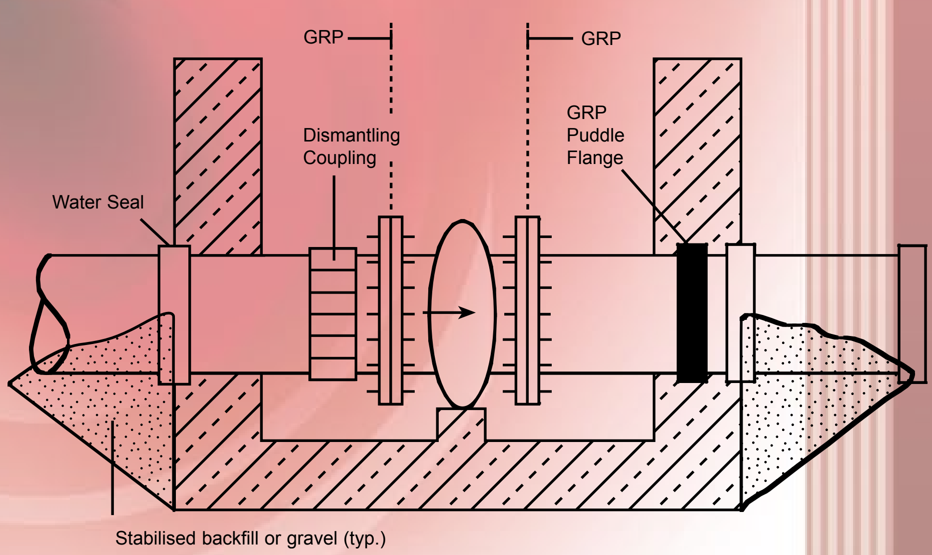

Figure 8–4 Type 4 – Use of puddle flange to accommodate thrust forces

This anchoring method (***Figure 8–5***) may be used for any application. The only limitation in use would be the size of the valve chamber. The valve chamber is to be designed as the thrust block. When the dimensions of the thrust block face required are larger than the physiType 5ensions of the valve chamber, extend the dimensions of the down-stream side of the valve chamber to meet the thrust block requirements. The thrust restraint flange is placed on the compression side of the valve to transfer the thrust directly to the chamber wall, which acts as a thrust block. The other end of the pipe system is relatively free to move axially to allow movement due to temperature change and Poisson effect.

The following guidelines should be observed in designing the Type 5 arrangement:

1. The weight of the valve is to be supported from the base of the valve chamber. The thrust from a closed valve is to be taken by a steel pipe stub anchored into the valve chamber wall by a welded flange on the compression side of the valve.

2. A flexible steel coupling or a transition mechanical coupling is to provide transition between the steel pipe stub and a standard FLOWTITE rocker pipe outside the valve chamber.

3. The other pipe leg is free to move axially through a sealing gasket in the valve. A concentration of reinforcement bars will be required to accept the axial forces from the embedded puddle flange.

4. The valve chamber is to be designed as a thrust block to resist axial thrust. The backfill selection, placement and compaction must be sufficient to resist settlement and lateral forces created by a valve closure. Lateral movement limited to 0.6 in (15 mm).

5. There must be a rocker pipe placed outside the valve chamber according to standard installation practices (see ***section 5.2*** ➔).

6. Use cement stabilised backfill, or gravel compacted to 90% relative compaction, to fill the void beneath the pipes exiting the valve chamber structure (see ***Figures 5–3 and 5–4*** ➔).

8.2 Air and Vacuum Valves

It is common practice to locate air or combination air/vacuum relief valves at high points in a long transmission line. The valves should be designed to slowly release any accumulated air in the high point of a line, which might limit a block flow. Likewise, vacuum relief valves limit the amount of negative pressure a pipeline might experience by opening when under-pressure is sensed by the valve. The detail design and sizing of these valves is beyond the scope of this installation guide. However, guidelines are offered here on the general layout of fittings and structures to accommodate these off-line valves. There are basically two ways air/vacuum relief valves can be accommodated in a FLOWTITE system. The most common method is to mount the valve directly on a vertical flange nozzle. Alternatively, for heavy valves a tangential nozzle can also be designed to accommodate the assembly. Details for both arrangements follow.

Small Air/Vacuum Valves

The simplest way to accommodate small air/vacuum valves is to mount the valve directly on top a vertical flanged nozzle

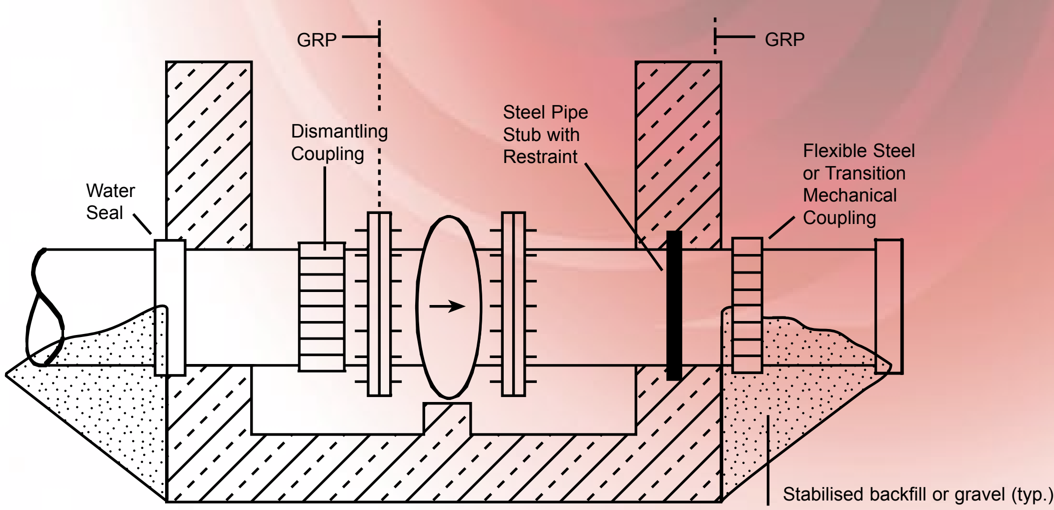

Figure 8–5 Anchoring

rising from the main below. Typically a concrete chamber houses the valve, providing safe and easy passage of air through the valve assembly. When designing and constructing the valve chamber directly over the pipe, it is important to ensure that the weight of the concrete chamber is not directly transferred to the vertical nozzle, and thus to the FLOWTITE pipe below. This can be avoided by having the vertical opening in the base of the chamber larger than the outside diameter of the FLOWTITE riser nozzle. ***Figure 8–6*** provides a general illustration of these desirable features.

Large Air/Vacuum Relief Valves (> 4 in [100mm])

In the case of larger air/vacuum relief valves, the preferred method of installing these heavier valves is not with their weight directly bearing on the riser, but with a tangential nozzle leading to the valve installed in an adjacent chamber.
The tangential nozzle can be parallel to the horizontal axis, or at a slight vertical angle (< 22.5 degrees) with an elbow. Please refer to **section 5** ➔.

Thrust Restraints, for guidance on whether a thrust block alone or a combination thrust and stress block would be required.
In general, if the tangential branch pipe's diameter (chord length) is more than 50% of the diameter of the header pipe then a thrust/stress block is required. Otherwise, only a thrust block is required.

Figure 8–7 provides a general illustration of the means to accommodating large air/vacuum valve with FLOWTITE pipe.

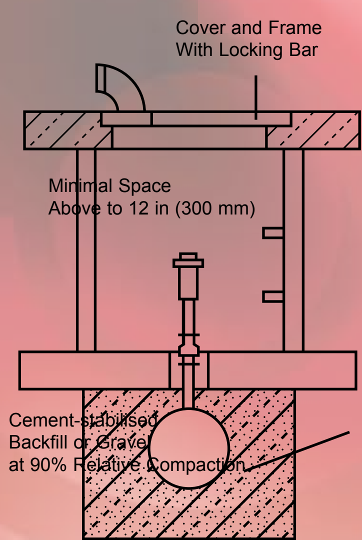

Figure 8–6
Accommodating a small diameter air/vacuum valve

8.3 Clean Out and Scour Valves

Accommodating clean outs and scour valves is similar to a large diameter air valve, only the branch nozzle is tangential to the bottom of the pipe. The same rules for thrust and thrust/stress blocks apply. If the tangential branch's pipe diameter (chord length) is more than 50% of the diameter of the header pipe then a thrust/stress block is required (section 7.1 ➔).

Otherwise, only a thrust block is required. ***Figure 8–8*** gives some typical arrangements for accommodating these types of appurtenances in a FLOWTITE pressure pipeline.

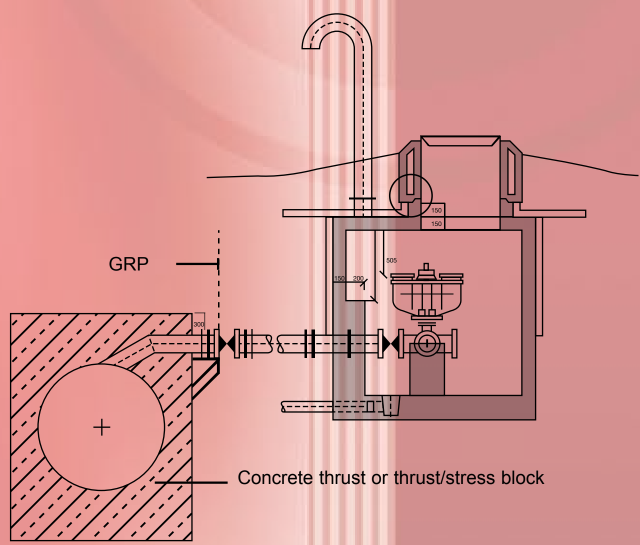

Figure 8–7 Accommodating a large diameter air/vacuum valve

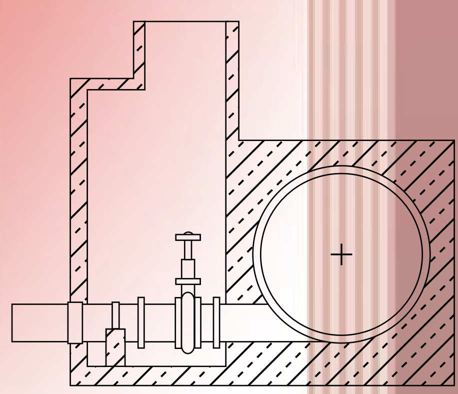

Figure 8–8 Accommodating clean out and scour valves

9 **Post-Installation**

9.1 Checking the Installed Pipe

Requirement: Maximum installed diametrical deflection must not exceed the values in ***Table 9–1*** initially. Bulges, flat areas or other abrupt changes of pipe wall curvature are not permitted. Pipes installed outside of these limitations may not perform as intended.

Checking to insure that the initial deflection requirements have been met is easy to do and should be done for each pipe immediately after completion of installation (typically within 24 hours after reaching maximum cover).
The expected initial pipe deflection after backfilling to grade level is less than 2% for most installations. A value exceeding this amount indicates that the desired quality of the installation has not been achieved and should be improved for the next pipes (i.e. increased pipe zone backfill compaction, coarser grained pipe zone backfill materials or wider trench, etc.).

Deflection measurements in each pipe installed are recommended as a good check on pipe installation quality. Never let pipe laying get too far ahead before verifying the installation quality. This will permit early detection and correction of inadequate installation methods.

Pipes installed with initial deflections exceeding the values in ***Table 9–1*** must be reinstalled so the initial deflection is less than those values. See section 9.2, Correcting Over-Deflected pipe, for limitations applicable to this work.

Procedure for checking the initial diametrical deflection for installed pipes:

1. Complete backfilling to grade.
2. Complete removal of temporary sheeting (if used).
3. Turn off the dewatering system (if used).
4. Measure and record the pipe's vertical diameter.
   Note: For small diameter pipes, a deflection testing device (commonly called a pig) may be pulled through the pipes to measure the vertical diameter.
5. Calculate vertical deflection:

$$\text{\% Deflection} = \frac{\text{Actual I.D.} - \text{Installed Vertical I.D.}}{\text{Actual I.D.}} \times 100$$

Actual I.D. may be verified or determined by measuring the diametres of a pipe not yet installed laying loose (no pipes stacked above) on a reasonably plane surface.

Calculate as follows (see ***Figure 9–1***):

$$\text{Actual I.D.} = \frac{\text{Vertical I.D.} + \text{Horizontal I.D.}}{2}$$

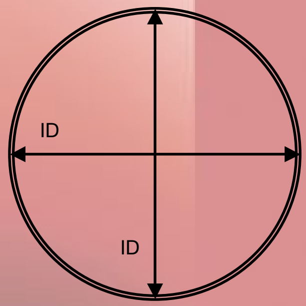

Figure 9–1
Determining actual pipe ID on pipe not yet installed

9.2 Correcting Over-Deflected Pipe

Pipes installed with initial diametrical deflections exceeding 3% must be corrected to ensure the long-term performance on the pipe.

Procedure

For pipe deflected up to 8% of diameter:

1. Excavate down to the haunch area, which is approximately 85% of the pipe diameter. Excavation just above and at the sides of the pipe should be done utilizing hand tools to avoid impacting the pipe with heavy equipment (***Figure 9–2***).
2. Inspect the pipe for damage. Damaged pipe should be repaired or replaced.
3. Re-compact haunch backfill, insuring it is not contaminated with unacceptable backfill material soil.
4. Re-backfill the pipe zone in lifts with the appropriate material, compacting each layer to the required relative compaction density.
5. Backfill to grade and check the pipe deflections to verify they have not exceeded 3%.

For pipe deflected greater than 8% pipe diameter:
Pipes with over 8% deflection should be replaced completely.

Caution: Do not attempt to jack or wedge the installed over-deflected pipe into a round condition. This may cause damage to the pipe.

If excavating multiple pipes, care must be taken to not mound the cover from one pipe over the adjacent one. The extra cover and reduction of side support could magnify an over-deflection situation.

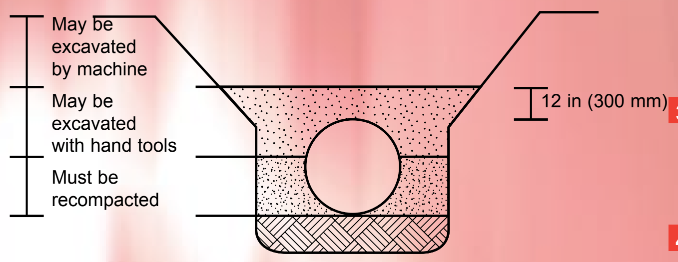

Figure 9–2 Excavating over-deflected pipe

9.3 Field Hydrotesting

Some job specifications require the completed pipe installation to be hydrostatically tested prior to acceptance and service. This is good practice as it can permit early detection and correction of some installation flaws, damaged products, etc. If a field hydrotest is specified, it must be done regularly as installation proceeds. Good construction practice would be to not exceed pipe testing with installation by more than approximately 3300 ft (1000 m) in order to properly assess the quality of work.

The first field hydrotest should ideally include at least one air valve or drainage chamber to assess the total pipeline system. In addition to routine care, normal precautions and typical procedures used in this work, the following suggestions should be noted:

1. Preparation Prior to Test – Inspect the completed installation to assure that all work has been finished properly. Of critical importance are:
   - Initial pipe deflection limited to 3%
   - Joints assembled correctly.
   - System restraints (i.e., thrust blocks and other anchors) in place and properly cured.
   - Flange bolting torqued per instructions.
   - Backfilling completed.
     SEE SECTION A.6 ➔ ON MINIMUM BURIAL DEPTH AND HIGH PRESSURE AND TESTING LIMITATIONS.
   - Valves and pumps anchored.
   - Backfill and compaction near structures and at closure pieces has been properly carried out.
2. Filling the Line with Water – Open valves and vents, so that all air is expelled from the line during filling, and avoid pressure surges.
3. Pressurize the line slowly. Considerable energy is stored in a pipeline under pressure, and this power should be respected.
4. Ensure the gauge location will read the highest line pressure or adjust accordingly. Locations lower in the line will have higher pressure due to additional head.
5. Ensure the maximum test pressure does not exceed 1.5 x PN. Normally the field test pressure is either a multiple of the operating pressure or the operating pressure plus a small incremental amount. However, in no case should the maximum field test pressure exceed 1.5 x PN.
6. If after a brief period for stabilization the line does not hold constant pressure, ensure that thermal effect (a temperature change), system expansion or entrapped air is not the cause. If the pipe is determined to be leaking and the location is not readily apparent, the following methods may aid discovery of the problem source:
   - Check flange and valve areas.
   - Check line tap locations.
   - Use sonic detection equipment.
   - Test the line in smaller segments to isolate the leak.

9.4 Field Joint Tester

Portable hydraulic field joint test equipment can be specially ordered and supplied for diametres 32 in (800 mm) and above. This equipment can be used to internally test selected pipe joints. It is required that each pipe adjacent to the joint under test be backfilled sufficiently to prevent pipe movement during testing. Additional details are available from the supplier's field Technician.

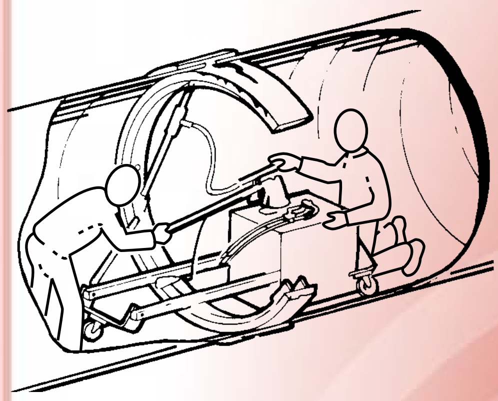

Figure 9–3 Field joint tester

! **Caution:** This equipment is designed to allow a test of the joint to verify that the joint has been assembled properly with gaskets in proper position. This equipment is limited to a maximum pressure test level of 85 psi (6 bar).

9.5 Field Air Test

An alternate leak test for gravity pipe (15 psi [1 bar]) systems may be conducted with air pressure instead of water. In addition to routine care, normal precautions and typical procedures used in this work, the following suggestions and criteria should be noted:

1. As with the hydrotest, the line should be tested in small segments, usually the pipe contained between adjacent manholes.

2. Ensure the pipeline and all materials, stubs, accesses, drops, etc. are adequately capped or plugged and braced against the internal pressure.

3. Slowly pressurize the system to 3.5 psi (0.24 bar). The pressure must be regulated to prevent over pressurisation (maximum 5 psi [0.35 bar]).

4. Allow the air temperature to stabilize for several minutes while maintaining the pressure at 3.5 psi (0.24 bar).

5. During this stabilization period, it is advisable to check all plugged and capped outlets with a soap solution to detect leakage. If leakage is found at any connection, release the system pressure, seal the leaky cap(s) or plug(s) and begin the procedure again at Step 3.

6. After the stabilization period, adjust the air pressure to 3.5 psi (0.24 bar)and shut-off or disconnect the air supply.

7. The pipe system passes this test if the pressure drop is 0.5 psi (0.035 bar) or less during the time periods given in ***Table 9–1***.

8. Should the section of line under test fail the air test acceptance requirements, the pneumatic plugs can becoupled fairly close together and moved up or down the line, repeating the air test at each location, until the leak is found. This leak location method is very accurate, pinpointing the location of the leak to within one or two metres. Consequently, the area that must be excavated to make repairs is minimized, resulting in lower repair costs and considerable saved time.

! **Caution**: **CONSIDERABLE ENERGY IS STORED IN A PIPELINE UNDER PRESSURE. THIS IS PARTICULARLY TRUE WHEN AIR (EVEN AT LOW PRESSURES) IS THE TEST MEDIUM. TAKE GREAT CARE TO BE SURE THAT THE PIPELINE IS ADEQUATELY RESTRAINED AT CHANGES IN LINE DIRECTION AND FOLLOW MANUFACTURERS' SAFETY PRECAUTIONS FOR DEVICES SUCH AS PNEUMATIC PLUGS.**

! **Note**: This test will determine the rate at which air under pressure escapes from an isolated section of the pipeline. It is suited to determining the presence or absence of pipe damage and/or improperly assembled joints.

Diameter (in)	Time (min)	Diameter (in)	Time (min)
12	7.75	42	26.25
16	10.00	48	30.00
18	11.25	54	33.75
20	12.50	60	37.50
24	15.00	63	39.50
30	18.75	72	45.00
33	20.75	84	52.50
36	22.50	96	60.00

Table 9–1 Test Time – Field Air Test

10 **Alternate Installations**

If the burial depth requirements for the selected pipe stiffness, installation type and native soil group exceeds feasible compaction limits alternative installation procedures must be considered.

Three alternative installation methods are available:

- Wider Trench
- Permanent Sheeting (see section 7.5 ➔)
- Stabilised Backfill (Cement)

10.1 Wide Trench

Increasing the trench width distances the poor native soil farther from the pipe allowing a deeper installation and higher allowable negative pressure (vacuum).

10.2 Cement Stabilised Backfill

Scope

Cement is mixed with moist sandy soil, and the mixture placed and compacted as a typical backfill soil. The amount of type 3 Portland cement added to the sandy soil is approximately 4 to 5 parts per hundred weight of the soil. The moisture level should be in the range of 5 to 10%.
The compaction density required is dependent on the cover depth prior to allowing the stabilised backfill to set. If the desired cover depth is small, the required density is low. The cement-stabilised backfill can set in one or two days and the cover fill can be placed to grade, with a maximum total cover depth of 16 ft (5 m).

Mixture

100 parts soil (dry weight), 4 to 5 parts type 3 Portland cement, and 12% water (+/-6%). Account for the natural moisture content of the soil when adding water. The soil can be type SC2 or SC3. Type SC2 soil is the easiest to mix; however, the other type may be used. Mixing can be accomplished on the ground by spreading a layer of backfill soil and a thin layer of cement over it, and then mixing the two together.

The mixing can be done by hand, with a hoe, or mechanically with any appropriate device. The backfill should be placed within two hours of mixing.

Compaction

The cement-stabilised backfill will achieve a high stiffness without the need for significant compaction. Be sure to place a backfill under the pipe haunches and compact with a haunch-compaction tool. A Whacker compactor is required to compact the cement-stabilised backfill next to the pipe. One pass of the compactor with 12 in (300 mm) lifts is sufficient for most conditions in which the cover depth is less than 6 ft (2 m).

Check the pipe deflection to assure the compaction is adequate to support the pipe. If initial deflection exceeds 2.5%, increase the amount of compaction or use less cover until the cement-stabilised backfill sets in one or two days.
If a significant depth of cover is to be placed before the cement-stabilised backfill is allowed to set, a higher level of compaction is required to prevent excessive pipe deflection. Keep the initial deflection to no more than 2.5%. The amount of compaction effort required is dependent on cover depth, lift height and specific soil used in the mixture.

It is also recommended that a stabilised backfill be used in the immediate vicinity of large thrust blocks, or valve chambers and in areas of significant over-excavation.

Notes

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Appendix

Appendix A – Installation Design

The long life and good performance of FLOWTITE pipe is ensured by proper handling and installation. FLOWTITE pipes are flexible and allow the designer to utilize the bedding and pipe zone backfill for support. Together the pipe and embedment material from a “pipe-soil system” that provides proven long-term performance.

This Appendix is based on the current AWWA approach.

The support of the surrounding soil is defined in terms of the constrained or one dimensional soil modulus, Ms, at pipe elevation. To determine Ms for a buried pipe, separate Ms values for native soil, Msn, and the pipe backfill surround, Msb, must be determined and then combined depending on the trench width.

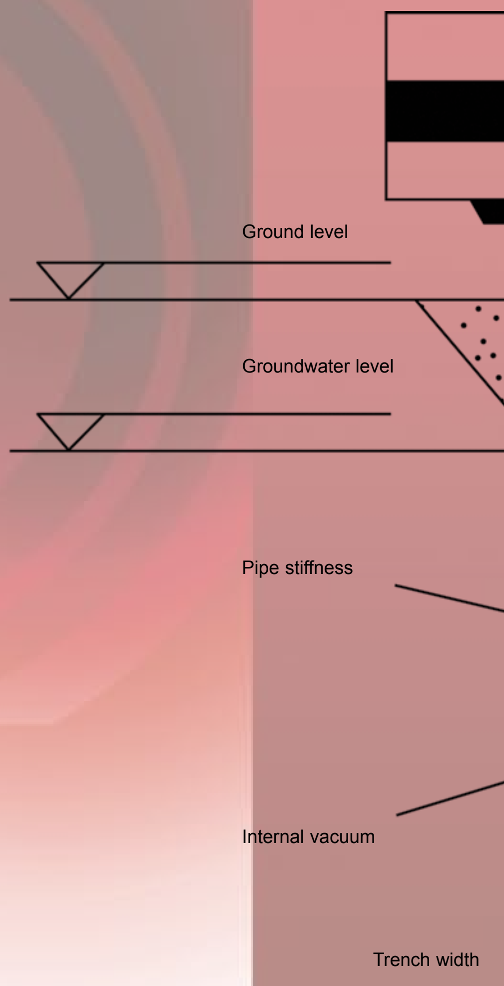
The most important installation design parametres are indicated in ***Figure A–1***. The native soil stiffness, burial depth, groundwater level, life load and internal vacuum must be determined according to the conditions along the route of the planned pipe installation. Based upon this information and available backfill material, backfill compaction, trench width and pipe stiffness is selected.

A.1 Design Principles

A flexible pipe like FLOWTITE will deflect when subjected to soil and traffic loads. When deflected the increase of the pipe horizontal diameter will develop passive soil resistance counteracting the deflection.
The amount of deflection needed to generate sufficient earth pressure to resist any given load will primarily depend on the stiffness of the backfill material and native soil as well as trench width. The initial deflection of the pipe measured after backfilling to level can therefore be considered as a direct indicator of the quality of the pipe installation.

Settlement and consolidation of the soil surrounding the pipe will result in an increase of the pipe deflection over time. Almost all of the increase in deflection will take place during the first 1 to 2 years after installation. After that the deflection will stabilize.

The initial deflections must not exceed 3% of diameter. Pipes installed outside this limit may not perform as intended.
The type of installation appropriate for FLOWTITE pipe varies with native soil characteristics, cover depth, loading conditions and available backfill materials. The native soil and backfill material must adequately confine the pipe to achieve proper pipe support.



Pipe installation design tables showing minimum backfill compaction are given in Appendix B ➔.
The most commonly encountered installation and operating conditions are covered. Tables are provided for selected combinations of 1) groundwater level, 2) traffic load, 3) internal vacuum and 4) trench width.

The tables show minimum backfill compaction at different burial depths for all practical combination of backfill materials, native soils and pipe stiffness. All of the tables are valid for working pressure anywhere in the range from atmospheric to nominal pressure of the pipe.

The expected initial pipe deflection is less than 2% for most installations given in Appendix B. Therefore, while an initial deflections in 3% is acceptable for the pipe performance, a value exceeding the expected amount indicates the installation intended has not been achieved and should be improved for the next pipes (i.e. increased pipe zone backfill compaction, coarser grained pipe zone backfill materials or wider trench, etc.).

Appendices from C through G give information on both native and backfill soils.

- **Appendix C** – Classification and Properties of Native Soils
- **Appendix D** – Classification and Properties of Backfill Soils
- **Appendix E** – Field Testing to assist Classification of Native Soils
- **Appendix F** – Compaction of Backfill
- **Appendix G** – Definitions and Terminology

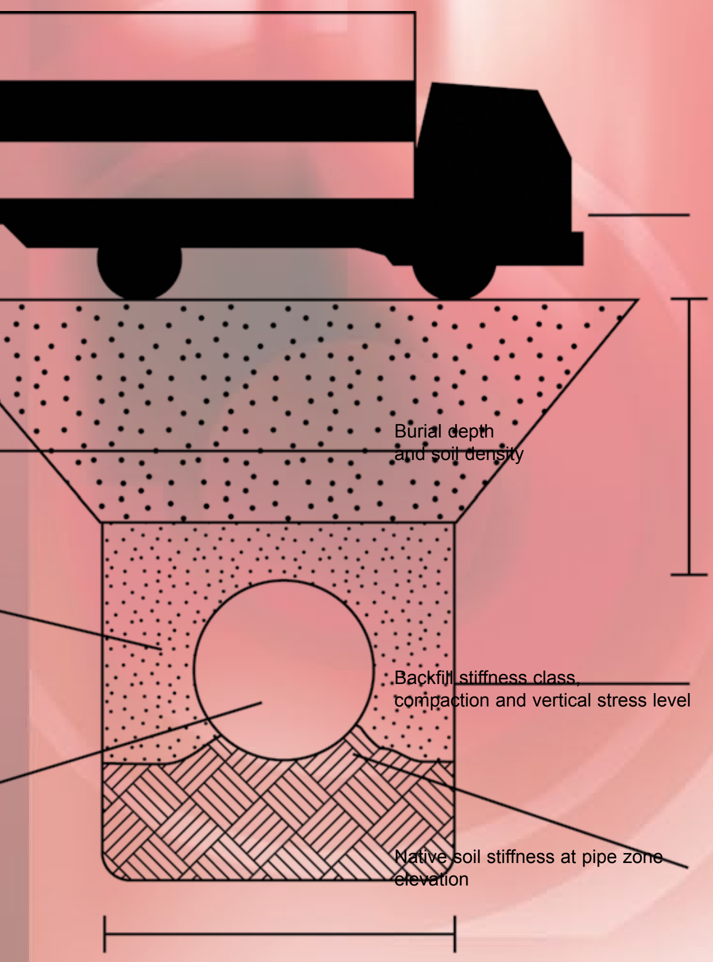


Figure A–1 Installation Design Parameters

A.2 Native Soil Stiffness Groups

The support of the native soil is defined in terms of the constrained or one dimensional soil modulus M_{sn} at pipe elevation. For design of pipe installations, native soils are grouped in stiffness groups. In ***Table A–1*** are brief descriptions of the native soil stiffness groups. Appendix C gives detailed definitions for native soil groups.

Testing of native soil should be done frequently and particularly where changes are suspected. Properties of importance are those obtained at the bed and pipe zone elevation. The blow counts or soil strengths must represent the most severe (weakest) condition expected to exist for any significant period of time. (Normally this occurs when the water table is at its highest elevation.)

A.3 Backfill Constrained Modulus, M_{sb}

The measure of the level of backfill soil support is expressed as the constrained soil modulus M_{sb} in MPa. For design of pipe installations, suitable backfill soils are classified in 4 different stiffness categories, SC1, SC2, SC3 and SC4. A brief description of the backfill stiffness categories is given in ***Table A–2.***

For any given backfill stiffness category, the higher the compaction the higher the soil modulus and the higher the support. In addition, the soil modulus also increases with the vertical soil stress level, i.e. with burial depth.

Table A–3 to ***Table A–6*** give the M_{sb} values for backfill stiffness categories SC1, SC2, SC3 and SC4 as a function of the % Standard Proctor Density (SPD) and vertical stress level.
The values apply to pipes installed above the groundwater level. For pipes installed below groundwater level, the constrained soil modulus will be reduced for lower stiffness class soils and lower compaction, see values in parenthesis.
The vertical stress level is the vertical effective soil stress at the pipe springline elevation. It is normally computed as the design soil unit weight times the depth of fill. Buoyant unit weight should be used below the groundwater level.

For description of backfill soil stiffness categories, see Appendix D.

Soil group	Granular		Cohesive		Modulus
	Blow count[1]	Description	q_u tons / ft^2	Description	M_{sn} psi
1	> 15	Compact	> 2.0	Very stiff	5000
2	8 - 15	Slightly compact	1.0 - 2.0	Stiff	3000
3	4 - 8	Loose	0.50 - 1.0	Medium	1500
4	2 - 4		0.25 - 0.50	Soft	700
5	1 - 2	Very loose	0.125 - 0.25	Very soft	200
6	0 - 1	Very very loose	0 - 0.125	Very very soft	50

[1] Standard penetration test per ASTM D1586

Table A–1 Native Soil Stiffness Groups. Values of Constrained Modulus, M_{sn}

Backfill Soil Stiffness Category	Description of Backfill Soils
SC1	Crushed rock with < 15% sand, maximum 25% passing the 3/8 in sieve and maximum 5% fines2).
SC2	Clean, coarse-grained soils: SW, SP1), GW, GP or any soil beginning with one of these symbols with 12% or less fines2).
SC3	Clean, coarse-grained soils with fines: GM, GC, SM, SC or any soil beginning with one of these symbols with 12% or more fines2). Sandy or gravely fine-grained soils: CL, ML, (or CL-ML, CL/ML, ML/CL) with 30% or more retained on a no. 200 sieve
SC4	Fine grained soils: CL, ML, (or CL-ML, CL/ML, ML/CL) with 30% or less retained on a no. 200 sieve

Note: Symbols in table are according to the Unified Soil Classification Designation, ASTM D2487
1) Uniform fine sand, SP, with more than 50% passing no. 100 sieve (0.006 in) is very sensitive to moisture and is not recommended as backfill.
2) % fines is the weight percentage of soil particles that pass no. 200 sieve with 0.003 in opening

Table A–2 Backfill Soil Type Classification

Burial Depth (Soil Density 120 pcf)	Vertical Stress Level	Compaction, % maximum Standard Proctor Density	
		Compacted	Dumped
ft	psi	psi	psi
1.2	1	2350	2000
6	5	3450	2600
12	10	4200	3000
24	20	5500	3450
48	40	7500	4250
72	60	9300	5000

Table A–3 M_{sb} for SC1 Backfill Soil

Burial Depth (Soil Density 120 pcf)	Vertical Stress Level	Compaction, % maximum Standard Proctor Density			
		100	95	90	85
ft	psi	psi	psi	psi	psi
1.2	1	2350	2000	1275 (1085)	470 (330)
6	5	3450	2600	1500 (1275)	520 (365)
12	10	4200	3000	1625 (1380)	570 (400)
24	20	5500	3450	1800 (1530)	650 (455)
48	40	7500	4250	2100 (1785)	825 (575)
72	60	9300	5000	2500 (2125)	1000 (700)

Table A–4 M_{sb} for SC2 Backfill Soil (reduced values below ground water table in parenthesis)

Burial Depth (Soil Density 120 pcf)	Vertical Stress Level	Compaction, % maximum Standard Proctor Density		
		95	90	85
ft	psi	psi	psi	psi
1.2	1	1415 (708)	670 (335)	360 (180)
6	5	1670 (835)	740 (370)	390 (195)
12	10	1770 (885)	750 (375)	400 (200)
24	20	1880 (940)	790 (395)	430 (215)
48	40	2090 (1045)	900 (450)	510 (255)
72	60	2300 (1150)	1025 (512)	600 (300)

Table A–5 M_{sb} for SC3 Backfill Soil (values below ground water level in parenthesis)

Burial Depth (Soil Density 120 pcf)	Vertical Stress Level	Compaction, % maximum Standard Proctor Density		
		95	90	85
ft	psi	psi	psi	psi
1.2	1	530 (159)	255 (77)	130 (39)
6	5	625 (188)	320 (96)	175 (53)
2	10	690 (207)	355 (107)	200 (60)
24	20	740 (222)	395 (119)	230 (69)
48	40	815 (245)	460 (138)	285 (86)
72	60	895 (269)	525 (158)	345 (104)

Table A–6 M_{sb} for SC4 Backfill Soil (values below ground water level in parenthesis)

! **Note:** M_{sb} values at intermediate vertical stress levels not given in ***Table A–3*** to ***Table A–6*** can be obtained by interpolation.

! **Note:** The % maximum standard proctor density indicates the dry density of the compacted soil as a percentage of maximum dry density determined in accordance with ASTM D 698.

A.4 Trench Width

The soil support for a buried pipe installation, expressed as the composite constrained soil modulus, M_s, depends on the constrained modulus of both the backfill and native soil, M_{sb} and M_{sn}, as well as the trench width.

For pipe installation in soft native soils where M_{sn} is lower than M_{sb}, the composite modulus, M_s, will be lower than the backfill modulus, M_{sb}. This effect is less pronounced for wider trenches and can be disregarded for trenches wider than 5 times the pipe diameter at elevation of the pipe springline. This means that a wider trench provides for better soil support.

For installations in firm native soils where M_{sn} is higher than M_{sb}, the composite modulus will be higher than the backfill modulus. This effect will be less pronounced for a wider trench, which in this case will provide less soil support.

The trench must always be wide enough to allow for adequate space to ensure proper placement and compaction of backfill in the haunch region. It must also be wide enough to safely operate compaction equipment without damaging the pipe.

A.5 Negative Pressure

In order to provide proper soil stabilizing support, a minimum burial depth of 3 ft (1 m) is recommended for negative pressure (vacuum) situations where the negative pressure is in excess of 3.5 psi (0.25 bar) for SN 8, 7.35 psi (0.5 bar) for SN 18 pipes.

The maximum allowable negative pressure (vacuum) in the pipe is a function of burial depth, native soil, pipe and backfill soil stiffness as well as trench width. See Appendix B ➔ for backfill compaction requirement for conditions with vacuum in the pipe.

Unburied Pipe Sections

Some sections of a buried pipeline, such as in valve pits or chambers, may be non-soil supported. As the stabilizing support of the soil is not present the negative pressure capability has to be evaluated separately. ***Table A–7*** gives the maximum allowable negative pressure for lengths between restraints of 10, 20 and 40 ft (3, 6 and 12 m).

DN	SN18			SN36			SN46			SN72		
(in)	10 ft	20 ft	40 ft	10 ft	20 ft	40 ft	10 ft	20 ft	40 ft	10 ft	20 ft	40 ft
12	4.05	3.65	3.65	7.70	7.35	7.35	9.30	9.30	9.30	14.7	14.7	14.7
16	4.65	3.65	3.65	8.40	7.35	7.35	9.65	9.30	9.30	14.7	14.7	14.7
18	4.65	3.75	3.65	8.70	7.40	7.35	10,0	9.40	9.30	14.7	14.7	14.7
20	5.65	3.75	3.65	9.40	7.40	7.35	10.2	9.40	9.30	14.7	14.7	14.7
24	6.95	3.90	3.65	11.6	7.50	7.35	12.2	9.50	9.30	14.7	14.7	14.7
30	9.55	4.05	3.65	14.7	7.80	7.35	14.7	9.60	9.30	14.7	14.7	14.7
36	11.2	4.65	3.65	14.7	8.55	7.35	14.7	10.3	9.30	14.7	14.7	14.7
42	11.9	5.20	3.75	14.7	9.30	7.40	14.7	10.7	9.40	14.7	14.7	14.7
48	13.8	7.70	3.75	14.7	11.1	7.50	14.7	11.8	9.50	14.7	14.7	14.7
54	14.7	9.00	3.90	14.7	14.2	7.70	14.7	14.7	9.80	14.7	14.7	14.7
60	14.7	10.4	4.05	14.7	14.4	7.80	14.7	14.7	9.90	14.7	14.7	14.7
63	14.7	10.6	4.20	14.7	14.7	8.10	14.7	14.7	10.1	14.7	14.7	14.7
72	14.7	11.1	4.65	14.7	14.7	8.55	14.7	14.7	10.7	14.7	14.7	14.7
78	14.7	11.7	5.10	14.7	14.7	9.15	14.7	14.7	11.0	14.7	14.7	14.7
84	14.7	12.2	5.35	14.7	14.7	9.55	14.7	14.7	11.5	14.7	14.7	14.7
96	14.7	13.6	6.50	14.7	14.7	11.0	14.7	14.7	13.0	14.7	14.7	14.7

Table A–7
Maximum Allowable Negative Pressure (psi) for Unburied Sections – Pipe Length between Restraints 10 ft / 20 ft and 40 ft

A.6 Burial Limitation – Minimum

General

Minimum recommended burial depth for pipes with operating pressures of 150 psi (10 bars) or less is 1.5 ft (0.5 m) provided that pipes are joined without vertical joint deflection. For operating and installation conditions involving traffic load, negative pressure, high pressure, high water table or frost, see requirements in the following sections.

Traffic Loading

In situations where pipes are to be buried under a roadway, or continuing traffic loading is anticipated, the backfill material should be compacted to grade level. Consult road construction codes of practice for local requirements and recommendations. Minimum cover restrictions may be reduced with special installations such as concrete encasement, concrete cover slabs, castings, etc.

The installation tables in Appendix B are based on an assumed AASHTO HS20 load. In general a minimum burial depth of 3 ft (1 m) is recommended good practice for traffic loading using well compacted granular soils as backfill. ***Table A–8*** shows the minimum burial depth for other traffic loadings.

Load Type	Traffic (Wheel) Load (lb)	Minimum Cover Depth (ft)
AASHTO HS20	16000	2.6
AASHTO HS25	20000	3.3
MOC	36000	5
Cooper E80 Railroad Engine		10

Table A–8 Minimum Cover Depths with Traffic Load in Standard Conditions

Construction Traffic Loading

In some cases large, heavy earth moving equipment or construction cranes may be present in or near the pipe installation area. These types of equipment can result in very high localized surface loads. The effects of such loading must be evaluated on a case by case basis to establish proper procedures and limits.

Negative Pressure

A minimum burial depth of 3 ft (1 m) is recommended for negative pressure (vacuum) situations where the negative pressure is in excess of 3.5 psi (0.25 bar) for SN 18 (SN 2500) and 7.5 psi (0.5 bar) for SN 36 (SN 5000) pipes.

High Pressure

High pressures require consideration of the possible uplift forces at joints both during operation and any field hydrotesting. For operating pressures of 225 psi (16 bar) and greater the minimum burial depth should be 4 ft for pipes of DN 12 in (300 mm) and larger.
During field hydrotesting at pressures below 225 psi (16 bar) the couplings should be backfilled at least to the crown with pipes backfilled to the minimum cover depth.
During field hydrotesting at pressures 225 psi (16 bar) and greater: For pipes in straight alignment backfill to the crown of the coupling or higher before performing the field hydrotest. Pipes must be backfilled to minimum cover. For pipes installed with angular deflection both the pipe and the coupling must be covered to the final grade before the field pressure test.

High Water Table

A minimum of 0.75 diameter of earth cover (minimum dry soil bulk density of 120 pcf [19 kN/m^3]) is required to prevent an empty submerged pipe from floating.
Alternatively, the installation may proceed by anchoring the pipes. If anchoring is proposed, restraining straps must be a flat material, minimum 1 in (25 mm) width, placed at maximum 3 ft (1 m) intervals. Consult the manufacturer for details on anchoring and minimum cover depth with anchors.

Frost Line

The minimum cover depth for FLOWTITE pipe, as any other pipe material, should be such that the pipe is buried BELOW the anticipated frost level, or consult the local construction codes of practice for other techniques when installing the pipe within the frost level.

A.7 Seismic Loading

Because of their flexibility FLOWTITE pipes have demonstrated excellent seismic behaviour. The structural analysis of pipes under earthquake loading is site specific, where moment magnitude, soil characteristics and the probability of the event are the main input. Consult your supplier for specific design considerations and analysis.

A.8 Backfill Migration

When open graded material is placed adjacent to a finer material, fines may migrate into the coarser material under the action of hydraulic gradient from groundwater flow. Significant hydraulic gradients may arise in the pipeline trench during construction, when water levels are controlled by pumping, or after construction, when permeable underdrain or embedment materials act as a drain under high ground water levels. Field experience shows that migration can result in significant loss of pipe support and increase of deflections.

The gradation and relative size of the embedment and adjacent materials must be compatible in order to minimize migration. In general, where significant groundwater flow is anticipated, avoid placing coarse, open-graded material, such as SC1, below or adjacent to finer material unless methods are employed to impede migration.
Consider the use of an appropriate soil filter or a geotextile filter fabric along the boundary of incompatible materials.
The following filter gradation criteria may be used to restrict migration of fines into the voids of coarser material under hydraulic gradient:

- $D_{15}/d_{85} < 5$ where D_{15} is the sieve opening size passing 15 percent by weight of the coarser material and d_{85} is the sieve opening size passing 85 percent by weight of the finer material.

- $D_{50}/d_{50} < 25$ where D_{50} is the sieve opening size passing 50 percent by weight of the coarser material and d_{50} is the sieve opening size passing 50 percent by weight of the finer material. This criterion need not apply if the coarser material is well graded (see ASTM D 2487).

If the finer material is a medium to highly plastic clay (CL or CH), then the following criterion may be used in lieu of the D_{15}/d_{85} criteria: $D_{15} < 0.02$ in (0.5 mm) where D_{15} is the sieve opening size passing 15 percent by weight of the coarser material.

The aforementioned criteria may need to be modified if one of the materials is gap graded. Materials selected for use based on filter gradation criteria should be handled and placed in a manner that will minimize segregation.
Where incompatible materials must be used, they must be separated by filter fabric designed to last the life of the pipeline to prevent wash-away and migration. The filter fabric must completely surround the bedding and pipe zone backfill material and must be folded over the pipe zone area in order to prevent contamination of the selected backfill material.

Appendix B – Installation Tables

Pipe installation design tables showing minimum backfill compaction are given in this Appendix. The minimum backfill compaction is given at different burial depths for all practical combinations of backfill stiffness category, native soil stiffness group and pipe stiffness. Both standard, $B_d/D = 1.8$ and wide, $B_d/D = 3.0$, trenches are covered. Tables are provided for selected combinations of 1) groundwater level, 2) traffic load and 3) internal vacuum. All of the tables are valid for working pressure anywhere in the range from atmospheric to nominal pressure of the pipe.

The minimum backfill compaction is expressed as percent standard proctor density for backfill soil categories SC2, SC3 and SC4. For crushed rock as backfill, SC1, the minimum compaction is expressed either as dumped, D, or compacted, C. Note that SC1 backfill material also has to be worked into the haunch zone for installation conditions where compaction is otherwise not required.

The compaction values recommended are to be considered as a minimum values and field densities should be at or higher than the requirement. Include considerations for seasonal variations when assessing the potential for moisture content of both in situ and backfill soils.

The backfill compaction tables are calculated following the current approach of AWWA assuming the soil and bedding properties listed below:

- Deflection lag factor, DL = 1.5
- Dry unit weight of overburden, gs,dry = 120 pcf (19 kN/m^3)
- Wet (buoyant) unit weight of overburden, gs, wet = 73.5 pcf (11.6 kN/m^3)
- Bedding coefficient (typical direct bury condition), k_x = 0.1

Backfill compaction tables have been calculated for the loading and installation conditions listed in ***Table B–1*** and ***Table B–2***.

Table B–1 shows combinations calculated for pipes to be installed with backfill configuration Type 1, see ***Figure 3–4*** ➔.

Traffic Load	Internal Vacuum	Ground Water	Trench Width at Pipe Springline	Installation Table
AASTHO	psi		B_d/D	
0	0	Below pipe	1.8 and 3.0	Table B–3
HS 20	0	Below pipe	1.8 and 3.0	Table B–4
0	14.7	Below pipe	1.8 and 3.0	Table B–5
0	0	To level	1.8 and 3.0	Table B–6
HS 20	0	To level	1.8 and 3.0	Table B–7
0	14.7	To level	1.8 and 3.0	Table B–8

Table B–1 Load Combinations for Type 1 Installation

! **Note**: For installations where both traffic load and vacuum can occur, use the highest compaction requirement of ***Table B–4*** and ***Table B–5*** for installations with ground water below pipe and the highest of ***Table B–7*** and ***Table B–8*** for installation with groundwater to level.

Table B–2 shows combinations calculated for pipes to be installed with backfill configuration Type 2 (split), see Figure 3–5 ➔.

Internal Vacuum	Ground Water	Trench Width at Pipe Springline	Backfill Below 0.6xDN	Backfill Above 0.6xDN		Installation Table
psi		Bd/D	Category	Category	% SPD	
0	Below pipe	1.8 and 3.0	SC1, SC2	SC3	85	Table B–9
0	Below pipe	1.8 and 3.0	SC1, SC2	SC4	90	Table B–9
7.35	Below pipe	1.8 and 3.0	SC1, SC2	SC3	85	Table B–10
7.35	Below pipe	1.8 and 3.0	SC1, SC2	SC4	90	Table B–10
14.7	Below pipe	1.8 and 3.0	SC1, SC2	SC3	85	Table B–11
14.7	Below pipe	1.8 and 3.0	SC1, SC2	SC4	90	Table B–11
0	To level	1.8 and 3.0	SC1, SC2	SC3	85	Table B–12
0	To level	1.8 and 3.0	SC1, SC2	SC4	95	Table B–12
7.35	To level	1.8 and 3.0	SC1, SC2	SC3	85	Table B–13
7.35	To level	1.8 and 3.0	SC1, SC2	SC4	95	Table B–13
14.7	To level	1.8 and 3.0	SC1, SC2	SC3	85	Table B–14
14.7	To level	1.8 and 3.0	SC1, SC2	SC4	95	Table B–14

Table B–2 Load Combinations for Type 2 Installation

For other installation and/or operating conditions, consult the appropriate AWWA or ATV installation design documents.

Type 1 Installation

No Traffic Load – No Internal Vacuum – Ground Water Below Pipe Invert

Native Soil Group	Burial Depth ft	Standard Trench, Bd/D = 1.8																Wide Trench, Bd/D = 3.0															
	Backfill	SC1				SC2				SC3				SC4				SC1				SC2				SC3				SC4			
		Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN			
		18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72
Group 1	3.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90
	4.5	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90
	6.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90
	10.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90
	15.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	90
	25.0	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95	D	D	D	D	90	90	90	90	90	90	90	90		95	95	95
	40.0	D	D	D	D	90	90	90	85	90	90	90	85				95	D	D	D	D	90	90	90	90	95	95	95	95				
	65.0	D	D	D	D	90	90	90	90	95	95	95	95					D	D	D	D	90	90	90	90				95				
	95.0	C	C	C	C	95	95	95	95									C	C	C	C	95	95	95	95								
Group 2	3.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90
	4.5	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90
	6.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90
	10.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90
	15.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	95	95	90	90
	25.0	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95	D	D	D	D	90	90	90	90	95	90	90	90				95
	40.0	D	D	D	D	90	90	90	90	95	95	95	90					D	D	D	D	90	90	90	90	95	95	95	95				
	65.0	C	D	D	D	95	90	90	90				95					C	C	C	C	95	95	95	95								
	95.0	C	C	C	C	100	100	100	100									C	C	C	C	95	95	95	95								
Group 3	3.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90
	4.5	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90
	6.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90
	10.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90
	15.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95
	25.0	D	D	D	D	90	90	90	85	90	90	90	85	95	95	95	95	D	D	D	D	90	90	90	90	95	95	95	95				
	40.0	D	D	D	D	90	90	90	90	95	95	95	95					D	D	D	D	90	90	90	90	95	95	95	95				
	65.0	C	C	C	C	100	100	100	100									C	C	C	C	95	95	95	95								
	95.0																	C	C	C	C	100	95	95	95								
Group 4	3.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90
	4.5	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90
	6.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90
	10.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90
	15.0	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	90	D	D	D	D	90	85	85	85	90	85	85	85	95	95	95	95
	25.0	C	D	D	D	95	90	90	90	95	95	95	95					D	D	D	D	90	90	90	90	95	95	95	95				
	40.0	C	C	C	C	100	100	100	95									D	D	D	D	90	90	90	90	95	95	95	95				
	65.0																	C	C	C	C	95	95	95	95								
	95.0																	C	C	C	C	100	100	100	100								
Group 5	3.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90
	4.5	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90
	6.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90
	10.0	D	D	D	D	90	90	85	85	95	90	90	85		95	95	90	D	D	D	D	85	85	85	85	85	85	85	85	95	90	90	90
	15.0	C	C	C	D	95	95	95	90				95					D	D	D	D	90	90	90	85	95	90	90	85				95
	25.0	C	C	C	C	100	100	100	100									D	D	D	D	90	90	90	90	95	95	95	95				
	40.0																	C	C	C	C	95	95	95	95								
	65.0																	C	C	C	C	95	95	95	95								
	95.0																	C	C	C	C	100	100	100	100								
Group 6	3.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90
	4.5	D	D	D	D	90	85	85	85	90	85	85	85	95	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90
	6.0	D	D	D	D	90	90	90	85	95	90	90	85			95	90	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90
	10.0	C	C	D	D	95	95	90	90			95	95					D	D	D	D	90	85	85	85	90	85	85	85	95	95	95	90
	15.0			C	C			100	100									D	D	D	D	90	90	90	90	95	95	95	95				
	25.0																	C	D	D	D	95	90	90	90		95	95	95				
	40.0																	C	C	C	C	95	95	95	95								
	65.0																	C	C	C	C	100	100	100	100								
	95.0																		C	C	C		100	100	100								

Table B–3 No Traffic Load – No Internal Vacuum – Ground Water Below Pipe Invert
Minimum Backfill Compaction, % Standard Proctor Density. (D=Dumped, C= Compacted)

Type 1 Installation	**Traffic Load AASHTO HS20 – No Internal Vacuum – Ground Water Below Pipe Invert**																																
Burial Depth ft / Backfill	Standard Trench, Bd/D = 1.8																Wide Trench, Bd/D = 3.0																Native Soil Group
	SC1				SC2				SC3				SC4				SC1				SC2				SC3				SC4				
	Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				
	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	
3.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					Group 1
4.5	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
6.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
10.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
15.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
25.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	90	90	90	90	90	90	90	90					
40.0	D	D	D	D	90	90	90	85	90	90	90	85					D	D	D	D	90	90	90	90	95	95	95	95					
65.0	D	D	D	D	90	90	90	90	95	95	95	95					D	D	D	D	90	90	90	90				95					
95.0	C	C	C	C	95	95	95	95									C	C	C	C	95	95	95	95									
3.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					Group 2
4.5	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
6.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
10.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
15.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
25.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	90	90	90	90	95	90	90	90					
40.0	D	D	D	D	90	90	90	90	95	95	95	90					D	D	D	D	90	90	90	90	95	95	95	95					
65.0	C	D	D	D	95	90	90	90				95					C	C	C	C	95	95	95	95									
95.0	C	C	C	C	100	100	100	100									C	C	C	C	95	95	95	95									
3.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					Group 3
4.5	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
6.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
10.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
15.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
25.0	D	D	D	D	90	90	90	85	90	90	90	85					D	D	D	D	90	90	90	90	95	95	95	95					
40.0	D	D	D	D	90	90	90	90	95	95	95	95					D	D	D	D	90	90	90	90	95	95	95	95					
65.0	C	C	C	C	100	100	100	100									C	C	C	C	95	95	95	95									
95.0																	C	C	C	C	100	95	95	95									
3.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					Group 4
4.5	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
6.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
10.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
15.0	D	D	D	D	90	85	85	85	90	85	85	85					D	D	D	D	90	85	85	85	90	85	85	85					
25.0	C	D	D	D	95	90	90	90	95	95	95	95					D	D	D	D	90	90	90	90	95	95	95	95					
40.0	C	C	C	C	100	100	100	95									D	D	D	D	90	90	90	90	95	95	95	95					
65.0																	C	C	C	C	95	95	95	95									
95.0																	C	C	C	C	100	100	100	100									
3.0	D	D	D	D	90	85	85	85	95	90	90	85					D	D	D	D	85	85	85	85	85	85	85	85					Group 5
4.5	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
6.0	D	D	D	D	85	85	85	85	90	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
10.0	D	D	D	D	90	90	90	85	95	95	95	85					D	D	D	D	85	85	85	85	85	85	85	85					
15.0	C	C	C	D	95	95	95	90				95					D	D	D	D	90	90	90	90	95	90	90	90					
25.0	C	C	C	C	100	100	100	100									D	D	D	D	90	90	90	90	95	95	95	95					
40.0																	C	C	C	C	95	95	95	95									
65.0																	C	C	C	C	95	95	95	95									
95.0																	C	C	C	C	100	100	100	100									
3.0	C	D	D	D	95	90	90	90				95					D	D	D	D	85	85	85	85	90	90	90	85					Group 6
4.5	D	D	D	D	90	90	90	85	95	95	95	90					D	D	D	D	85	85	85	85	85	85	85	85					
6.0	C	D	D	D	95	90	90	90		95	95	90					D	D	D	D	85	85	85	85	85	85	85	85					
10.0	C	C	C	D	95	95	95	90				95					D	D	D	D	90	85	85	85	90	90	90	85					
15.0				C				100									D	D	D	D	90	90	90	90	95	95	95	95					
25.0																	C	C	C	D	95	95	95	90		95	95	95					
40.0																	C	C	C	C	95	95	95	95									
65.0																	C	C	C	C	100	100	100	100									
95.0																		C	C	C		100	100	100									

Table B–4 Traffic Load AASHTO HS20 – No Internal Vacuum – Ground Water Below Pipe Invert Minimum Backfill Compaction, % Standard Proctor Density. (D=Dumped, C= Compacted)

Type 1 Installation — **No Traffic Load – 14.7 psi Internal Vacuum – Ground Water Below Pipe Invert**

Native Soil Group	Burial Depth ft \ Backfill	Standard Trench, Bd/D = 1.8																Wide Trench, Bd/D = 3.0															
		SC1				SC2				SC3				SC4				SC1				SC2				SC3				SC4			
		Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN			
		18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72
Group 1	3.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	95	90	90	90
	4.5	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	95	90	90	90
	6.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	95	90	90	90
	10.0	D	D	D	D	85	85	85	85	85	85	85	85	95	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	95	95	90	90
	15.0	D	D	D	D	85	85	85	85	85	85	85	85	95	90	90	90	D	D	D	D	90	85	85	85	90	85	85	85	95	95	95	90
	25.0	D	D	D	D	90	85	85	85	90	85	85	85	95	95	95	95	D	D	D	D	90	90	90	90	95	90	90	90		95	95	95
	40.0	D	D	D	D	90	90	90	85	95	90	90	85				95	D	D	D	D	90	90	90	90	95	95	95	95				
	65.0	C	D	D	D	95	90	90	90		95	95	95					C	D	D	D	95	90	90	90				95				
	95.0	C	C	C	C	100	95	95	95									C	C	C	C	100	95	95	95								
Group 2	3.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	95	90	90	90
	4.5	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	95	90	90	90
	6.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	95	90	90	90
	10.0	D	D	D	D	85	85	85	85	85	85	85	85	95	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	95	95	90	90
	15.0	D	D	D	D	85	85	85	85	85	85	85	85	95	90	90	90	D	D	D	D	90	85	85	85	90	85	85	85		95	95	90
	25.0	D	D	D	D	90	85	85	85	90	85	85	85		95	95	95	D	D	D	D	90	90	90	90	95	90	90	90				95
	40.0	D	D	D	D	90	90	90	90	95	95	95	90					D	D	D	D	90	90	90	90	95	95	95	95				
	65.0	C	D	D	D	95	90	90	90				95					C	C	C	C	95	95	95	95								
	95.0		C	C	C		100	100	100									C	C	C	C	100	95	95	95								
Group 3	3.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	95	90	90	90
	4.5	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	95	90	90	90
	6.0	D	D	D	D	85	85	85	85	85	85	85	85	90	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	95	90	90	90
	10.0	D	D	D	D	85	85	85	85	85	85	85	85	95	90	90	90	D	D	D	D	90	85	85	85	90	85	85	85	95	95	95	90
	15.0	D	D	D	D	90	85	85	85	90	85	85	85	95	95	95	90	D	D	D	D	90	85	85	85	95	85	85	85		95	95	95
	25.0	D	D	D	D	90	90	90	85	95	90	85	85		95	95	95	D	D	D	D	90	90	90	90	95	95	95	95				
	40.0	C	D	D	D	95	90	90	90		95	95	95					C	D	D	D	95	90	90	90		95	95	95				
	65.0		C	C	C		100	100	100									C	C	C	C	95	95	95	95								
	95.0																	C	C	C	C	100	100		95								
Group 4	3.0	D	D	D	D	85	85	85	85	85	85	85	85	95	90	90	90	D	D	D	D	85	85	85	85	90	85	85	85	95	90	90	90
	4.5	D	D	D	D	85	85	85	85	85	85	85	85	95	90	90	90	D	D	D	D	85	85	85	85	85	85	85	85	95	95	90	90
	6.0	D	D	D	D	85	85	85	85	85	85	85	85	95	90	90	90	D	D	D	D	90	85	85	85	90	85	85	85	95	95	90	90
	10.0	D	D	D	D	90	85	85	85	90	85	85	85	95	90	90	90	D	D	D	D	90	85	85	85	90	85	85	85	95	95	95	90
	15.0	D	D	D	D	90	90	90	85	95	90	85	85		95	95	90	D	D	D	D	90	90	90	85	95	90	85	85		95	95	95
	25.0	C	D	D	D	95	90	90	90		95	95	95					D	D	D	D	90	90	90	90	95	95	95	95				
	40.0		C	C	C		100	100	95									C	D	D	D	95	90	90	90		95	95	95				
	65.0																	C	C	C	C	100	95	95	95								
	95.0																		C	C	C		100	100	100								
Group 5	3.0	D	D	D	D	90	90	90	85	95	90	90	85			95	90	D	D	D	D	90	85	85	85	90	85	85	85	95	95	95	90
	4.5	C	D	D	D	95	90	90	85	95	95	90	85				95	D	D	D	D	90	85	85	85	90	85	85	85		95	95	90
	6.0	C	D	D	D	95	90	90	85		95	95	85				95	D	D	D	D	90	85	85	85	90	85	85	85		95	95	90
	10.0	C	D	D	D	95	90	90	90		95	95	90					D	D	D	D	90	90	90	85	95	90	85	85		95	95	95
	15.0	C	C	C	D	100	95	95	90				95					D	D	D	D	90	90	90	85	95	95	90	85				95
	25.0		C	C	C		100	100	100									C	D	D	D	95	90	90	90		95	95	95				
	40.0																	C	C	C	C	95	95	95	95								
	65.0																	C	C	C	C	100	95	95	95								
	95.0																		C	C	C		100	100	100								
Group 6	3.0		C	C	D		95	95	90				95					D	D	D	D	90	90	90	85	95	90	90	85		95	95	95
	4.5		C	C	D		95	95	90				95					D	D	D	D	90	90	90	85	95	90	90	85		95	95	95
	6.0		C	C	C		95	95	95				95					D	D	D	D	90	90	90	85	95	90	90	85				95
	10.0		C	C	C		100	100	95									D	D	D	D	90	90	90	85	95	95	90	85				95
	15.0				C				100									C	D	D	D	95	90	90	90	95	95	95	95				
	25.0																	C	D	D	D	95	90	90	90		95	95	95				
	40.0																	C	C	C	C	100	95	95	95								
	65.0																	C	C	C	C	100	100	100	100								
	95.0																			C	C			100	100								

Table B–5 No Traffic Load – 14.7 psi Internal Vacuum – Ground Water Below Pipe Invert Minimum Backfill Compaction, % Standard Proctor Density. (D=Dumped, C= Compacted)

Type 1 Installation	No Traffic Load – No Internal Vacuum – Ground Water to Grade Level																																
Native Soil Group	Backfill	Standard Trench, Bd/D = 1.8																Wide Trench, Bd/D = 3.0															
		SC1				SC2				SC3				SC4				SC1				SC2				SC3				SC4			
		Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN			
	Burial Depth ft	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72
Group 1	3.0	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95
	4.5	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95
	6.0	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95
	10.0	D	D	D	D	85	85	85	85	85	85	85	85		95	95	95	D	D	D	D	85	85	85	85	85	85	85	85				95
	15.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	90	90	90	85	95	95	95	85				
	25.0	D	D	D	D	90	90	90	90	95	95	95	95					D	D	D	D	90	90	90	90	95	95	95	95				
	40.0	D	D	D	D	90	90	90	90	95	95	95	95					D	D	D	D	90	90	90	90								
	65.0	C	D	D	D	95	90	90	90									C	C	C	C	95	95	95	95								
	95.0	C	C	C	C	100	95	95	95									C	C	C	C	100	95	95	95								
Group 2	3.0	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95
	4.5	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95
	6.0	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95
	10.0	D	D	D	D	85	85	85	85	85	85	85	85		95	95	95	D	D	D	D	85	85	85	85	85	85	85	85				95
	15.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	90	90	90	85	95	95	95	85				
	25.0	D	D	D	D	90	90	90	90	95	95	95	95					D	D	D	D	90	90	90	90	95	95	95	95				
	40.0	D	D	D	D	90	90	90	90	95	95	95	95					D	D	D	D	90	90	90	90								
	65.0	C	C	C	C	95	95	95	95									C	C	C	C	95	95	95	95								
	95.0		C	C	C		100	100	100									C	C	C	C	100	95	95	95								
Group 3	3.0	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95
	4.5	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95
	6.0	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95
	10.0	D	D	D	D	85	85	85	85	85	85	85	85		95	95	95	D	D	D	D	85	85	85	85	85	85	85	85				95
	15.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	90	90	90	85	95	95	95	85				
	25.0	D	D	D	D	90	90	90	90	95	95	95	95					D	D	D	D	90	90	90	90			95	95				
	40.0	D	D	D	D	95	90	90	90									D	D	D	D	95	90	90	90								
	65.0		C	C	C		100	100	100									C	C	C	C	95	95	95	95								
	95.0																	C	C	C	C	100	100	100	100								
Group 4	3.0	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95
	4.5	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95
	6.0	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95
	10.0	D	D	D	D	85	85	85	85	85	85	85	85		95	95	95	D	D	D	D	85	85	85	85	85	85	85	85				95
	15.0	D	D	D	D	90	90	90	85	95	95	95	85					D	D	D	D	90	90	90	90	95	95	95	95				
	25.0	C	D	D	D	95	95	95	90									D	D	D	D	90	90	90	90				95				
	40.0	C	C	C	C	100	100	100	100									C	D	D	D	95	95	95	95								
	65.0																	C	C	C	C	100	95	95	95								
	95.0																		C	C	C		100	100	100								
Group 5	3.0	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95
	4.5	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95
	6.0	D	D	D	D	85	85	85	85	85	85	85	85		95	95	95	95	D	D	D	85	85	85	85	85	85	85	85		95	95	95
	10.0	D	D	D	D	90	90	90	85	95	95	95	85					D	D	D	D	85	85	85	85	85	85	85	85				
	15.0	C	C	C	D	95	95	95	95									D	D	D	D	90	90	90	90	95	95	95	95				
	25.0				C				100									D	D	D	D	95	90	90	90								
	40.0																	C	C	C	C	95	95	95	95								
	65.0																	C	C	C	C	100	100	100	100								
	95.0																		C	C	C		100	100	100								
Group 6	3.0	D	D	D	D	85	85	85	85	90	85	85	85		95	95	95	D	D	D	D	85	85	85	85	85	85	85	85	95	95	95	95
	4.5	D	D	D	D	90	85	85	85	95	85	85	85			95	95	95	D	D	D	85	85	85	85	85	85	85	85		95	95	95
	6.0	D	D	D	D	90	90	90	85		95	95	85				95	D	D	D	D	85	85	85	85	85	85	85	85				95
	10.0	C	C	C	D	95	95	95	90									D	D	D	D	90	90	90	85	95	95	95	85				
	15.0				C				100									D	D	D	D	90	90	90	90				95				
	25.0																	C	C	C	D	95	95	95	95								
	40.0																	C	C	C	C	95	95	95	95								
	65.0																		C	C	C		100	100	100								
	95.0																																

Table B-6 No Traffic Load – No Internal Vacuum – Ground Water to Grade Level
Minimum Backfill Compaction, % Standard Proctor Density. (D=Dumped, C= Compacted)

Type 1 Installation

Traffic Load AASHTO HS20 – No Internal Vacuum – Ground Water to Grade Level

Burial Depth ft	Standard Trench, Bd/D = 1.8																Wide Trench, Bd/D = 3.0																Native Soil Group
Backfill	SC1				SC2				SC3				SC4				SC1				SC2				SC3				SC4				
	Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				
	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	
3.0	D	D	D	D	85	85	85	85	90	85	85	85					D	D	D	D	85	85	85	85	90	90	90	85					Group 1
4.5	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
6.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
10.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
15.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	90	90	90	85	95	95	95	85					
25.0	D	D	D	D	90	90	90	90	95	95	95	95					D	D	D	D	90	90	90	90	95	95	95	95					
40.0	D	D	D	D	90	90	90	90	95	95	95	95					D	D	D	D	90	90	90	90									
65.0	C	D	D	D	95	90	90	90									C	C	C	C	95	95	95	95									
95.0	C	C	C	C	100	95	95	95									C	C	C	C	100	95	95	95									
3.0	D	D	D	D	85	85	85	85	90	85	85	85					D	D	D	D	85	85	85	85	90	90	90	85					Group 2
4.5	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
6.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
10.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
15.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	90	90	90	85	95	95	95	85					
25.0	D	D	D	D	90	90	90	90	95	95	95	95					D	D	D	D	90	90	90	90	95	95	95	95					
40.0	D	D	D	D	90	90	90	90	95	95	95	95					D	D	D	D	90	90	90	90									
65.0	C	C	C	C	95	95	95	95									C	C	C	C	95	95	95	95									
95.0		C	C	C		100	100	100									C	C	C	C	100	95	95	95									
3.0	D	D	D	D	85	85	85	85	90	85	85	85					D	D	D	D	85	85	85	85	90	90	90	85					Group 3
4.5	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
6.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
10.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
15.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	90	90	90	85	95	95	95	85					
25.0	D	D	D	D	90	90	90	90	95	95	95	95					D	D	D	D	90	90	90	90				95					
40.0	D	D	D	D	95	95	95	90									D	D	D	D	95	90	90	90									
65.0		C	C	C		100	100	100									C	C	C	C	95	95	95	95									
95.0																	C	C	C	C	100	100	100	100									
3.0	D	D	D	D	85	85	85	85	90	85	85	85					D	D	D	D	85	85	85	85	90	90	90	85					Group 4
4.5	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
6.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
10.0	D	D	D	D	85	85	85	85	85	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
15.0	D	D	D	D	90	90	90	85	95	95	95	85					D	D	D	D	90	90	90	90	95	95	95	95					
25.0	C	D	D	D	95	95	95	90									D	D	D	D	90	90	90	90									
40.0	C	C	C	C	100	100	100	100									C	D	D	D	95	95	95	95									
65.0																	C	C	C	C	100	95	95	95									
95.0																		C	C	C		100	100	100									
3.0	D	D	D	D	90	85	85	85		95	95	90					D	D	D	D	85	85	85	85	95	90	90	90					Group 5
4.5	D	D	D	D	90	85	85	85	95	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
6.0	D	D	D	D	90	85	85	85	95	85	85	85					D	D	D	D	85	85	85	85	85	85	85	85					
10.0	D	D	D	D	90	90	90	85		95	95	85					D	D	D	D	90	85	85	85	95	85	85	85					
15.0	C	C	C	D	95	95	95	95									D	D	D	D	90	90	90	90	95	95	95	95					
25.0				C				100									D	D	D	D	95	90	90	90									
40.0																	C	C	C	C	95	95	95	95									
65.0																	C	C	C	C	100	100	100	100									
95.0																		C	C	C		100	100	100									
3.0	C	D	D	D	95	95	95	90									D	D	D	D	90	90	90	85	95	95	95	90					Group 6
4.5	C	D	D	D	95	90	90	90				95					D	D	D	D	90	85	85	85	95	85	85	85					
6.0	C	D	D	D	95	95	95	90				95					D	D	D	D	90	85	85	85	95	95	95	85					
10.0	C	C	C	D	95	95	95	95									D	D	D	D	90	90	90	85	95	95	95	85					
15.0				C				100									D	D	D	D	90	90	90	90				95					
25.0																	C	C	C	D	95	95	95	95									
40.0																	C	C	C	C	95	95	95	95									
65.0																		C	C	C		100	100	100									
95.0																																	

Table B–7 Traffic Load AASHTO 20 – No Internal Vacuum – Ground Water to Grade Level Minimum Backfill Compaction, % Standard Proctor Density. (D=Dumped, C= Compacted)

Type 1 Installation

No Traffic Load – 14.7 psi Internal Vacuum – Ground Water to Grade Level

Native Soil Group	Burial Depth ft	Standard Trench, Bd/D = 1.8																Wide Trench, Bd/D = 3.0															
	Backfill	SC1				SC2				SC3				SC4				SC1				SC2				SC3				SC4			
		Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN			
		18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72
Group 1	3.0	D	D	D	D	85	85	85	85	90	85	85	85				95	D	D	D	D	90	85	85	85	95	90	90	85				
	4.5	D	D	D	D	85	85	85	85	85	85	85	85				95	D	D	D	D	90	85	85	85	95	85	85	85				
	6.0	D	D	D	D	85	85	85	85	85	85	85	85				95	D	D	D	D	90	85	85	85	95	85	85	85				
	10.0	D	D	D	D	90	85	85	85	95	85	85	85					D	D	D	D	90	90	85	85	95	95	85	85				
	15.0	D	D	D	D	90	85	85	85	95	85	85	85					D	D	D	D	90	90	90	85	95	95	95	85				
	25.0	D	D	D	D	90	90	90	90	95	95	95	95					D	D	D	D	90	90	90	90		95	95	95				
	40.0	D	D	D	D	90	90	90	90		95	95	95					C	D	D	D	95	90	90	90								
	65.0	C	C	D	D	100	95	95	90									C	C	C	C	100	95	95	95								
	95.0		C	C	C		100	95	95									C	C	C	C	100	100	95	95								
Group 2	3.0	D	D	D	D	85	85	85	85	90	85	85	85			95	95	D	D	D	D	90	85	85	85	95	90	90	85				
	4.5	D	D	D	D	85	85	85	85	85	85	85	85				95	D	D	D	D	90	85	85	85	95	85	85	85				
	6.0	D	D	D	D	85	85	85	85	85	85	85	85				95	D	D	D	D	90	85	85	85	95	85	85	85				
	10.0	D	D	D	D	90	85	85	85	95	85	85	85					D	D	D	D	90	90	85	85	95	95	85	85				
	15.0	D	D	D	D	90	85	85	85	95	85	85	85					D	D	D	D	90	90	90	85	95	95	95	85				
	25.0	D	D	D	D	90	90	90	90		95	95	95					D	D	D	D	95	90	90	90				95				
	40.0	C	D	D	D	95	90	90	90				95					C	D	D	D	95	95	95	90								
	65.0		C	C	C		95	95	95									C	C	C	C	100	95	95	95								
	95.0				C				100										C	C	C		100	100	95								
Group 3	3.0	D	D	D	D	85	85	85	85	90	85	85	85			95	95	D	D	D	D	90	85	85	85	95	90	90	85				
	4.5	D	D	D	D	85	85	85	85	85	85	85	85				95	D	D	D	D	90	85	85	85	95	85	85	85				
	6.0	D	D	D	D	85	85	85	85	85	85	85	85				95	D	D	D	D	90	85	85	85	95	85	85	85				
	10.0	D	D	D	D	90	85	85	85	95	85	85	85					D	D	D	D	90	90	90	85	95	95	85	85				
	15.0	D	D	D	D	90	90	90	85	95	95	85	85					D	D	D	D	90	90	90	90		95	95	95				
	25.0	D	D	D	D	95	90	90	90		95	95	95					D	D	D	D	95	90	90	90				95				
	40.0	C	C	D	D	100	95	95	90									C	D	D	D	95	95	90	90								
	65.0			C	C			100	100									C	C	C	C	100	95	95	95								
	95.0																		C	C	C		100	100	100								
Group 4	3.0	D	D	D	D	85	85	85	85	95	90	85	85				95	D	D	D	D	90	85	85	85	95	90	90	90				
	4.5	D	D	D	D	90	85	85	85	95	85	85	85				95	D	D	D	D	90	85	85	85	95	85	85	85				
	6.0	D	D	D	D	90	85	85	85	95	85	85	85				95	D	D	D	D	90	90	90	85	95	95	85	85				
	10.0	D	D	D	D	90	90	90	85	95	95	85	85					D	D	D	D	90	90	90	85	95	95	95	85				
	15.0	C	D	D	D	95	90	90	90		95	95	95					D	D	D	D	90	90	90	90		95	95	95				
	25.0		C	D	D		95	95	90									C	D	D	D	95	90	90	90				95				
	40.0		C	C	C		100	100	100									C	C	D	D	95	95	95	95								
	65.0																	C	C	C	C	100	100	95	95								
	95.0																		C	C	C		100	100	100								
Group 5	3.0	C	D	D	D	95	90	90	85		95	95	90					D	D	D	D	90	90	90	85	95	95	95	90				
	4.5	C	D	D	D	95	90	90	90			95	95					D	D	D	D	90	90	90	85	95	95	85	85				
	6.0	C	D	D	D	95	90	90	90				95					D	D	D	D	90	90	90	85	95	95	95	85				
	10.0	C	C	D	D	100	95	95	90									D	D	D	D	90	90	90	90		95	95	95				
	15.0		C	C	C		100	95	95									D	D	D	D	95	90	90	90				95				
	25.0				C				100									C	D	D	D	95	95	95	90								
	40.0																	C	C	C	C	100	95	95	95								
	65.0																		C	C	C		100	100	100								
	95.0																				C				100								
Group 6	3.0		C	C	D		95	95	95									D	D	D	D	90	90	90	85		95	95	95				
	4.5		C	C	C		100	100	95									D	D	D	D	90	90	90	90		95	95	95				
	6.0		C	C	C		100	95	95									D	D	D	D	90	90	90	90		95	95	95				
	10.0			C	C			100	95									D	D	D	D	95	90	90	90			95	95				
	15.0																	C	D	D	D	95	90	90	90								
	25.0																	C	C	C	D	100	95	95	95								
	40.0																	C	C	C	C	100	100	95	95								
	65.0																			C	C			100	100								
	95.0																																

Table B–8 No Traffic Load – 14.7 psi Vacuum – Ground Water to Grade Level
Minimum Backfill Compaction, % Standard Proctor Density. (D=Dumped, C= Compacted)

Type 2 Installation

No Traffic Load – No Internal Vacuum – Ground Water Below Pipe Invert

Native Soil Group	Upper Backfill →	Standard Trench, Bd/D = 1.8																Wide Trench, Bd/D = 3.0															
		SC3 85% SPD								SC4 90% SPD								SC3 85% SPD								SC4 90% SPD							
	Backfill →	SC1				SC2				SC1				SC2				SC1				SC2				SC1				SC2			
		Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN			
	Burial Depth ft	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72
Group 1	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	4.5	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	6.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	10.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	15.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	25.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	90	90	90	90		D	D	D		90	90	90
	40.0	D	D	D	D	90	90	90	85			D	D			90	90		D	D	D		90	90	90								
	65.0		D	D	D		90	90	90												C				95								
Group 2	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	4.5	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	6.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	10.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	15.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	25.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	90	90	90	90		D	D	D		90	90	90
	40.0	D	D	D	D	90	90	90	90			D	D			90	90		D	D	D		90	90	90								
	65.0			C	C			95	95																								
Group 3	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	4.5	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	6.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	10.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	15.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	90	85	85	85
	25.0	D	D	D	D	90	90	90	85	D	D	D	D	90	90	90	90	D	D	D	D	90	90	90	90		D	D	D		90	90	90
	40.0		D	D	D		90	90	90			C	D			95	90		D	D	D		90	90	90								
	65.0																																
Group 4	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	4.5	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	6.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	10.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	15.0	D	D	D	D	85	85	85	85	D	D	D	D	90	85	85	85	D	D	D	D	90	85	85	85	D	D	D	D	90	90	90	85
	25.0	C	C	C	D	95	95	95	90		C	C	C		95	95	95	D	D	D	D	90	90	90	90			D	D			90	90
	40.0			C	C			100	100											C	C			95	95								
	65.0																																
Group 5	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	4.5	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	6.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	10.0	D	D	D	D	90	90	90	85	D	D	D	D	90	90	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	15.0	C	C	C	C	100	95	95	95		C	C	C		95	95	95	D	D	D	D	90	90	90	85	D	D	D	D	90	90	90	90
	25.0																		D	D	D		90	90	90				D				90
	40.0																				C				95								
	65.0																																
Group 6	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	4.5	D	D	D	D	90	85	85	85	D	D	D	D	90	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	6.0	D	D	D	D	90	90	90	85	D	D	D	D	90	90	90	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	10.0	C	C	C	D	100	95	95	90		C	C	D		95	95	90	D	D	D	D	90	85	85	85	D	D	D	D	90	85	85	85
	15.0																	D	D	D	D	90	90	90	90		D	D	D		90	90	90
	25.0																			C	C			95	95								
	40.0																																
	65.0																																

Table B–9 No Traffic Load – No Internal Vacuum – Ground Water Below Pipe Invert
Minimum Backfill Compaction, % Standard Proctor Density. (D=Dumped, C= Compacted)

Type 2 Installation

No Traffic Load – 7.35 psi Internal Vacuum – Ground Water Below Pipe Invert

Native Soil Group	Upper Backfill →	Standard Trench, Bd/D = 1.8																Wide Trench, Bd/D = 3.0															
		SC3 85% SPD								SC4 90% SPD								SC3 85% SPD								SC4 90% SPD							
	Backfill →	SC1				SC2				SC1				SC2				SC1				SC2				SC1				SC2			
		Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN			
	Burial Depth ft	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72
Group 1	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	4.5	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	6.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	10.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	15.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	25.0	D	D	D	D	85	85	85	85		D	D	D		85	85	85		D	D	D		90	90	90				D				90
	40.0		D	D	D		90	90	85				D				90			D	D			90	90								
	65.0				D				90																								
Group 2	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	4.5	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	6.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	10.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	15.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	25.0	D	D	D	D	85	85	85	85		D	D	D		85	85	85		D	D	D		90	90	90				D				90
	40.0		D	D	D		90	90	90				D				90				D				90								
	65.0				C				95																								
Group 3	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	4.5	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	6.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	10.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	15.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	25.0		D	D	D		90	90	85			D	D			90	90		D	D	D		90	90	90				D				90
	40.0			D	D			90	90											D	D			90	90								
	65.0																																
Group 4	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	4.5	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	6.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	10.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	15.0	D	D	D	D	85	85	85	85		D	D	D		85	85	85	D	D	D	D	90	85	85	85			D	D			90	85
	25.0			C	D			95	90				C				95			D	D			90	90								
	40.0																																
	65.0																																
Group 5	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	4.5	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	6.0	D	D	D	D	85	85	85	85		D	D	D		85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	10.0		D	D	D		90	85	85			D	D			85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	15.0				C				95										D	D	D		90	90	85				D				90
	25.0																				D				90								
	40.0																																
	65.0																																
Group 6	3.0				D				85				D				85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	4.5				D				85									D	D	D	D	85	85	85	85		D	D	D		85	85	85
	6.0				D				85									D	D	D	D	85	85	85	85		D	D	D		85	85	85
	10.0																		D	D	D		85	85	85			D	D			85	85
	15.0																			D	D			90	90								
	25.0																																
	40.0																																
	65.0																																

Table B–10 No Traffic Load – 7.35 psi Internal Vacuum – Ground Water Below Pipe Invert
Minimum Backfill Compaction, % Standard Proctor Density. (D=Dumped, C= Compacted)

Type 2 Installation		No Traffic Load – 14.7 psi Internal Vacuum – Ground Water Below Pipe Invert																															
Native Soil Group	Upper Backfill	Standard Trench, Bd/D = 1.8																Wide Trench, Bd/D = 3.0															
		SC3 85% SPD								SC4 90% SPD								SC3 85% SPD								SC4 90% SPD							
	Backfill	SC1				SC2				SC1				SC2				SC1				SC2				SC1				SC2			
		Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN			
	Burial Depth ft	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72
Group 1	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	4.5	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	6.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	10.0	D	D	D	D	85	85	85	85		D	D	D		85	85	85	D	D	D	D	85	85	85	85			D	D			85	85
	15.0	D	D	D	D	85	85	85	85		D	D	D		85	85	85		D	D	D		85	85	85				D				85
	25.0		D	D	D		85	85	85				D				85			D	D			90	90								
	40.0		D	D	D		90	90	85																								
	65.0				D				90																								
Group 2	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	4.5	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	6.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	10.0	D	D	D	D	85	85	85	85		D	D	D		85	85	85	D	D	D	D	85	85	85	85			D	D			85	85
	15.0	D	D	D	D	85	85	85	85		D	D	D		85	85	85		D	D	D		85	85	85				D				85
	25.0		D	D	D		85	85	85				D				85			D	D			90	90								
	40.0			D	D			90	90																								
	65.0																																
Group 3	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	4.5	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	6.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	10.0	D	D	D	D	85	85	85	85		D	D	D		85	85	85		D	D	D		85	85	85			D	D			85	85
	15.0		D	D	D		85	85	85			D	D			85	85		D	D	D		85	85	85				D				85
	25.0		D	D	D		90	85	85				D				90				D				90								
	40.0				D				90																								
	65.0																																
Group 4	3.0	D	D	D	D	85	85	85	85		D	D	D		85	85	85		D	D	D		85	85	85		D	D	D		85	85	85
	4.5	D	D	D	D	85	85	85	85		D	D	D		85	85	85	D	D	D	D	85	85	85	85			D	D			85	85
	6.0	D	D	D	D	85	85	85	85		D	D	D		85	85	85		D	D	D		85	85	85			D	D			85	85
	10.0		D	D	D		85	85	85		D	D	D		85	85	85		D	D	D		85	85	85				D				85
	15.0			D	D			85	85				D				85			D	D			85	85								
	25.0				D				90																								
	40.0																																
	65.0																																
Group 5	3.0				D				85				D				85		D	D	D		85	85	85				D				85
	4.5				D				85										D	D	D		85	85	85				D				85
	6.0				D				85										D	D	D		85	85	85				D				85
	10.0																			D	D			85	85								
	15.0																				D				85								
	25.0																																
	40.0																																
	65.0																																
Group 6	3.0																				D				85								
	4.5																			D	D			85	85								
	6.0																				D				85								
	10.0																				D				85								
	15.0																																
	25.0																																
	40.0																																
	65.0																																

Table B–11 No Traffic Load – 14.7 psi Internal Vacuum – Ground Water Below Pipe Invert
Minimum Backfill Compaction, % Standard Proctor Density. (D=Dumped, C= Compacted)

Type 2 Installation

No Traffic Load – No Internal Vacuum – Ground Water to Grade Level

Native Soil Group	Upper Backfill →	Standard Trench, Bd/D = 1.8																Wide Trench, Bd/D = 3.0															
		SC3 85% SPD								SC4 95% SPD								SC3 85% SPD								SC4 95% SPD							
	Backfill →	SC1				SC2				SC1				SC2				SC1				SC2				SC1				SC2			
		Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN			
	Burial Depth ft	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72
Group 1	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	4.5	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	6.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	10.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	15.0	D	D	D	D	85	85	85	85		D	D	D		85	85	85	D	D	D	D	90	90	90	85			D	D			90	90
	25.0	D	D	D	D	90	90	90	90										D	D	D		90	90	90								
	40.0				D				90																								
	65.0																																
Group 2	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	4.5	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	6.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	10.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	15.0	D	D	D	D	85	85	85	85		D	D	D		85	85	85	D	D	D	D	90	90	90	85			D	D			90	90
	25.0	D	D	D	D	90	90	90	90										D	D	D		90	90	90								
	40.0				D				90																								
	65.0																																
Group 3	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	4.5	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	6.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	10.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	15.0	D	D	D	D	85	85	85	85		D	D	D		85	85	85	D	D	D	D	90	90	90	85			D	D			90	90
	25.0		D	D	D		90	90	90											D	D			90	90								
	40.0				C				95																								
	65.0																																
Group 4	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	4.5	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	6.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	10.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	15.0	D	D	D	D	90	90	90	85		D	D	D		90	90	90	D	D	D	D	90	90	90	90				D				90
	25.0			C	C			95	95												D				90								
	40.0																																
	65.0																																
Group 5	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	4.5	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	6.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	10.0	D	D	D	D	90	90	90	85	D	D	D	D	90	90	90	85	D	D	D	D	85	85	85	85		D	D	D		90	90	85
	15.0			C	C			95	95										D	D	D		90	90	90								
	25.0																																
	40.0																																
	65.0																																
Group 6	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	4.5	D	D	D	D	90	85	85	85	D	D	D	D	90	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85
	6.0	C	D	D	D	95	90	90	85		D	D	D		90	90	85	D	D	D	D	85	85	85	85	D	D	D	D	90	85	85	85
	10.0			C	D			95	95									D	D	D	D	90	90	90	85		D	D	D		90	90	85
	15.0																			D	D			90	90								
	25.0																																
	40.0																																
	65.0																																

Table B–12 No Traffic Load – No Internal Vacuum – Ground Water to Grade Level
Minimum Backfill Compaction, % Standard Proctor Density. (D=Dumped, C= Compacted)

Type 2 Installation	No Traffic Load – 7.35 psi Internal Vacuum – Ground Water to Grade Level																																
Native Soil Group		Standard Trench, Bd/D = 1.8																Wide Trench, Bd/D = 3.0															
	Upper Backfill	SC3 85% SPD								SC4 95% SPD								SC3 85% SPD								SC4 95% SPD							
	Backfill	SC1				SC2				SC1				SC2				SC1				SC2				SC1				SC2			
		Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN				Pipe SN			
	Burial Depth ft	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72
Group 1	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	4.5	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	6.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	10.0	D	D	D	D	85	85	85	85		D	D	D		85	85	85	D	D	D	D	85	85	85	85				D				85
	15.0	D	D	D	D	85	85	85	85				D				85		D	D	D		90	90	85								
	25.0			D	D			90	90																								
	40.0																																
	65.0																																
Group 2	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	4.5	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	6.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	10.0	D	D	D	D	85	85	85	85		D	D	D		85	85	85	D	D	D	D	85	85	85	85				D				85
	15.0	D	D	D	D	85	85	85	85				D				85		D	D	D		90	90	85								
	25.0			D	D			90	90																								
	40.0																																
	65.0																																
Group 3	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	4.5	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	6.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	10.0	D	D	D	D	85	85	85	85		D	D	D		85	85	85	D	D	D	D	85	85	85	85				D				85
	15.0		D	D	D		85	85	85				D				85		D	D	D		90	90	85								
	25.0				D				90																								
	40.0																																
	65.0																																
Group 4	3.0	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	4.5	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85	D	D	D	D	85	85	85	85		D	D	D		85	85	85
	6.0	D	D	D	D	85	85	85	85		D	D	D		85	85	85	D	D	D	D	85	85	85	85			D	D			85	85
	10.0	D	D	D	D	85	85	85	85		D	D	D		85	85	85		D	D	D		85	85	85				D				85
	15.0		D	D	D		90	90	85												D				90								
	25.0																																
	40.0																																
	65.0																																
Group 5	3.0		D	D	D		85	85	85		D	D	D		85	85	85		D	D	D		85	85	85		D	D	D		85	85	85
	4.5		D	D	D		85	85	85			D	D			85	85	D	D	D	D	85	85	85	85			D	D			85	85
	6.0		D	D	D		85	85	85				D				85	D	D	D	D	85	85	85	85				D				85
	10.0				D				85										D	D	D		85	85	85								
	15.0																				D				90								
	25.0																																
	40.0																																
	65.0																																
Group 6	3.0																				D				85				D				85
	4.5																		D	D	D		85	85	85				D				85
	6.0																		D	D	D		85	85	85								
	10.0																				D				85								
	15.0																																
	25.0																																
	40.0																																
	65.0																																

Table B–13 No Traffic Load – 7.35 psi Internal Vacuum – Ground Water to Grade Level Minimum Backfill Compaction, % Standard Proctor Density. (D=Dumped, C= Compacted)

Type 2 Installation

No Traffic Load – 14.7 psi Internal Vacuum – Ground Water to Grade Level

Standard Trench, Bd/D = 1.8

Native Soil Group	Burial Depth ft	SC3 85% SPD								SC4 95% SPD							
		SC1 Pipe SN				SC2 Pipe SN				SC1 Pipe SN				SC2 Pipe SN			
		18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72
Group 1	3.0		D	D	D		85	85	85			D	D			85	85
	4.5	D	D	D	D	85	85	85	85				D				85
	6.0	D	D	D	D	85	85	85	85				D				85
	10.0		D	D	D		85	85	85								
	15.0		D	D	D		85	85	85								
	25.0				D				90								
	40.0																
	65.0																
Group 2	3.0		D	D	D		85	85	85			D	D			85	85
	4.5	D	D	D	D	85	85	85	85				D				85
	6.0	D	D	D	D	85	85	85	85				D				85
	10.0		D	D	D		85	85	85								
	15.0		D	D	D		85	85	85								
	25.0				D				90								
	40.0																
	65.0																
Group 3	3.0		D	D	D		85	85	85			D	D			85	85
	4.5	D	D	D	D	85	85	85	85				D				85
	6.0	D	D	D	D	85	85	85	85				D				85
	10.0		D	D	D		85	85	85								
	15.0			D	D			85	85								
	25.0																
	40.0																
	65.0																
Group 4	3.0				D				85				D				85
	4.5		D	D	D		85	85	85				D				85
	6.0		D	D	D		85	85	85				D				85
	10.0			D	D			85	85								
	15.0																
	25.0																
	40.0																
	65.0																
Group 5	3.0																
	4.5																
	6.0																
	10.0																
	15.0																
	25.0																
	40.0																
	65.0																
Group 6	3.0																
	4.5																
	6.0																
	10.0																
	15.0																
	25.0																
	40.0																
	65.0																

Wide Trench, Bd/D = 3.0

Native Soil Group	Burial Depth ft	SC3 85% SPD								SC4 95% SPD							
		SC1 Pipe SN				SC2 Pipe SN				SC1 Pipe SN				SC2 Pipe SN			
		18	36	46	72	18	36	46	72	18	36	46	72	18	36	46	72
Group 1	3.0				D				85								
	4.5		D	D	D		85	85	85								
	6.0		D	D	D		85	85	85								
	10.0			D	D			85	85								
	15.0				D				85								
	25.0																
	40.0																
	65.0																
Group 2	3.0				D				85								
	4.5		D	D	D		85	85	85								
	6.0		D	D	D		85	85	85								
	10.0			D	D			85	85								
	15.0				D				85								
	25.0																
	40.0																
	65.0																
Group 3	3.0				D				85								
	4.5		D	D	D		85	85	85								
	6.0		D	D	D		85	85	85								
	10.0			D	D			85	85								
	15.0																
	25.0																
	40.0																
	65.0																
Group 4	3.0																
	4.5		D	D	D		85	85	85								
	6.0			D	D			85	85								
	10.0				D				85								
	15.0																
	25.0																
	40.0																
	65.0																
Group 5	3.0																
	4.5				D				85								
	6.0				D				85								
	10.0																
	15.0																
	25.0																
	40.0																
	65.0																
Group 6	3.0																
	4.5																
	6.0																
	10.0																
	15.0																
	25.0																
	40.0																
	65.0																

Upper Backfill / Backfill: Native Soil Group

Table B–14 No Traffic Load – 14.7 psi Internal Vacuum – Ground Water to Grade Level Minimum Backfill Compaction, % Standard Proctor Density. (D=Dumped, C= Compacted)

Appendix C

Classification and Properties of Native Soils

For the analysis of pipe installation requirements, the native soils are classified in six groups and related to stiffness through blow counts as defined by a standard penetration test using a split barrel sampler, ASTM D1586. These native soils, which form the trench walls, range from very stable, dense granular soils and very hard cohesive soils to relatively weak, fine grained soils. These same native soils may be considered for use as backfill.

1. Blows/foot from standard penetration test, ASTM D1586.
2. For higher blow counts, M_{sn} values increase, Reaching 50,000 psi (345 MPa) for rock.
3. When a geotextile pipe zone wrap is used, M_{sn} values for poor soils can be greater than those listed above.
4. When permanent solid sheeting designed to last the life of the pipeline is used in the pipe zone, the constrained soil modulus shall be based solely on the backfill modulus. **Correlation to other test methods.**

There are several different cone penetrometer tests in use around the world. With the potential for significant variations in these different tests, an approximate correlation to standard penetrometer blow counts, N, based on ASTM D1586 can be provided. With the output of the cone penetrometer test, qu, expressed in kg/cm^2 the corresponding standard penetrometer blow count, N is:

N = qu/4 for mechanical cone penetrometer
N = qu/3 for electrical cone penetrometer

Representation of the native soil is given in ***Table C–1***, which follows the general recommendations provided in AWWA M45. The blow count to be used is the lowest value found over an extended period of time in the pipe zone. Normally, the weakest condition of the soil exists when the soil has been subjected to wet conditions for an extended period.

Soil	Granular		Cohesive		Modulus
group	Blow count[1]	Description	q_u tons/ft^2	Description	M_{sn} psi
1	> 15	Compact	> 2.0	Very stiff	5000
2	8 - 15	Slightly compact	1.0 - 2.0	Stiff	3000
3	4 - 8	Loose	0.50 - 1.0	Medium	1500
4	2 - 4		0.25 - 0.50	Soft	700
5	1 - 2	Very loose	0.125 - 0.25	Very soft	200
6	0 - 1	Very very loose	0 - 0.125	Very very soft	50

[1] Standard penetration test per ASTM D1586

Table C–1 Native Soil Stiffness Groups. Values of Constrained Modulus, M_{sn}

Appendix D

Classification and Properties of Backfill Soils

To be used as backfill for pipes, the soil must provide stiffness to the pipe/soil system and maintain the required stiffness with time. The variety of potential soils that can be used as pipe zone backfill is limitless. Pipe zone backfill may be selected from the soil removed from the trench or may require special soils to be imported to the job site, if the trenched soils are not adequate to serve as backfill. The practical selection of a pipe zone backfill soil depends on ease of compaction to achieve the needed stiffness and availability. Soils suitable to be used as backfill materials are classified in 4 stiffness categories.

Soil Stiffness Category 1, SC1

SC1 materials provide maximum pipe support for a given compaction due to low content of sand and fines. With minimum effort these materials can be installed at relatively high stiffness over a wide range of moisture contents. In addition, the high permeability of SC1 materials may aid in the control of water and are often desirable for embedment in rock cuts where water is frequently encountered.
However, when groundwater flow is anticipated, consideration should be given to the potential of migration of fines from adjacent materials into the open graded SC1 material, see section A.8 ➔.

Soil Stiffness Category 2, SC2

SC2 materials, when compacted, provide a relatively high level of pipe support. However, open graded groups may allow migration and should be checked for compatibility with adjacent materials, see section A.8 ➔.

Soil Stiffness Category 3, SC3

SC3 materials provide less support for a given density than SC1 or SC2 materials. Higher levels of compaction effort are required and moisture content must be near optimum to achieve the required density. These materials provide a reasonable level of pipe support once proper density has been achieved.

Soil Stiffness Category 4, SC4

SC4 materials require geotechnical evaluation prior to use. The moisture content must be near optimum to achieve the required density. When properly placed and compacted, SC4 materials can provide a reasonable level of pipe support. These materials are, however, not suitable for deep burial depths and traffic loads or for compaction with high energy vibratory compactors and tampers. SC4 materials should not be used where water conditions in the trench prevent proper placement and compaction. General guidelines for classifying backfill soils in stiffness categories are given in ***Table D–1***. For any given backfill stiffness category the higher the compaction the higher the soil modulus and the higher the support. In addition, the soil modulus also increases with the vertical soil stress level i.e. with burial depth.

Table D–2 to ***Table D–5*** give the M_{sb} values for backfill stiffness categories SC1, SC2, SC3 and SC4 as a function of the % Standard Proctor Density (SPD) and vertical stress level. The values apply for pipes installed above the groundwater level. For pipes installed below groundwater level, the constrained soil modulus will be reduced for lower stiffness class soils and lower compaction, see values in parenthesis. The vertical stress level is the vertical effective soil stress at the pipe springline elevation. It is normally computed as the design soil unit weight times the depth of fill. Buoyant unit weight should be used below the groundwater level.

Backfill Soil Stiffness Category	Description of Backfill Soils
SC1	Crushed rock with < 15% sand, maximum 25% passing the 3/8 in sieve and maximum 5% fines[2].
SC2	Clean, coarse-grained soils: SW, SP[1], GW, GP or any soil beginning with one of these symbols with 12% or less fines[2].
SC3	Clean, coarse-grained soils with fines: GM, GC, SM, SC or any soil beginning with one of these symbols with 12% or more fines[2]. Sandy or gravely fine-grained soils: CL, ML, (or CL-ML, CL/ML, ML/CL) with 30% or more retained on a no. 200 sieve
SC4	Fine grained soils: CL, ML, (or CL-ML, CL/ML, ML/CL) with 30% or less retained on a no. 200 sieve

Note: Symbols in table are according to the Unified Soil Classification Designation, ASTM D2487
[1] Uniform fine sand, SP, with more than 50% passing no. 100 sieve (0.006 in) is very sensitive to moisture and is not as backfill.
[2] % fines is the weight percentage of soil particles that pass no. 200 sieve with 0.003 in opening

Table D–1 Backfill Soil Type Classification

Burial Depth (Soil Density 120 pcf)	Vertical Stress Level	Compaction, % maximum Standard Proctor Density	
		Compacted	Dumped
ft	psi	psi	psi
1.2	1	2350	2000
6	5	3450	2600
12	10	4200	3000
24	20	5500	3450
48	40	7500	4250
72	60	9300	5000

Table D–2 M_{sb} for SC1 Backfill Soil

Burial Depth (Soil Density 120 pcf)	Vertical Stress Level	Compaction, % maximum Standard Proctor Density			
		100	95	90	85
ft	psi	psi	psi	psi	psi
1.2	1	2350	2000	1275 (1085)	470 (330)
6	5	3450	2600	1500 (1275)	520 (365)
12	10	4200	3000	1625 (1380)	570 (400)
24	20	5500	3450	1800 (1530)	650 (455)
48	40	7500	4250	2100 (1785)	825 (575)
72	60	9300	5000	2500 (2125)	1000 (700)

Table D–3 M_{sb} for SC2 Backfill Soil (reduced values below ground water table in parenthesis)

Burial Depth (Soil Density 120 pcf)	Vertical Stress Level	Compaction, % maximum Standard Proctor Density		
		95	90	85
ft	psi	psi	psi	psi
1.2	1	1415 (708)	670 (335)	360 (180)
6	5	1670 (835)	740 (370)	390 (195)
12	10	1770 (885)	750 (375)	400 (200)
24	20	1880 (940)	790 (395)	430 (215)
48	40	2090 (1045)	900 (450)	510 (255)
72	60	2300 (1150)	1025 (512)	600 (300)

Table D–4 M_{sb} for SC3 Backfill Soil (values below ground water level in parenthesis)

Burial Depth (Soil Density 120 pcf)	Vertical Stress Level	Compaction, % maximum Standard Proctor Density		
		95	90	85
ft	psi	psi	psi	psi
1.2	1	530 (159)	255 (77)	130 (39)
6	5	625 (188)	320 (96)	175 (53)
2	10	690 (207)	355 (107)	200 (60)
24	20	740 (222)	395 (119)	230 (69)
48	40	815 (245)	460 (138)	285 (86)
72	60	895 (269)	525 (158)	345 (104)

Table D–5 M_{sb} for SC4 Backfill Soil (values below ground water level in parenthesis)

! **Note**: M_{sb} values at intermediate vertical stress levels not given in ***Table D–2*** to ***Table D–5*** can be obtained by interpolation. The % maximum standard proctor density indicates the dry density of the compacted soil as a percentage of maximum dry density determined in accordance with ASTM D 698.

Appendix E

Field Testing to assist Classification of Native Soils

Native Soil Characteristic	Measurable Group
1	Can be barely penetrated with thumb
2	Can be penetrated with thumb to 0.16 in (4 mm)
3	Can be penetrated with thumb to 0.40 (10 mm)
4	Can be penetrated with thumb to 1 in (25 mm)
5	Can be penetrated by thumb to 2 in (50 mm)
6	Can be penetrated by fist to 1 in (25 mm)

Table E 1 – Simple Field Test Determining Soil Group[1)]

1) Based on Peck, Hanson and Thornburn, "Foundation engineering", 2nd Ed., John Wiley and Sons, Inc., 1974 and ASTM D2488.

Appendix F

Compaction of Backfill

This appendix provides helpful tips for compacting the various types of backfill. The maximum and minimum allowable installation depths will be effected by the selection and compaction of pipe zone backfill. The stiffer the soil, the deeper a given pipe can be installed to achieve a limited deflection or vacuum. This guide offers a general background for soil behaviour to provide a better understanding of our installation criteria. Include considerations for seasonal variations when assessing the potential for moisture content of both in situ and backfill soils. The compaction value recommended to provide a soil modulus value is to be considered as a minimum value and field densities should be at or higher than the requirement.

As a means of "calibrating" an installation method with a given backfill type, we recommend that specific attention be given to compaction techniques and relative compaction result during the installation of the initial sections of pipe used at a given installation site. By correlating the resulting compaction as a function of the soil type, method of placement of soil in the haunch zones and side fill areas, compaction methods for haunch and side fill areas, lift heights used, moisture content and number of passes, a good "feel" for the efforts needed for installation can be determined. When these initial pipes are installed, testing should be conducted frequently to assure compaction and pipe deflection criteria are being achieved. With this correlation, a technique for compacting a given soil type can be "calibrated" and the frequency for testing can be reduced. With this correlation, the workers gain a good understanding of the requirements for proper installation when using a specific backfill type for a specific set of requirements. (ASTM D5080 offers a reasonable method for rapidly measuring field density and moisture content of soils.) There are many methods available for measuring field density of the compacted backfill.

A measurement of the increase in the vertical diameter of the pipe is a reasonable measure of compaction effort used during the installation and another good "calibration" measurement. If backfill has been properly placed and compacted in the haunch areas of the pipe, a good method for judging compaction is the vertical diameter measurement when the backfill placement has reached the top of the pipe (or at any stage if consistently monitored). However, be aware that when using high levels of compaction effort, excessive vertical increase in diameter may result. If this condition occurs, contact the pipe supplier for assistance, and do not continue with the installation using the method that creates the excessive increase in vertical diameter.

Pipe zone backfill materials should be placed and compacted in uniform lifts on both sides of the pipe. For backfill placement and compaction in the haunch areas, start compacting under the pipe and work away from the pipe. For side fill, compaction usually progresses best when the backfill is compacted at the trench wall first and compaction progresses toward the pipe. Usually the number of "passes" or repeated applications of the compaction equipment (at a constant rate of movement) will increase the compaction. A good way to determine a sufficient compaction method is to measure the compaction and other response measurements as a function of the number of passes of a given compaction device. Use the number of passes and other criteria such as moisture content and vertical deflection as a means of controlling the installation procedure. If the compaction equipment is changed, the number of passes to achieve the specified compaction may be affected. Heavier and wider plate vibrators typically compact deeper and to a higher degree than lighter and narrower ones. Likewise, the smaller and lighter impact compactors have a less effective depth than the larger, heavier ones.

Compaction over the top of the pipe must assure that there is sufficient material to not impact the pipe. At least 6 in (150 mm) cover should be sufficient when using a hand operated plate vibrator compactor; however, 12 in (300 mm) is recommended when using a hand operated impact compactor. A compaction of no more than 85% SPD can realistically be achieved when compacting the first 12 in (300 mm) lift directly over the pipe crown (top).
Backfill soils that are granular in character provide relatively high stiffness with minimal compaction effort.

Compact granular soils have little tendency to creep or consolidate with time. Granular soils are less sensitive to moisture, both at the time of placement and during long-term use. When finer grained soils are used as backfill, the support for the pipe is typically reduced. Granular soil with more than 12% by weight of fines (soils with particle size less than 75 microns) are significantly affected by the characteristic of the finer materials. If the fines are mostly silts (37 to 75 microns), the typical soils are moisture sensitive, have a tendency to be transported by flowing water and require some additional effort to compact. If the fines are mostly clay (less than 37 microns and cohesive), the soils are more moisture sensitive, which reduces stiffness, and the soil will creep with time. Typically, more compaction effort is needed to achieve the required density. By limiting soils to a liquid limit of 40%, the highly moisture sensitive and plastic soils will be eliminated from use.

Backfill Types SC1 and SC2 are relatively easy to use and very reliable as backfill materials for pipe. These soils have low moisture sensitivity. Backfill can be easily compacted using a plate vibrator compactor in 8 to 12 in (200 to 300 mm) lifts. Occasionally, a filter fabric should be used in combination with gravel soils to preclude fines migration and sub-sequent loss of pipe support. See Section A.8 for criteria ➔.

Backfill Type SC3 soils are acceptable and often readily available as backfill materials for pipe installations. Many local soils, in which the pipe is installed, are Type SC3 and therefore the trenched soil can be directly reused as pipe-zone backfill. Care is to be taken with these soils as they can be moisture sensitive. The characteristics of Type SC3 soil are often dictated by the characteristics of the fines. Moisture control may be required when compacting the soil to achieve the desired density with reasonable compaction energy and easily used compaction equipment. Compaction can be achieved by using an impact compactor in 4 to 8 in (100 to 200 mm) lifts.

Backfill type SC4 can only be used as pipe-zone backfill with the following precautions:

- Moisture content must be controlled during placement and compaction.
- Do not use in installations with unstable foundations or with standing water in the trench.
- Compaction techniques may require considerable energy, and practical limitations of relative compaction and resulting soil stiffness must be considered.
- When compacting, use lifts of 4 to 6 in (100 to 150 mm) with an impact compactor such as Whacker or pneumatic rammer (pogo stick).
- Compaction tests should be conducted periodically to assure proper that compaction is achieved. See Appendix F for further information ➔.

The compaction of finer grain backfill is most easily accomplished when the material is at or near its optimum moisture content.

When backfilling reaches pipe springline, all compaction should start near the trench sides and proceed towards the pipe.

It is recommended that placing and compacting of the pipe zone backfill is done in such a way as to cause the pipe to ovalise slightly in the vertical direction. Initial vertical ovalisation, however, must not exceed 1.5% of pipe diameter as measured when backfill reaches pipe crown. The amount of initial ovalisation obtained will be related to the energy required to achieve the relative compaction needed. The high energy levels that may be necessary with backfill Types SC3 and SC4 may lead to exceeding the limit. If this occurs consider a higher stiffness pipe or other backfill materials or both.

Appendix G

Definitions and Terminology

Term	Description
Nominal diameter, DN	The diameter classification of pipe, expressed in inch (mm).
Nominal Pressure, PN	The pressure rating of a pipe, expressed in psi (bar).
Nominal Stiffness, SN	The minimum initial specific stiffness, EI/D3, of a pipe as measured by a load required to deflect a pipe ring, expressed in psi (N/m^2).
Pipe crown	The top inside surface of the pipe.
Pipe invert	The bottom inside surface of a pipe.
Depth of bury	The depth of cover over the top of a pipe.
Deflection	The change in vertical diameter typically expressed as a percentage of the nominal pipe diameter.
Springline	The mid height of the pipe, the 90 and 270 degree locations of a pipe as measured from the top centre of the pipe.
Constrained soil modulus, Ms	A secant modulus of soil measured by a one dimensional compression test used to describe soil stiffness.
Standard Proctor Density, SPD	The maximum dry density obtained at optimum moisture content when tested by ASTM D698, used to define 100% standard proctor density.
Percent Standard Proctor Density	The achieved dry density/maximum dry density expressed in %.
Blow Counts	The number of impacts of a 140 pound (64 kg) hammer dropping 30 inches (76 cm) to drive a split barrel sampler 12 inches (300 mm) by ASTM D1586.

Appendix H

Approximate Weights for Pipes and Couplings

DN in	SN18 lbs/ft*	SN36 lbs/ft*	SN46 lbs/ft*	SN72 lbs/ft*	Coupling lbs/ft**
12	6	8	8	9	7
16	10	13	14	16	8
18	13	17	18	19	9
20	17	21	22	25	10
24	24	30	32	37	17
30	37	45	49	56	25
36	52	64	70	80	28
42	70	87	93	108	34
48	91	113	127	141	41
54	115	145	156	180	53
60	133	165	179	206	59
63	145	181	196	226	64
72	183	229	247	284	75
78	225	281	304	350	87
84	272	340	367	424	98
96	324	403	437	503	109

* Based on PN 50 which is the heaviest pipe
** Based on PN 250 which is the heaviest coupling

Appendix I

Joint Lubricant Requirements

Nominal Pipe Diameter (in)	Nominal Amount of Lubricant (lb) Required per Joint
12 to 20	0.17
24 to 30	0.25
36 to 42	0.35
48	0.45
54	0.55
60 to 63	0.65
72	0.80
78	0.90
84	1.0
96	1.1

! **Note**: Lubricants amounts are based on lubricating two gaskets and two spigot ends per joint. Factory pre-assembled coupling joints will only require half the above amounts per joint.

Appendix J

Cleaning of Flowtite Sewer Pipe

There are several methods used to clean gravity sewer lines, depending on diameter and the degree and nature of blockage. All of these methods use either mechanical means or water jetting to clean the interior of the pipe. When mechanical means are employed, we recommend the use of plastic scrapers to avoid damage to the pipe's inner surface.

The use of high pressure water, emitted through jet nozzles, is a practice followed in some countries for cleaning sewer pipes. However, water emitted under high pressure through a jet nozzle can cause damage to most materials if not properly controlled. Based on experience gained with water jet cleaning of GRP sewer pipes, the following guidelines must be adhered to in order to avoid damage to the installed pipes.

Cleaning of Sewer and Pressure-Sewer Pipes (FS and FPS)

1. Maximum input pressure of 1750 psi (120 bars)*. Due to the smooth interior surface of GRP pipe, adequate cleaning and removal of blockages can normally be achieved below this pressure.

2. Nozzles with jet holes around the circumference are to be preferred. Nozzles with cleaning chains or wires, as well as rotating, aggressive or damaging nozzles are to be avoided.

3. The water discharge angle should not be greater than 30°. A smaller angle than 20° is usually sufficient for GRP pipe, as the smooth surface of the material inhibits adhesion, and only washing of the interior is of essence.

4. The number of jet holes should be 6 to 8 and hole size must be at least 0.095 in (2.4 mm).

5. The external surface of the nozzle shall be smooth and the maximum weight 10 lb (4.5 kg). Nozzle length corresponding to that weight should be at least 6.7 in (170 mm). For small and medium range diameters,12 in to 30 in (300 mm to 750 mm), lighter nozzles, approximately 5.5 lb (2.5 kg), shall be used.

6. The forward and backward moving speed of the nozzle shall be limited to 98 ft/min (30 m/min). Uncontrolled movement of the nozzle is not allowed. When inserting the nozzle into the pipe care should be taken to prevent it from hitting the pipe wall.

7 Jetting/swabbing sleds with several runners give a greater distance between nozzle and pipe wall, resulting in a less aggressive cleaning.

8 The use of equipment or pressures that do not meet the above criteria could cause damage to the installed pipe.

Minor, local chipping of the surface of the abrasion layer is not considered to have detrimental effect on the operational performance of the pipe.

For further questions please consult the supplier.

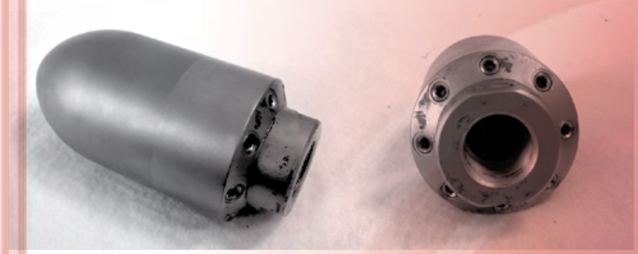


Figure J–1 Nozzle with jet holes around the circumference, 10 lb (4.5 kg)

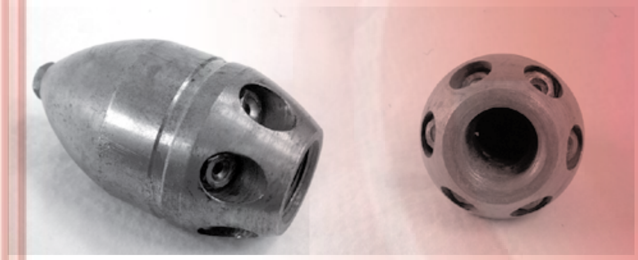


Figure J–2 Nozzle with jet holes around the circumference, 5.5 lb (2.5 kg)

*The cleaning is only allowed to be done with a jet-power-density of 520 hp/in² (600 W/mm²). Experiences have shown that if one uses the set up nozzle and jet holes and a flow rate of 79 gal/min (300 l/min), a pressure of 1750 psi (120 bars) will occur. "

Notes

Cleaning of Pressure Pipes (FP)

These guidelines are to be used when Flowtite pressure pipes (FP) are used in sewer applications.

1 Maximum input to 1150 psi (80 bars). Due to the smooth interior surface of GRP pipe, adequate cleaning and removal of blockages can normally be achieved below this pressure.

2 Nozzles with jet holes around the circumference are to be preferred. Nozzles with cleaning chains or wires, as well as rotating, aggressive or damaging nozzles are to be avoided.

3 The water discharge angle must be between 6° and 15° relative to the pipe axis.

4 The number of jet holes should be 6 to 8 or more and hole size must be at least 0.095 in (2.4 mm).

5 The external surface of the nozzle shall be smooth and the maximum weight 5.5 lb (2.5 kg).

6 The forward and backward moving speed of the nozzle shall be limited to 98 ft/min (30 m/min). Uncontrolled movement of the nozzle is not allowed. When inserting the nozzle into the pipe care should be taken to prevent it from hitting the pipe wall.

7 Jetting/swabbing sleds with several runners give a greater distance between nozzle and pipe wall are required (see ***Figure J–3***).

8 The use of equipment or pressures that do not meet the above criteria could cause damage to the installed pipe.

For further questions please consult the supplier.

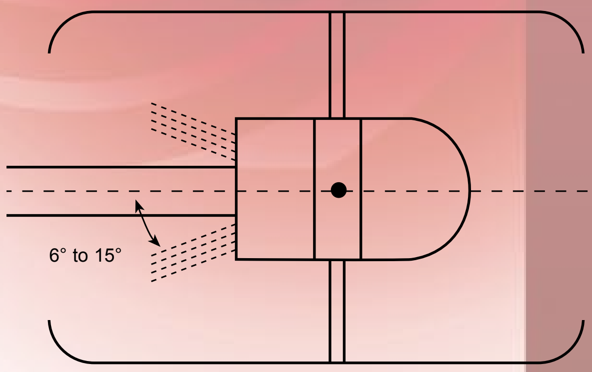
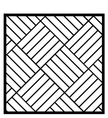


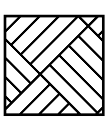
Figure J–3 Jetting/swabbing sleds

Notes

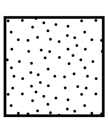
Profiles for Fillings



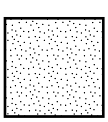
Bedding / Foundation compacted



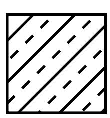
Bedding / Foundation



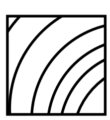
Backfill



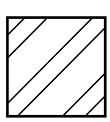
Backfill compacted



Concrete



Wood



Stone

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