Oregon Department of Transportation

Chapter 11
Pipe Materials and Design



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11.1 Introduction

This chapter provides guidance on the selection and application of pipe materials used in hydraulic design and construction. Material choice influences the performance, longevity, and maintenance needs of culverts, storm and sanitary systems. Proper selection depends on hydraulic, structural requirements, as well as compatibility with environmental site conditions, and sediment transport.

This chapter outlines the advantages, limitations, and appropriate uses of commonly accepted pipe materials in accordance with ODOT standards.



Sections marked with this icon indicate a Required Design Policy. These policies are mandatory and must be followed in all designs. The icon serves as a visual reminder to highlight design requirements.

11.2 Deviations from Design Standards

Design deviations from the standards and requirements of this chapter require approval by the State Hydraulic Engineer. The deviation must provide justification and supporting documentation that the proposed alternative is designed in accordance with acceptable engineering practices. Deviations are to be designed in accordance with accepted engineering practice and applicable AASHTO, ASTM, or AWWA standards, as appropriate. The following is a list of common deviations from standards:

- Not submitting soil and water (when present) samples for laboratory testing of pH and resistivity
- Not meeting the required design pipe service life requirements
- Use of pipe materials not allowed in Table 11 - 2 or Table 11 - 4
- Use of alternative pipe material or configurations not identified in this chapter
- Noncompliance with allowable minimum or maximum cover limits

Follow procedures for submitting design deviations outlined in Policy Chapter. Obtain the hydraulics design deviation approvals as early as possible and prior to the design acceptance package (DAP). All deviations must demonstrate equivalent or improved performance relative to the governing hydraulic, structural, and durability requirements defined in this chapter.

11.3 Pipe Classification

For consistency in design and construction, ODOT has grouped pipes used in highway projects into four main categories based on their function and application. This classification helps guide design decisions and material selection appropriate for each group's function. The four categories are: Culvert Pipe, Storm Sewer Pipe, Sanitary Sewer Pipe and Perforated Drain Pipe. Each category is described in the following subsections.

To support appropriate material selection, pipe materials should conform to applicable AASHTO, ASTM, AWWA, and ODOT standards for material properties, manufacture, and installation These standards cover factors including cell class, material strength, internal diameter, loadings, and pipe wall thickness.

11.3.1 Culvert Pipe

A culvert is a closed conduit used to convey water along or under the highway system, or past flow obstructions. Culverts are installed to maintain hydraulic continuity of natural and constructed drainage systems. They function to pass design flows while reducing the risk of roadway overtopping, embankment scour, and impacts to adjacent properties.

11.3.2 Storm Sewer Pipe

A storm sewer is a closed drainage system consisting of inlets, manholes, and conduits used to collect and convey stormwater runoff. Storm sewer pipes are designed to convey stormwater runoff collected from roadways, shoulders, and adjacent developed areas to a discharge point, such as an outfall, outlet or to a stormwater management facility. All storm sewer systems require pressure testing in accordance with Standard Specification 00445. Pressure testing identifies leaking seams, joints, or other deficiencies from installation or manufacturing.

11.3.3 Perforated Drain Pipe

A perforated pipe is a pipe designed with small holes or slits, known as perforations along the pipe surface. These pipes are used to manage excess water by collecting and conveying the water away from areas such as stormwater facilities, roadbeds or retaining walls. Perforated drain pipes are typically small in diameter (6 to 8 inches), although larger diameters may be specified depending on design requirements.

11.3.4 Sanitary Sewer Pipe

Sanitary sewer pipes are used to convey domestic or industrial wastewater to treatment facilities. While not typically owned or maintained by the highway agency, these pipes may be present within or adjacent to the highway right-of-way.

11.4 Pipe Material Selection Process

Selecting pipe materials requires consideration of the required design service life to ensure long-term performance. The required design service life is defined in Section 11.5, and is determined before evaluating candidate pipe materials.

Table 11 - 1 provides an outline for evaluating and selecting pipe materials. The process guides the designer through service life requirements by pipe classification, durability, hydraulic performance, and structural requirements. This process supports consistent evaluation of material alternatives and ensures long-term performance requirements are met during selection.

Table 11 - 1 Pipe Material Selection Process

Steps	Design Considerations	Chapter References
1	Determine design service life for the application Select preliminary approved materials by application	11.5 Design Service Life
2	Review pipe material options, including coatings, connections, and corrugations	11.6 Pipe Materials
3	Evaluate hydraulic performance and Manning's n	11.6.4 Manning's n
4	Evaluate site conditions for: corrosion, chlorides and sulfates, and abrasion	11.7 Material Performance
5	Evaluate pipe for needed corrosion or abrasion mitigation or protection	11.8 Chemical and Physical Site Conditions
6	Select appropriate pipe material for wildfire-prone areas	11.9 Material Selection in Fire Prone Areas
7	Verify fill height for minimum and maximum cover limits. Confirm bedding and pipe zone, meet design requirements	11.11 Installation Requirements
8	Review shallow cover and protective measures if needed.	11.11.1 Shallow Cover Conditions
9	Compare alternative material designs, including cost and select final pipe solutions	Reevaluate steps 2- 8 above if needed.
10	List the selected pipe material and any cost-effective alternate materials identified in Step 9 on the Pipe Data Sheet.	

11.5 Design Service Life

Minimum design service life criteria are established to guide material selection based on application type, potential safety impacts, and long-term replacement costs.

> **Design service life:** The expected operational lifespan of a culvert, storm sewer, perforated drain pipe, or sanitary sewer pipe before material deterioration significantly affects hydraulic or structural performance.

Table 11 - 2 lists the minimum design service lives and approved pipe materials by type of hydraulic application.

Table 11 - 2 Required Design Service Life and Approved Pipe Materials

Pipe Service Life and Materials

■ Recommended - meets expected performance, durability, and maintenance requirements.
● Limited - Acceptable with design or site considerations; may need additional evaluation or protection.
X Not Allowed - Prohibited due to performance, durability, or policy limitations
- Not Applicable

Application Type	Design Service Life (years)	Galvanized Steel	Aluminumized Steel	Polymer Coated Steel	Aluminum	Ductile Iron Pipe	Concrete – Reinforced (III – IV)	Concrete – Non-Reinforced	HDPE Solid Wall +	Corrugated HDPE	PVC ++	Polypropylene Pipe ++	HDPE - Steel Reinforced
Culverts													
All Cross Culverts	**75**	■	■	■	■	■	■	X	●	X	X	X	●
Approach Roads	**25**	■	■	■	■	■	■	X	■	●	■	●	■
Outside of shoulders / Roadway Fill	**50**	■	■	■	■	■	■	●	■	■	■	■	■
Storm Drain													
Within Traveled Way / Shoulders	**75**	■	■	■	■	■	■	X	●	X	●	●	●
Outside Traveled Way / Shoulders	**50**	■	■	■	■	■	■	●	■	■	■	■	■
Perforated Drains													
All Cross Drains	**75**	■	■	-	■	-	■	-	●	●	■	■	-
Outside Traveled Way / Shoulders	**25**	■	■	-	■	-	■	-	■	■	■	■	-
Sanitary Sewer	Check with local municipality or jurisdiction for requirements if the project is under their control.												

+ HDPE solid wall connections must be fused for all cross culvert applications.
++ See Table 11 - 4 Approved Thermoplastic Pipe Applications.

Designers are responsible for evaluating site-specific conditions and selecting materials that meet or exceed the required design service life to ensure long-term performance and public safety. When multiple design lives are specified for an installation, the longer design life governs.

11.6 Pipe Materials

This section provides descriptions and performance characteristics of common pipe materials used in hydraulic infrastructure, including culverts, storm sewers, and sanitary sewer pipes. Material selection is important to ensure structural integrity, hydraulic efficiency, and long-term durability under varying environmental conditions.

See Section 11.8.1 for guidance on evaluating corrosive environments and selecting appropriate protective measures for all pipe materials.

11.6.1 Concrete Pipe

Concrete pipe is primarily used for culverts and storm sewers. Long-term performance makes concrete pipe a standard material in transportation infrastructure. Types include non-reinforced (NRCP) and reinforced (RCP), and reinforced concrete box culverts (RCBC) with selection based on loading conditions and design requirements. Concrete pipe strength is categorized from Class I through Class V, with structural capacity increasing with each class. Class 1 NRCP, Class II NRCP, and Class II RCP lack structural strength for most applications and are rarely used.

RCP combines concrete to resist compressive forces with embedded steel reinforcement to handle tensile forces. Concrete pipe is classified as a rigid pipe, relying primarily on structural strength to support load.

RCBCs are reinforced structures with a rectangular cross-section, making them suitable for shallow cover conditions. RCBCs are also classified as rigid structures, relying primarily on structural strength to support applied loads.

Caution is advised when using concrete pipe in sanitary sewers, as hydrogen sulfide gas buildup can cause severe corrosion and deterioration. Protective linings or coatings are recommended in areas prone to high concentrations of sulfide gas. If a local municipality owns the pipe, consult the agency regarding approved material alternatives at a given location.

11.6.1.1 Concrete Pipe Connections

Several joint systems are used to connect concrete pipe and meet performance requirements. Precast concrete pipe joints are manufactured in two types: tongue and groove, and bell and spigot. Figure 11 - 1 and Figure 11 - 2 show example connection types.

Joints with a groove or bell utilize a rubber gasket, which fits against the shoulder or in the groove of the joint. Rubber gasketed pipe joints are frequently used where infiltration, exfiltration, or internal pressure is a factor in the design and are required for storm sewer and culvert applications. This joint provides great shear strength, excellent watertightness and flexibility.

For tongue-and-groove joints, a mastic field-applied sealant may be used to supplement joint sealing. The mastic improves bearing contact between joint faces and is not intended to replace gasketed joints where watertight performance is required.

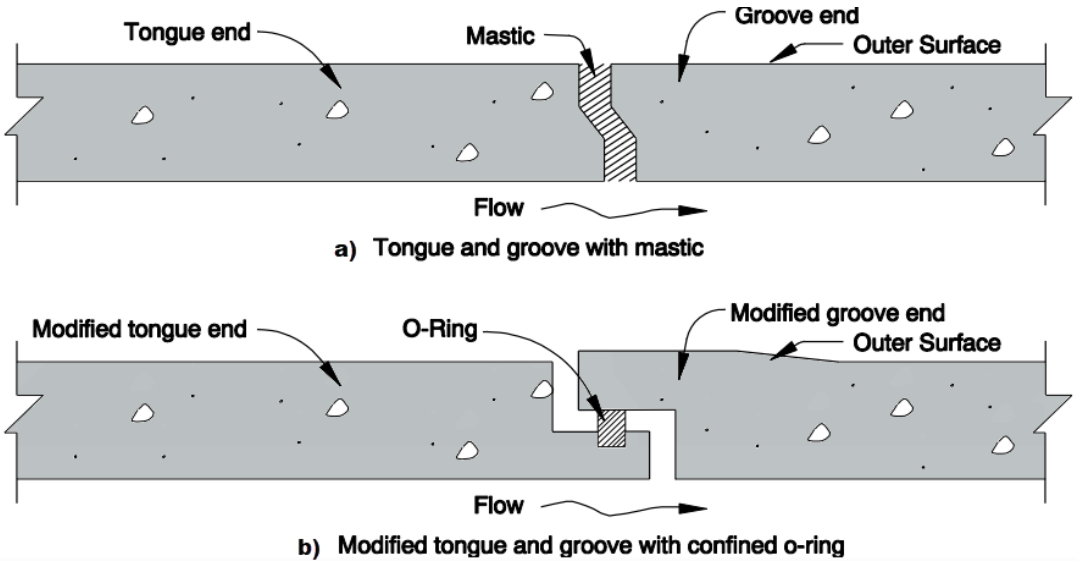


Figure 11 - 1 Concrete Modified Tongue and Groove Connection

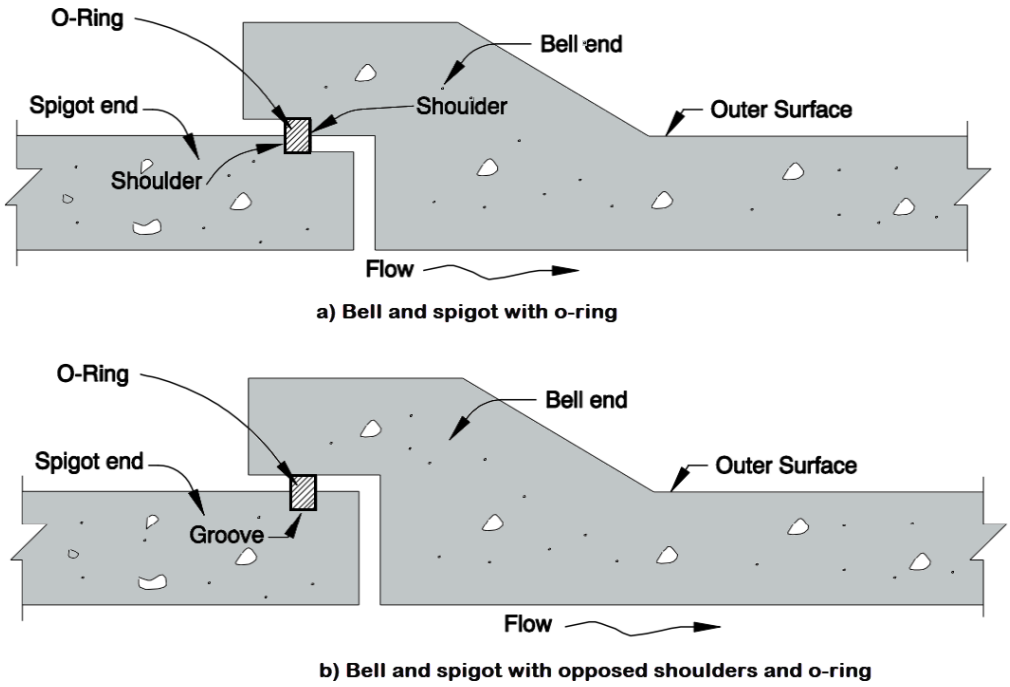


Figure 11 - 2 Concrete Bell and Spigot Joints

Pipe sections near culvert ends can separate if there is a loss of support from the underlying fill. Install tie-bars at the first two and last two pipe joints, as shown in Oregon Standard Drawing RD318.

Precautions must be taken when concrete pipe is placed on grades greater than 10 percent or when significant settlement is expected, as joint separation may occur. Allowable methods and materials for joining concrete pipes are described in the Oregon Standard Specifications for Construction.

11.6.2 Metal Pipe

Metal pipes systems are fabricated from a variety of base metals including aluminum, steel, and ductile iron. Each material is selected for strength, durability, and corrosion resistance. Protective coatings are applied to metal pipe to increase durability in corrosive environments. Metal pipe is available in a range of sizes and shapes. Common configurations include corrugated steel pipe (CSP), spiral-welded steel pipe, and ductile iron pipe.

Metal pipes are classified as flexible pipe, and resist loads primarily through soil–structure interaction with the surrounding bedding and backfill. Common use of metal pipes are culverts and storm sewers due to their strength, durability, and ease of fabrication.

Aluminum

Aluminum pipe is fabricated from corrosion-resistant aluminum alloys, providing excellent resistance to weathering and corrosion. When aluminum is exposed to water and air, an oxide layer forms that protects the underlying metal. Aluminum pipe performs best in soils with a pH between 4.0 - 9.0 and resistivity above 1,000 ohm-cm. Aluminum pipes are available as corrugated or spiral-ribbed.

Aluminum is the preferred metal pipe alternative for marine and coastal environments due to the strong resistance to chloride-induced corrosion compared to steel-based materials. Performance is dependent on site-specific conditions, including exposure severity and the potential for galvanic corrosion at connections.

Steel

Steel pipe provides high strength and stiffness, making this material suitable for a wide range of culvert and storm sewer applications. Bare steel is susceptible to corrosion when exposed to soil, water, and especially marine environments. To improve corrosion resistance, protective coatings are applied to extend the service life. See Section 11.6.2.1 for additional information on steel pipe coatings.

Ductile Iron

Ductile iron pipe (DIP) is a strong, durable pipe used primarily for high-pressure water distribution and sanitary sewer systems. In transportation applications, DIP is selected as an alternative where other prospective pipe materials do not satisfy site-specific cover constraints identified in manufacturer fill height tables. Thickness class for DIP ranges from 50 to 56, specifying the minimum wall thickness to withstand external loads. Pressure classes range from 150 to 350 psi, defining the pipe's capacity to resist internal pressure for water and wastewater applications. See Section 11.11.1, Shallow Cover Conditions, for additional guidance.

11.6.2.1 Steel Pipe Coatings

Protective coatings are applied to steel pipe to improve corrosion resistance and extend service life in aggressive environments. Coatings act as a barrier between the metal and the soil or

water, reducing oxidation and chemical attack. Selection of coating type should consider soil and water pH, resistivity, abrasion, and required design service life. For guidance on the evaluation and mitigation of corrosion and abrasion, see Sections 11.7 and 11.8.

Aluminized Steel

Aluminized steel pipe is steel coated with an aluminum-silicon alloy. The aluminum layer forms a barrier against moisture and oxygen, reducing oxidation of the steel substrate. Aluminized steel pipe provides greater durability than galvanized steel and performs best in alkaline soils with a pH between 5.0 - 9.0 and resistivity above 1,500 ohm-cm. Low-resistivity, acidic, or chloride-rich soils may reduce service life.

Galvanized Steel

Galvanized steel pipe is produced by hot-dip coating steel with a layer of zinc. The zinc layer offers both barrier and sacrificial protection, delaying corrosion of the underlying steel. Galvanized pipe performs best in neutral to slightly basic soils (pH 6.0–10.0) with resistivity above 1,500 ohm-cm. Galvanized pipe is less durable than aluminized or polymer-coated steel and should not be used in highly acidic or chloride-rich soils.

Polymer Coated Steel

Polymer-coated steel pipe is galvanized steel with a bonded polyethylene or polyolefin film applied to both interior and exterior surfaces. This coating provides a corrosion and abrasion-resistant barrier, making the pipe suitable for soils with pH between 4.0 and 10.0 and low resistivity. Polymer coated steel is used in highly corrosive environments where extended service life is required. Polymeric coatings must meet the minimum thickness requirements in ASTM A742 or AASHTO M 246.

Use of polymer-coated steel pipe is limited to diameters of 36 inches and under due to manufacturing and coating application constraints. Use of larger diameters requires approval from the State Hydraulics Section.

11.6.2.2 Corrugations and Manufacturing Thickness

Corrugated metal pipe (CMP) is produced with three types of corrugation geometry: annular, helical, and spiral rib. Corrugation size and geometry influence the pipe's structural capacity, durability, and hydraulic performance. The corrugations are defined by their pitch (the distance between corrugation crests) and depth (the distance from crest to trough) as shown in Figure 11 - 3. Larger corrugation sizes are used as the pipe diameter increases.

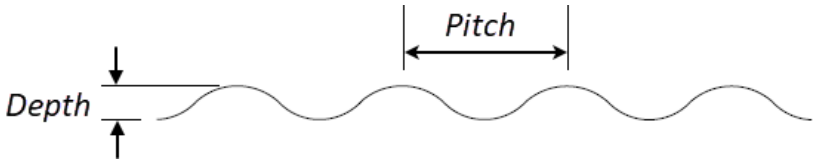


Figure 11 - 3 Corrugation Diagram

Common metal corrugation sizes include (pitch x depth):

- 2 2/3 inches x 1/2 inches
- 3 inches x 1 inch
- 5 inches x 1 inch
- 6 inches x 2 inches

Annular Corrugations

Annular corrugations are oriented perpendicular to the pipe's longitudinal axis, forming a series of evenly spaced rings around the pipe, see Figure 11 - 4. This configuration provides high radial strength and resistance to deformation. Annular corrugations are common on older corrugated metal pipe. They are used on the ends of pipes with helical corrugations to facilitate band coupling.

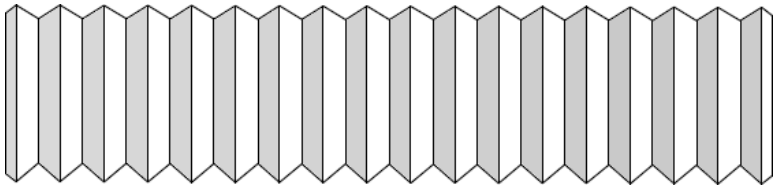


Figure 11 - 4 Annular Corrugations

Helical Corrugations

Helical corrugations form a continuous spiral along the length of the pipe and are the most commonly manufactured corrugation type, see Figure 11 - 5. The spiral seam may be fabricated with a gasketed lock-seam for watertightness or a non-gasketed lock-seam. This design produces a continuous interior wall without circumferential ridges, improving hydraulic efficiency in certain diameters.

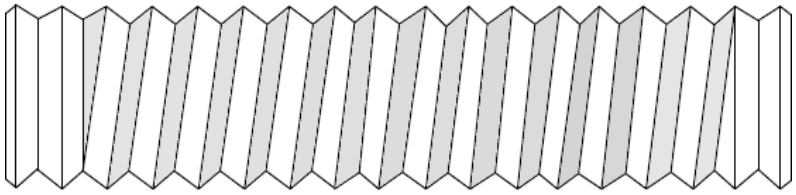


Figure 11 - 5 Helical Corrugations

Spiral Rib

Spiral rib pipe combines a helical seam with rectangular external ribs that wrap around the pipe similar to helical pipe, see Figure 11 - 6. The interior wall between ribs is nearly smooth, providing a low Manning's *n* value comparable to reinforced concrete or smooth plastic pipes.

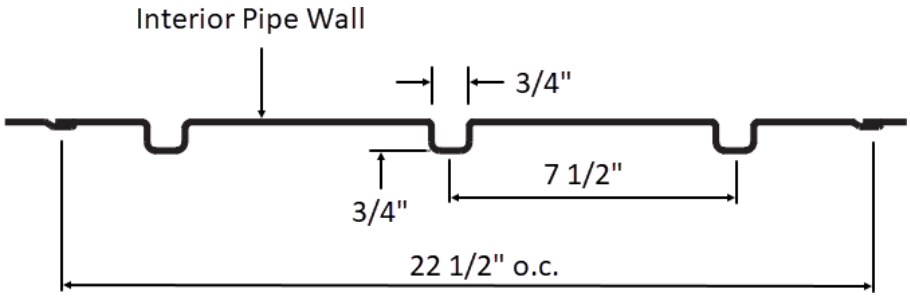


Figure 11 - 6 Spiral Rib with Locking Seam (*National Corrugated Steel pipe Association*)

Wall Thickness

Wall thickness is specified to the nearest 0.001 inch. Standard wall thicknesses and corresponding gage values are listed in Table 11 - 3. Gage values are commonly used in the pipe industry and specifications.

Table 11 - 3 Manufacture Thickness and Gage Values

Material	Manufacture Thickness	Gage	Material	Manufacture Thickness	Gage
Galvanized Steel	0.064 in	16	Aluminum	0.060 in	16
	0.079 in	14		0.075 in	14
	0.109 in	12		0.105 in	12
	0.138 in	10		0.135 in	10
	0.168 in	8		0.164 in	8

Note: Applies to uncoated or metallic-coated pipes. See Fill Height Tables in the Oregon Standard Drawings for available thicknesses.

11.6.2.3 Metal Pipe Connections

Corrugated metal pipe joints use a metal coupling band and a neoprene gasket to connect adjacent pipe sections. The bands are typically made from the same material as the pipe to prevent galvanic corrosion. When connecting dissimilar metals, a full-width neoprene gasket is used to prevent galvanic action. The gasket also provides a positive connection between sections and helps achieve soil-tight or watertight performance, depending on project requirements. See Figure 11 - 7 below:

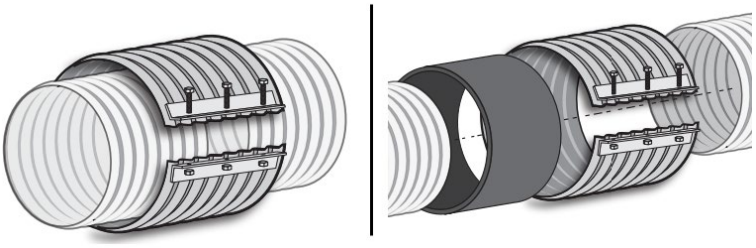


Figure 11 - 7 CMP Metal Band Connectors (*TrueNorth Steel*)

These joints are capable of withstanding significant tensile forces and perform well in culvert applications. However, they typically do not meet pressure test requirements for storm sewers, sanitary sewers, irrigation systems and siphons. Coupling bands and installation details are shown in the 300 series of the Oregon Standard Drawings.

11.6.3 Thermoplastic Pipe

Types of thermoplastic pipe include polyvinyl chloride (PVC), polypropylene (PP), and high-density polyethylene (HDPE). These pipes are widely used for culvert, storm sewer, perforated drains, and sanitary sewer applications. When used in the appropriate application, thermoplastic pipe can provide an economical alternative to concrete and metal pipe.

Thermoplastic pipe is classified as a flexible pipe, meaning loads are resisted primarily by the bedding and backfill surrounding the pipe. Performance depends on the pipe material type and wall configuration. Proper bedding, compaction, and uniform support along the pipe barrel and at joints are important for preventing deformation or damage during installation.

Table 11 - 4 summarizes typical thermoplastic pipe applications and suitability under highway travel lanes, medians, and approaches.

Polyvinyl Chloride Pipe

PVC provides good resistance to corrosion across a broad range of soil and water pH conditions. PVC pipe is available in solid-wall and profile-wall configurations. Common applications include storm sewer, sanitary sewer, and perforated drainage systems. Pressure-rated Classes C900 and C905 are commonly used for low-cover conditions.

Polypropylene Pipe

Polypropylene pipe is available in solid wall, double wall and triple wall profile, and provides good resistance to corrosion across a broad range of soil and water pH conditions. Common applications include storm sewer, sanitary sewer, and perforated drainage systems.

Double Wall PP: Combines a smooth interior for hydraulic efficiency with a corrugated exterior for structural performance.

Triple Wall PP: Incorporates an additional structural layer to increase stiffness and load-bearing capacity.

Compared to corrugated HDPE, polypropylene pipe generally provides increased stiffness. This makes PP suitable for applications requiring greater structural rigidity while maintaining flexible soil-pipe interaction.

High-Density Polyethylene Pipe

High Density Polyethylene pipe is available in a dual-wall, triple-wall, and solid-wall profiles. HDPE provides good chemical resistance and long-term durability. Common applications for PE pipe include median drains, roadway approach culverts, and drainage systems adjacent to highways.

Corrugated Dual-Wall: Combines a smooth interior for hydraulic efficiency with a corrugated exterior for structural performance.

Corrugated Triple-Wall: Includes a corrugated exterior wall, an intermediate structural wall, and a smooth interior wall to provide increased stiffness and load-bearing capacity.

Corrugated HDPE pipe is not permitted under highway travel lanes or shoulders due to the limited structural strength provided by the thin-wall profile. Both pipes are susceptible to deformation, long term creep, joint misalignment, and joint failure under highway loading.

Solid-wall HDPE pipe has a smooth wall with uniform thickness and is suitable for culverts, stormwater systems, and sanitary sewers. For culverts installed under highway travel lanes, solid-wall HDPE pipe is limited to installations with butt-fused joints to provide a continuous structure and prevent joint misalignment that could compromise the water or soil-tight seal.

In slide-prone areas, solid-wall HDPE is very effective when butt-fused joints are combined with slip joints, allowing controlled longitudinal movement without compromising the pipe system. Place the slip joint at the appropriate end of the culvert to accommodate movement, refer to ODOT Standard Detail 1340.

Steel-Rib Reinforced Polyethylene

Steel-Rib Reinforced Polyethylene pipe (SRPEP) is a thermoplastic pipe with a smooth interior wall and an exterior profile reinforced with high-strength galvanized steel ribs. The continuous reinforcing ribs are fully encased within the polyethylene profile to provide structural stiffness, see Figure 11 - 8. The pipe profile is manufactured from a stress-rated thermoplastic meeting ASTM material standards. SRPEP is manufactured using a helical winding process that produces a continuously fusion-welded lap seam.

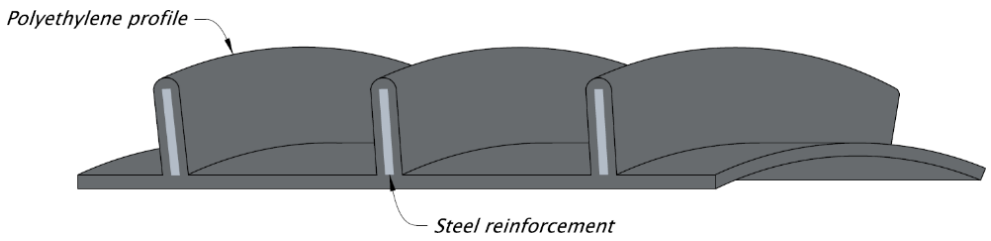


Figure 11 - 8 Steel Rib HPDE Pipe

Table 11 - 4 Approved Thermoplastic Pipe Applications

Pipe Material	Pipe Classification	Allowable Use
PVC (C900 and C905)	Storm Sewer, Sanitary, Perforated Drain	✓
Polypropylene (PP)	Storm Sewer, Sanitary, Perforated Drain	✓
Dual or Triple Wall Corrugated HDPE[1]	Storm Sewer, Sanitary, Perforated Drain	✓
Solid Wall HDPE Butt-(Fused)	Culverts, Storm Sewer, Sanitary, Perforated Drain	✓
Steel Reinforced	Culverts, Storm Sewer, Sanitary	✓

[1] Is not permitted under highway travel lanes or shoulders. Ideal for median drains, roadway approach culverts, and systems adjacent to the highway.

11.6.3.1 Thermoplastic Pipe Connections

Thermoplastic pipe connections vary by material and wall configuration. Proper jointing is necessary to maintain structural integrity, ensure joint performance (e.g., soil-tight or watertight), and support long-term performance. Table 11 - 5 summarizes connection types used for thermoplastic pipe materials and their joint characteristics. Refer to the individual thermoplastic pipe sections and Table 11 - 4 for material-specific limitations and suitability for highway applications.

Table 11 - 5 Thermoplastic Pipe Connection Types by Material

Pipe Material	Connection Type[1]	Remarks
PVC	Gasketed bell and spigot	Pressure rated
Polypropylene	Gasketed bell and spigot	Double-wall watertight Triple-wall pressure rated
Dual & Triple-Wall Corrugated HDPE	Gasketed bell and spigot	Soil and watertight
Solid-Wall HDPE	Butt-fused Mechanical coupler with gasket	Continuous with no mechanical joints Up to 36 inches in diameter
SRPEP	Flat gasket with CMP coupling band. Gasket bell and spigot Electrofusion or extrusion-welded	Soil-tight Low head applications (3 psi joint) or quick-connect (10 psi joint) Water-tight up to 30 psi.

[1] Installed connections in accordance with manufacturer instructions and applicable ASTM standards.

11.6.4 Hydraulic Roughness – Manning's n

Hydraulic roughness represents the resistance a pipe surface exerts on flowing water and is commonly expressed using Manning's *n*. This coefficient depends on the material, corrugations, and any linings or coatings. Selecting an appropriate Manning's n influences flow capacity, velocity, and water surface profiles. Table 11 - 6 summarizes typical Manning's n values for common pipe materials, including the effects of corrugation size.

For design and capacity evaluation, hydraulic analyses should consider both a baseline Manning's *n* representing new pipe conditions and an adjusted Manning's *n* reflecting anticipated or observed field conditions over time. This field-based Manning's *n* will be higher than the new pipe value, accounting for factors such as joint deformation, corrosion, and abrasion, which increase surface roughness and reduce hydraulic efficiency over the service life.

Table 11 - 6 Manning's *n* Values

Pipe Material	Corrugations	Corrugation Size	Manning's n[1]
Concrete Pipe (Pre-cast)	-	-	0.011 – 0.015
Concrete Box	-	-	0.012 – 0.018
Corrugated Metal Pipe and Arch-Pipe (*n* varies with barrel size)[2]	Annular	2-2/3 by 1/2 inch 3 by 1 inch 5 by 1 inch	0.022 – 0.027 0.027 – 0.028 0.025 – 0.026
Structural Plate[2]		6 by 2 inch 9 by 2-1/2 inch	0.33 – 0.035 0.33 – 0.037
Corrugated Metal Pipe and Arch-Pipe (*n* varies with barrel size)[2]	Helical	2-2/3 by 1/2 inch 3 by 1 inch 5 by 1 inch	0.011 – 0.023 0.022 – 0.027 0.022 – 0.025
Spiral Rib Metal Pipe	Helical	3/4 by 3/4 @ 7-1/2 inch O.C. 3/4 by 3/4 @ 8-1/2 inch O.C.	0.012 – 0.013
Polyvinyl Chloride Pipe	Smooth Corrugated	-	0.010 – 0.015 0.018 – 0.025
Polyethylene – smooth interior	-	-	0.009 – 0.011

[1] Listed n-values apply to circular pipes flowing full.

[2] For pipe materials with an applied coating, calculate a composite roughness coefficient.

Culverts are often fabricated or repaired using different materials or coatings for portions of the perimeter. Examples of repairs include paved inverts, partially lined pipes, or spot repairs. In fish passage applications, culverts are often countersunk and partially filled with natural materials to simulate the streambed. To account for the varying surface roughness, a composite Manning's *n* value is used. This value is determined by weighting each material's roughness according to the length of perimeter occupied by that material, providing a representative

measure of overall flow resistance. The composite Manning's n value can be calculated by the following equation:

$$n_c = \left[\sum_{i=1}^{G}\left(\frac{p_i {n_i}^{1.5}}{p}\right)\right]^{0.67} \qquad \text{Equation 11 - 1}$$

Where:

n_c = composite or weighted Manning's n value
G = number of different roughness materials in the perimeter
p = total wetted perimeter
n_i = roughness coefficient for subsection i
p_i = wetted perimeter of subsection i in feet

Based on Equation 11 - 1 the composite Manning's n can be rewritten as:

$$n_c = \left[\frac{p_1 n_1^{1.5} + p_2 n_2^{1.5} + \cdots + p_G n_G^{1.5}}{p}\right]^{0.67}$$

11.7 Chemical and Physical Site Conditions

The durability of pipe materials is governed by site-specific conditions that influence corrosion and abrasion over the service life of the installation. Soil and water characteristics, including pH, resistivity, and the presence of chlorides and sulfates, define the chemical environment surrounding the pipe. Hydraulic conditions and transported sediment define the potential for abrasion.

These factors are evaluated using laboratory testing and site observations to identify degradation mechanisms and inform material selection. The resulting assessment provides the basis for pipe durability design in Section 11.8, including mitigation measures and wall thickness requirements needed to achieve the required service life.

11.7.1 Corrosion

Corrosion is the chemical or electrochemical deterioration generally limited to metal pipes that reduces culvert service life. This attack results from interactions with surrounding soil and water chemistry, as well as adjacent construction materials such as lime-treated base and Portland cement. For reinforced concrete pipes, corrosion may occur in the reinforcing steel due to moisture and chlorides penetrating the concrete, leading to cracking and loss of capacity over time.

Laboratory testing of representative soil and water samples is mandatory for all projects, and multiple soil types may require additional sampling. Test results for pH and resistivity provide the basis for evaluating corrosion risk and guiding initial pipe material selection.

11.7.1.1 pH – Hydrogen-Ion

Soil and water reaction (pH) is a measure of acidity or alkalinity. Chemically, pH is a measurement of the hydrogen ion activity (H^+) in solution. The pH scale ranges from 0 to 14, with a pH of 7 considered neutral. Values greater than 7 indicate basic or alkaline conditions, while values below 7 indicate acidic conditions. Both soil and water pH influence the corrosion potential of pipe materials, with conditions closer to neutral being less aggressive.

11.7.1.2 Soil and Water Resistivity

Soil and water resistivity is a measure of the ability of soil or water to convey electrical current and is expressed in ohm-centimeters. Resistivity is influenced by factors such as moisture content, dissolved salts, temperature, and soil composition. Lower resistivity values indicate a greater ability to conduct electricity and are associated with increased corrosion potential, while higher resistivity values correspond to less aggressive conditions.

11.7.2 Chlorides

Chlorides are soluble salts commonly present in soils and water and are typically reported in parts per million (ppm). Chloride concentrations may occur naturally, in marine environments, or from de-icing chemicals applied to roadways.

Chlorides increase the electrical conductivity of soil and water and can accelerate corrosion of metal pipe materials by disrupting protective oxide layers on metal surfaces. Elevated chloride levels may also contribute to corrosion of steel reinforcement in concrete pipes. Refer to section 11.8.3.1 for CMP coatings that are used for increased chloride resistance.

11.7.3 Sulfates

Sulfates occur naturally in certain soils and groundwater, reported in parts per million (ppm). Sulfate concentrations depend on soil mineralogy, groundwater chemistry, and local geologic conditions. Sulfates can originate from sanitary or industrial wastewater, where microbial activity can convert sulfates to hydrogen sulfide, which may form sulfuric acid and create corrosive conditions.

High sulfate concentrations react chemically with components of concrete, causing expansion, cracking, or deterioration over time. Sulfates may also contribute to corrosive soil conditions that affect metal pipe materials. Both natural and wastewater-derived sulfates should be considered when evaluating pipe durability, available geotechnical investigations, laboratory testing and any water quality data.

11.7.4 Abrasion

Abrasion occurs when waterborne sand, gravel, or rock particles wear away pipe material, shortening the service life. Damage is typically concentrated at the pipe invert and, if severe,

can lead to structural failure. Pipe material selection and coatings must account for potential abrasion to ensure the structure meets or exceeds the required design service life.

11.8 Pipe Durability Design

Pipe durability design considers the combined effects of corrosion and abrasion to determine appropriate materials, protective measures, and the final pipe wall thickness over the design service life. Corrosion and abrasion are evaluated independently and then combined to establish the governing durability requirements.

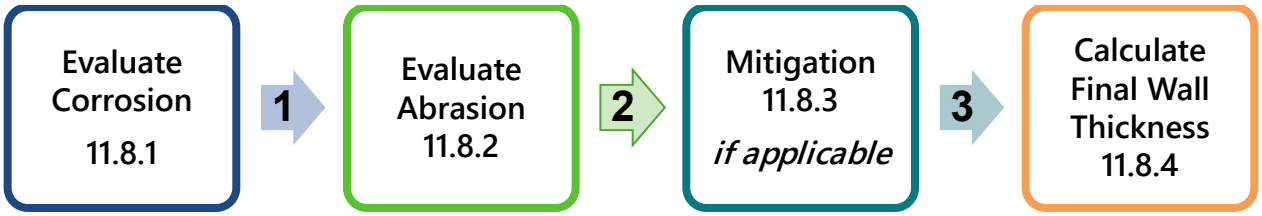


Figure 11 - 9 Corrosion & Abrasion Process

11.8.1 Corrosion Assessment and Service Life

Corrosion assessment is based on site-specific soil and water characteristics, including pH, resistivity, and regional environmental conditions. These parameters define the baseline corrosion environment used to evaluate pipe material longevity. Figure 11-10 provides the corrosion assessment process used to evaluate site conditions, estimate service life, and support material selection.

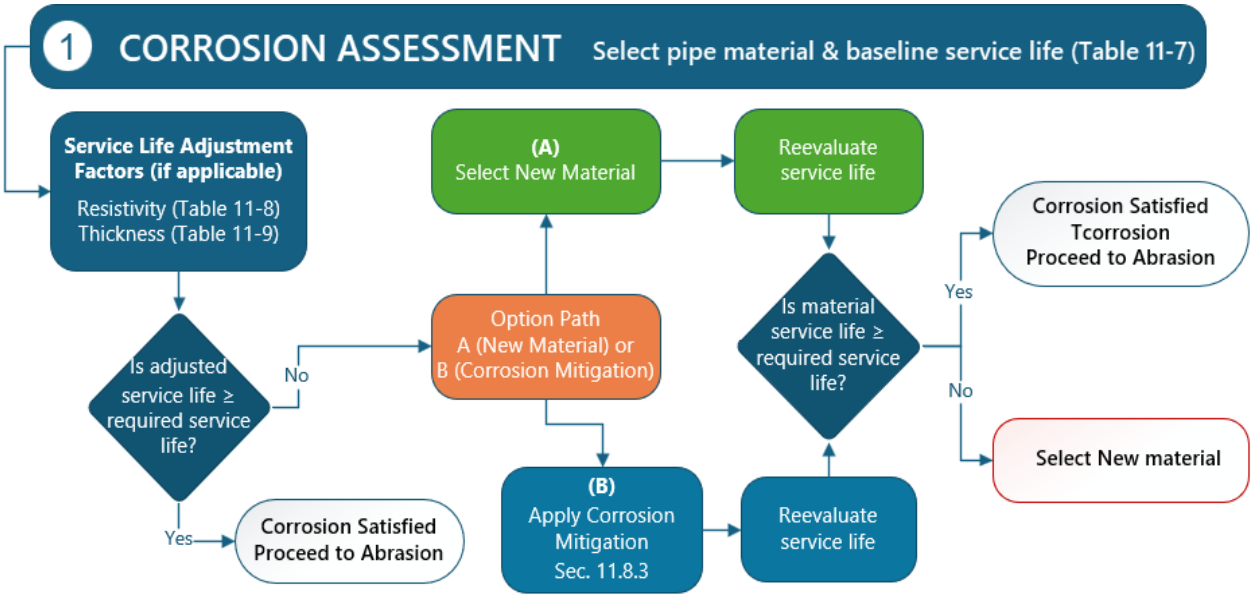


Figure 11 - 10 Corrosion Assessment

Although pH and resistivity are primary indicators, galvanized steel service life decreases west of the Cascades, see Table 11 - 7. In these regions, wetter soils, oxygen availability, chlorides and sulfates, organic acids, and microbial activity reduce service life even when pH and resistivity appear favorable.

Laboratory analysis of soil and water is required and provides the baseline for evaluating corrosion risk. For projects with multiple soil types additional sampling may be required. Table 11 - 7 summarizes common culvert materials and their typical service lives.

Where multiple materials satisfy the minimum service life requirement, selection should consider constructability, availability, hydraulic performance, and compatibility with corrosion protection measures.

Table 11 - 7 Pipe Materials Service Life

Pipe Material	Water & Soil pH	Soil Resistivity (ohm-cm)	[1]Service Life (years)	
			East of Cascades	West of Cascades
Galvanized Steel	4.5 – 6.0	1500 – 2000	30	15
	6.0 – 7.0	1500 – 2000	35	20
	7.0 – 10.0	1500 – 2000	40	25
Aluminized Steel	5.0 – 9.0	>1500	75	75
Aluminum Alloy	4.0 - 9.0	>1000	75	75
Concrete	4.0 - 10.0	>1500	75	75
PVC	4.0 – 10.0	Not applicable	75	75
HDPE	2.0 – 14.0	Not applicable	75	75

[1] Service life of 0.064 inch thick corrugated steel or 0.060 inch thick corrugated aluminum.

Galvanized steel service life is increased using resistivity multipliers in Table 11 - 8.

Table 11 - 8 Galvanized Steel Resistivity Adjustment

Soil Resistivity (ohm-cm)	Service Life Factor
2000 to less than 3000	1.2
3000 to less than 4000	1.4
4000 to less than 5000	1.6
5000 to less than 7000	1.8
more than 7000	2.0

Selecting a greater pipe wall thickness can increase service life. Adjustment factors for different materials and wall thickness are provided in Table 11 - 9.

Table 11 - 9 Thickness Adjustment Factors

Material	Thickness	Material	Thickness	Service Life Factor
Aluminum	0.078 in	Steel	0.079 in	1.2
	0.105 in		0.109 in	1.4
	0.135 in		0.138 in	1.6
	0.164 in		0.168 in	1.8

Following application of Table 11 - 8 and Table 11 - 9, the corrosion assessment results are used to determine the corrosion thickness component (**C**orrosion). This value is used along with abrasion losses (**A**brasion) to determine the final wall thickness in Section 11.8.4.

For protective systems that provide the full required design service life, the corrosion component (**c**orrosion) may be considered negligible.

11.8.2 Abrasion Assessment and Wear Rates

Abrasion potential is evaluated using site-specific hydraulic conditions and streambed characteristics identified through field investigations. Evaluation is based on bed material size, flow velocity, and channel slope. This may be supplemented by observed abrasion performance of nearby infrastructure conveying similar hydraulic and sediment conditions. Abrasion resistance can be evaluated using one of the following approaches:

- Method A – Empirical Abrasion Method, using Table 11 - 10 and Table 11 - 11.
- Method B – Analytical Wear Calculation, using Table 11 - 12 and Equation 11 - 3

The Empirical Method classifies abrasion potential based on site characteristics, while the Analytical Method provides a calculated wear rate for use in design wall thickness determination. Method selection depends on site conditions, available data, and design requirements.

The Empirical Method is used where a standard abrasion classification is sufficient, while the Analytical Method is used where a quantified wear rate is required. Where uncertainty exists, apply the Empirical Method first, with progression to the Analytical Method when a more detailed design basis is needed.

Figure 11-11 provides the abrasion assessment process used to evaluate abrasion potential and estimate material loss. Abrasion assessment results are used to determine the abrasion thickness component (**T**abrasion). This value is used along with abrasion losses (**T**corrosion) to determine the final wall thickness in Section 11.8.4.

Where site conditions indicate negligible abrasion potential or calculated wear is minimal, the abrasion thickness component (**T**abrasion) may be considered negligible.

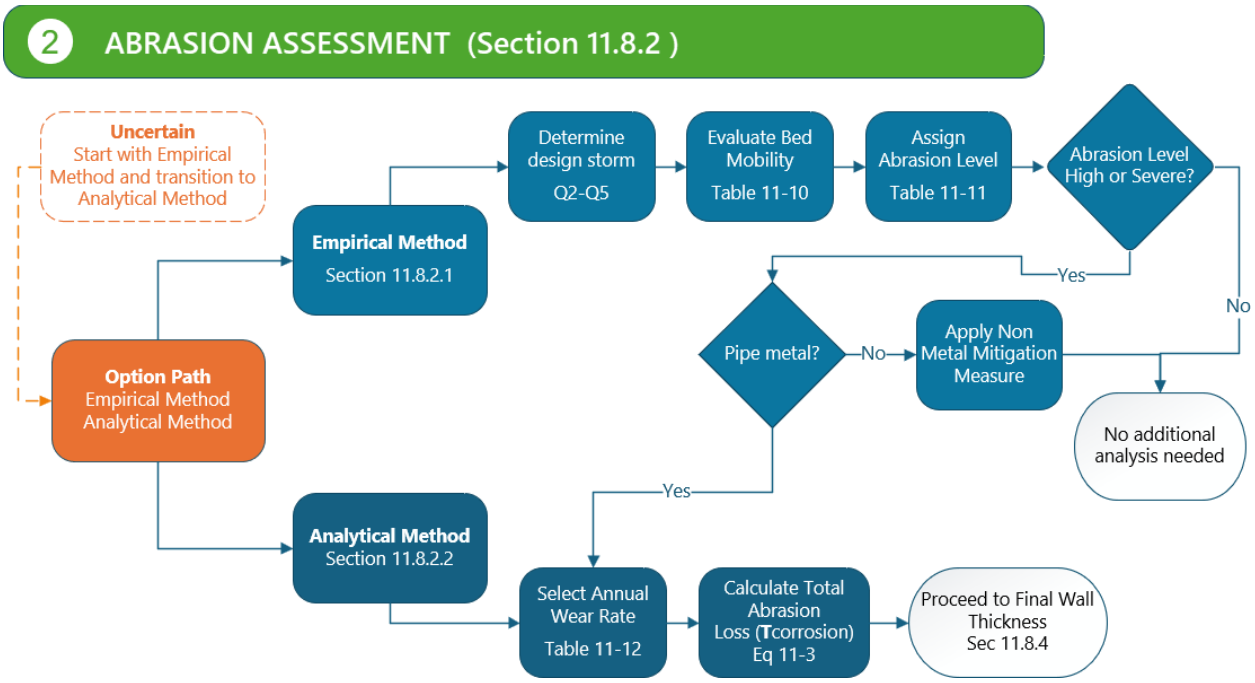


Figure 11 - 11 Abrasion Assessment

11.8.2.1 Empirical Abrasion Method

To evaluate abrasion conditions, design storm events, Q2–Q5, are compared with streambed stability. Governing particle mobility is determined using velocity thresholds provided in Table 11 - 10. The abrasion level is based on the resulting particle size.

The non-scour velocity defines the upper limit for a stable, erosion-resistant streambed. This velocity represents the onset of widespread bed movement and channel instability, not initial particle motion. When design velocity exceeds the threshold for a given particle size and flow depth, the material becomes mobile. The resulting wear depends on the flow energy and mode of transport:

- **Suspended load:** Fine particles carried throughout the flow create a distributed abrasive effect on the wetted perimeter.
- **Bed load**: At velocities near the non-scour threshold, larger particles roll or bounce along the bottom. This localized invert wear is the primary focus of protective measures.

The following procedure provides a method for evaluating culvert abrasion potential using site conditions and hydraulic parameters in conjunction with Table 11 - 10 and Table 11 - 11.

Step 1 – Hydraulic Conditions

Determine design hydraulic conditions for the selected storm events (Q2/Q5), including mean depth and design velocity.

Step 2 – Evaluate Bed Material Mobility

Determine the mobilized bed material using Table 11 - 10 and the design hydraulic conditions:

- Compare design velocity (Q2 or Q5) to non-scour velocity thresholds
- Identify particle sizes where design velocity (Q2 or Q5) ≥ the non-scour velocity
- Select the largest particle size mobilized under the design velocity (Q2 or Q5)

Compare the calculated mobilized bed material with field-observed conditions:

- Use field-observed bed material when finer than the calculated mobilized size
- Do not assign material based on isolated non-representative coarse particles

Step 3 – Assign Abrasion Level

Assign an abrasion level using Table 11 - 11 based on the following:

- Channel slope, Design velocity (Q2 or Q5), Representative mobilized bed material

Table 11 - 10 Bed Materials Moved by Various Flow Depths and Velocities

Approximate Nonscour Velocities (fps)					
Bed Material	**Grain Size (in.)**	**Mean Flow Depth Velocities (fps)**			
--	**--**	**1.3 ft**	**3.3 ft**	**6.6 ft**	**9.8 ft**
Boulders	> 10	15.1	16.7	19.0	20.3
Large cobbles	5 – 10	11.8	13.4	15.4	16.4
Small cobbles	2.5 – 5	7.5	8.9	10.2	11.2
Very coarse gravel	1.25 – 2.5	5.2	6.2	7.2	8.2
Coarse gravel	0.63 – 1.25	4.1	4.7	5.4	6.1
Medium gravel	0.31 – 0.63	3.3	3.7	4.1	4.6
Fine gravel	0.16 – 0.31	2.6	3.0	3.3	3.8
Very fine gravel	0.079 – 0.16	2.2	2.5	2.8	3.1
Very coarse sand	0.039 – 0.079	1.8	2.1	2.4	2.7
Coarse sand	0.020 – 0.039	1.5	1.8	2.1	2.3
Medium sand	0.010 – 0.020	1.2	1.5	1.8	2.0
Fine sand	0.005 – 0.010	1.0	1.3	1.6	1.8
Cohesive Soils	--	--	--	--	--
Heavy sandy loam	--	3.3	3.9	4.6	4.9
Light sandy loam	--	3.1	3.9	4.6	4.9
Soil loss, post settlement	--	2.6	3.3	3.9	4.3

Notes: 1. Adapted from the NHI *Highways in the River Environment* course and Keown et al.
2. Mean flow depth is the cross-sectional area of the waterway divided by the water surface width.

Abrasion levels are assigned using the criteria in Table 11 - 11, which is adapted from the Washington Department of Transportation Hydraulics Manual. All criteria are not required to be met; selection is based on overall site conditions.

Table 11 - 11 Abrasion Levels and Classification

Abrasion Level	Typical Bed Material	Slope & Velocity (fps)	General Recommended Protection
None	Nonabrasive silts and clays	No limitation	Standard factory coatings are adequate
Low	Little to no bed load	S < 1% ν < 3	Standard factory coatings are adequate.
Medium	Minor bed load, mainly sands, silts, clays	S = 1-2% ν < 6	Corrosion protection adequate; consider thicker metal if local abrasion observed.
High	Moderate bed load, mainly sand and gravels (particle size up to 3 in.)	S = 2-4% 6 < ν < 15	[1]Increase metal thickness, coatings or a paved invert. For RCBC, increase thickness of bottom slab.
Severe	Heavy bed load, mainly sand and gravels (particle size > 3 in.)	ν > 15 S > 4%	Use sacrificial plates or liners; consider open-bottom or embedded culvert, or a bridge. Thermoplastic not recommended.

Note: 1) For increased pipe thickness use Analytical Wear Equation Method in Section 11.8.2.2

11.8.2.2 Analytical Wear Equation Method

The analytical method provides a screening-level estimate of abrasion based on hydraulic velocity and material type where detailed bed characterization is unavailable. The annual wear rate used to estimate abrasion loss is obtained from Table 11 - 12. These values, expressed in mils per year (1 mil = 0.001 in.), are based on flow velocity and channel material conditions.

Table 11 - 12 Annual Wear Rate (mils/yr)

Flow Velocity	Abrasion Level	Galvanized Steel	Aluminum Steel (type 2)	Aluminum
≤ 1	None	0	0	0
≥ 1 to ≤ 6	Low to Medium	0	0	0 to 1.1
> 6 to ≤ 8	High	0	0	1.1 to 1.5
> 8 to ≤ 12	High	0.5 to 1	0.5 to 1	1.5 to 3
> 12 to ≤ 15	High	1 to 3.5	1 to 3.5	3 to 10.5
> 12 to <18	Severe	2.5 to 8	2.5 to 8	7.5 to 24

Note: Data adapted from Caltrans Table 855.2.D. Velocity ranges may overlap to reflect transitional site conditions. Use engineering judgment when selecting the appropriate abrasion level and wear rate.

Total abrasion thickness loss is the cumulative material loss over the design service life. Abrasion thickness loss is determined by applying the annual wear rate over the selected design service life and converting mils to inches.

$$T_{Abrasion} = \frac{Annual\ Wear\ Rate \times\ Design\ Service\ life}{1000} \qquad \text{Equation 11 - 2}$$

For conservative design in variable site conditions, use the upper bound of the wear rate range. The total abrasion loss is then used in Section 11.8.4 to determine the required final pipe wall thickness.

11.8.3 Corrosion and Abrasion Mitigation

Mitigation measures are used to reduce material loss and extend the service life of pipe installations where corrosion and abrasion risks are present. These measures must be compatible and collectively achieve the required design service life defined in Section 11.5.

11.8.3.1 Corrosion Protection Measures

In corrosive soils and water, protective systems may be required to extend service life. Selection is based on site conditions, material type, and compatibility with abrasion. Estimated service-life extensions for protective systems are provided in Table 11 - 13 for metal pipes.

Moderate corrosive soils exhibit corrosion potential for buried metal pipes based on soil resistivity, pH, and soluble salts, consistent with FHWA guidance and AASHTO practice.

Table 11 - 13 Service-Life Add-On for Protective Coatings for Metal Pipes

Coating / Protection	Additional (yrs.)	Corrosion	Chlorides & Sulfates	Application Notes
Polymeric coating	50	■	■	High protection: High abrasion level (lower velocity range only)
Cement-mortar lining	25	■	●	Effective in moderate corrosive soils, some chemical resistance.
Polyethylene encasement	50	■	■	Corrosion barrier for aggressive soils

■ Recommended - meets expected performance, durability requirements.

● Limited - Acceptable with design or site considerations; may need additional evaluation or protection.

Note: Actual service-life extension for all protective measures depends on site-specific conditions.
Note 2: Refer to Section 11.7.4 for guidance on evaluating abrasion and control measures.

Table 11 - 14 provides estimated service-life extensions for common concrete pipe coatings based on their resistance to corrosion, chlorides, and sulfates. In high hydrogen sulfide or sulfuric acid environments, consult the manufacturer or where the project is under local jurisdictional control, contact the local authority to confirm coating suitability.

Table 11 - 14 Service-Life Add-On for Protective Coatings for Concrete Pipes

Coating / Protection	Additional (yrs.)	Corrosion	Chlorides & Sulfates	Considerations
Epoxy	20	■	■	Durable, excellent chemical resistance
Polyurethane	15	■	■	Resistant to chemical attack. Effectiveness varies with abrasion level.
Vinyl Ester / Novolac	25	■	■	High chemical resistance

■ Recommended - meets expected performance, durability requirements.

Note: Actual service-life extension for all protective measures depends on site-specific conditions.

11.8.3.2 Abrasion Protection Measures

Abrasion mitigation measures are selected following the determination of the abrasion level. Selection should prioritize the most cost-effective method for achieving the required design life. Mitigation strategies include:

- Increased wall thickness
- Polymeric coatings
- Reinforced concrete paving
- Sacrificial plates.

In high and severe abrasion environments, alternative designs such as open-bottom culverts, embedded culverts, or bridges may be more appropriate. Thermoplastic materials are generally not recommended where high velocities and coarse bed loads are present.

Selected abrasion mitigation measures must ensure compatibility with corrosion protection systems. The combined abrasion and corrosion design must meet the required design service life.

11.8.4 Final Metal Pipe Wall Thickness

The final wall design thickness is determined by independently evaluating structural and durability requirements. Structural capacity is governed by fill height conditions. Durability is determined by anticipated corrosion and abrasion losses over the design life.

The governing thickness is the greater of the structural requirement or the durability requirement. This ensures the pipe satisfies both load-carrying capacity and service-life requirements.

$$T_{Design} = max\ of\ (T_{Fill}, T_{Durability}) \qquad \text{Equation 11 - 3}$$

Where:

T_{Fill} = minimum structural thickness from ODOT fill height tables
$T_{Durability}$ = total thickness to accommodate anticipated material loss over the design service life

The durability components are defined in Equation 11 - 5:

$$T_{Durability} = T_{Corrosion} + T_{Abrasion}$$ Equation 11 - 4

Where:

$T_{Corrosion}$ = thickness based on pipe class selection in Section 11.8.1
$T_{Abrasion}$ = abrasion allowance determined using Equation 11 - 3

For protective systems that provide the full required design service life, the corrosion and/or abrasion components may be considered negligible as determined in Sections 11.8.1 - 11.8.3

11.9 Material Selection in Fire Prone Areas

Selecting the appropriate pipe material in wildfire-prone areas is important to reduce the potential impacts on human safety and the highway infrastructure. Pipe materials must withstand high temperatures, radiant heat, and potential firebrand exposure.

Wildfires can reach peak temperatures exceeding 1,832°F, with average temperatures of 1112°F –1292°F. However, the temperature of a wildfire's flames can vary depending on the height, with lower thermocouples measuring higher temperatures. Wildfires primarily spread through three methods: radiation, firebrands, and convection.

Table 11 - 15 Methods of How Wildfires Spread

Method	Explanation
Radiation	Transfer of heat through air by electromagnetic waves, which preheat and dehydrate fuels to their ignition point. Can ignite combustible materials from up to 150 feet or more.
Firebrands	Burning materials or embers transported by wind. Can ignite materials ahead of the fire front (culverts contain dry vegetation or other combustible materials).
Convection	Flames occur within columns of heat known as convection columns and can ignite anything flammable they contact. Convection requires the flame to be in contact with the structure.

Concrete and metal pipes can withstand higher temperatures than thermoplastic and aluminum. However, exposure of metal to extreme temperatures and rapid heating and cooling can alter the chemical and physical properties, leading to reduced structural strength. Thermoplastic and aluminum pipes are more susceptible to structural damage from exposure to higher temperatures and wind-borne firebrands.

The Wildfire Hazard Map was developed through research by Oregon State University and the



Figure 11 - 13 Talent OR, 2020 Concrete



Figure 11 - 12 Phoenix OR, 2020 HPDE

Oregon Forestry Department. The map identifies three hazard zones based on an integrated measure of burn probability and fire intensity.

- High Wildfire Hazard – equal to or greater than the 90th percentile
- Moderate Wildfire Hazard - 40th – 90th percentile
- Low Wildfire Hazard – equal to or less than the 40th percentile

Burn probability represents the average annual likelihood of wildfire at a specific location and is reported as a fraction. For example, a burn probability of 0.01 indicates a fire is expected once every 100 years on average, or there is a 1% chance of a fire in any given year. Wildfire intensity refers to the amount of energy a wildfire produces and is reported as 'flame length.' Fire intensity is influenced by factors such as weather, topography, and fuel characteristics (Dunn & McEvoy, 2024). Table 11 - 16 outlines the design policy for pipe material selection to help mitigate wildfire impacts on culverts across the three hazard zones.

Table 11 - 16 Culvert Material Fire Design

Material Design Measures	Material Use Range - Hazard Score
Concrete pipe	High - Low
Steel pipe	Medium - Low
Thermoplastic & Aluminum	Low

11.10 Pipe and Soil–Structure Interaction

Installation and cover requirements govern the performance of flexible and rigid pipe systems. These requirements address soil–pipe interaction, installation quality, and cover, which directly influence post-construction structural performance.

11.10.1 Flexible Pipe

Flexible pipe systems, including steel pipe and thermoplastic pipe, rely on interaction with the surrounding backfill to resist applied loads. Unlike rigid pipe systems, flexible pipes deform under load and provide limited resistance to bending without soil support. Minor deflection is expected and is considered part of normal flexible pipe behavior

Structural performance depends on proper installation, including bedding, backfill placement, and compaction in accordance with design specifications to ensure pipe performance. Proper installation practices, including alignment, jointing, and construction support, help prevent localized distortion that can reduce structural capacity or affect long-term performance.

Deflection provides a practical measure of installed system performance and soil support conditions. Increasing deflection generally indicates reduced backfill support or variability in installation quality. Deflection is the percent reduction in vertical diameter relative to the nominal inside diameter.

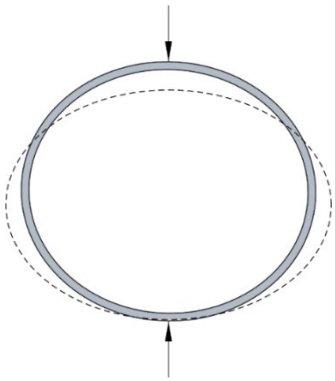


Figure 11 - 14 Deflection of Flexible Pipe

Deflection is evaluated using the following ranges:

- 0 to 5 percent: **Expected performance**.
- Greater than 5 to 7.5 percent: **Reduced performance.** A remediation plan is required.
- Greater than 7.5 percent: **Unsatisfactory performance.** Structural performance is not consistent with design intent, and pipe replacement is typically required.

Large culverts, including long-span structures or aluminum structures, may require stiffening elements to limit deflection under external loads. Stiffening systems can include circumferential ribs or longitudinal elements. Circumferential stiffeners are typically metal ribs attached to the exterior of the pipe. Longitudinal stiffeners are commonly reinforced concrete thrust beams

installed prior to backfill, providing longitudinal and circumferential support and improving load transfer during backfill placement.

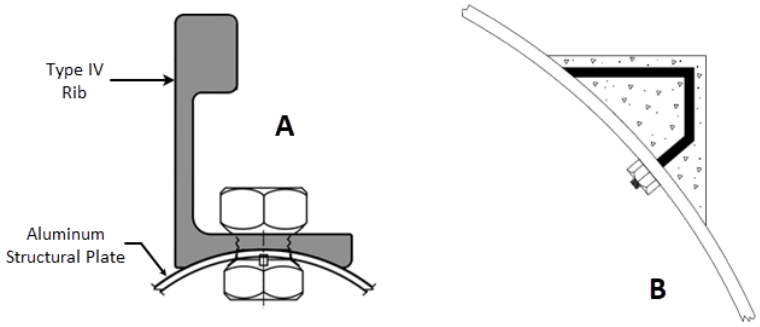


Figure 11 - 15: A) Circumferential Stiffener and B) Longitudinal Thrust Beam

11.10.2 Rigid Pipes

Reinforced concrete pipe combines concrete to resist compressive forces with embedded steel reinforcement to handle tensile forces. Under normal conditions, the pipe behaves as a composite structure, with both materials contributing to load resistance. Minor cracking may occur at low stress levels and is expected behavior. These minor hairline cracks form well below the pipe's design load and do not indicate structural problems.

Concrete is classified as a rigid pipe, relying primarily on concrete's structural strength to support external loads. Some additional support is provided by the surrounding bedding and backfill. During installation, the pipe must be uniformly supported to prevent point load concentrations along the barrel or at the joints.

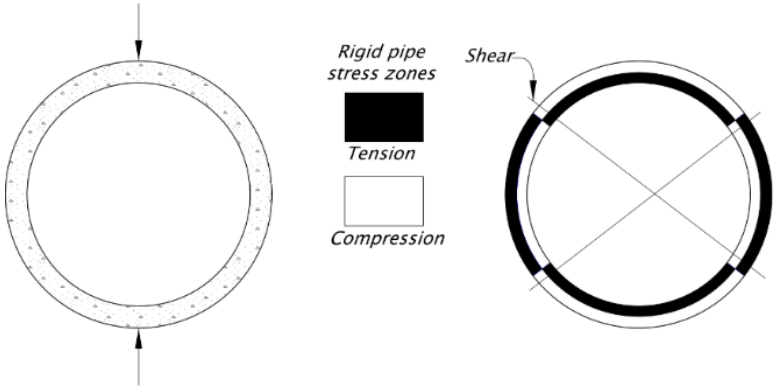


Figure 11 - 16 Concrete Stress Zones

11.11 Installation and Cover Requirements

Installation and cover requirements govern buried pipe systems by establishing minimum and maximum cover limits that control performance under traffic and earth loads. These

requirements also define soil–pipe interaction through bedding, pipe zone, and backfill, which together control load distribution, deformation response, and long-term structural behavior.

Fill Heights and Cover Requirements

An essential aspect of pipe selection is the depth of cover over the pipe. The cover dissipates live loads from traffic during construction and throughout the service life of the facility. This depth, referred to as cover depth or fill height, often governs pipe material selection, shape and size.

Allowable minimum and maximum cover limits are provided in the Oregon Standard Drawings RD300 series. For products listed on the ODOT Qualified Products List that are not included in the Oregon Standard Drawings or AASHTO specifications, use the manufacturer's minimum and maximum cover limits. Evaluate materials not covered by the Oregon Standard Drawings or AASHTO specifications for resistance to live loads and earth pressures.

The structural performance of solid-wall HDPE pipe (ASTM F714 or AWWA C906) is influenced by factors such as dimension ratio (DR), wall stiffness, live loading, and long-term deflection. As a result, use the manufacturer's minimum and maximum cover limits.

The cover depth serves two distinct loading conditions:

Temporary construction cover: the depth of cover during construction activities prior to final roadway completion. During construction, a minimum of two feet of material is required above the crown of the pipe to prevent damage from vehicle or construction equipment.

Final cover (In-service) - the permanent condition once the facility is completed and in operation. This condition governs long-term performance under traffic loading and full embankment overburden.

Minimum cover is measured from the top of the pipe to the top of the subgrade surface. Pipes having less than the minimum cover may be damaged or distorted by wheel or live loads from traffic or construction equipment. Protective measures for shallow cover conditions are provided in Section 11.11.1

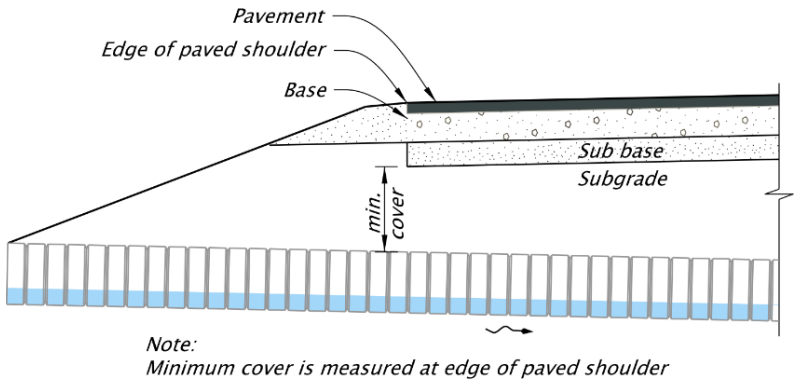


Figure 11 - 17 Minimum Pipe Cover

Maximum cover is measured from the top of the pipe to the roadway pavement surface. Where the maximum allowable cover is exceeded, pipes may be distorted or crushed by overburden earth loads. Protective measures such as pipe encasement can be used to prevent damage from excessive cover heights.

Bedding, Pipe zone, and Backfill

Buried pipe performance depends on interaction between the pipe and surrounding soil system, and is divided into three zones: bedding, pipe zone, and backfill. These zones govern support conditions, load distribution, and deformation behavior for both flexible and rigid pipe materials. These zones rely on a uniform, stable foundation to perform as intended. See Figure 11 - 15 for a typical trench detail.

- **Trench Backfill:** Placed above the pipe zone to restore the trench or embankment to finished grade and provide required cover contributing to overall stability and load transfer.
- **Pipe Zone:** Extends from the bedding to the height above the pipe shown in Standard Drawings RD300 for round pipe and RD304 for arch pipe. This is the primary pipe–soil interaction zone, controlling deflection, load distribution, and long-term performance, particularly for flexible pipe.
- **Bedding**: Provides a prepared interface between the foundation and pipe, establishing a uniform surface at grade and correcting minor irregularities. This layer ensures consistent pipe support and proper placement.

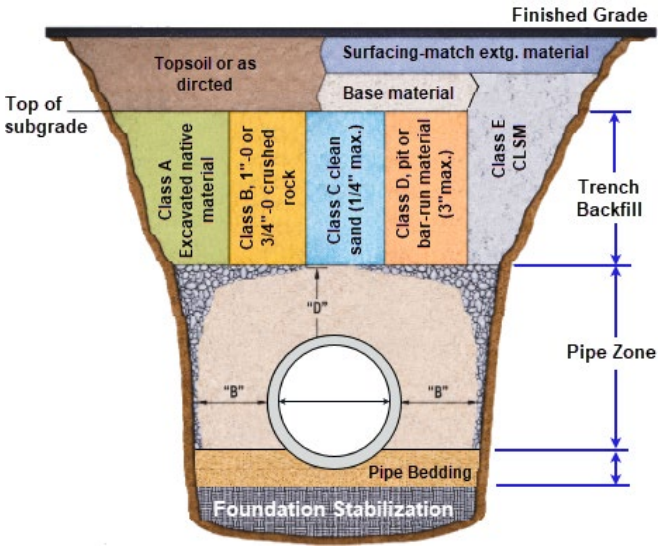


Figure 11 - 18 Trench Detail

Across all zones, installation quality is important to achieve required design behavior. Improper compaction may allow migration of fines or development of flow paths along the pipe exterior, resulting in piping and loss of pipe zone support.

When unstable or unsuitable soil is encountered at the trench bottom, trench foundation is required. It stabilizes the trench by providing uniform and stable support for the pipe along the grade and elevation. A weak or non-uniform foundation can compromise bedding support and lead to differential settlement of the pipe system. The geotechnical engineer provides the foundation stabilization design.

11.11.1 Shallow Cover Conditions

Shallow cover conditions occur where the depth of cover over a pipe is less than the minimum required for either temporary construction loading or final installation. These conditions increase structural demand on the pipe and require additional design or construction measures to prevent damage.

Design under shallow cover conditions considers pipe material behavior, soil–pipe interaction, and construction and service loads. Requirements for DIP and PVC differ due to their structural response and are addressed in the following subsections.

If the minimum cover for either finished or temporary conditions cannot be met, or if heavy construction equipment is anticipated, mitigation measures are required to prevent excessive stress or damage, as described below.

Ductile Iron Pipe

DIP is a rigid pipe system whose strength comes primarily from the pipe wall, making DIP well suited for shallow cover installations. Minimum thickness classes are based on typical interstate and highway loading conditions and engineered granular backfill.

Under shallow cover conditions, verify pipe thickness class based on anticipated earth loads, live loads, and construction loading. Table 11 - 17 summarizes the minimum cover requirements and recommendations for DIP. Higher thickness classes may be required for larger diameters, high traffic volumes, or atypical loading conditions. Maximum allowable fill height tables are available from manufacturers. Corrosion protection may be required for DIP in aggressive soils/water. Refer to Section 11.8 for protective coating guidance.

Table 11 - 17 DIP Installation - Minimum Cover

Pipe Diameter	Minimum Cover		Requirements
	[1] Final	[2] Temporary	
12 – 18 in.	1.0 ft	1.5 ft	Minimum thickness class 51
18 – 24 in.	1.0 ft	1.5 ft	Class 52 or higher based on live loads (HL-93)
24 – 30 in.	1.3 ft	1.5 ft	Class 52 or higher based on live loads (HL-93)

> 30 in.	Case-specific	Case-specific	Use manufacturer tables and consult with project structural engineer

1 Table only applies to type 4 trench, see Figure 11-18

2 Temporary: minimum cover until the finished installation

Although ductile iron may be listed as an option for a project, the material is generally prohibitive for most applications. Where ductile iron pipe is specified as the only allowable material, the cost estimate should be adjusted to reflect the increased cost.

PVC Pipe C900 and C905

C900 and C905 PVC pipe is a flexible, solid-wall pipe that relies on surrounding soil for structural support. These two pipes are an alternative to DIP, offering durability and corrosion resistance.

Under shallow cover conditions, inadequate soil support or improper bedding and backfill can increase the risk of pipe deflection or cracking. Compared to DIP, C900 and C905 are more sensitive to bedding and backfill quality. Proper compaction, trench configuration, and pipe zone materials are essential to ensure pipe performance and structural stability. Table 11 - 18 summarizes the allowable use of PVC pipe in shallow cover conditions. Refer to ODOT's Standard Drawing RD388 for minimum cover requirements and Dimension Ratio (RD) values.

Table 11 - 18 Shallow Cover Conditions - Allowable Use of C900 and C905 PVC[1]

Category	Recommended Application	Not Recommended
Traffic and Live Loads	Moderate loading with minimum cover met	Interstates / State priority routes; high loads; heavy construction equipment
Bedding, Backfill and Compaction	Bedding / backfill materials allow uniform placement and compaction	[2]Bedding and backfill conditions prevent uniform placement or compaction
Corrosion Environment	aggressive soils/water (acidic, high sulfate, or highly conductive).	-----

1 Table only applies to type 4 trench, see Figure 11-18

2 Occurs in wet trenches, highly plastic soils, rock excavation, or restricted access for compaction.

Protective Measures for Shallow Cover Conditions

For cover heights less than the required minimum cover for finished installation or less than the temporary construction cover, a site-specific structural design is needed to protect the pipe. One or more of the following measures should be considered for DIP, C900 or C905 PVC pipe:

- Increase DIP pipe thickness class or select a higher pressure class
- Select a lower DR for PVC pipe. DR is the ratio of a pipe's outside diameter to the pipe's minimum wall thickness.

- Provide a protective concrete cradle or encasement (can also be used for maximum cover).*****
- Install a concrete load-distribution slab to reduce stress on the pipe.*****
- Use temporary plating during construction.

*** Design Note:** Consult the pavement design engineer when considering placing pavement directly over a concrete cradle, concrete encasement, or concrete load-distribution slab. Coordinate with the geotechnical engineer and bridge engineer during the design of a concrete load-distribution slab to address foundation, structural, and loading requirements.

Verify minimum fill heights using manufacturer tables and ODOT's Oregon Standard Drawings RD300 series. Site-specific conditions, including live loads and soil type, may require additional structural analysis.