Chapter 8 Pipe Classifications and Materials

8-1 Introduction

WSDOT uses several types of pipe for highway construction activities. To simplify contract plan and specification preparation, pipes have been grouped into five primary categories:

- Drain pipe
- Underdrain pipe
- Culvert pipe
- Storm sewer pipe
- Sanitary sewer pipe

Each category is intended to serve specific purposes and is described further in Section 8-2.

Within each pipe classification there are several types of pipe materials, each with unique characteristics used in different conditions. Pipe material selection includes hydraulic characteristics, site conditions, geologic conditions, corrosion resistance, safety considerations, and cost. Section 8-3 provides a detailed discussion of the different pipe materials that are generally used in WSDOT design.

The type of material that is appropriate for a project is dependent on several factors including pipe strength and corrosion and abrasion potential (Sections 8-4, 8-5, and 8-6); fill height (Section 8-12); the required pipe size, debris passage, and necessary end treatments (Chapter 3); and ease of fish passage (Chapter 7). Except for sizing the pipe, end treatments, and fish passage, each of these issues is further discussed in this chapter along with guidelines to assist the PEO in selecting the appropriate pipe material for a project site and application (Section 8-4).

This chapter also provides additional information about joining pipe materials (Section 8-7), use of pipe anchors (Section 8-8), acceptable forms of pipe rehabilitation (Section 8-9), design and installation techniques for pipe (Section 8-10), and abandoned pipe guidelines (Section 8-11).

Pipe producers follow specifications (ASTM, AASHTO, American Water Works Association [AWWA]) covering the manufacture of pipes and parameters such as cell class, material strength, internal diameter, loadings, and wall thickness. When these standards are referenced, the current-year standards shall apply.

Pipe materials and installation methods shall conform with WSDOT's *Standard Specifications* and *Standard Plans* whenever possible. Other specifications may be used when the *Standard Specifications* and *Standard Plans* are not applicable.

8-2 Pipe Classifications

This section examines the five primary categories of pipes used in WSDOT projects: drain pipe, underdrain pipe, culvert pipe, storm sewer pipe, and sanitary sewer pipe.

8-2.1 *Drain Pipe*

Drain pipe is small-diameter pipe (usually less than 24-inch diameter) used to convey roadway runoff or groundwater away from the roadway profile. Drain pipe is not allowed to cross under the roadway profile and is intended for use in easily accessible locations should it become necessary to maintain or replace the pipe. The minimum design life expectancy is 25 years and no protective treatment is required.

Drain pipe applications include simple slope drains and small-diameter "tight lines" used to connect underdrain pipe to storm sewers. Slope drains generally consist of one or two inlets with a pipe conveying roadway runoff down a fill slope. These drain pipes are relatively easy to install and are often replaced when roadway widening or embankment slope grading occurs. Slope drains are most critical during the first few years after installation, until the slope embankment and vegetation have had a chance to stabilize.

Drain pipe smaller than 12 inches in diameter can withstand fill heights of 30 feet or more without experiencing structural failure. All of the materials listed in WSDOT's *Standard Specifications* are adequate under these conditions. For drain pipe applications using pipe diameters 12 inches or larger, or with fill heights greater than 30 feet, the PEO shall specify only those materials listed in both the *Standard Specifications* and the fill height tables in Section 8-12.

8-2.2 *Underdrain Pipe*

Underdrain pipe is small-diameter perforated pipe intended to intercept groundwater and convey it away from areas such as roadbeds or retaining walls. Underdrain applications use 6- to 8-inch-diameter pipe, but larger diameters can be specified. The minimum design life expectancy is 25 years, and no protective treatment is required. The *Standard Specifications* list applicable materials for underdrain pipe.

Underdrain pipe is generally used in conjunction with well-draining backfill material and a construction geotextile. Details regarding the various applications of underdrain pipe are described in WSDOT's *Design Manual*, the WSDOT *Plan Sheet Library*, and the *Standard Plans*. The hydraulic design of underdrain pipe is discussed in Chapter 6.

8-2.3 *Culvert Pipe*

A culvert is a conduit under a roadway or embankment used to maintain flow from a natural channel or drainage ditch. Culverts are generally more difficult to replace than drain pipe, especially when located under high fills or major highways. Because of this, a minimum design life expectancy of 50 years is required for all culverts. Metal culvert pipes require a protective coating at some locations. Details are described in Section 8-5.3.1.

The maximum and minimum fill heights over a pipe material are provided in Section 8-12. For materials or sizes not provided in Section 8-12, contact the State Hydraulics Office or review the *Standard Specifications*.

The hydraulic design of culverts is discussed in Chapter 3. In addition to the hydraulic constraints of a location, the final decision regarding the appropriate culvert size may be governed by fish passage requirements, as discussed in Chapter 7.

Culvert shapes, sizes, and applications can vary substantially from one location to another. Listed below is a discussion of the various types of culverts that may appear on a contract.

8-2.3.1 Circular and Schedule Culvert Pipe

Circular culvert pipe measuring 12 to 48 inches in diameter is designated as "schedule pipe" and shall be selected unless a pipe material is excluded for engineering reasons. The pipe schedule table listed in Section 7-02 of the *Standard Specifications* includes the structurally suitable pipe alternatives available for a given culvert diameter and fill height. Additionally, Figure 8-8, Figure 8-10, and Figure 8-12 provide the PEO with a list of pipe alternatives and protective treatment depending on the corrosion zone. All schedule pipe shall be installed in accordance with Section 8-10.4.

Schedule culvert pipe shall be specified as "Schedule_Culv. Pipe____in Diam." On the contract plan sheets. Schedule pipe must be treated with the same protective coatings as other culvert pipe.

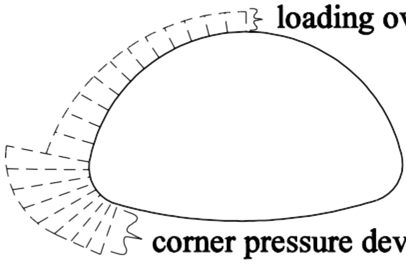
The type of material for circular culvert pipe measuring 54 to 120 inches in diameter shall be designated on the plan sheets. The structure notes sheet shall include any acceptable alternative material for that particular installation. A schedule table for these large sizes has not been developed because of their limited use. Also, structural, hydraulic, or aesthetic issues may control the type of material to be used at a site, and a specific design for each type of material available is necessary.

8-2.3.2 Pipe Arches

Pipe arches, sometimes referred to as "squash pipe," are circular culverts that have been reshaped into a structure with a circular top and a flat, wide bottom. For a given vertical dimension, pipe arches provide a larger hydraulic opening than a circular pipe. This can be useful in situations with minimal vertical clearances. Pipe arches also tend to be more effective than circular pipe in low flow conditions (such as fish passage flows) because pipe arches provide most of their hydraulic opening near the bottom of the structure, resulting in lower velocities and more of the main channel being spanned.

The primary disadvantage to using pipe arches is that the fill height range is somewhat limited. Because of the shape of the structure, significant corner pressures are developed in the haunch area as shown in Figure 8-1. The ability of the backfill to withstand the corner pressure near the haunches tends to be the limiting factor in pipe arch design and is demonstrated in the fill height tables shown in Section 8-12.

Figure 8-1 Typical Soil Pressure Surrounding a Pipe Arch



8-2.3.3 Structural Plate Culverts

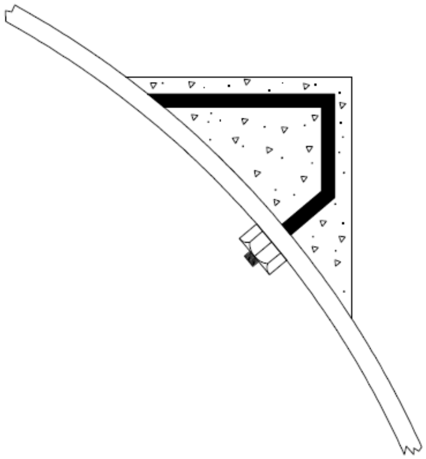
Structural plate culverts are steel or aluminum structures delivered to the project site as unassembled plates of material and bolted together. Structural plate culverts are large diameter—from 10 to 40 feet or more—and are available in several different shapes including circular, pipe arch, elliptical, and bottomless arch with footings. These structures are designed to span the main channel of a stream and are a viable option when fish passage is a concern.

The material requirements for structural plate culverts are described in the *Standard Specifications*. Aluminum structural plate culverts can be used anywhere in the state, regardless of the corrosion zone. Steel structure plate culverts are not permitted in salt water or Corrosion Zone III, as described in Section 8-4. The protective coatings described in Section 8-5.3.1 shall not be specified for use on these types of culverts because the coatings interfere with the bolted seam process.

To compensate for the lack of protective treatment, structural plate furnished in galvanized steel shall be specified with 1.5 ounces per square foot (oz/ft^2) of galvanized coating on each plate surface (galvanized culvert pipe is manufactured with 1 oz/ft^2 of galvanized coating on each pipe surface). The design of structural plate culverts may also add extra plate thickness to the bottom plates to compensate for corrosion and abrasion in high-risk areas. Increasing the gage thickness in this manner can provide a service life of 50 years or more for a small cost increase.

Longitudinal or circumferential stiffeners may be added to prevent excessive deflection due to dead and/or live loads on larger structural plate culverts. Circumferential stiffeners are usually metal ribs bolted to the outside of the culvert. Longitudinal stiffeners may be metal or reinforced concrete thrust beams, as shown in Figure 8-2. The thrust beams are added to the structure prior to backfill. Concrete thrust beams provide circumferential and longitudinal stiffening and a solid vertical surface for soil pressures to act on; the solid surface also facilitates backfilling.

Figure 8-2 Concrete Thrust Beams Used as Longitudinal Stiffeners



Another method for diminishing loads placed on large-span culverts is to construct a reinforced concrete distribution slab over the top of the backfill above the culvert. The distribution slab is used in low-cover applications and distributes live loads into the soil column adjacent to the culvert. The State Hydraulics Office shall be consulted to assist in the design of this type of structure.

8-2.3.4 Private Road Approach and Driveway Culverts

The requirements for culverts placed under private road approaches and driveways are less stringent than the requirements for culverts placed under roadways.

For the purpose of this chapter the terms “access,” “approach,” and “driveway” are referred as “driveway” to remain consistent with the WSDOT *Design Manual*.

8-2.3.4.1 Applicable Criteria

The requirements in this section apply to a drainage pipe constructed within an existing WSDOT drainage ditch to accommodate and maintain stormwater drainage underneath a driveway. Driveway culverts are off the main line of the highway, so minimal hazard is presented to the traveling public if a failure occurs. The requirements for culverts placed under driveways are less stringent than the requirements for culverts placed under roadways except those identified as fish barriers by WDFW. Fish barrier private road approach and driveway culverts need to follow WDFW water crossing design guidelines. Culverts that cross bioswales are treated in a different manner. See Section 8-2.3.4.9.

8-2.3.4.2 Culvert Replacement

At a minimum, the replacement culvert shall have the same size, slope, and material type as the existing culvert. If the culvert is replaced because of the failure of the existing culvert, an appropriate hydraulic evaluation shall be done to prevent future problems.

8-2.3.4.3 Construction Material

Within the WSDOT ROW, driveway culverts shall be constructed from material selection guidance as described in Section 8-3.

8-2.3.4.4 Minimum Size

Private road approach and driveway culverts shall be sized to pass the 10-year ditch flow capacity without overtopping the driveway. The minimum size for driveway culverts shall be 12 inches in diameter for round pipe or an equivalent cross-sectional area for arch or elliptical shapes.

8-2.3.4.5 Maximum Length

The length of a culvert will vary depending on the connection width, side slopes, and ditch depth. Use the minimum length of pipe necessary to span a driveway plus allow for appropriate end walls because a longer pipe may get clogged more easily, which frequently creates maintenance problems.

8-2.3.4.6 Minimum Cover

Driveway culverts shall be provided with the minimum cover recommended by the pipe structural design requirements, or 1 foot, whichever is greater. It is difficult to provide a minimum 2-foot cover over the top of these culverts. Therefore, private road approach and driveway culverts can be specified without the protective treatments described in Section 8-5.3.1, and the minimum fill heights listed in Section 8-12 can be reduced to 1 foot (0.3 m).

If live loads approaching AASHTO HS-25 loading will consistently be traveling over the culvert and if the fill height is less than 2 feet, only pipes meeting the minimum fill height described in Section 8-12 shall be specified.

8-2.3.4.7 Culvert End Treatments

All driveway culverts shall be provided with end treatments on the upstream and downstream ends of the culvert to protect and help maintain the integrity of the culvert opening. Headwalls and/or wingwalls and flared end sections are acceptable end treatments.

8-2.3.4.8 Minimum Slope

A minimum slope shall be provided to achieve the minimum velocities outlined in Section 3-3.5.

8-2.3.4.9 Design Documentation of Driveway Culverts

Additional information must be included in the drainage report and on the construction drawings for new developments, where the use of roadside ditches and driveway culverts is proposed. Driveway culverts shall be designed and documented in the development's drainage report, based on the tributary area at the downstream lot line. The construction drawings shall include information regarding sizes, materials, locations, lengths, grades, and end treatments for all driveway culverts. Typical driveway crossing/culvert details shall be included in the construction drawings. The construction drawings must address the roadside ditch section in detail to ensure that adequate depth is provided to accommodate the driveway culverts, including the minimum cover, and considering overtopping of the driveway when the culvert capacity is exceeded.

If driveways or approach roads cross a bioswale, the culvert shall be checked to establish that the backwater elevation would not exceed the banks of the swale. See Section 3-4.7 for energy dissipation requirements.

8-2.3.4.10 Culvert Extension

Culvert extension shall be as per guidance outlined in Section 3-3.1.6.

8-2.3.5 Concrete Box Culverts

Concrete box culverts are generally constructed of precast reinforced concrete, though some older ones may be cast-in-place. They have two configurations—monolithic (one-piece box) and split box. These structures are available in various spans and rises and can be used with varying cover, including no cover. Skew angles can be incorporated into the design and precast wing walls, headwalls, and aprons are available.

All precast box culverts shall be installed in accordance with the manufacturer's recommendations. Design and submittal requirements are listed in the *Standard Specifications*. For extending or new construction of cast-in-place box culverts, contact the State Hydraulics Office.

The dimensions and reinforcement requirements for precast box culverts are described by AASHTO. AASHTO M 259 describes precast box culverts with fill heights ranging from 2 to less than 20 feet. Refer to Section 8-12.2 for additional guidance on the use of concrete structures in shallow cover applications. If a precast box culvert is specified on a contract, the appropriate AASHTO specification shall be referenced, along with a statement requiring the contractor to submit engineering calculations demonstrating that the box culvert meets the particular requirements of the AASHTO specification.

8-2.3.6 Three-Sided Concrete Box Culverts

Three-sided structures shall meet the design criteria as specified in the *Bridge Design Manual* and the *Standard Specifications*. In addition to the hydraulic opening required, a location must be evaluated for suitability of the foundation material, footing type and size, and scour potential. A scour analysis is required for designs of all three-sided structures.

8-2.4 *Storm Sewer Pipe*

A storm sewer is defined as one or more inlet structures, connected by pipe for the purpose of collecting pavement drainage. Storm sewers are usually placed under pavement in urbanized areas and, for this reason, are costly to replace. The minimum design life of a storm sewer pipe is 50 years.

The pipe schedule table in the *Standard Specifications* lists all of the structurally suitable pipe alternatives available for a given culvert diameter and fill height. Additionally, Figure 8-8, Figure 8-10, and Figure 8-12 provide the PEO with a list of pipe alternatives and protective treatments depending on the corrosion zone. All schedule pipe shall be installed in accordance with Section 8-10.4.

All storm sewer pipes must be pressure tested. Pressure testing indicates the presence of leaking seams or joints or other structural deficiencies that may have occurred during the manufacturing or installation of the pipe. The *Standard Specifications* describe the types of pressure tests that are available.

Metal storm sewer pipe requires the same protective coating to resist corrosion as culvert pipe. In addition, ungasketed helical-seam metal pipes may require coatings to enable the pipe to pass one of the pressure tests described above. Gasketed helical-lock seams and welded and remetallized seams are tight enough to pass the pressure test without a coating but may still require a coating for corrosion purposes in some areas of the state. Pipe used for storm sewers must be compatible with the structural fill height tables for maximum and minimum amounts of cover shown in Section 8-12.

8-2.5 *Sanitary Sewer Pipe*

Sanitary sewers and side sewers consist of pipes and manholes intended to carry either domestic or industrial sanitary wastewater. Any sanitary sewer work on WSDOT projects will likely consist of replacement or relocation of existing sanitary sewers for a municipal sewer system. Therefore, the pipe materials will be in accordance with the requirements of the local health department, sewer district, and the *Standard Specifications*.

8-3 Pipe Materials

Various types of pipe material are available for each classification described in Section 8-2. Each type of material has unique properties for structural design, corrosion/abrasion resistance, and hydraulic characteristics, which are further discussed in this section to assist the PEO in selecting the appropriate pipe materials.

Several pipe materials are acceptable to WSDOT, depending on the pipe classification (see the *Standard Specifications*). WSDOT's policy is to allow and encourage all schedule pipe alternatives that will function properly at a reasonable cost.

If one or more of the schedule pipe alternatives at any location are not satisfactory, or if the project has been designed for a specific pipe material, the schedule alternate or alternates shall be so stated on the plans, usually on the structure note sheet. Pipe materials shall conform to the *Hydraulics Manual*, the *Standard Specifications*, and the *Standard Plans*.

Justification for not providing a pipe material, as limited by the allowable fill heights, corrosion zones, soil resistivity, and limitations of pH for steel and aluminum pipe shall be justified in the hydraulic report (Chapter 1) and within the PS&E. Cost will not normally be a sufficient reason except in large structures such as box culverts or structural plate pipes.

Frequently, structural requirements may have more control over acceptable material than hydraulic requirements.

When drain, culvert, or sewer pipe is being constructed for the benefit of cities or counties as part of the reconstruction of their facilities and they request a certain type of pipe, the PEO may specify a particular type without alternatives; however, the city or county must submit a letter stating its justification. Existing culverts shall be extended with the same pipe material and no alternatives are required.

8-3.1 *Concrete Pipe*

This section presents design criteria for concrete pipe, including drain pipe; underdrain pipe; and culvert, storm, and sanitary sewer pipe.

8-3.1.1 Concrete Drain Pipe

Concrete drain pipe is non-reinforced. The strength requirements for concrete drain pipe are less than the strength requirements for other types of concrete pipe. Also, concrete drain pipe can be installed without the use of O-ring gaskets or mortar, which tends to permit water movement into and out of joints.

8-3.1.2 Concrete Underdrain Pipe

Concrete underdrain pipe is no longer used. Additional guidance will be provided in future revisions to the *Hydraulics Manual*.

8-3.1.3 Concrete Culvert, Storm, and Sanitary Sewer Pipe

Concrete culvert, storm, and sanitary sewer pipe can be either plain or reinforced. Plain concrete pipe does not include steel reinforcing. Reinforced concrete pipe is available in Classes I through V. The amount of reinforcement in the pipe increases as the class designation increases. Correspondingly, the structural capacity of the pipe also increases. Because of its lack of strength, Class I reinforced concrete pipe is rarely used and is not listed in the fill height tables of Section 8-12.

The reinforcement placed in concrete pipe can be either circular or elliptical. Elliptically designed reinforcing steel is positioned for tensile loading near the inside of the barrel at the crown and invert, and at the outside of the barrel at the springline. As shown in Figure 8-15, a vertical line drawn through the crown and invert is referred to as the minor axis of reinforcement. The minor axis of reinforcement will be clearly marked by the manufacturer; the pipe must be handled and installed with the axis placed in the vertical position.

Concrete joints use rubber O-ring gaskets, allowing the pipe to meet the pressure-testing requirements for storm sewer applications. The joints, however, do not have any tensile strength and in some cases can pull apart, as discussed in Section 8-7. For this reason, concrete pipe shall not be used on grades over 10 percent without the use of pipe anchors, as discussed in Section 8-8.

Concrete pipe is permitted anywhere in the state, regardless of corrosion zone, pH, or resistivity. It has a smooth interior surface, which gives it a relatively low Manning's roughness coefficient (Table 4-1). The maximum fill height for concrete pipe is limited to about 30 feet or less. However, concrete pipe is structurally superior for carrying wheel loads with shallow cover. For installations with less than 2 feet of cover, concrete pipe is an acceptable alternative. Table 8-3 lists the class of pipe that shall be specified under these conditions.

Concrete is classified as a rigid pipe, which means that applied loads are resisted primarily by the strength of the pipe material, with some additional support given by the strength of the surrounding bedding and backfill. Additional information regarding the structural behavior of rigid pipes is provided in Section 8-10.3. During the installation process, pipe shall be uniformly supported to prevent point load concentrations from occurring along the barrel or at the joints.

Potential difficulties during installation include the weight of concrete pipe and, for sanitary sewer applications, hydrogen sulfide buildup. The PEO shall follow the recommendations of the local sewer district or municipality when deciding if concrete pipe is an acceptable alternate at a given location.

8-3.2 *Metal Pipe: General*

Metal pipe is available in galvanized steel, aluminized steel, or aluminum alloy. All three types of material can be produced with helical corrugations, annular corrugations, or as spiral rib pipe.

Metal pipe is classified as a flexible pipe, which means that applied loads are resisted primarily by the strength of the bedding and backfill surrounding the pipe, with some additional support given by the pipe material itself. Because of the dependence upon bedding strength and backfill material, it is critical that metal pipe be installed in accordance with the requirements of Section 8-10.4 to ensure proper performance.

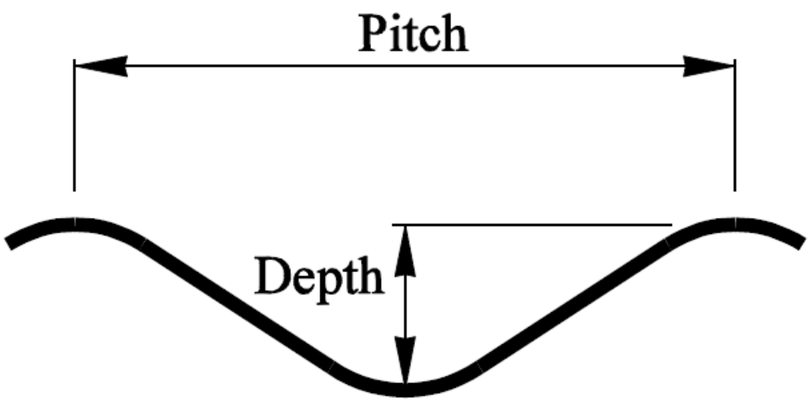
Metal pipe is available in a wide range of sizes and shapes and, depending on the type of material corrugation configuration, can be used with fill heights up to 100 feet or more. Metal pipe is susceptible to both corrosion and abrasion; methods for limiting these issues are covered in Sections 8-5.3 and 8-6.

8-3.2.1 Helical Corrugations

Most metal pipe produced today is helically wound, where the corrugations are spiraled along the flow line. The seam for this type of pipe is continuous, and also runs helically along the pipe. The seam can be either an ungasketed lock seam (not pressure testable) or it could be gasketed lock seams (pressure-testable seams). If ungasketed lock seam pipe is used in storm sewer applications, it is generally necessary to coat the pipe with Treatment 1 (Section 8-5.3.1) for the pipe to pass the pressure testing requirements.

Helically wound corrugations are available in several standard sizes, including 2⅔-inch pitch by ½-inch depth, 3-inch by 1-inch, and 5-inch by 1-inch. Corrugation sizes are available in several gage thicknesses, depending on the pipe diameter and fill height. Larger corrugation sizes are used as the pipe diameter exceeds about 60 inches. A typical corrugation section is shown in Figure 8-3.

Figure 8-3 Typical Corrugation Section



As a result of the helical manufacturing process, the Manning's roughness coefficient for smaller-diameter—24 inches or less—metal pipe approaches the Manning's roughness coefficient for smooth wall pipe materials, such as concrete and thermoplastic pipe. This similarity will generally allow metal pipe to be specified as an alternative to smooth wall pipe without increasing the diameter. However, in situations where small changes in the headwater or head loss through a system are critical, or where the pipe diameter is greater than 24 inches, the PEO shall use the Manning's roughness coefficient specified in Table 4-1 to determine if a larger-diameter metal pipe alternative is required.

8-3.2.2 Annular Corrugations

Metal pipe can be produced with annular corrugations, where the corrugations are perpendicular to the flow line of the pipe. The seams for this type of pipe are both circumferential and longitudinal and are joined by rivets. The Manning's roughness coefficient for all annularly corrugated metal pipes is specified in Table 4-1. The fill heights shown in Section 8-12 apply to both helical and annular corrugated metal pipe.

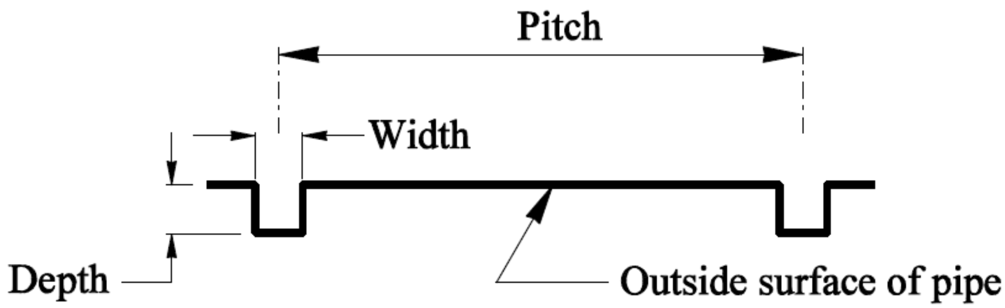
The typical corrugation section shown in Figure 8-3 is the same for annular corrugations, except that annular corrugations are available only in 2⅔-inch by ½-inch and 3-inch by 1-inch sizes.

8-3.2.3 Spiral Rib

Spiral rib pipe uses the same manufacturing process as helically wound pipe but, instead of using a standard corrugation pitch and depth, spiral rib pipe comprises rectangular ribs between flat wall areas. A typical spiral rib section is shown in Figure 8-4. Two profile configurations are available: ¾-inch width by ¾-inch depth by 7½-inch pitch or 1-inch by 1-inch by 11-inch. The seams for spiral rib pipe are either ungasketed-lock seams for non-pressure-testable applications or gasketed-lock seam for pressure-testable applications. If ungasketed lock seam pipe is used in storm sewer applications, it is generally necessary to coat the pipe with protective Treatment 1 (Section 8-5.3.1) for the pipe to pass the pressure-testing requirements.

The primary advantage of spiral rib pipe is that the rectangular rib configuration provides a hydraulically smooth pipe surface for all diameters, with a Manning's roughness coefficient specified in Table 4-1.

Figure 8-4 Typical Spiral Rib Section



8-3.2.4 Galvanized Steel

Galvanized steel consists of corrugated or spiral rib steel pipe with 1 oz/ft^2 of galvanized coating on each surface of the pipe. Plain galvanized steel pipe is the least durable pipe from a corrosion standpoint and is not permitted when the pH is less than 5.0 or greater than 8.5 or if the soil resistivity is less than 1,000 ohm-cm. Galvanized steel pipe will, however, meet the required 50-year life expectancy for culvert and storm sewers installed in Corrosion Zone I, as described in Section 8-4. In more corrosive environments, such as Corrosion Zone II or III described in Section 8-4, galvanized-steel pipe must be treated with a protective coating for the pipe to attain the required 50-year service life.

8-3.2.5 Aluminized Steel

Aluminized steel consists of corrugated or spiral rib steel pipe with an aluminum protective coating applied both inside and out. The aluminized coating is more resistant to corrosion than galvanized-steel pipe and is considered to meet the 50-year life expectancy in both Corrosion Zones I and II without the use of protective coatings. Aluminized steel is not permitted when the pH is less than 5.0 or greater than 8.5 or if the soil resistivity is less than 1,000 ohm-cm.

8-3.2.6 Aluminum Alloy

Aluminum alloy (aluminum) consists of corrugated or spiral rib pipe and has been shown to be more resistant to corrosion than either galvanized or aluminized steel. When aluminum is exposed to water and air, an oxide layer forms on the metal surface, creating a barrier between the corrosive environment and the pipe surface. As long as this barrier is allowed to form, and is not disturbed once it forms, aluminum pipe will function well.

Aluminum meets the 50-year life expectancy for both Corrosion Zones I and II. It can also be used in Corrosion Zone III, provided that the pH is between 4 and 9; the resistivity is 500 ohm-cm or greater; and the pipe is backfilled with clean, well-draining, granular material. The backfill specified in Section 8-10.4 will meet this requirement.

Aluminum shall not be used when backfill material has a high clay content, because the backfill material can prevent oxygen from getting to the pipe surface and consequently, the protective oxide layer will not form. For the same reason, aluminum pipe generally shall not be coated with the protective treatments discussed in Section 8-5.3.1.

8-3.2.7 Ductile-Iron Pipe

Ductile-iron pipe is an extremely strong, durable pipe designed primarily for use in high-pressure water distribution and sanitary sewer systems. Ductile-iron pipe is acceptable for culvert and storm sewers use; it is more expensive but is useful for shallow cover and deep installations. Ductile-iron pipe is acceptable with as little as 0.5 foot of cover in most installations. Deep fill heights are available from manufacturers and concurrence with the State Hydraulics Office. Joint systems for ductile-iron pipe include push-on, mechanical, or flanged. Depending on the type of joint, the pipe may be plain end, grooved, or flanged.

8-3.3 *Thermoplastic Pipe: General*

Thermoplastic is a term used to describe several types of pipes including corrugated polyethylene, solid-wall high-density polyethylene (HDPE), polypropylene (PP), and polyvinyl chloride (PVC). These pipes are allowed for use in drain, underdrain, culvert, storm sewer, and sanitary sewer applications, although not all types of thermoplastic pipe are allowed for use in all applications. The PEO must reference the appropriate section of the *Standard Specifications* to determine the allowable thermoplastic pipe for a given application.

Thermoplastic pipe is classified as a flexible pipe, which means that applied loads are resisted primarily by the strength of the bedding and backfill surrounding the pipe, with some additional support given by the pipe material itself. Because of the dependence upon the strength of the bedding and backfill material, it is critical that thermoplastic pipe be installed in accordance with the requirements of Section 8-10.4 to ensure proper performance.

The physical properties of thermoplastic pipe are such that the pipe is resistant to both pH and resistivity. As a result, thermoplastic pipe is an acceptable alternative in all three corrosion zones statewide, and no protective treatment is required. Laboratory testing indicates that the resistance of thermoplastic pipe to abrasive bed loads is equal to or greater than that of other types of pipe material. However, because thermoplastic pipe cannot be structurally reinforced, it shall not be used for severely abrasive conditions as described in Table 8-1.

Thermoplastic pipe is lightweight when compared to other pipe alternatives. This can simplify pipe handling because large equipment may not be necessary during installation. However, the light pipe weight can lead to soil or water flotation problems in the trench, requiring additional effort to secure the line and grade of the pipe. The allowable fill height and diameter range for thermoplastic pipe are somewhat limited. This may preclude thermoplastic pipe being specified for use in some situations.

Any exposed end of thermoplastic pipe used for culvert or storm sewer applications shall be mitered to match the surrounding embankment or ditch slope. The ends shall be mitered no flatter than 4H:1V, as a loss of structural integrity tends to occur after that point. It also becomes difficult to adequately secure the end of the pipe to the ground.

The minimum length of a section of mitered pipe shall be at least 6 times the diameter of the pipe, measured from the toe of the miter to the first joint under the fill slope. This distance into the fill slope will provide enough cover over the top of the pipe to counteract typical hydraulic uplift forces that may occur. For thermoplastic pipe 30 inches in diameter and larger, a Standard Plan B-75.20-03 headwall shall be used in conjunction with a mitered end.

8-3.3.1 Corrugated Polyethylene for Drains and Underdrains

Corrugated polyethylene used for drains and underdrains is a single-wall pipe, corrugated inside and outside. It is available in diameters up to 10 inches. This type of pipe is extremely flexible and can be manipulated easily on the job site should it become necessary to bypass obstructions during installation (see Chapter 3 for treating the exposed end for flotation.)

8-3.3.2 PVC Drain and Underdrain Pipe

PVC drain and underdrain pipe is a solid-wall pipe with a smooth interior and exterior. It is available in diameters up to 8 inches. This type of pipe is delivered to the job site in 20-foot lengths and has a significant amount of longitudinal beam strength. This characteristic is useful when placing the pipe at a continuous grade but can also make it more difficult to bypass obstructions during installation (see Chapter 3 for treating the exposed end for flotation).

8-3.3.3 Corrugated Polyethylene Culvert and Storm Sewer Pipe

Corrugated polyethylene used for culverts and storm sewers is double-walled, with a corrugated outer wall and a smooth interior. This type of pipe can be used under all state highways, subject to the fill height and diameter limits described in Section 8-12 and the *Standard Specifications*.

The primary difference between polyethylene used for culvert applications and polyethylene used for storm sewer applications is the type of joint specified. In culvert applications, the joint is not completely watertight and may allow an insignificant amount of infiltration. The culvert joint will prevent soils from migrating out of the pipe zone and is intended to be similar in performance to the coupling band and gasket required for metal pipe. If a culvert is to be installed where a combination of a high water table and fine-grained soils near the trench are expected, the joint used for storm sewer applications shall be specified. The storm sewer joint will eliminate the possibility of soil migration out of the pipe zone and will provide an improved connection between sections of pipe.

In storm sewer applications, all joints must be capable of passing WSDOT's pressure test requirements. Because of this requirement, the allowable pipe diameter for storm sewer applications may possibly be less than the allowable diameter for culvert applications. The PEO shall consult WSDOT's Qualified Products List for the current maximum allowable pipe diameter for both applications. Corrugated polyethylene is a petroleum-based product and may ignite under certain conditions. If maintenance practices such as ditch or field burning are anticipated near the inlet or outlet of a pipe, polyethylene shall not be allowed as a pipe alternative.

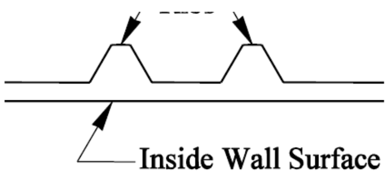
8-3.3.4 Solid-Wall PVC Culvert, Storm, and Sanitary Sewer Pipe

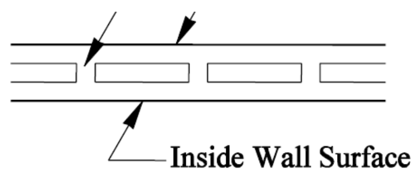
Solid-wall PVC culvert, storm, and sanitary sewer pipe is a solid-wall pipe with a smooth interior and exterior. This type of pipe can be used under all state highways, subject to the fill height and diameter limits described in Section 8-12 and the *Standard Specifications*. This type of pipe is used primarily in water line and sanitary sewer applications but may occasionally be used for culverts or storm sewers. The only joint available for this type of PVC pipe is a watertight joint conforming to the requirements of the *Standard Specifications*.

8-3.3.5 Profile-Wall PVC Culvert and Storm Sewer Pipe

Profile-wall PVC culvert and storm sewer pipe consists of pipe with an essentially smooth waterway wall braced circumferentially or spirally with projections or ribs, as shown in Figure 8-5. The pipe may have an open profile, where the ribs are exposed, or the pipe may have a closed profile, where the ribs are enclosed in an outer wall. This pipe can be used under all state highways, subject to the fill height and diameter limits described in Section 8-12 and the *Standard Specifications*. The only joint available for profile-wall PVC culvert and storm sewer pipe is a watertight joint conforming to the requirements of the *Standard Specifications*.

Figure 8-5 Typical Profile Wall PVC Cross Sections





8-3.3.6 Polypropylene Culvert and Storm Sewer Pipe

PP pipe is similar in style to corrugated polyethylene pipe; the difference is in the compounds used to produce the pipe. The pipe is either double-walled (corrugated inside and outside) or triple-walled (smooth inside and out) with a corrugated inner wall. The joint systems are bell and spigot and are soil-tight and watertight.

The compounds used in this pipe produce a much stiffer profile, making it a good choice for storm and sanitary sewer applications where line and grade may be critical. It is also highly resistant to corrosive materials and abrasion. It is costlier than normal corrugated polyethylene pipe.

8-3.3.7 Steel Rib Reinforced Polyethylene Culvert and Storm Sewer Pipe

Steel rib reinforced polyethylene pipe has a fairly thin wall profile; the inner wall is smooth, and the outer wall has ribs that are steel encased in polyethylene. This profile creates a lightweight, strong, corrosion- and abrasion-resistant pipe. Gasketed joints are made by bell-and-spigot connections in smaller diameters, and a welded or electrofusion joint creates a watertight connection in larger diameters.

8-3.3.8 Solid-Wall HDPE

Solid-wall HDPE pipe is used primarily for trenchless applications but occasionally this type of pipe is used for specific applications including bridge drainage, drains or outlet locations on very steep slopes, water line installations, and sanitary sewer lines. Solid-wall HDPE pipe is often an economical choice for deep fill applications or shallow cover down to 0.5 foot. This type of pipe is engineered to provide balanced properties for strength, toughness, flexibility, wear resistance, chemical resistance, and durability.

The pipe may be joined using many conventional methods, but the preferred method is by heat fusion. Properly joined, the joints provide a leakproof connection that is as strong as the pipe itself. There are a wide variety of grades and cell classifications for this pipe; contact the State Hydraulics Office for specific pipe information.

8-4 Pipe Corrosion Zones and Pipe Alternative Selection

Once a PEO has determined the pipe classification needed for an application, the next step is to ensure that the pipe durability will extend for the entire design life. Pipe durability can be evaluated by determining the corrosion and abrasion potential of a given site and then choosing the appropriate pipe material and protective treatment for that location.

To simplify this process, Washington State has been divided into three corrosion zones, based upon the general corrosive characteristics of that particular zone. A map delineating the three zones is shown in Figure 8-6. A flow chart and corresponding acceptable pipe alternative list have been developed for each of the corrosion zones and are shown in Figure 8-7 through Figure 8-12. The flow charts and pipe alternative lists can be used to develop acceptable pipe alternatives for a given location.

The flow charts and pipe alternative lists do not account for abrasion, as bed loads moving through pipes can quickly remove asphalt coatings applied for corrosion protection. If abrasion is expected to be significant at a given site, the guidelines discussed in Table 8-1 shall be followed.

When selecting a pipe alternative, the PEO shall consider the degree of difficulty that will be encountered in replacing a pipe at a future date. Drain pipes are relatively shallow and are readily replaced. Culverts tend to have greater depth of cover and pass under the highway alignment, making them more difficult to replace. Storm sewers are generally used in congested urban areas with significant pavement cover, high traffic use, and a multitude of other buried utilities in the same vicinity. For these reasons, storm sewers are generally considered to be the most expensive and most difficult to replace and should have a long design life.

When special circumstances exist (i.e., extremely high fills or extremely expensive structure excavation) the PEO shall use good engineering judgment to justify the cost-effectiveness of a more expensive pipe option or a higher standard of protective treatment than is recommended on the figures in this section.

8-4.1 *Corrosion Zone I*

With the exceptions noted below, Corrosion Zone 1 encompasses most of eastern Washington and is considered the least corrosive part of the state. Plain galvanized steel, untreated aluminized steel, aluminum alloy, thermoplastic, and concrete pipe may all be used in Corrosion Zone I. (See Figure 8-7 and Figure 8-8 for a complete listing of acceptable pipe alternatives for culvert and storm sewer applications.)

The following parts of eastern Washington that are not within Corrosion Zone I are categorized as Corrosion Zone II:

- Okanogan Valley
- Pend Oreille Valley
- Disautel-Nespelem vicinity

8-4.2 *Corrosion Zone II*

Most of western Washington, with the exceptions noted below, along with the three areas of eastern Washington identified above make up Corrosion Zone II. This is an area of moderate corrosion activity. Untreated aluminized steel, aluminum alloy, thermoplastic, and concrete pipe may be used in Corrosion Zone II. (See Figure 8-9 and Figure 8-10 for a complete listing of acceptable pipe alternatives for culvert and storm sewer applications.)

Parts of western Washington that are not within Corrosion Zone II are placed into Corrosion Zone III:

1. Whatcom County lowlands, described by the following:
   a. State Route (SR) 542 from its origin in Bellingham to the junction of SR 9
   b. SR 9 from the junction of SR 542 to the international boundary
   c. All other roads/areas lying northerly and westerly of the above routes
2. Lower Nisqually Valley
3. Low-lying roadways in the Puget Sound basin and coastal areas subjected to the influence of saltwater bays, marshes, and tide flats. As a general guideline, this shall include areas with elevations less than 20 feet above the average high tide elevation. Along the Pacific coast and the Straits of Juan de Fuca, areas within 300 to 600 feet of the edge of the average high tide can be influenced by salt spray and shall be classified as Corrosion Zone III. However, this influence can vary significantly, depending on the roadway elevation and the presence of protective bluffs or vegetation. In these situations, the PEO is encouraged to evaluate existing pipes near the project to determine the most appropriate corrosion zone designation.

8-4.3 *Corrosion Zone III*

The severely corrosive areas identified above make up Corrosion Zone III. Concrete and thermoplastic pipe are allowed for use in this zone without protective treatments. Aluminum alloy is permitted only as described in Section 8-3. (See Figure 8-11 and Figure 8-12 for a complete listing of all acceptable pipe alternatives for culvert and storm sewer applications.)

Figure 8-6 Washington State Corrosion Zones

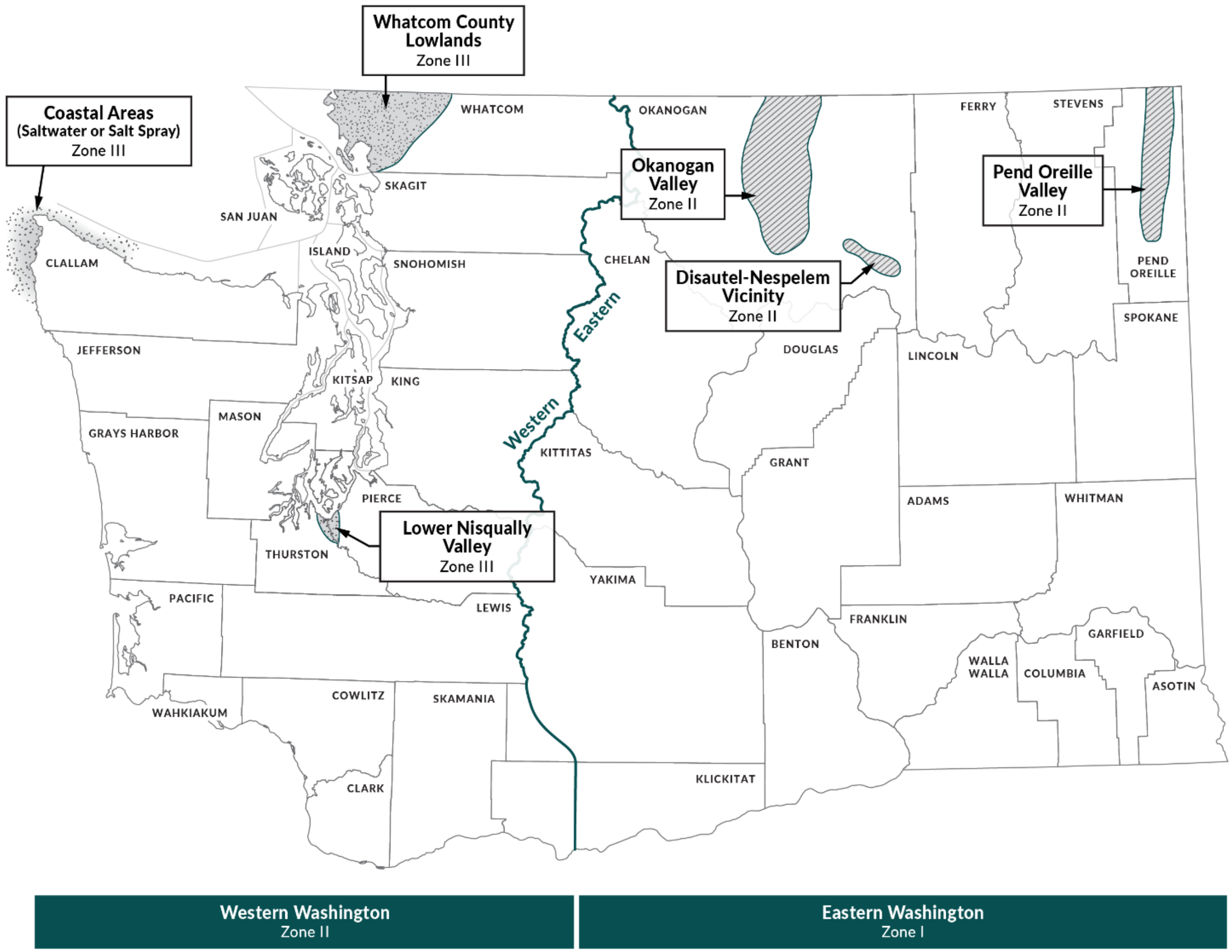
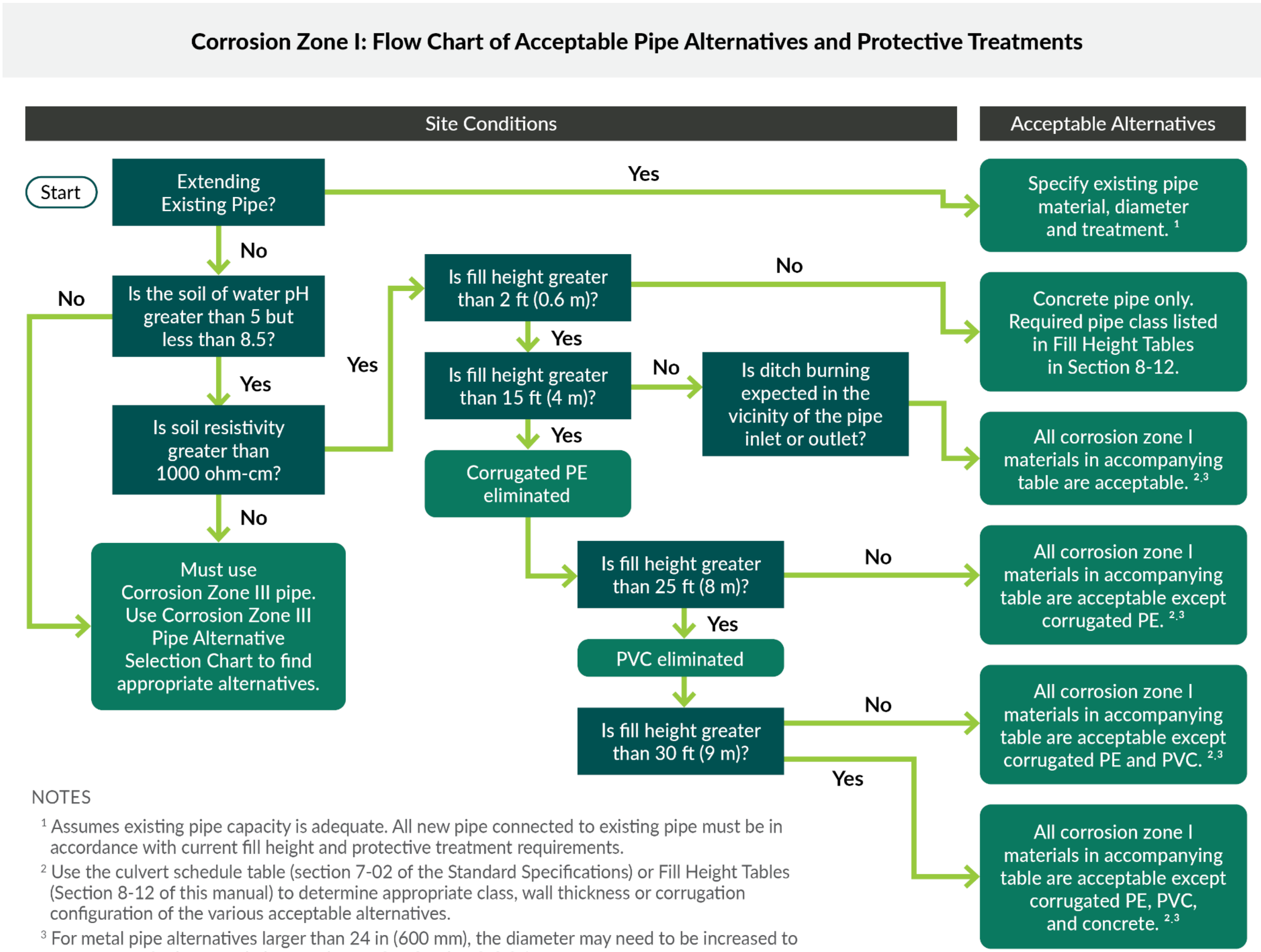


Figure 8-7 Corrosion Zone I: Flow Chart of Acceptable Pipe Alternatives and Protective Treatments



NOTES

[1] Assumes existing pipe capacity is adequate. All new pipe connected to existing pipe must be in accordance with current fill height and protective treatment requirements.

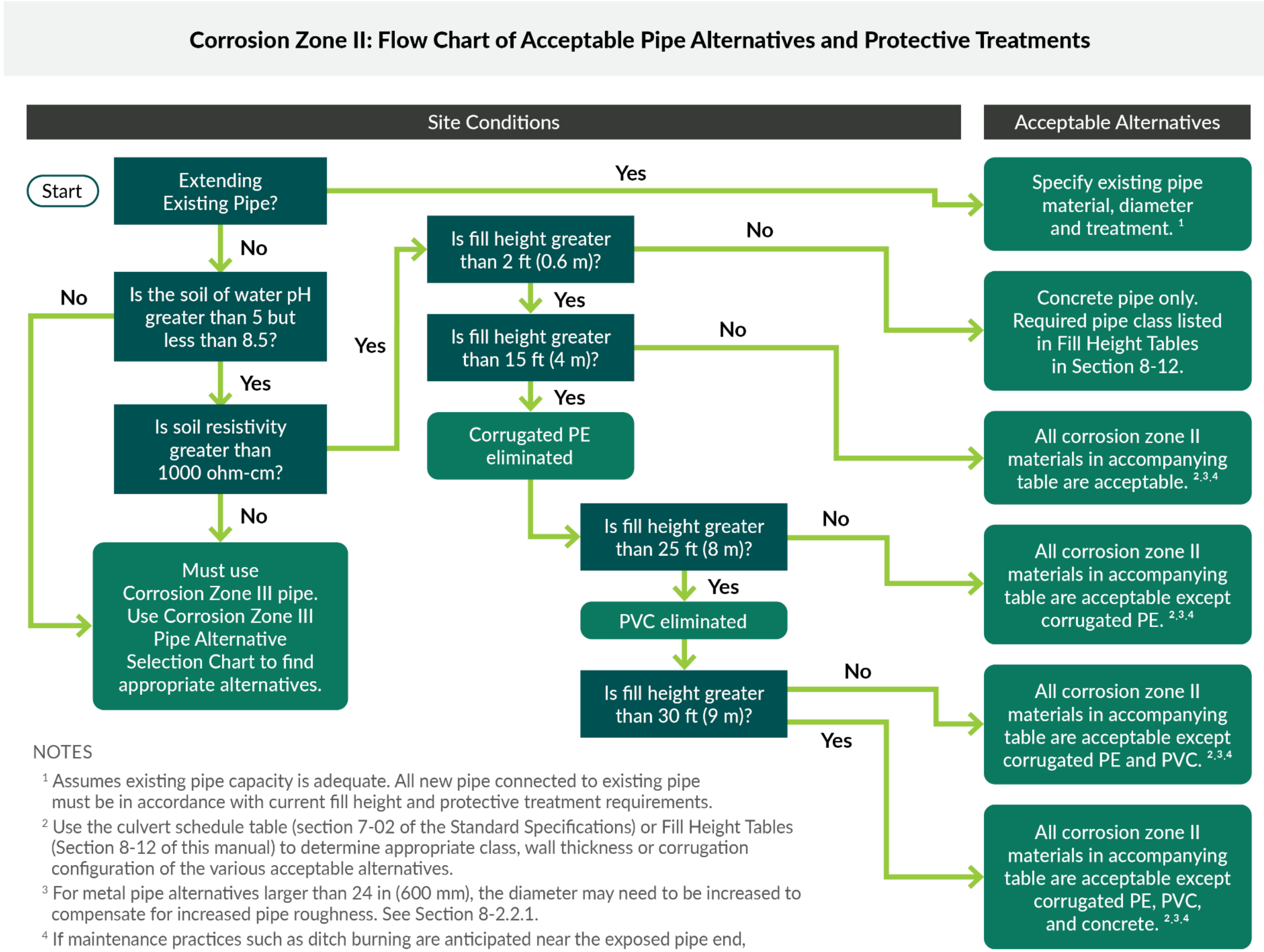
[2] Use the culvert schedule table (section 7-02 of the Standard Specifications) or Fill Height Tables (Section 8-12 of this manual) to determine appropriate class, wall thickness or corrugation configuration of the various acceptable alternatives.

[3] For metal pipe alternatives larger than 24 in (600 mm), the diameter may need to be increased to compensate for increased pipe roughness. See Section 8-2.2.1.

Figure 8-8 Corrosion Zone I: Acceptable Pipe Alternatives and Protective Treatments

Culverts	Storm sewers
Schedule pipe: Schedule____culvert pipe If Schedule pipe not selected, then: **Concrete:** • Plain concrete culvert pipe • Cl__reinforced concrete culvert pipe **PVC:** • Solid wall PVC culvert pipe • Profile wall PVC culvert pipe **Polyethylene** • Corrugated polyethylene culvert pipe • Solid-wall HDPE pipe **Polypropylene culvert pipe** **Steel** • Plain galvanized steel culvert pipe • Plain aluminized steel culvert pipe **Aluminum:** • Plain aluminum culvert pipe	**Concrete:** • Plain concrete storm sewer pipe • Cl.___Reinforced concrete storm sewer pipe **PVC:** • Solid-wall PVC storm sewer pipe • Profile-wall PVC storm sewer pipe **Polyethylene:** • Corrugated polyethylene storm sewer pipe • Solid-wall HDPE pipe **Polypropylene storm sewer pipe** **Steel:** • Plain galvanized steel storm sewer pipe with gasketed or welded and remetallized seams • Plain aluminized steel storm sewer pipe with gasketed or welded and remetallized seams **Steel spiral rib:** • Plain galvanized steel spiral rib storm sewer pipe with gasketed or welded and remetallized seams **Aluminum spiral rib:** • Plain aluminum spiral rib storm sewer pipe with gasketed seams

Figure 8-9 Corrosion Zone II: Flow Chart of Acceptable Pipe Alternatives and Protective Treatments



NOTES

[1] Assumes existing pipe capacity is adequate. All new pipe connected to existing pipe must be in accordance with current fill height and protective treatment requirements.

[2] Use the culvert schedule table (section 7-02 of the Standard Specifications) or Fill Height Tables (Section 8-12 of this manual) to determine appropriate class, wall thickness or corrugation configuration of the various acceptable alternatives.

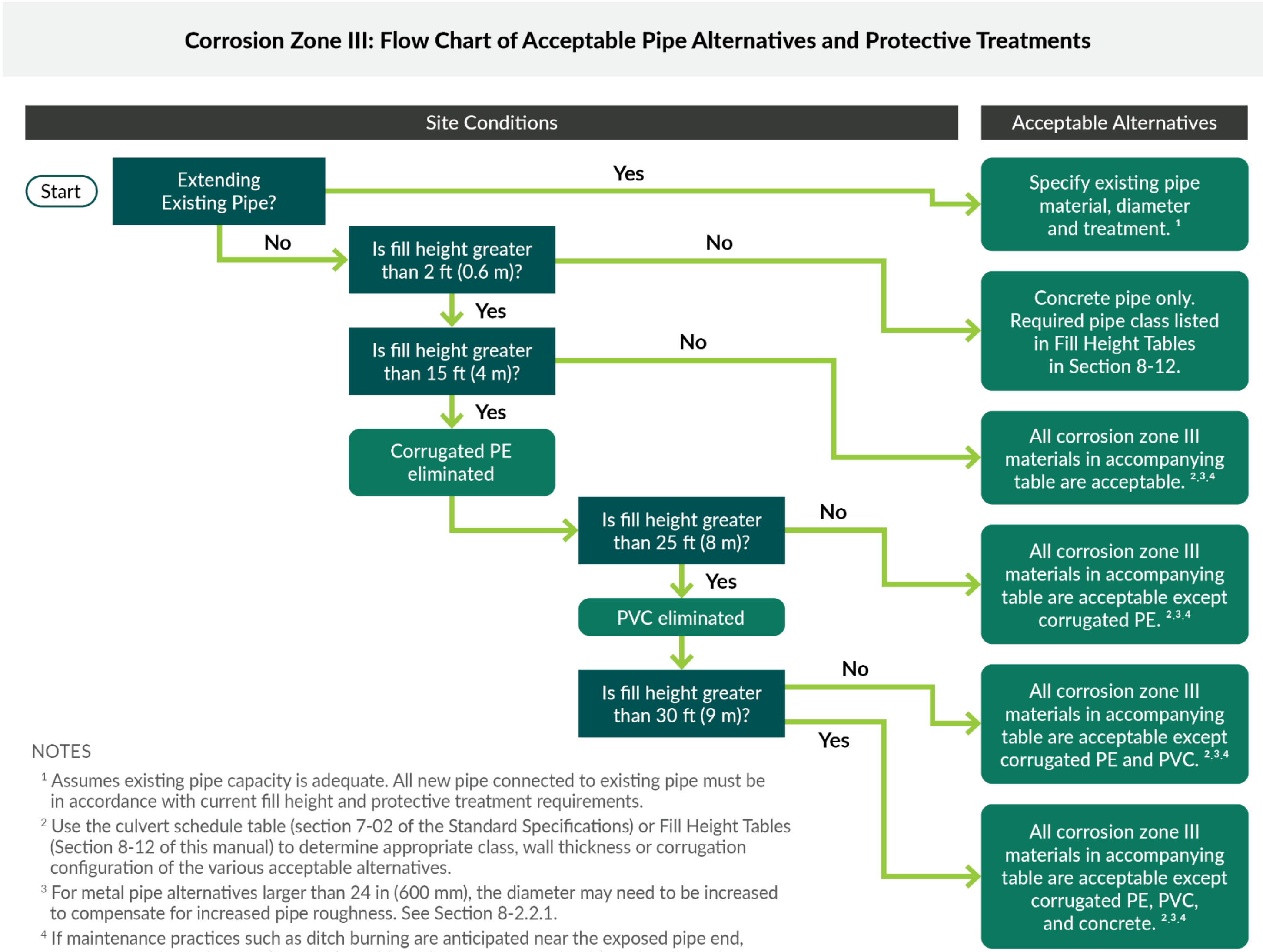
[3] For metal pipe alternatives larger than 24 in (600 mm), the diameter may need to be increased to compensate for increased pipe roughness. See Section 8-2.2.1.

[4] If maintenance practices such as ditch burning are anticipated near the exposed pipe end, corrugated polyethylene and metal pipe with asphalt treatments should not be allowed.

Figure 8-10 Corrosion Zone II: Acceptable Pipe Alternatives and Protective Treatments

Culverts	Storm Sewers
Schedule pipe: Schedule_____culvert pipe If Schedule pipe not selected, then: **Concrete:** • Plain concrete culvert pipe • Cl___reinforced concrete culvert pipe **PVC:** • Solid wall PVC culvert pipe • Profile wall PVC culvert pipe **Polyethylene:** • Corrugated polyethylene culvert pipe • Solid-wall HDPE pipe **Polypropylene culvert pipe** **Steel** • Plain aluminized steel culvert pipe **Aluminum:** • Plain aluminum culvert pipe	**Concrete:** • Plain concrete storm sewer pipe • Cl.___Reinforced concrete storm sewer pipe **PVC:** • Solid-wall PVC storm sewer pipe • Profile-wall PVC storm sewer pipe **Polyethylene:** • Corrugated polyethylene storm sewer pipe • Solid-wall HDPE pipe **Polypropylene storm sewer pipe** **Steel:** • Plain aluminized steel spiral rib storm sewer pipe with gasketed or welded and remetallized seams **Steel spiral rib:** • Plain aluminized steel spiral rib storm sewer with gasketed or welded or welded and remetallized seams **Aluminum:** • Plain aluminum storm sewer pipe with gasketed seams **Aluminum spiral rib:** • Plain aluminum spiral rib storm sewer pipe with gasketed seams

Figure 8-11 Corrosion Zone III: Flow Chart of Acceptable Pipe Alternatives and Protective Treatments



NOTES

[1] Assumes existing pipe capacity is adequate. All new pipe connected to existing pipe must be in accordance with current fill height and protective treatment requirements.

[2] Use the culvert schedule table (section 7-02 of the Standard Specifications) or Fill Height Tables (Section 8-12 of this manual) to determine appropriate class, wall thickness or corrugation configuration of the various acceptable alternatives.

[3] For metal pipe alternatives larger than 24 in (600 mm), the diameter may need to be increased to compensate for increased pipe roughness. See Section 8-2.2.1.

[4] If maintenance practices such as ditch burning are anticipated near the exposed pipe end, corrugated polyethylene and metal pipe with asphalt treatments should not be allowed.

Figure 8-12 Corrosion Zone III: Acceptable Pipe Alternatives and Protective Treatments

Culverts	Storm Sewers
Schedule pipe: Schedule____culvert pipe____in. diam. If schedule pipe not selected, then: **Concrete:** • Plain concrete culvert pipe • Cl__reinforced concrete culvert pipe **PVC:** • Solid wall PVC culvert pipe • Profile wall PVC culvert pipe **Polyethylene** • Corrugated polyethylene culvert pipe • Solid-wall HDPE pipe **Polypropylene culvert pipe** **Aluminum:** • Plain aluminum culvert pipe	**Concrete:** • Plain concrete storm sewer pipe • Cl.__Reinforced concrete storm sewer pipe **PVC:** • Solid-wall PVC storm sewer pipe • Profile-wall PVC storm sewer pipe **Polyethylene:** • Corrugated polyethylene storm sewer pipe • Solid-wall HDPE pipe **Polypropylene storm sewer pipe** **Aluminum:** • Plain aluminum storm sewer pipe with gasketed seams **Aluminum spiral rib:** • Plain aluminum spiral rib storm sewer pipe with gasketed seams

8-5 Corrosion

Corrosion is the destructive attack on a material by a chemical or electrochemical reaction with the surrounding environment. Corrosion is generally limited to metal pipes, and the parameters that tend to have the most significant influence on the corrosion potential for a site is the soil or water pH and the soil resistivity.

8-5.1 *pH*

The pH is a measurement of the relative acidity of a given substance. The pH scale ranges from 1 to 14, with 1 being extremely acidic, 7 being neutral, and 14 being extremely basic. The closer a pH value is to 7, the less potential the pipe has for corroding. When the pH is less than 5.0 or greater than 8.5, the site will be considered unsuitable and only Corrosion Zone III pipes, as discussed in Section 8-4.3, are acceptable.

The total number of pH tests required for a project will vary depending on different parameters, including the type of structures to be placed, the corrosion history of the site, and the project length and location. The general criteria listed below serve as minimum guidelines for determining the appropriate number of tests for a project:

1. **Size and importance of the drainage structure:** A project comprising large culverts or storm sewers under an interstate or other major arterial warrant testing at each culvert or storm sewer location, while a project comprising small culverts under a secondary highway may need only a few tests for the entire length of the project.

2. **Corrosion history of the project location:** A site in an area of the state with a high corrosion potential would warrant more tests than a site in an area of the state with a low corrosion potential.
3. **Distance of the project:** Longer projects tend to pass through several soil types and geologic conditions, increasing the likelihood of variable pH readings. Tests shall be taken at each major change in soil type or topography, or in some cases, at each proposed culvert location. Backfill material that is not native to the site and that will be placed around metal pipe shall also be tested.
4. **Initial testing results:** If initial pH tests indicate that the values are close to or outside of the acceptable range of 5.0 to 8.5, or if the values vary considerably from location to location, additional testing may be appropriate.

8-5.2 *Resistivity*

Resistivity is the measure of the ability of soil or water to pass electric current. The lower the resistivity value is, the easier it is for the soil or water to pass current, resulting in increased corrosion potential. If the resistivity is less than 1,000 ohm-cm for a location, then Corrosion Zone III pipe materials are the only acceptable alternatives. Resistivity tests are usually performed in conjunction with pH tests, and the criteria for frequency of pH testing shall apply to resistivity testing as well.

8-5.3 *Corrosion Control Methods*

This section presents corrosion control methods, including protective treatments and increased gage thickness.

8-5.3.1 Protective Treatments

Corrugated steel pipe may be coated on both sides with a polymer coating conforming to AASHTO M 246. The coating shall be a minimum of 10 mils thick and be composed of polyethylene and acrylic acid copolymer.

The protective treatments, when required, shall be placed on circular pipe and pipe arch culverts. Structural plate pipes do not require protective treatment, as described in Section 8-2.3.3. Protective treatments are not allowed for culverts placed in fish-bearing streams. This may preclude the use of metal culverts in some applications.

The treatments specified in this section are the standard minimum applications, which are adequate for a large majority of installations; however, a more stringent treatment may be used at the PEO’s discretion. When unusually abrasive or corrosive conditions are anticipated, and it is difficult to determine which treatment would be adequate, either the HQ Materials Laboratory or State Hydraulics Office shall be consulted.

8-5.3.2 Increased Gage Thickness

As an alternative to asphalt protective treatments, the thickness of corrugated steel pipes can be increased to compensate for loss of metal due to corrosion or abrasion. The California Transportation Department (Caltrans) has developed a methodology to estimate the expected service life of untreated corrugated steel pipes. The method uses pH, resistivity, and pipe thickness and is based on data taken from hundreds of culverts throughout California. Copies of the design charts for this method can be obtained from the State Hydraulics Office.

8-6 Abrasion

Abrasion is the wearing away of pipe material by water carrying sands, gravels, and rocks. All types of pipe material are subject to abrasion and can experience structural failure around the pipe invert if not adequately protected. Four abrasion levels have been developed to assist the PEO in quantifying the abrasion potential of a site. The abrasion levels are identified in Table 8-1.

The abrasion level descriptions are intended to serve as general guidance only; not all of the criteria listed for a particular abrasion level need to be present to justify placing a site at that level. Included with each abrasion level description are guidelines for providing additional invert protection. The PEO is encouraged to use those guidelines in conjunction with the abrasion history of a site to achieve the desired design life of a pipe.

In streams with significant bed loads, placing culverts on flat grades can encourage bed load deposition within the culvert. This can substantially decrease the hydraulic capacity of a culvert, ultimately leading to plugging or potential roadway overtopping on the upstream side of the culvert. As a standard practice, culvert diameters shall be increased two or more standard sizes over the required hydraulic opening in situations where abrasion and bed load concerns have been identified.

Table 8-1 Pipe Abrasion Levels

Abrasion Level	General Site Characteristics	Recommended Invert Protection
Non-abrasive	• Little or no bed load • Slope less than 1% • Velocities less than 3 ft/s	Generally, most pipes may be used under these circumstances, if a protective treatment is deemed necessary for metal pipes, any of the protective treatments specified in Section 8-5.3.1 would be adequate.
Low abrasive	• Minor bed loads of sands, silts, and clays • Slopes 1%–2% • Velocities less than 6 ft/s	For metal pipes, an additional gage thickness may be specified if existing pipes in the vicinity show susceptibility to abrasion, or any of the protective treatments specified in Section 8-5.3.1 would be adequate.
Moderately abrasive	• Moderate bed loads of sands and gravels, with stone sizes up to about 3 inches • Slopes 2%–4% • Velocities from 6 to 15 ft/s	Metal pipe thickness shall be increased one or two standard gages. The PEO may want to consider a concrete-lined alternative. Concrete pipe and box culverts shall be specified with an increased wall thickness or an increased concrete compressive strength. Thermoplastic pipe may be used without additional treatments.
Severely abrasive	• Heavy bed loads of sands, gravel, and rocks, with stone sizes up to 12 inches or larger • Slopes steeper than 4% • Velocities greater than 15 ft/s	Metal pipe thickness shall be increased at least two standard gages, or the pipe invert shall be lined with concrete. Box culverts shall be specified with an increased wall thickness or an increased concrete compressive strength. Sacrificial metal pipe exhibits better abrasion characteristics than metal or concrete. However, it generally cannot be reinforced to provide additional invert protection and shall not be used in this condition.

8-7 Pipe Joints

Culverts, storm sewers, and sanitary sewers require the use of gasketed or fused joints to restrict the amount of leakage into or out of the pipe. The type of gasket material varies, depending on the pipe application and the type of pipe material being used. The *Standard Plans* and *Standard Specifications* shall be consulted for specific descriptions of the types of joints, coupling bands, and gaskets for the various types of pipe material.

Corrugated metal pipe joints incorporate the use of a metal coupling band and neoprene gasket that strap on around the outside of the two sections of pipe to be joined. This joint provides a positive connection between the pipe sections and is capable of withstanding significant tensile forces. These joints work well in culvert applications but usually do not meet the pressure test requirements for storm sewer applications.

Concrete pipe joints incorporate the use of a rubber O-ring gasket and are held together by friction and the weight of the pipe. Precautions must be taken when concrete pipe is placed on grades greater than 10 percent or in fills where significant settlement is expected, because it is possible for the joints to pull apart. Outlets to concrete pipe must be properly protected from erosion because a small amount of undermining could cause the end section of pipe to disjoin, ultimately leading to failure of the entire pipe system. Concrete joints, because of the O-ring gasket, function well in culvert applications and also consistently pass the pressure testing requirements for storm sewers.

Thermoplastic pipe joints vary; some are similar in performance to either the corrugated metal pipe joint or the concrete pipe joint described above, while others are completely watertight and as strong as the pipe itself. The following joint types are available for thermoplastic pipe:

- Integral, gasketed bell ends that positively connect to the spigot end
- Slip-on bell ends connected with O-ring gaskets on the spigot end
- Strap-on corrugated coupling bands
- Snap together, or threaded, bell and spigot connections
- Butt fusion welded or electrofusion coupling
- Mechanical or flanged

All types of joints have demonstrated adequate pull-apart resistance and can generally be used on most highway or embankment slopes.

8-8 Pipe Anchors

Pipe anchor installation is rare and usually occurs when a pipe or half pipe is replaced above ground on a very steep (15 to 20 percent grade) or highly erosive slope. In these cases, the pipe diameter is relatively small (10 inches or smaller). Continuous polyethylene tubing may be used without the need for anchors because there are no joints in the pipe. On larger pipes, solid-wall HDPE pipe with fused joints may be used without the use of pipe anchors. For further design guidance, contact the State Hydraulics Office.

8-8.1 *Thrust Blocks*

Thrust blocks shall be designed to help stabilize fittings (tees, valves, bends, etc.) of water mains or pressure mains from movement by increasing the soil-bearing area. The key to sizing a thrust block is a correct determination of the soil-bearing value. These values can range from less than 1,000 pounds per square foot for soft soils to many thousands of pounds per square foot for hard rock. A correctly sized thrust block will also fail unless the block is placed against undisturbed soil with the face of the block perpendicular to the direction of and centered on the line of the action of the thrust. (See Standard Plan B-90.40-01, Standard Plan for Concrete Thrust Block, for details on placement and sizing of a thrust block for various fittings.)

8-9 Pipe Rehabilitation: Trenchless Technology

Deteriorated pipes can affect the pipes' structural integrity and lead to roadway failures and development of sinkholes. Pipe deterioration could include longitudinal or circular cracks, joint separations, root intrusions, deformation, erosion, voids outside the pipes, and bedding erosion. Depending on the type of deterioration, failure to repair deteriorated pipes within certain time frames , which can lead to roadway failures, embankment failures, or sinkhole development.

The most common option for a deteriorated pipe is to remove the existing culvert and replace it with a new one.

For locations where replacing the pipe is not feasible, it may be possible to use rehabilitation methods to restore the structural integrity of the pipe system, with minimal impact to roadway traffic. These methods are referred to as trenchless technology because minimal trenching is needed.

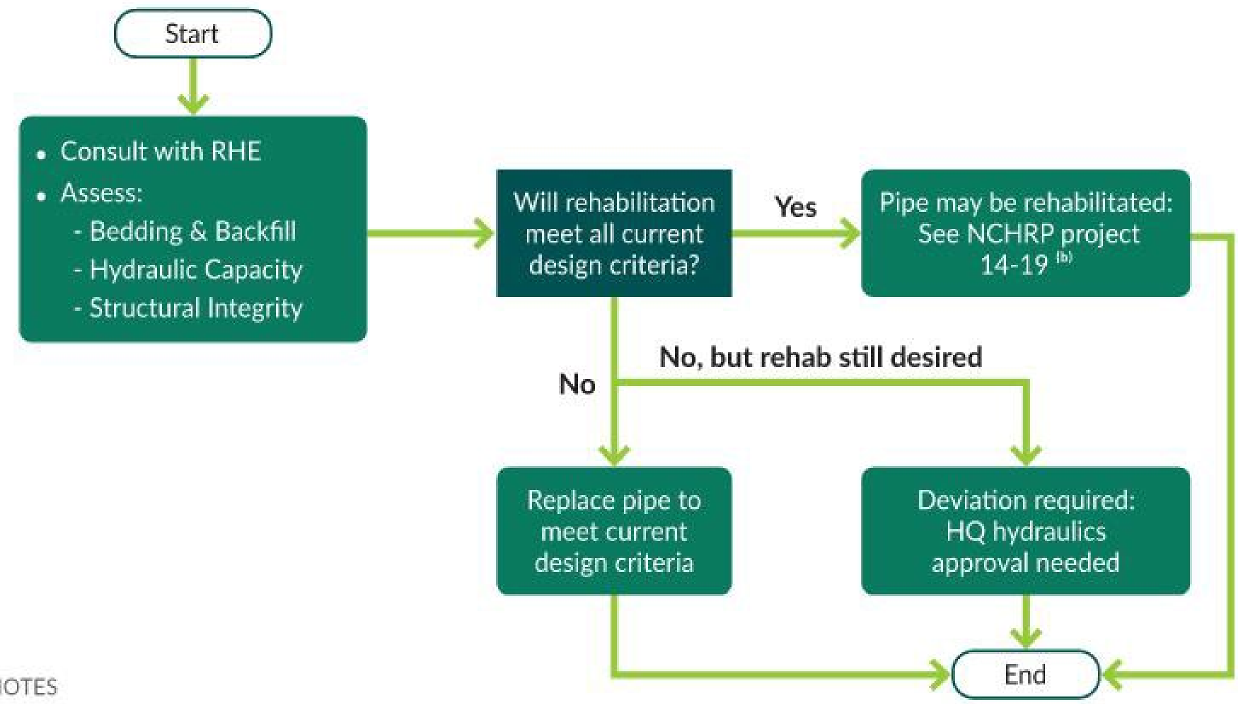
Prior to selecting a trenchless technology method, the PEO shall investigate the feasibility of a pipe being rehabilitated to provide a long-term fix. The investigation shall include, at a minimum:

- **Evaluation of the pipe bedding and backfill conditions:** The pipe bedding and backfill shall be evaluated to determine if the existing conditions meet current design criteria. For example, if the existing pipe has cracked, water may have leaked through the pipe wall and caused erosion of the bedding material. In this case, the void spaces may need to be grouted between the backfill and the host pipe prior to rehabilitation.
- **Analysis of the hydraulic capacity of pipe:** The hydraulic capacity of a rehabilitated pipe shall be analyzed using the same criteria required for a new pipe. This includes a complete basin analysis as the contributing area may have changed since the original pipe was designed. Also, many trenchless technologies involve methods that reduce the diameter of the host pipe. For crossing culverts, if the pipe diameter is reduced, it must be analyzed as a culvert. Evaluate the inlet or outlet control and upstream and downstream impacts, and maintain the minimum pipe diameter requirement. HDPE and PVC liners are typically strong enough to withstand the loads, and they can last more than 50 years. However, these liners would reduce the inside diameter of the pipes, and this could be an issue for crossing culverts. Minimum pipe diameters must be maintained. The Manning's n values of HDPE and PVC liners are typically smaller than those of corrugated metal pipes and cement concrete pipes; therefore, flow capacity might not be an issue. However, flow capacity analysis is still required.
- **Evaluation of the structural integrity of the pipe:** The structural integrity of the pipe shall be evaluated to determine if the host pipe is strong enough to tolerate the trenchless technology. This will involve contacting the State Hydraulics Office for guidance on inspecting the pipe and developing a risk assessment. The vendors providing the trenchless technology shall also be consulted for determining the minimum structural requirements of the pipe. When evaluating the structural integrity of the pipes, the host pipes are excluded in the calculation. The liners must be able to withstand the dead loads and live loads. All pipes under rails must be sleeved. Cured-in-place pipe (CIPP) liners are typically very thin, and they may not be able to withstand the loads as required. If selected, certification from the manufacturer is required to testify that the liner is capable of withstanding the loads.

- **Evaluation of cost and age of the pipe:** The rehabilitative cost shall be determined as well as the replacement the replacement cost. Determine the age of the pipe as well as its original design life when installed.
- **Evaluation of design life:** All liners must have a lifespan of 50 years or longer. Certification from the manufacturer is required.
- **Evaluation of environmental impacts:** All liners must not have negative impacts on the environment. Consult with HQ ESO and Hydraulics for review and approval.

If this analysis indicates that rehabilitating the pipe using trenchless methods will meet all current design criteria, then the pipe may be rehabilitated. If the analysis indicates that the rehabilitated pipe will not meet current design criteria, then it must be replaced with one that does, or a deviation must be received from the State Hydraulics Office. See Figure 8-13.

Figure 8-13 Replace or Rehabilitate Decision Tree



NOTES

[a] See Chapter 3, Chapter 6, or other applicable chapters.

[b] http://onlinepubs.trb.org/onlinepubs/project14-19/index.html

8-9.1 *Trenchless Techniques for Pipe Rehabilitation*

Several rehabilitation methods are available that can restore structural integrity to the pipe system while minimally affecting roadway traffic. As the name implies, these methods involve minimal trenching along with the ability to retrofit or completely replace a pipe without digging up the pipe.

- **Sliplining** is a technique that involves inserting a full round pipe with a smaller diameter into the host pipe and then filling the space between the two pipes with grout.
- **Pipe bursting** is a technique where a pneumatically operated device moves through the host pipe, bursting it into pieces. Attached to the device is a pipe string, usually thermally fused HDPE. Using this method and depending on the soil type, the new pipe may be a larger diameter than the pipe being burst.
- **Tunneling**, while more expensive than the other methods, may be the only feasible option for placing large-diameter pipes under interstates or major arterials.
- **Horizontal directional drilling (HDD)** is a technique that uses guided drilling for creating an arc profile. This technique can be used for drilling long distances such as under rivers, lagoons, or highly urbanized areas. The process involves three main stages: (1) drilling a pilot hole, (2) pilot hole enlargement, and (3) pullback installation of the carrier pipe.
- **Pipe jacking or ramming** is probably most commonly used method. Pipe diameters less than 48 inches can be jacked both economically and easily. Pipe diameters to 144 inches are possible; however, the complexity and cost increase with the diameter of the pipe. Protective treatment is not required on smooth-walled steel pipe used for jacking installations; however, jacked pipes require extra wall thickness to accommodate the expected jacking stresses
- **CIPP lining** is a trenchless method of storm sewer pipe rehabilitation. It requires little or no digging and significantly less time to complete than other sewer repair methods. CIPP involves inserting a resin-impregnated glass-reinforced thermosetting plastic (GRP) liner or flexible liner inside the existing pipe, inflating the liner, and exposing it to heat or ultraviolet (UV) light to dry and harden the liner inside the pipe. The liner essentially forms a smooth surface inside the existing pipe, restoring it to near-new condition. The host pipe is assumed to be fully deteriorated in the structural integrity calculations to determine the required thickness of the liner itself may not be able to withstand the design live and dead loads. CIPP liners are relatively less expensive than other materials, and they are easier to install. However, certain installation protocols must be followed; otherwise, temporary impacts on the environment could occur. GRP lining using UV cure shall be the preferred method. See additional guidelines in General Special Provision 7-SA1.FR7 (currently under final subject-matter expert review) for specifics. Consult with HQ ESO or the State Hydraulics Office for more guidance.

GRP liner or flexible felt tube liner are placed inside an existing host pipe by one of the following methods:

- Inverting in place using compressed air
- Pulling in place with a winch

The lining does not come in standard sizes but is designed specifically for the individual pipeline to be rehabilitated, with variable diameters/shapes (i.e., round, elliptical, oval, etc.) and wall thickness. When necessary, a minimum thickness of the liner can be specified to provide additional service life for abrasive conditions. See *Hydraulics Manual* Section 8-6 and Table 8-1 for guidelines regarding abrasion. Grouting may be required if the host pipe has minor corrosion or minor cracks. There shall be no annular space between the host pipe and liner.

A GRP liner, or felt tube liner, saturated with a thermosetting resin is either pulled into the existing pipe or inverted through as air pressure pushes the tube tightly against the pipe wall. The UV light source is then inserted in the tube and heated to the curing temperature of 160 to 180 degrees Fahrenheit. The plastic resin on the tube cures to solid pipe inside the existing pipe, creating a new lining. Installation goes quickly, leaving no annular space to be sealed. Odd cross sections, bends, and minor deformations can be accommodated. This method is particularly useful when flow capacity must be maintained or slightly increased by lowering the Manning's n value.

Concrete culverts subject to sulfate attack are especially good candidates for this repair method or metal pipes where the reduction in diameter using other lining methods is not acceptable.

For the pulled-in-place installation method, a winched cable is placed inside the existing pipe. The resin-impregnated liner is connected to the free end of the cable and then pulled into place between drainage structures or culvert ends. The cable is disconnected, the two ends are plugged, and the liner is inflated (approximately 8 pounds per square inch [psi]) before curing by use of UV light. For resin control, the General Special Provisions (GSP 7-SA1.FR7) require chemically resistant UV-cured isophthalic polyester resin or vinyl ester resin. The contractor shall also send resin samples per GSP 7-SA1.FR7 to an independent third-party laboratory certified by the American Association for Laboratory Accreditation (A2LA) for quality assurance infrared fingerprinting. The tube shall include an impermeable inner and outer foil layer (liner) to contain potential resin immigration and contamination, and the inner foil layer should easily remove from the inside tube wall or remain if fabricated as a permanent part of the cured fabric tube (refer to GSP 7-SA1.FR7).

When curing using UV light a fiberglass and resin tube is used and no refrigeration is necessary; no heated water/steam is used. Cure times are quicker than the other methods; however, there is a thickness limitation of 1 inch because the maximum thickness for light curing is limited to 0.5 inch per run.

Site setup is a high proportion of costs on small projects. Prior to UV cure, the host pipe shall be cleaned to remove debris, sediment, and any other accumulated material. Removed sediment-laden washout and debris shall be disposed of per WSDOT *Standard Specifications*. After pipe cleaning, the host pipe shall also be inspected per GSP "Video Pipe Inspection" (currently under final subject-matter expert review) to check for unanticipated obstructions, reduction in cross-sectional areas, sags, and structural defects to determine all the point repairs prior to lining the pipe to be rehabilitated.

After completion of UV cure, core restrained samples shall be obtained to be sent to an independent third-party laboratory certified by A2LA (refer to GSP 7-SA1.FR7) for physical properties tests such as flexural strength and flexural modulus of elasticity. Post-installation inspection shall be conducted per GSP "Video Pipe Inspection" to check if there are any imperfections such as wrinkles, fins, tears, holes, blisters, and delamination. Failed installations shall not be accepted by WSDOT. For full details of failed installations and required remedies, refer to GSP 7-SA1.FR7.

In general, the following steps are sequentially performed:

1. Install pipe plugs upstream and downstream of the storm sewer pipes and install diversion (if needed)
2. Clean, inspect (pre-install), and prepare host pipe for cleaning (voids in backfill may need grouting; remove protrusions greater than 0.5 inch, record exact locations of lateral pipes)
3. Prepare liner: GRP or felt tube liner is vacuum impregnated with resin
4. Install liner
5. Cure (UV) liner
6. Take test samples
7. Conduct final (post-install) inspection
8. Repair as needed
9. Remove pipe plugs and diversion (if needed)

Spray lining could be an option if the host pipes are big enough. The materials could be cement or polymer, and the liners could be installed with or without the wire mesh or reinforced bars. Without the host pipe, the liners could provide very little strength to significant strength to withstand the loads. Similarly, the liner lifespan depends on the material and construction method.

8-10 Pipe Design

This section presents pipe design alternatives.

8-10.1 *Categories of Structural Materials: Rigid or Flexible*

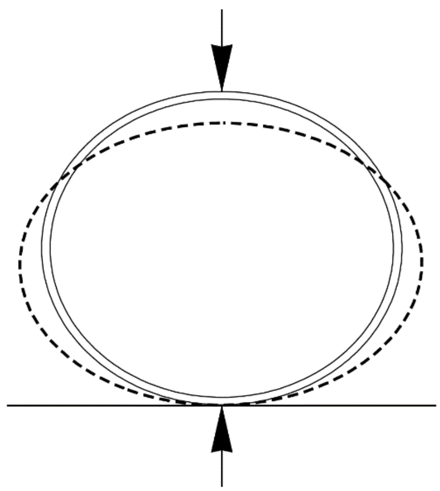
Based upon material type, pipes can be divided into two broad structural categories: flexible and rigid. Flexible pipes have little structural bending strength. The material they are made of, such as corrugated metal or thermoplastic, can be flexed or distorted significantly without cracking. Flexible pipes depend on support from the backfill to resist bending. Rigid pipes are stiff and do not deflect appreciably. The material they are made of, such as concrete, provides the primary resistance to bending.

8-10.2 *Structural Behavior of Flexible Pipes*

A flexible pipe is a composite structure made up of the pipe barrel and the surrounding soil. The barrel and soil are both vital elements to the structural performance of the pipe. Flexible pipe has relatively little bending stiffness or bedding strength on its own. As loads are applied to the pipe, the pipe attempts to deflect. In the case of round pipe, the vertical diameter decreases and the horizontal diameter increases, as shown in Figure 8-14. When adequate soil support and backfill material are well compacted around the pipe, the increase in the horizontal diameter of the pipe is resisted by the lateral soil pressure. The result is a relatively uniform radial pressure around the pipe, which creates a compressive force in the pipe walls called thrust. To ensure that a stable soil envelope around the pipe is attained during construction, follow the guidelines in Section 8-10.4 for backfill and installation.

As vertical loads are applied, a flexible culvert attempts to deflect. The vertical diameter decreases while the horizontal diameter increases. Soil pressures resist the increase in horizontal diameter. The thrust can be calculated, based on the diameter of the pipe and the load placed on the top of the pipe, and is then used as a parameter in the structural design of the pipe.

Figure 8-14 Deflection of Flexible Pipes

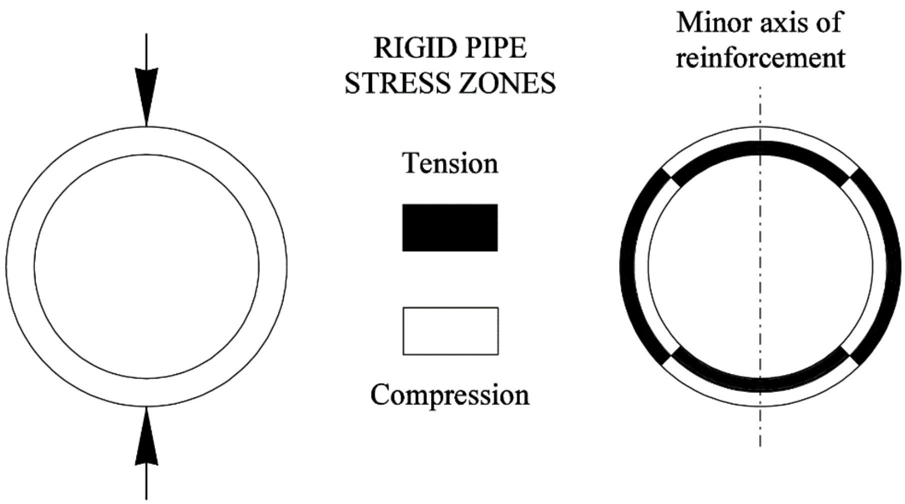


The flexibility of a pipe also allows for some bend in the horizontal when designing the pipe layout. The PEO shall limit the bend to a maximum of 1.5 degrees. This same allowable bend does not apply to pipe profiles, which shall be designed to be straight. When bends occur in the profile, “bellies” form that cause sediment to accumulate.

8-10.3 *Structural Behavior of Rigid Pipes*

The load-carrying capability of rigid pipes is essentially provided by the structural strength of the pipe itself, with some additional support given by the surrounding bedding and backfill. When vertical loads are applied to a rigid pipe, zones of compression and tension are created as illustrated in Figure 8-15. Reinforcing steel can be added to the tension zones to increase the tensile strength of concrete pipe. The minor axis for elliptical reinforcement is discussed in Section 8-3.1.

Figure 8-15 Zones of Tension and Compression in Rigid Pipes



Rigid pipe is stiffer than the surrounding soil and it carries a substantial portion of the applied load. Shear stress in the haunch area can be critical for heavily loaded rigid pipe on hard foundations, especially if the haunch support is inadequate. Standard Plan B-55.20-03 and the *Standard Specifications* describe the backfill material requirements and installation procedures required for placing the various types of pipe materials. The fill height tables for concrete pipe shown in Section 8-12 were developed assuming that those requirements were followed during installation.

8-10.4 *Foundations, Bedding, and Backfill*

A foundation capable of providing uniform and stable support is important for both flexible and rigid pipes. The foundation must be able to uniformly support the pipe at the proposed grade and elevation without concentrating the load along the pipe. Establishing a suitable foundation requires removal and replacement of any hard spots or soft spots that would result in load concentration along the pipe.

Bedding is needed to level out any irregularities in the foundation and to ensure adequate compaction of the backfill material. (See the *Standard Plans* for Pipe Zone Bedding and Backfill and the *Standard Specifications* Backfilling for guidelines.) Any trenching conditions not described in the *Standard Plans* or *Standard Specifications* require approval from the State Hydraulics Office.

The bedding equal to one-third of the pipe outside diameter shall be loosely placed directly under the pipe, while the remainder shall be compacted to a minimum 90 percent of maximum density per AASHTO guidelines. The importance of proper backfill for flexible and rigid pipe is discussed in Sections 8-10.2 and 8-10.3, respectively.

The bedding and backfill must also be installed properly to prevent piping from occurring. Piping is a term used to describe the movement of water around and along the outside of a pipe, washing away backfill material that supports the pipe. Piping is primarily a concern in culvert applications, where water at the culvert inlet can saturate the embankment and move into the pipe zone. Piping can be prevented through the use of headwalls, dikes, or plugs. Headwalls are described in Chapter 3 and dikes and plugs are discussed in the *Standard Specifications*.

To simplify measurement and payment during construction, all costs associated with furnishing and installing the bedding and backfill material within the pipe zone are included in the unit contract price of the pipe.

8-11 Abandoned Pipe Guidelines

Abandoned pipes shall be removed, plugged per *Standard Specification 7-08.3(4),* or filled with controlled-density fill (CDF) per *Standard Specification 2-09.3(1)E.* If it is not practical to remove the pipe, the pipe can be abandoned in place and the pipe ends can be plugged as specified in the *Standard Specifications.* All pipes shall be evaluated prior to abandonment by the project PEO, RHE, or State Hydraulics Office to determine what potential hazards are associated with pipe failure. If a pipe failure could cause a collapse of the roadway prism, the pipe shall either be removed or completely filled with a CDF that meets the requirements per the *Standard Specifications.* See the decision tree for pipe abandonment in Figure 8-16 and pipe abandonment determination schematic in Figure 8-17.

Figure 8-16 Decision Tree for Pipe(s) to be Abandoned

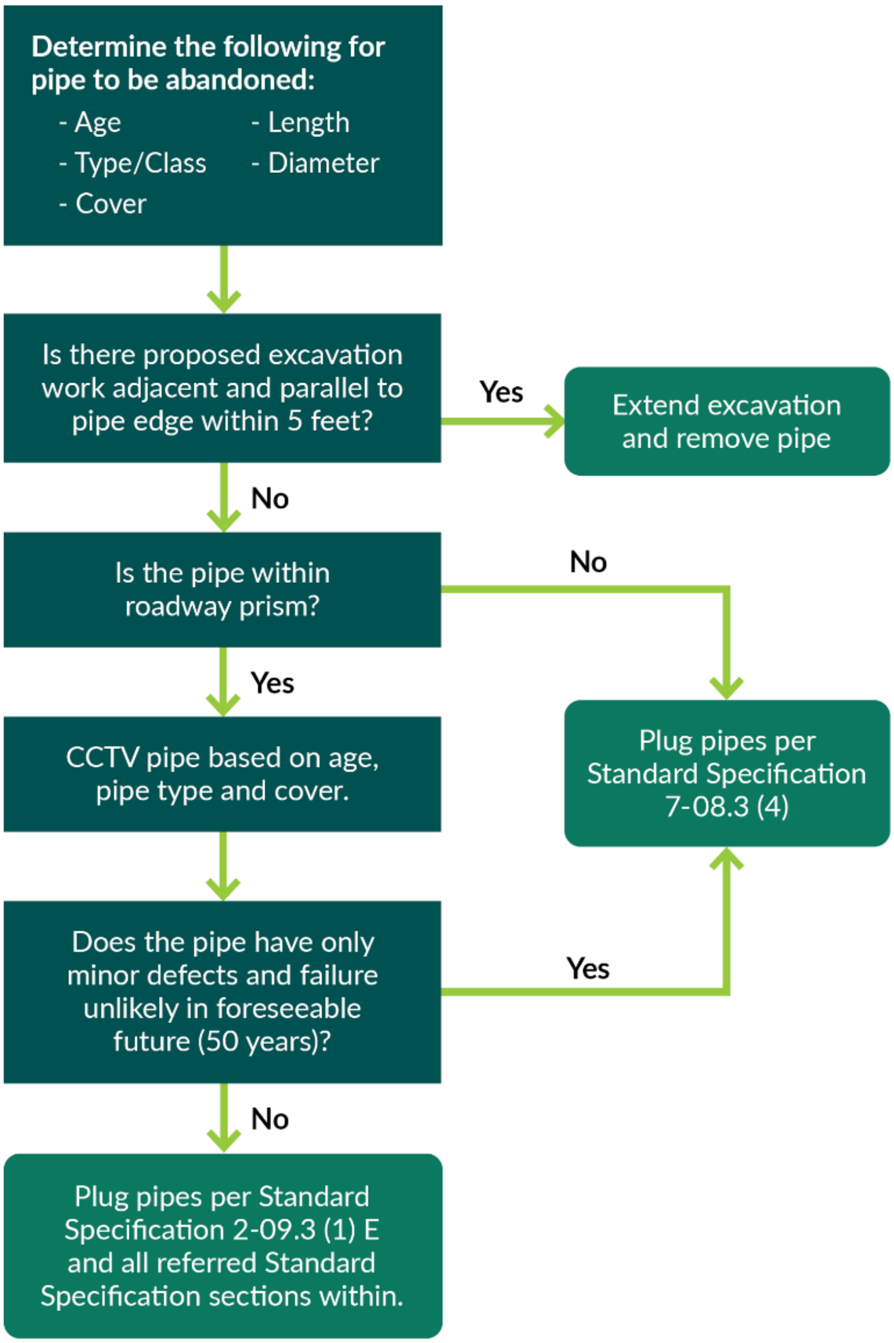
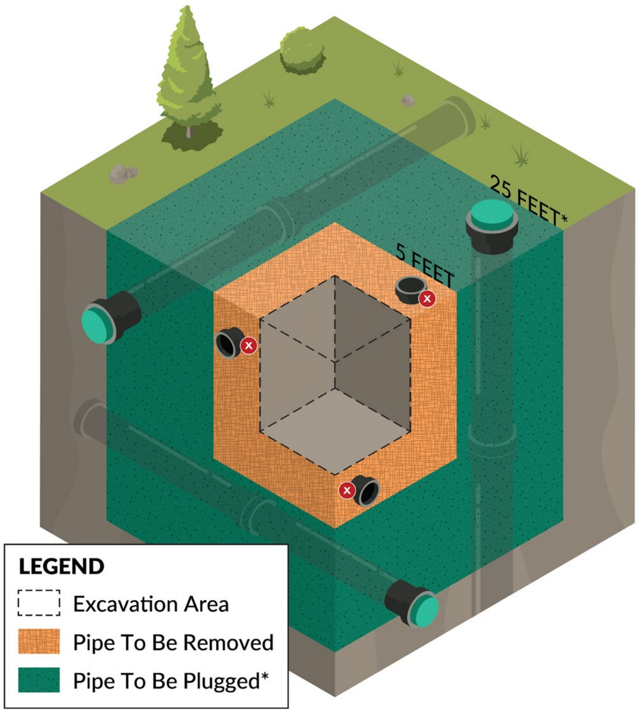


Figure 8-17 Pipe abandonment determination schematic



Note: if the distance between the edge of the excavation area and the edge of the pipe is greater than 5 feet horizontally or vertically, plug and abandon pipe. Refer to Section 8-11 and pipe abandonment tree chart above.

8-12 Structural Analysis and Fill Height Tables

The State Hydraulics Office, using currently accepted design methodologies, has performed a structural analysis for the various types of pipe material available. The results are shown in the fill height tables at the end of this section (Table 8-2 through Table 8-19). The fill height tables demonstrate the maximum and minimum amounts of cover that can be placed over an existing or new pipe, assuming that the pipe is installed in accordance with WSDOT specifications. All culverts, storm sewers, and sanitary sewers shall be installed within the limitations shown in the fill height tables.

The PEO shall specify the same wall thickness or class of material for the entire length of a given pipe, and that specification will be based on the most critical load configuration experienced by any part of the pipe. This will negate the necessity of removing structurally inadequate pipe sections at some point in the future should roadway widening occur. Additionally, when selecting corrugated pipe, the PEO shall review all of the tables in Section 8-12.3 and select the most efficient corrugation thickness for the pipe diameter. For fill heights in excess of 100 feet, coordination with the HQ Geotechnical, Bridge and Structures, and Hydraulics Offices is required for review and approval.

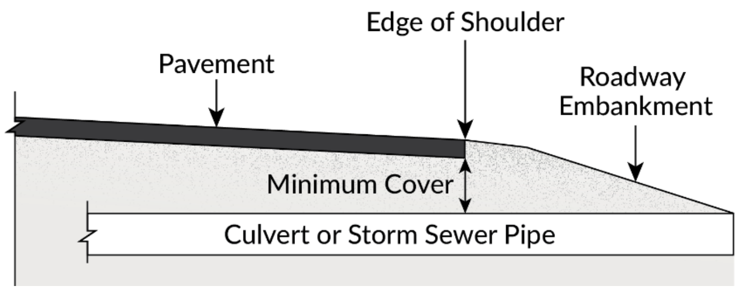
When a pipe is rehabilitated with a liner, the liner must be able to withstand the loads without the host pipe included in the calculations.

8-12.1 *Pipe Cover*

Pipe systems shall be designed to provide at least 2 feet of cover over the pipe, measured from the outside diameter of the pipe to the bottom of pavement (see Figure 8-18). This measurement does not include any asphalt or concrete paving above the top course. Unless the contract plans specify a specific pipe material, the PEO shall plan for the schedule pipe fill heights as described in the *Standard Specifications*. If there is no possibility of a wheel load over the pipe, a PEO may request using non-scheduled pipe with approval from the State Hydraulics Office through a deviation.

During construction, more restrictive fill heights are required, and are specified in the *Standard Specifications*. The restrictive fill heights are intended to protect pipe from construction loads that can exceed typical highway design loads.

Figure 8-18 Pipe Minimum Cover



NOTES:
(1) Minimum thickness of cover is measured at edge of shoulder.
(2) Minimum cover is measured from outside diameter of pipe to bottom of pavement.
(3) All pipes not listed in Table 8-19 of Hydraulic Manual shall have minimum cover of 2.0 feet.
(4) Provide supporting calculations and references for the proposed pipes if minimum cover is less than 2.0 feet.
(5) Consult RHO or State Hydraulics Office if minimum cover is less than 2.0 feet.

8-12.1.1 Pipe Sleeve

The pipe shall be sleeved when it is located underneath railroad guideways. The sleeves must be able to withstand the dead and live loads. The sleeve must be extended 10 feet out from the edge of the guideway.

8-12.2 *Shallow Cover Installation*

In some cases, it is not possible to lower a pipe profile to obtain the necessary minimum cover. In those cases, pipe of the class shown in Table 8-19 may be specified. Included in that table are typical pipe wall thicknesses for a given diameter. The pipe wall thickness must be taken into consideration in low cover applications.

In addition to circular pipe, concrete box culverts and concrete arches are available for use in shallow cover installations. For three-sided or box concrete culverts, the PEO must verify that the shallow cover will still provide HS 25 loading. Other options include ductile-iron pipe, plain steel pipe, PP pipe, or the placement of a concrete distribution slab. The PEO shall consult with either the RHO/contact or the State Hydraulics Office for additional guidance on the use of these structures in this application.

8-12.3 Fill Height Tables

Table 8-2 through Table 8-19 are fill height tables.

Table 8-2 Concrete Pipe

Pipe Diameter (in.)	Maximum Cover in Feet				
	Plain AASHTO M 86	Class II AASHTO M 170	Class III AASHTO M 170	Class IV AASHTO M 170	Class V AASHTO M 170
12	18	12	17	38	42
18	18	13	17	40	42
24	16	13	17	40	42
30	--	13	17	40	42
36	--	12	17	40	42
48	--	12	17	40	42
60	--	12	17	40	42
72	--	12	17	39	42
84	--	12	16	39	42

Notes:
-- = not applicable
Minimum cover is 2 feet.
In. = inch

Table 8-3 Concrete Pipe for Shallow Cover Installations

Pipe Diameter (in.)	Pipe Wall Thickness (in.)	Minimum Cover in Feet			
		Plain AASHTO M 86	Class III AASHTO M 170	Class IV AASHTO M 170	Class V AASHTO M 170
12	2	1.5	1.5	1.0	0.5
18	2.5	1.5	1.5	1.0	0.5
24	3	1.5	1.5	1.0	0.5
30	3.5	1.5	1.5	1.0	0.5
36	4	1.5	1.0	1.0	0.5
48	5	--	1.0	1.0	0.5
60	6	--	1.0	1.0	0.5
72	7	--	1.0	1.0	0.5
84	8	--	1.0	1.0	0.5

Notes:
-- = not applicable
in. = inch

Table 8-4 Corrugated Steel Pipe: 2⅔ in. × ½ in. Corrugations—AASHTO M 36

Pipe Diameter (in.)	Maximum Cover in Feet				
	0.064 in. 16 ga	0.079 in. 14 ga	0.109 in. 12 ga	0.138 in. 10 ga	0.168 in. 8 ga
12	100	100	100	100	--
18	100	100	100	100	--
24	98	100	100	100	100
30	78	98	100	100	100
36a	65	81	100	100	100
42[a]	56	70	98	100	100
48[a]	49	61	86	100	100
54[a]	--	54	76	98	100
60[a]	--	--	68	88	100
66[a]	--	--	--	80	98
72[a]	--	--	--	73	90
78[a]	--	--	--	--	80
84[a]	--	--	--	--	69

Notes:
-- = not applicable
ga = gage
in. = inch
Minimum cover is 2 feet.
a. The PEO shall consider the most efficient corrugation for the pipe diameter.

Table 8-5 Corrugated Steel Pipe: 3 in. × 1 in. Corrugations—AASHTO M 36

Pipe Diameter (in.)	Maximum Cover in Feet				
	0.064 in. 16 ga	0.079 in. 14 ga	0.109 in. 12 ga	0.138 in. 10 ga	0.168 in. 8 ga
36	75	94	100	100	100
42	64	80	100	100	100
48	56	70	99	100	100
54	50	62	88	100	100
60	45	56	79	100	100
66	41	51	72	92	100
72	37	47	66	84	100
78	34	43	60	78	95
84	32	40	56	72	89
90	30	37	52	67	83
96	--	35	49	63	77
102	--	33	46	59	73

Pipe Diameter (in.)	Maximum Cover in Feet				
	0.064 in. 16 ga	0.079 in. 14 ga	0.109 in. 12 ga	0.138 in. 10 ga	0.168 in. 8 ga
108	--	--	44	56	69
114	--	--	41	53	65
120	--	--	39	50	62

Notes:
-- = not applicable
ga = gage
in. = inch
Minimum cover is 2 feet.

Table 8-6 Corrugated Steel Pipe: 5 in. × 1 in. Corrugations—AASHTO M 36

Pipe Diameter (in.)	Maximum Cover in Feet				
	0.064 in. 16 ga	0.079 in. 14 ga	0.109 in. 12 ga	0.138 in. 10 ga	0.168 in. 8 ga
30	80	100	100	100	100
36	67	83	100	100	100
42	57	71	100	100	100
48	50	62	88	100	100
54	44	55	78	100	100
60	40	50	70	90	100
66	36	45	64	82	100
72	33	41	58	75	92
78	31	38	54	69	85
84	28	35	50	64	79
90	26	33	47	60	73
96	--	31	44	56	69

Notes:
-- = not applicable
ga = gage
in. = inch
Minimum cover is 2 feet.

Table 8-7 Corrugated Steel Structural Plate Circular Pipe: 6 in. × 2 in. Corrugations

Pipe Diameter (in.)	Minimum Cover (ft)	Maximum Cover in Feet						
		0.111 in. 12 ga	0.140 in. 10 ga	0.170 in. 8 ga	0.188 in. 7 ga	0.218 in. 5 ga	0.249 in. 3 ga	0.280 in. 1 ga
60	2	42	63	83	92	100	100	100
72	2	35	53	69	79	94	100	100
84	2	30	45	59	67	81	95	100
96	2	27	40	52	59	71	84	92
108	2	23	35	46	53	64	75	81

Pipe Diameter (in.)	Minimum Cover (ft)	Maximum Cover in Feet						
		0.111 in. 12 ga	0.140 in. 10 ga	0.170 in. 8 ga	0.188 in. 7 ga	0.218 in. 5 ga	0.249 in. 3 ga	0.280 in. 1 ga
120	2	21	31	42	47	57	67	74
132	2	19	29	37	42	52	61	66
144	2	18	26	37	40	47	56	61
156	2	16	24	31	36	43	52	56
168	2	15	22	30	33	41	48	53
180	2	14	20	28	31	38	44	49
192	2	--	19	26	30	35	42	46
204	3	--	18	24	28	33	40	43
216	3	--	--	23	26	31	37	41
228	3	--	--	--	25	30	35	39
240	3	--	--	--	23	29	33	37

Notes:
-- = not applicable
ga = gage
in. = inch
6 in. × 2 in. corrugations require field assembly for multiplate; diameter is too large to ship in full section.

Table 8-8 Corrugated Steel Pipe Arch: 2⅔ in. × ½ in. Corrugations—AASHTO M 36

Span × Rise (in. × in.)	Min Corner Radius (in.)	Thickness		Minimum Cover (ft)	Maximum Cover in Feet for Soil-Bearing Capacity of:	
		in.	Gage		2 tons/ft^2	3 tons/ft^2
17 × 13	3	0.064	16 ga	2	12	18
21 × 15	3	0.064	16 ga	2	10	14
24 × 18	3	0.064	16 ga	2	7	13
28 × 20	3	0.064	16 ga	2	5	11
35 × 24	3	0.064	16 ga	2.5	NS	7
42 × 29	3.5	0.064	16 ga	2.5	NS	7
49 × 33	4	0.079	14 ga	2.5	NS	6
57 × 38	5	0.109	12 ga	2.5	NS	8
64 × 43	6	0.109	12 ga	2.5	NS	9
71 × 47	7	0.138	10 ga	2	NS	10
77 × 52	8	0.168	8 ga	2	5	10
83 × 57	9	0.168	8 ga	2	5	10

Notes:
ft^2 = square feet
ga = gage
in. = inch
NS = not suitable

Table 8-9 Corrugated Steel Pipe Arch: 3 in. × 1 in. Corrugations—AASHTO M 36

Span × Rise (in. × in.)	Corner Radius (in.)	Thickness		Minimum Cover (ft)	Maximum Cover in Feet for Soil-Bearing Capacity of:	
		in.	Gage		2 tons/ft^2	3 tons/ft^2
40 × 31	5	0.079	14 ga	2.5	8	12
46 × 36	6	0.079	14 ga	2	8	13
53 × 41	7	0.079	14 ga	2	8	13
60 × 46	8	0.079	14 ga	2	8	13
66 × 51	9	0.079	14 ga	2	9	13
73 × 55	12	0.079	14 ga	2	11	16
81 × 59	14	0.079	14 ga	2	11	17
87 × 63	14	0.079	14 ga	2	10	16
95 × 67	16	0.079	14 ga	2	11	17
103 × 71	16	0.109	12 ga	2	10	15
112 × 75	18	0.109	12 ga	2	10	16
117 × 79	18	0.109	12 ga	2	10	15
128 × 83	18	0.138	10 ga	2	9	14
137 × 87	18	0.138	10 ga	2	8	13
142 × 91	18	0.168	10 ga	2	7	12

Notes:

ft^2 = square feet
ga = gage
in. = inch

Table 8-10 Corrugated Steel Structural Plate Pipe Arch: 6 in. × 2 in. Corrugations

Span × Rise (ft.-in. × ft.-in.)	Corner Radius (in.)	Thickness		2 TSF Soil-Bearing Capacity		3 TSF Soil-Bearing Capacity	
		in.	Gage	Min. Cover (ft)	Max. Cover (ft)	Min. Cover (ft)	Max. Cover (ft)
6-1 × 4-7	18	0.111	12 ga	2	16	2	24
7-0 × 5-1	18	0.111	12 ga	2	14	2	21
7-11 × 5-7	18	0.111	12 ga	2	13	2	19
8-10 × 6-1	18	0.111	12 ga	2	11	2	17
9-9 × 6-7	18	0.111	12 ga	2	10	2	15
10-11 × 7-1	18	0.111	12 ga	2	9	2	14
11-10 × 7-7	18	0.111	12 ga	2	7	2	13
12-10 × 8-4	18	0.111	12 ga	2.5	6	2	12
13-3 × 9-4	31	0.111	12 ga	2	13	2	17[a]
14-2 × 9-10	31	0.111	12 ga	2	12	2	16[a]
15-4 × 10-4	31	0.140	10 ga	2	11	2	15[a]
16-3 × 10-10	31	0.140	10 ga	2	11	2	14[a]
17-2 × 11-4	31	0.140	10 ga	2.5	10	2.5	13[a]
18-1 × 11-10	31	0.168	8 ga	2.5	10	2.5	12[a]
19-3 × 12-4	31	0.168	8 ga	2.5	9	2.5	13

Notes:

ft. = feet
ga = gage
in. = inch
TSF = tons per square foot

a. Fill limited by the seam strength of the bolts. Additional sizes are available. Contact the OSC Hydraulics Office for more information.

Table 8-11 Aluminum Pipe: 2⅔ in. × ½ in. Corrugations—AASHTO M 196

Pipe Diameter (in.)	Maximum Cover in Feet				
	0.060 in. (16 ga)	0.075 in. (14 ga)	0.105 in. (12 ga)	0.135 in. (10 ga)	0.164 in. (8 ga)
12	100	100	--	--	--
18	75	94	100	--	--
24	56	71	99	--	--
30	--	56	79	--	--
36	--	47	66	85	--
42	--	--	56	73	--
48	--	--	49	63	78
54	--	--	43	56	69
60	--	--	--	50	62
66	--	--	--	--	56
72	--	--	--	--	45

Notes:
-- = not applicable
in. = inch
ga = gage
Minimum cover is 2 feet.

Table 8-12 Aluminum Pipe: 3 in. × 1 in. Corrugations—AASHTO M 196

Pipe Diameter (in.)	Maximum Cover in Feet				
	0.060 in. (16 ga)	0.075 in. (14 ga)	0.105 in. (12 ga)	0.135 in. (10 ga)	0.164 in. (8 ga)
36	43	65	76	98	--
42	36	46	65	84	--
48	32	40	57	73	90
54	28	35	50	65	80
60	--	32	45	58	72
66	--	28	41	53	65
72	--	26	37	48	59
78	--	24	34	44	55
84	--	--	31	41	51
90	--	--	29	38	47
96	--	--	27	36	44
102	--	--	--	33	41
108	--	--	--	31	39
114	--	--	--	--	37
120	--	--	--	--	35

Notes:
-- = not applicable
in. = inch
ga = gage
Minimum cover is 2 feet.

Table 8-13 Aluminum Structural Plate: 9 in. × 2 in. Corrugations with Galvanized Steel Bolts

Pipe Diameter (in.)	Maximum Cover in Feet						
	0.100 in.	0.125 in.	0.150 in.	0.175 in.	0.200 in.	0.225 in.	0.250 in.
60	31	45	60	70	81	92	100
72	25	37	50	58	67	77	86
84	22	32	42	50	58	66	73
96	19	28	37	44	50	57	64
108	17	25	33	39	45	51	57
120	15	22	30	35	40	46	51
132	14	20	27	32	37	42	47
144	12	18	25	29	33	38	43
156	--	17	23	27	31	35	39
168	--	--	31	25	29	33	36
180	--	--	--	23	27	30	34

Notes:

-- = not applicable
in. = inch
Minimum cover is 2 feet.

Table 8-14 Aluminum Pipe Arch: 2⅔ in. × ½ in. Corrugations—AASHTO M 196

Span × Rise (in. × in.)	Corner Radius (in.)	Thickness		Minimum Cover (ft)	Maximum Cover in Feet for Soil-Bearing Capacity of:	
		in.	Gage		2 tons/ft^2	3 tons/ft^2
17 × 13	3	0.060	16 ga	2	12	18
21 × 15	3	0.060	16 ga	2	10	14
24 × 18	3	0.060	16 ga	2	7	13
28 × 20	3	0.075	14 ga	2	5	11
35 × 24	3	0.075	14 ga	2.5	NS	7
42 × 29	3.5	0.105	12 ga	2.5	NS	7
49 × 33	4	0.105	12 ga	2.5	NS	6
57 × 38	5	0.135	10 ga	2.5	NS	8
64 × 43	6	0.135	10 ga	2.5	NS	9
71 × 47	7	0.164	8 ga	2	NS	10

Notes:

ft^2 = square feet
ga = gage
in. = inch
NS = not suitable

Table 8-15 Aluminum Pipe Arch: 3 in. × 1 in. Corrugations—AASHTO M 196

Span × Rise (in. × in.)	Corner Radius (in.)	Thickness		Minimum Cover (ft)	Maximum Cover in Feet for Soil-Bearing Capacity of:	
		in.	Gage		2 tons/ft^2	3 tons/ft^2
40 × 31	5	0.075	14 ga	2.5	8	12
46 × 36	6	0.075	14 ga	2	8	13
53 × 41	7	0.075	14 ga	2	8	13
60 × 46	8	0.075	14 ga	2	8	13
66 × 51	9	0.060	14 ga	2	9	13
73 × 55	12	0.075	14 ga	2	11	16
81 × 59	14	0.105	12 ga	2	11	17
87 × 63	14	0.105	12 ga	2	10	16
95 × 67	16	0.105	12 ga	2	11	17
103 × 71	16	0.135	10 ga	2	10	15
112 × 75	18	0.164	8 ga	2	10	16

Notes:
ft^2 = square feet
ga = gage
in. = inch

Table 8-16 Aluminum Structural Plate Pipe Arch: 9 in. × 2⅔ in. Corrugations, ¼ in. Steel Bolts, 4 Bolts/Corrugation

Span × Rise (ft-in. × ft-in.)		Corner Radius (in.)	Min. Gage Thickness (in.)	Min. Cover (ft)	Maximum Cover[a] in Feet for Soil-Bearing Capacity	
					2 tons/ft^2	3 tons/ft^2
a	5-11 × 5-5	31.8	0.100	2	24[b]	24[b]
b	6-11 × 5-9	31.8	0.100	2	22[b]	22[b]
c	7-3 × 5-11	31.8	0.100	2	20[b]	20[b]
d	7-9 × 6-0	31.8	0.100	2	28[b]	18[b]
e	8-5 × 6-3	31.8	0.100	2	17[b]	17[b]
f	9-3 × 6-5	31.8	0.100	2	15[b]	15[b]
g	10-3 × 6-9	31.8	0.100	2	14[b]	14[b]
h	10-9 × 6-10	31.8	0.100	2	13[b]	13[b]
i	11-5 × 7-1	31.8	0.100	2	12[b]	12[b]
j	12-7 × 7-5	31.8	0.125	2	14	16[b]
k	12-11 × 7-6	31.8	0.150	2	13	14[b]
l	13-1 × 8-2	31.8	0.150	2	13	18[b]
m	13-11 × 8-5	31.8	0.150	2	12	17[b]
n	14-8 × 9-8	31.8	0.175	2	12	18
o	15-4 × 10-0	31.8	0.175	2	11	17

	Span × Rise (ft-in. × ft-in.)	Corner Radius (in.)	Min. Gage Thickness (in.)	Min. Cover (ft)	Maximum Cover[a] in Feet for Soil-Bearing Capacity	
					2 tons/ft^2	3 tons/ft^2
p	16-1 × 10-4	31.8	0.200	2	10	16
q	16-9 × 10-8	31.8	0.200	2.17	10	15
r	17-3 × 11-0	31.8	0.225	2.25	10	15
s	18-0 × 11-4	31.8	0.255	2.25	9	14
t	18-8 × 11-8	31.8	0.250	2.33	9	14

Notes:

in. = inch

ft^2 = square feet

a. Additional sizes and varying cover heights are available, depending on gage thickness and reinforcement spacing. Contact the State Hydraulics Office for more information.

b. Fill limited by the seam strength of the bolts.

Table 8-17 Steel and Aluminized Steel Spiral Rib Pipe: ¾ × 1 × 11½ in. or ¾ × ¾ × 7½ in. Corrugations—AASHTO M 36

Diameter (in.)	Maximum Cover in Feet		
	0.064 in. 16 ga	0.079 in. 14 ga	0.109 in. 12 ga
18	50	72	--
24	50	72	100
30	41	58	97
36	34	48	81
42	29	41	69
48	26	36	61
54	21	32	54
60	19	29	49

Notes:

-- = not applicable

ga = gage

in. = inch

Minimum cover is 2 feet.

Table 8-18 Aluminum Alloy Spiral Rib Pipe: ¾ × 1 × 11½ in. or ¾ × ¾ × 7½ in. Corrugations—AASHTO M 196

Diameter (in.)	Maximum Cover in Feet			
	0.060 in. 16 ga	0.075 in. 14 ga	0.105 in. 12 ga	0.135 10 ga
12	35	50	--	--
18	34	49	--	--
24	25	36	63	82
30	19	28	50	65
36	15	24	41	54
42	--	19	35	46
48	--	17	30	40
54	--	14	27	35
60	--	12	24	30

Notes:
-- = not applicable
ga = gage
in. = inch
Minimum cover is 2 feet.

Table 8-19 Thermoplastic and Ductile-Iron Pipe

Solid-Wall PVC	Profile-Wall PVC	Corrugated Polyethylene
ASTM D 3034 SDR 35 3 in. to 15 in. diameter ASTM F 679 Type 1 18 in. to 48 in. diameter	AASHTO M 304 or ASTM F 794 Series 46 4 in. to 48 in. diameter	AASHTO M 294 Type S 12 in. to 60 in. diameter
40 ft max, 2 ft min. All diameters	40 ft max, 2 ft min. All diameters	18 ft max, 2 ft min. All diameters
Solid-Wall HDPE	**Polypropylene**	**Ductile-Iron Pipe**
Std Spec 9-05.23	Std Spec 9-05.24 12 in. to 60 in. diameter	Std Spec 9-05.13 12 in. to 48 in. diameter
18 ft max, 0.5 ft min. All diameters	21 ft max, 1 ft min. All diameters	25 ft max, 0.5 ft min. All diameters

Notes:
in. = inch
For cover, refer to Section 8-12.3.