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TECHNICAL MANUAL

Hydraulics Manual

M 23-03.01

July 2008

Environmental and Engineering Programs

Hydraulics Office

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6-1 Introduction

A storm drain (storm sewer) is a network of pipes that convey surface drainage from catch basins or other surface inlets, through manholes, to an outfall. Storm drains are defined as closed pipe networks connecting two or more inlets, see Figure 6-1.

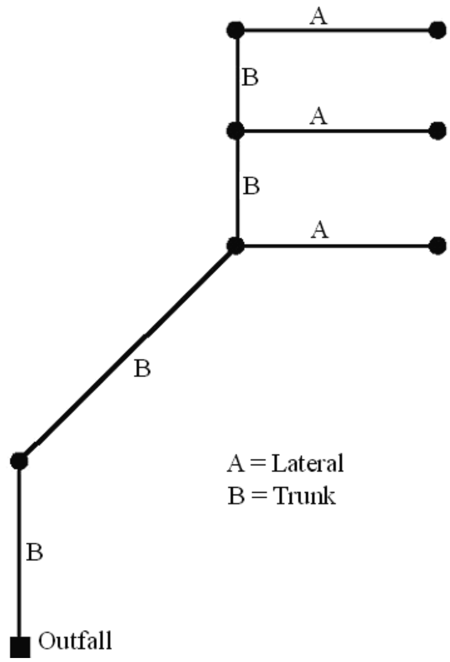
All storm drain designs will be based on an engineering analysis which takes into consideration runoff rates, pipe flow capacity, hydraulic grade line, soil characteristics, pipe strength, potential construction problems, and potential runoff treatment issues. The majority of time spent on a storm drain design is calculating runoff from an area and designing a pipe to carry the flow. A storm drain design may be performed by hand calculations or by one of several available computer programs and spreadsheets.

Runoff is determined using the Rational Method, the Santa Barbara Urban Hydrograph (SBUH) method; see Chapter 2 for further discussion. Pipe capacity is calculated using Manning's Equation, which relates the pipe capacity to the pipe diameter, slope, and roughness. The Region's Hydraulics Engineer reviews the design and if required the Headquarters (HQ) Hydraulics Office provides final approval as part of the hydraulics report review, see Chapter 1 for further approval guidelines.

6-2 Design Features

Along with determining the required pipe sizes for flow conveyance, storm drain system design incorporates the following features:

1. **Soil Conditions** — Soil with adequate bearing capacity must be present to interact with the pipes and support the load imparted by them. Surface and subsurface drainage must be provided to assure stable soil conditions. Soil resistivity and pH must also be known so the proper pipe material will be used.
2. **Inlet Spacing and Capacity** — Design guidelines are detailed in Chapter 5, Drainage of Highway Pavements. For minimum clearance between culverts and utilities, designers should consult the Region Utilities Office for guidance.
3. **Junction Spacing** — Junctions (catch basins, grate inlets and manholes) should be placed at all breaks in grade and horizontal alignment. Pipe runs between junctions should not exceed 300 feet (100 meters) for pipes smaller than 48 inches (1,200 millimeters) in diameter and 500 feet (150 meters) for pipes 48 inch (1,200 millimeters) or larger in diameter. When grades are flat, pipes are small or there could be debris issues; designers should consider reducing the minimum spacing. Region Maintenance should be consulted for final approval on maximum spacing.
4. **Future Expansion** — If it is anticipated that a storm drain system may be expanded in the future, provision for the expansion shall be incorporated into the current design. Additionally, prior to expanding an existing system, the existing system should be inspected for structural integrity and hydraulic capacity.
5. **Velocity** — The velocity of flow should be 3 feet per second (1.0 meter per second) or greater to prevent the pipes from clogging due to siltation. Velocity of flow should not be excessively high since high flow velocities (approaching and above 10 feet per second) produce very large energy losses in the storm drain system and also cause abrasion of the pipes. The velocity should be calculated under full flow condition even if the pipe is only flowing partially full with the design storm.



A lateral(s) discharges into a trunk line. The trunk line then receives the discharge and conveys it to an outfall. Storm drains are classified as a network that has at least two inlets connected by pipes.

Storm Drain Structure

Figure 6-1

6. **Grades at Junctions** — Pipe crowns of branch or trunk lines entering and exiting junctions should be at the same elevation. If a lateral is placed so its flow is directed against the main flow through the manhole or catch basin, the lateral invert must be raised to match the crown of the inlet pipe. (A crown is defined as the highest point of the internal surface of the transverse cross section of a pipe.)

7. **Minimum Pipe Diameter** — The minimum pipe diameter shall be 12 inch (300 millimeters), except that single laterals less than 50 feet (15 meters) long may be 8 inches (200 millimeters) in diameter (some manufacturers are unable to add protective treatment for 8 inches storm drain pipe).

8. **Maximum Pipe Diameter** – Designers should verify the maximum allowable pipe diameter into a drainage structure prior to design. Some standard plans for drainage structures have pipe allowances clearly stated in tables for various pipe materials.

9. **Energy Losses** — Energy losses are calculated to determine the hydraulic grade line. Energy losses only need to be calculated when the losses occurring might be significant; see section 6-6 for a discussion on calculating energy losses. Possible situations of concern include the following:

   - High flow velocities through the system.
   - Pipes are on flat slopes.
   - Inlet and outlet pipes forming a sharp angle at junctions.
   - Multiple flows entering a junction.
   - Pipes entering and leaving the junction are very shallow.

10. **Increase in Profile Grade** — In cases where the roadway or ground profile grades increase downstream along a storm drain, a smaller diameter pipe may be sufficient to carry the flow at the steeper grade. However, due to maintenance concerns, the Washington State Department of Transportation (WSDOT) design practices do not allow pipe diameters to decrease in downstream runs.

    Consideration could be given in such cases to running the entire length of pipe at a grade steep enough to allow use of the smaller diameter pipe. Although this will necessitate deeper trenches, the trenches will be narrower for the smaller pipe and therefore the excavation may not substantially increase. A cost analysis is required to determine whether the savings in pipe costs will offset the cost of any extra structure excavation.

11. **Outfalls** — An outfall can be any structure (man-made or natural) where stormwater from WSDOT highways is conveyed off of the ROW. Outfalls must conform to the requirements of all federal, state, and local regulations and documented as described in Appendix 1-3 of this manual.

    Additional considerations for outfalls include energy dissapators and tidal gates. Energy dissipators prevent erosion at the storm drain outfall, for design guidance see section 3-4.7 of this manual. Installation of tide gates may be necessary when the outfall is in a tidal area, consult the Region Hydraulics Engineer for further guidance.

12. **Location** — Medians usually offer the most desirable storm drain location. In the absence of medians, a location beyond the edge of pavement on state right of way or on easements is preferable. It is generally recommended when a storm drain is placed beyond the edge of the pavement that a one-trunk system, with connecting laterals, be used instead of running 2 separate trunk lines down each side of the road.

13. **Confined Space and Structures -** Per WAC 296, any structure (catch basin, manhole, grate inlet, or underground detention vault) more than 4 feet in depth is considered a confined space. As such, any structure exceeding 4 feet in depth that could be accessed by personnel must be equipped with a ladder. To determine if personnel will access the structure or if a Vactor Hose will be used for maintenance, consult the local maintenance office. Structures over 15 feet in depth should be avoided due to the limitations of WSDOT Vactor Trucks. Any design requiring a structure deeper than 15 feet must consult the Region Hydraulics Office for design approval. Underground detention vaults should only be considered as a last resort due to the overall expense of maintenance. Designers should consult the Region Maintenance Office and Region Hydraulic Engineer before including a vault in any design.

6-3 Data for Hydraulics Report

The design of a storm drain system requires that data be collected and documented in an organized fashion. A Hydraulics Report should be submitted which contains the related calculations (whether performed by hand or computer). See Appendix 1-3 of this manual for guidelines on what information should be submitted and recommendations on how it should be organized.

6-4 Storm Drain Design — Handheld Calculator Method

6-4.1 General

Storm drain design can be accomplished with a handheld calculator using the Rational Method and Figure 6-4.1 to show calculations. Figure 6-4.1 has five divisions: Location, Discharge, Drain Design, Drain Profile, and Remarks. These divisions are further expanded in the subsections below.

6-4.2 Location

The “Location” section gives all the layout information of the drain.

Column 1 gives a general location reference for the individual drain lines, normally by the name of a street or a survey line.

Columns 2 and 3 show the stationing and offset of the inlets, catch basins, or manholes either along a roadway survey line or along a drain line.

6-4.3 Discharge

The “Discharge” section presents the runoff information and total flow into the drain.

Column 4 is used to designate the drainage areas that contribute to particular point in the drain system. The drainage areas should be numbered or lettered according to some reference system on the drainage area maps. The type of ground cover (pavement, median, etc.) may be indicated. Since drainage areas must be subdivided according to soil and ground cover types, a drainage area may have several different parts.

Column 5 shows the area of the individual drainage areas listed in Column 4 in acres (hectares).

Column 6 shows the rational method runoff coefficient (see Chapter 2). Each individual drainage area must have a corresponding runoff coefficient.

Column 7 is the product of Columns 5 and 6. Column 7 is also the effective impervious area for the subsection.

Column 8, the summation of CA, is the accumulation of all the effective impervious area contributing runoff to the point in the system designated in Column 2. All the individual areas in Column 7 contributing to a point in Column 2 are summed.

Column 9 shows the time of concentration to the structure indicated in Column 2. Section 2-5.3 of this manual details how to calculate the time of concentration. Generally the time chosen here would be the longest time required for water to travel from the most hydraulically remote part of the storm drain system to this point. This would include flow over the drainage basin and flow through the storm drain pipes. The time of concentration should be expressed to the nearest minute and as discussed in Chapter 2 is never less than 5 minutes.

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Axle Spacing Report for Overweight Permits

Refer to this number when applying for Special Permits *(Assigned by WSDOT)* → Report Number

Name of Owner		Contact Name	
Address	City	State	Zip
Phone *(Include Area Code)*		Fax *(Include Area Code)*	

Description of Equipment ***(This section must be filled out completely.)*** **Unit No.**

	# Tires	Size		# Tires	Size		# Tires	Size
Axle 1			**Axle 7**			**Axle 13**		
Axle 2			**Axle 8**			**Axle 14**		
Axle 3			**Axle 9**			**Axle 15**		
Axle 4			**Axle 10**			**Axle 16**		
Axle 5			**Axle 11**			**Axle 17**		
Axle 6			**Axle 12**			**Axle 18**		

Axle Spacings Which axle(s), if any, is a lift axle? ________ Is it self-steering? ☐ Yes ☐ No

1-2 ____ Ft. ____ In.
2-3 ____ Ft. ____ In. 6-7 ____ Ft. ____ In. 10-11 ____ Ft. ____ In. 14-15 ____ Ft. ____ In.
3-4 ____ Ft. ____ In. 7-8 ____ Ft. ____ In. 11-12 ____ Ft. ____ In. 15-16 ____ Ft. ____ In.
4-5 ____ Ft. ____ In. 8-9 ____ Ft. ____ In. 12-13 ____ Ft. ____ In. 16-17 ____ Ft. ____ In.
5-6 ____ Ft. ____ In. 9-10 ____ Ft. ____ In. 13-14 ____ Ft. ____ In. 17-18 ____ Ft. ____ In.

Maximum Allowable Axle Weights ***(For WSDOT Use Only)***

1 ____ Lbs. 6 ____ Lbs. 11 ____ Lbs. 15 ____ Lbs.
2 ____ Lbs. 7 ____ Lbs. 12 ____ Lbs. 16 ____ Lbs.
3 ____ Lbs. 8 ____ Lbs. 13 ____ Lbs. 17 ____ Lbs.
4 ____ Lbs. 9 ____ Lbs. 14 ____ Lbs. 18 ____ Lbs.
5 ____ Lbs. 10 ____ Lbs.

Max. Legal Capacity ________ **Lbs.** **Gross Weight Limit** ________ **Lbs.**

Axle Restrictions and Remarks

Note: RCW 46.44.091 requires applications to move any combination of vehicles in excess of 200,000 Lbs. GVW to be submitted in writing 30 days prior to the proposed move.

For WSDOT Use Only

Signed: ____________________ ____________
Analysis Performed By Date

DOT Form 560-013 EF
Revised 9/07

CARRY A VALIDATED COPY OF THIS FORM ON THE VEHICLE DESCRIBED

Storm Drain Design Calculations **(WSDOT Form 235-013)**

Figure 6-4.1

When the runoff from a drainage area enters a storm drain and the time of concentration (Tc) of the new area is shorter than the accumulated Tc of the flow in the drain line, the added runoff should be calculated using both values for Tc. First the runoff from the new area is calculated for the shorter Tc. Next the combined flow is determined by calculating the runoff from the new area using the longer Tc and adding it to the flow already in the pipe. The Tc that produces the larger of the two flows is the one that should be used for downstream calculations for the storm drain line.

The easiest method for determining the Tc of the flow already in the system (upstream of the structure in Column 2) is to add the Tc from Column 9 of the previous run of pipe (this value should be on the row above the row that is currently being filled in) to the time it took the flow to travel through the previous run of pipe. To determine the time of flow (or more correctly, the travel time) in a pipe, the velocity of flow in the pipe and the length of the pipe must be calculated. Velocity is computed using Manning's Equation and is found in Column 16 of the previous run of pipe. The length used is the value entered in Column 18 for the previous run of pipe. Obviously, this calculation is not performed for the very first (most upstream) run of pipe in a storm drain system.

$$T_1 = \frac{L}{60V}$$

Where: T_1 = Time of concentration of flow in pipe in minutes
L = Length of pipe in feet (meters) Column 18
V = Velocity in ft/s (m/s) Column 16 of the previous run of pipe

The designer should note that this calculation assumes that the pipe is flowing full. It is accurate for pipes flowing slightly less than half full up to completely full. It will be slightly conservative for Tc calculations when the pipe is flowing significantly less than half full.

Column 10 shows the rainfall intensity corresponding to the time indicated in Column 9 and the location of the project.

The intensity is in inches per hour to the nearest hundredth for English units (millimeters per hour to the nearest tenth). The rainfall intensity used is a 25 year recurrence interval for storm drain laterals and trunks and the 10 year recurrence interval for laterals without trunks. See Chapter 2 for a complete description of how this intensity can be determined. Projects in eastern Washington should also consult Chapter 4 of the *Highway Runoff Manual* for further design guidance.

Column 11 shows the amount of runoff to the (nearest tenth of a cubic foot per second) (nearest hundredth of a cubic meter per second) up to the point indicated in Column 2. It is computed as the product of Columns 8 and 10. This is simply applying the rational method to compute runoff from all the drainage area upstream of the pipe being analyzed.

Column 12 shows any flow, other than the runoff calculated in Column 11, to the nearest tenth of a cubic foot per second (nearest hundredth of a cubic meter per second) that is entering the system up to the point indicated in Column 2. It is rare to have flow entering a system other than runoff from the drainage basin but this does occur. For instance, when an underdrain, which is draining ground water, is connected to the storm drain. The label for this column indicates that these flows are considered constant for the duration of the storm so they are independent of the time of concentration.

This column is also used when the junction is a drywell and a constant rate of flow is leaving the system through infiltration. When this occurs the value listed in Column 12 is negative. See Section 6-7 for a complete discussion of drywells.

Column 13 is the sum of columns 11 and 12 and shows the total flow in cubic feet per second to the nearest tenth (cubic meters per second to the nearest hundredth) to which the pipe must be designed.

6-4.4 Drain Design Section

This section presents the hydraulic parameters and calculations required to design storm drain pipes.

Column 14 shows the pipe diameter in feet (millimeters). This should be a minimum of 8 inches or 0.67 feet (200 millimeters) for any pipe run with a length of 50 feet (15 meters) or less. Pipes runs longer than 50 feet (15 meters) must have a minimum diameter of 12 inches or 1 foot (300 millimeters). Pipe sizes should never decrease in the downstream direction.

The correct pipe size is determined through a trial and error process. The engineer selects a logical pipe size that meets the minimum diameter requirements and a slope that fits the general slope of the ground above the storm drain. The calculations in Column 17 are performed and checked against the value in Column 13. If Column 17 is greater than or equal to Column 13, the pipe size is adequate. If Column 17 is less than Column 13 the pipe does not have enough capacity and must have its diameter or slope increased after which Column 17 must be recalculated and checked against Column 13.

Column 15, the pipe slope, is expressed in feet per foot (meters per meter). This slope is normally determined by the general ground slope but does not have to match the surface ground slope. The designer should be aware of buried utilities and obstructions, which may conflict, with the placement of the storm drain.

Column 16 shows the full flow velocity. It is determined by Manning's Equation, which is shown below. The velocity is calculated for full flow conditions even though the pipe is typically flowing only partially full. Partial flows will be very close to the full flow velocity for depths of flow between 30 percent and 100 percent of the pipe diameter.

$$V = \frac{1.486}{n} R^{\frac{2}{3}} \sqrt{S} = \frac{1.486}{n} \left[\frac{D}{4}\right]^{\frac{2}{3}} \sqrt{S} \quad \text{(English Units)} \qquad (6\text{-}1)$$

$$V = \frac{1}{n} R^{\frac{2}{3}} \sqrt{S} = \frac{1}{n} \left[\frac{D}{4}\right]^{\frac{2}{3}} \sqrt{S} \quad \text{(Metric Units)}$$

Where:
- V = Velocity in ft/s (m/s)
- D = Pipe diameter in feet (meters)
- S = Pipe slope in feet/foot (meters/meter)
- n = Manning's roughness coefficient (see Appendix 4-1)

Extremely high velocities should be avoided because of excessive abrasion in the pipe and erosion at the outlet of the system. Drop manholes should be considered for pipe velocities over 10 fps (3.0 meters per second). The engineer should also keep in mind that energy losses at junctions become significant above 6 feet per second (2 meters per second).

The minimum velocity as determined by this equation is 3 feet per second (1 meter per second).

Column 17, the pipe capacity, shows the amount of flow in cubic feet per second (cubic meters per second), which can be taken by the pipe when flowing full. It is computed using the following formula:

$$Q = VA = V\frac{\pi D^2}{4} \qquad (6\text{-}2)$$

Where: Q = Full flow capacity in cfs (cms)
V = Velocity as determined in Column 16 in ft/s (m/s)
A = Cross sectional area of pipe in feet squared (meters sq)
D = Diameter of pipe in feet (meters)

6-4.5 Drain Profile

Columns 18 through 23, The drain profile section includes a description of the profile information for each pipe in the storm drain system. It describes the pipe profile and the ground profile. The ground elevations should be finished elevations, to the hundredth of a foot. The items in this section are generally self-explanatory. The only exception is Column 18, the length shown is the horizontal projection of the pipe, in feet (meters), from the center to center of appurtenances. Generally, profiles should be set to provide a minimum of 2 feet (0.6 meters) of cover over the top of the pipe, see Chapter 8 for further design guidance.

6-4.6 Remarks

Column 24, Remarks is for any information, which might be helpful in reviewing the calculations. This space should note unique features such as drop manholes, long times of concentration, changes in the type of pipe, or changes in design frequency.

6-5 Storm Drain Design — Computer Analysis

With the addition of personal computers to most engineering workstations, storm drain design by handheld calculator has become less prevalent. Storm drain design by computer analysis offers some distinct advantages over calculations performed by hand. Chief among these advantages is the decreased amount of time required to perform the pipe sizing and hydraulic grade line calculations and the reduced chance for calculation errors.

Some computer programs will use the rational method for storm drain design while others will use a hydrograph method such as the SBUH method. Both of these methods are valid for WSDOT storm drain design; however, they will yield different peak runoff values. This is most distinct for drainage basins that have very short times of concentration. As a basin’s time of concentration extends beyond 15 minutes the two methods yield more similar answers. This difference in peak runoff values ends up having little effect on storm drain design since runoff from basins with short times of concentration tends to be small and the required pipe size is determined by the minimum allowable pipe size. As flows entering the system increase to the point that minimum pipe sizes are no longer the governing factor, the associated time of concentration becomes greater and the two methods produce similar peak flow rates.

There are several commercially available computer programs for storm drain design. Each of these programs has certain features that make them unique from other programs but the primary calculations are performed the same way. Because of this, nearly any commercially available computer programs that perform storm drain design are acceptable for designing WSDOT storm drains.

The HQ Hydraulics Office has purchased the computer program Storm Shed 3G for the Washington State Ferries Division and each WSDOT Region house whenever designing storm drains. Training material for Storm Shed 3G has been developed specifically for WSDOT applications and is available on the HQ Hydraulics Web page or designers can consult the HQ Hydraulics Office for additional technical assistance. To obtain the latest version of Storm Shed 3G software contact the HQ Hydraulics Office or your Region Hydraulic Engineer. Prior to using Storm Shed 3G, the storm drains should be located using a Microsoft® Excel Pavement Drainage Spreadsheet. A spreadsheet is available on the HQ Hydraulic web page at: http://www.wsdot.wa.gov/eesc/design/hydraulics. The spreadsheet lacks the advanced features found in commercially available computer programs but does offer a simple and effective way to locate storm drains.

6-6 Hydraulic Grade Line

The hydraulic grade line (HGL) should be designed with a space of air between the top of water and the inside of the pipe. In this condition the flow is considered open channel and the HGL is the water surface elevation traveling through the storm drain system. If the HGL becomes higher than the crown elevation of the pipe the system will start to operate under pressure flow. In a pressure flow condition, flow could discharge out the inlet of a catch basin or manhole causing possible displacement of the inlet. A displaced inlet can cause severe traffic safety problems and should always be avoided. Fortunately, if the storm drain pipes are designed as discussed in the previous sections, then the HGL will only become higher than the catch basin or manhole rim elevation when energy losses become significant or if the cover over a storm drain is low (less than 5 feet). Regardless of the design conditions, the HGL should always be evaluated especially when energy losses become significant or when the pipes are installed under low cover at very flat gradients.

Typically when flow velocities in storm drains are moderate (less than 6.6 ft/s), energy losses are insignificant and can be ignored. However, when flow velocities become higher, energy losses need to be calculated. Once energy losses are calculated, the HGL can be calculated to determine if the storm drain will function properly.

The HGL can only be calculated after the storm drain system has been designed. The HGL is calculated beginning at the most downstream point of the storm drain and ending at the most upstream point, which is exactly the opposite direction that was used to design the pipe sizes.

The water surface elevation at the storm drain outfall must be known or calculated since it acts as the starting elevation of the HGL. Refer to Chapter 3 for an explanation on calculating water surface elevations at the downstream end of a pipe (the tailwater is calculated the same for storm drain outfalls and culverts). Once the tailwater elevation is known, the energy loss (usually called head loss) from friction is calculated for the most downstream run of pipe and the applicable minor losses are calculated for the first junction upstream of the outfall. All of these head losses are added to the water surface elevation at the outfall to obtain the water surface elevation at the first upstream junction (also the HGL at that junction). The head losses are then calculated for the next upstream run of pipe and junction and they are added to the water surface elevation of the first junction to obtain the water surface elevation of the second upstream junction. This process is repeated until the HGL has been computed for each junction. The flow in most storm drainpipes is subcritical;

however, if any pipe is flowing supercritical (see Chapter 4 for an explanation of subcritical and supercritical flow) the HGL calculations are restarted at the junction on the upstream end of the pipe flowing supercritical. The HGL calculation process is represented in equation form below:

$$\mathrm{WSEL}_{\mathrm{J1}} = \mathrm{WSEL}_{\mathrm{OUTFALL}} + \mathrm{H}_{\mathrm{f1}} + \mathrm{H}_{\mathrm{e1}} + \mathrm{H}_{\mathrm{ex1}} + \mathrm{H}_{\mathrm{b1}} + \mathrm{H}_{\mathrm{m1}} \tag{6-3}$$

$$WSEL_{J2} = WSEL_{J1} + H_{f2} + H_{e2} + H_{ex2} + H_{b2} + H_{m2}$$

$$\ldots$$

$$WSEL_{Jn+1} = WSEL_{Jn} + H_{fn+1} + H_{en+1} + H_{exn+1} + H_{bn+1} + H_{mn+1}$$

Where: WSEL = Water surface elevation at junction noted

H_f = Friction loss in pipe noted (see Section 6-6.1)

H_e = Entrance head loss at junction noted (see Section 6-6.2)

H_{ex} = Exit head loss at junction noted (see Section 6-6.2)

H_b = Bend head loss at junction noted (see Section 6-6.3)

H_m = Multiple flow head loss at junction noted (see Section 6-6.4)

As long as the HGL is lower than the rim elevation of the manhole or catch basin, the design is acceptable. If the HGL is higher than the rim elevation, flow will exit the storm drain and the design is unacceptable. The most common way to lower the HGL below the rim elevation is to lower the pipe inverts for one or more runs of the storm drain or increase the pipe diameter.

6-6.1 Friction Losses in Pipes

Head loss due to friction is a result of the kinetic energy lost as the flow passes through the pipe. The rougher the pipe surface is, the greater the head loss is going to be. Head loss from friction can be calculated with the following equation.

$$H_f = L\left[\frac{2.15Qn}{D^{2.667}}\right]^2 \text{ (English Units)} \qquad (6\text{-}4)$$

$$H_f = L\left[\frac{3.19Qn}{D^{2.667}}\right]^2 \text{ (Metric Units)}$$

Where: H_f = Head loss due to friction in feet (meters)

L = Length of pipe in feet (meters)

Q = Flow in pipe in cfs (cms)

n = Manning's roughness coefficient (see Appendix 4-1)

D = Diameter of pipe in feet (meters)

6-6.2 Junction Entrance and Exit Losses

When flow enters a junction, it loses all of its velocity. As a result, there is an associated head loss equal to one velocity head. Then when the flow exits the junction and accelerates into the next pipe, there is another head loss equal to approximately half of one velocity head. These two head losses can be represented with the following equations (Metric and English units use the same equations).

$$H_e = \frac{V_2^{\,2}}{2g}$$

$$H_{ex} = 1.0\left(\frac{V^2}{2g} - \frac{V_d^{\,2}}{2g}\right) \approx \frac{V^2}{4g} \qquad (6\text{-}5)$$

Where H_e = head loss from junction entrance in feet (meters)

H_{ex} = head loss from junction exit in feet (meters)

V = flow velocity in pipe in feet per second (m/s)

V_d = channel velocity downstream of outlet in feet per second (m/s)

g = gravitational acceleration constant

6-6.3 Losses From Changes in Direction of Flow

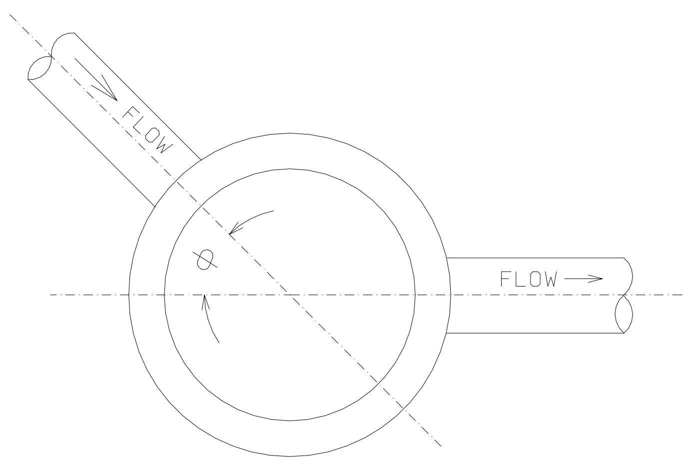
When flow changes direction inside of a junction, there is an associated head loss. The amount of head loss that will occur is dependent on how great the change is. As the angle between the inflow and outflow pipes increase, the amount of head loss increases. This head loss can be calculated with the following equation (metric and English units use the same equation).

$$H_b = K_b \frac{V^2}{2g} \tag{6-5}$$

Where: H_b = Head loss from change in direction in feet (meters)

K_b = Head loss coefficient for change in direction, see below:

K_b	Angle of Change in Degrees
0.00	0
0.19	15
0.35	30
0.47	45
0.56	60
0.64	75
0.70	90 and greater



Changes in Direction of Flow

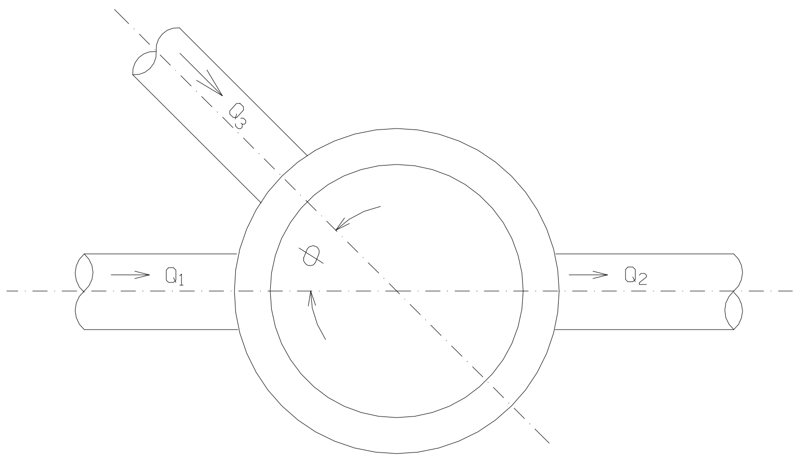
Figure 6-6.3

6-6.4 Losses From Multiple Entering Flows

When flow enters a junction from more than one pipe there is an associated head loss. The head loss is dependent on the amount of flow in each pipe and direction that each pipe enters the junction. This head loss can be calculated with the following equation (Metric and English units use the same equation).

$$H_m = \frac{Q_2 V_2^2 - Q_1 V_1^2 - \cos\phi Q_3 V_3^2}{2gQ_2} \qquad (6\text{-}6)$$

Where H_m = Head loss from multiple flows in feet (meters)



Multiple Flows Entering a Junction

Figure 6-6.4

6-7 Drywells

A drywell is a manhole or catch basin typically precast that is perforated to allow flow into the soil and in some situations when allowed in a storm drain to exit the system. Standard Plan B-<u>20.20 </u>of the WSDOT *Standard Plans for Road, Bridge, and Municipal Construction* depicts a typical drywell. Chapter 530 in the *Design Manual* also provides information on the appropriate geotextile (Class A Underground drainage with moderate survivability) to select for the installation of the drywell as well as *Standard Specifications* 9-12.7, 9-33, and 9-03.12(5).

The primary advantage of drywells is that they reduce flooding by discharging flow into ground water instead of discharging it to surface waters such as rivers and creeks.

A secondary advantage of drywells when allowed is to reduce the flow in a storm drain system and thus reduce the sizes of the pipes in the system. For installation of a drywell to be practical, the surrounding soil should have an infiltration that follow the guidance in the Soil Suitability Criteria section of Chapter 4 in the *Highway Runoff Manual*. Soil infiltration rates should always be determined using soil analysis by a licensed geotechnical engineer. Designing with incorrect soil infiltration rates is a primary cause of failure for systems with drywells.

When allowed, drywells can be designed with inlet and outlets pipes or without pipes. In either case, the designer must first determine the maximum amount of flow that will leave the system through the drywell, see Chapter 4 of the *Highway Runoff Manual* provides guidance on how to establish this flow. The flow rate is then used in one of two ways.

1. **Stand alone drywells -** If the drywells are standing alone, that is there are no pipes connecting them and the only flow into them is through a grate on top of each drywell, the design is performed by simply calculating the amount of flow that enters the drywell through the grate and comparing it with the peak rate of flow that will infiltrate from the drywell. The designer must limit the amount of area draining to each drywell such that the flow out of the drywell through infiltration always exceeds the amount of flow entering the drywell.
2. **Drywells that are part of a storm drain system -** When allowed, drywells can be connected to a storm drain system. To calculate the flow leaving the junction, subtract the rate of infiltration flow leaving the drywell from the flow entering the drywell. When using Figure 6-4.1 to perform the calculations, the flow infiltrating out of the drywell should be shown in Column 12 as a negative value to indicate that there is a constant flow leaving the system at this point. The designer should note that normally pipe sizes are not allowed to decrease in the downstream direction; however, if the flow value in Column 13 becomes less than zero, there may be no need for an outlet pipe since all flow will leave the drywell through infiltration.

Designers should be aware of potential impacts drywell infiltration may have on ground water. Removing pollutants from stormwater, also referred to as runoff treatment, before discharging to ground water is always advisable. In many areas of western Washington and areas of eastern Washington, runoff treatment is required prior to infiltrating runoff. Uncontaminated or properly treated stormwater must be in accordance with Ecology's Underground Injection Control Program UIC (WAC 173-218). See Chapters 4 and 5 of the *Highway Runoff Manual* for a complete discussion on drywells, runoff treatment, and flow control.

6-8 Pipe Materials for Storm Drains

When designing a storm drain network, the designer should review section 8-2 (Pipe Materials), as well as the list of acceptable pipe material (schedule pipe) in Section 7-04 (Storm Sewers) of the *Standard Specifications*. Storm drain pipe is subject to some use restrictions, which are detailed in section 8-1.4 (Storm Sewer Pipe) of this manual.

Pipe flow capacity depends on the roughness coefficient, which is a function of pipe material and manufacturing method. Fortunately, most storm drain pipes are 24 inches (600 millimeters) in diameter or less. Studies have shown that all the common schedule pipe materials have a similar roughness coefficient in these sizes. For calculations, the designer should use a roughness coefficient of 0.013 when all schedule pipes 24 inches (600 millimeters) or smaller are acceptable. For larger diameter pipes, the designer should calculate the required pipe size using the largest Manning's Roughness Coefficient for all the acceptable schedule pipe values listed in Appendix 4-A of this manual. In the event a single pipe alternative has been selected, the designer should design the required pipe size using the applicable Manning's Roughness Coefficient for that material listed in Appendix 4-A.

In estimating the quantity of structure excavation for design purposes at any location where alternate pipes are involved, estimate the quantity of structure excavation on the basis of concrete pipe since it has the largest outside diameter.

6-9 Subsurface Drainage

Subsurface drainage is provided for control of ground water encountered at highway locations. Ground water, as distinguished from capillary water, is free water occurring in a zone of saturation below the ground surface. The subsurface discharge depends on the effective hydraulic head and on the permeability, depth, slope, thickness, and extent of the aquifer.

The solution of subsurface drainage problems often calls for specialized knowledge of geology and the application of soil mechanics. The designer should work directly with the Region Materials Engineer as subsurface conditions are determined and recommendations are made for design in the Soil's Report.

Typical subdrain installations would be those provided for control of seepage in cuts or side hills or the lowering of the ground water table for proper subgrade drainage.

Subsurface drainage pipe size is determined by the same method used to design regular storm drain pipes. The only difference is that the flow used for the calculations is the predicted infiltration from groundwater into the system instead of flow entering the system from roadway drainage. When subsurface drainage is connected to a storm drain system, the invert of the underdrain pipe shall be placed above the operating water level in the storm drain. This is to prevent flooding of the underdrain system and defeating its purpose.

Contents

Chapter 8 Pipe Classifications and Materials

The Washington State Department of Transportation (WSDOT) utilizes a number of different types of pipe for highway construction activities. In order to simplify contract plan and specification preparation, pipes have been grouped into five primary categories; drain pipe, underdrain pipe, culvert pipe, storm sewer pipe and sanitary sewer pipe. Each category is intended to serve specific purposes and is described further in Section 8-1.

Within each pipe classifications there are several types of pipe materials that may be used, 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 8-2 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 dependant on several factors: including but not limited to: fill height (Section 8-11), the required size (Chapter 3) and strength of the pipe, corrosion and abrasion potential (Section 8-4 through 8-6), fish passage (Chapter 7), debris passage, and necessary end treatments (Chapter 3). 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 designer in selecting the material for a pipe that is appropriate for a project site and application (Section 8-4).

This chapter also provides additional information about joining pipe materials, use of pipe anchors, acceptable forms of pipe rehabilitation, abandoned pipe guidelines, and design and installation techniques for pipe.

Pipe producers follow specifications (ASTM, AASHTO, AWWA) covering the manufacture of pipes and specify parameters like cell class, material strength, internal diameter, loadings, and wall thickness. When these standards are referenced, the current year standards shall apply.

8-1 Classifications of Pipe

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

8-1.1 Drain Pipe

Drain pipe is small diameter pipe (usually less than 24 inch (600 mm)) and is 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 to be used in locations that can be accessed easily should it become necessary to maintain or replace the pipe. The minimum design life expectancy is 25 years and no protective treatment is required.

Typical 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 generally 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 inch (300 mm) can withstand fill heights of 30 feet (10 meters) or more without experiencing structural failure. All of the materials listed in Division 7-01 of WSDOT's *Standard Specifications* are adequate under these conditions. For drain pipe applications utilizing pipe diameters 12 inch (300 mm) or larger, or with fill heights greater than 30 feet (10 meters), the designer should specify only those materials that are listed in both Division 7-01 of the *Standard Specifications and* the fill height tables of Section 8-11.

8-1.2 Underdrain Pipe

Underdrain pipe is small diameter perforated pipe intended to intercept groundwater and convey it away from areas such as roadbeds or from behind retaining walls. Typical underdrain applications utilize 6 to 8 inch (150 to 200 mm) diameter pipe, but larger diameters can be specified. The minimum design life expectancy is 25 years, and no protective treatment is required. Division 7-01 of the *Standard Specifications* lists 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 *Design Manual* Chapter 530 and WSDOT CADD Detail Library.

8-1.3 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 shown in the tables of Section 8-11. For materials or sizes not shown in the tables of Section 8-11, contact the HQ Hydraulics Office or section 7-02 of 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 to be used 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 typical contract.

8-1.3.1 Circular and Schedule Culvert Pipe

Circular culvert pipe from 12 inch (300 mm) to 48 inch (1200 mm) in diameter is designated as "schedule pipe" and should be selected unless a pipe material is excluded for engineering reasons. The pipe schedule table listed in Division 7-02 of the *Standard Specification,* includes all of the structurally suitable pipe alternates available for a given culvert diameter and fill height. Additionally, Figures 8-4.1B, .2B, and .3B provide the designer 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.

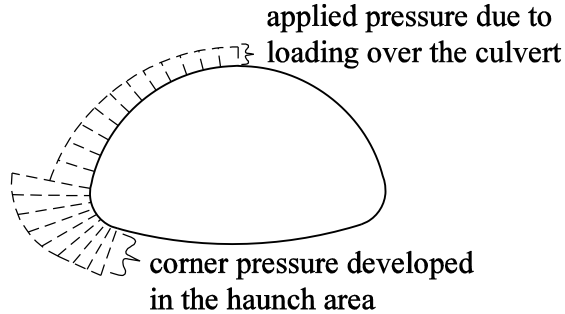
Schedule culvert pipe should be specified as "Schedule _____ Culv. Pipe ____ in (mm) Diam." on the contract plan sheets. Schedule pipe must be treated with the same protective coatings as other culvert pipe.

The type of material for circular culvert pipe from 54 inch (1350 mm) to 120 inch (3000 mm) shall be designated on the plan sheets. The structure notes sheet should include any acceptable alternate material for that particular installation. A schedule table for these large sizes has not been developed due to 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 generally necessary.

8-1.3.2 Pipe Arches

Pipe arches, sometimes referred to as "squash pipe," are circular culverts that have been reshaped into a structure that has a circular top and a relatively 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 a majority 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. Due to the shape of the structure, significant corner pressures are developed in the haunch area as shown in Figure 8-1.3.2. 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 8-11.



Typical Soil Pressure Surrounding a Pipe Arch

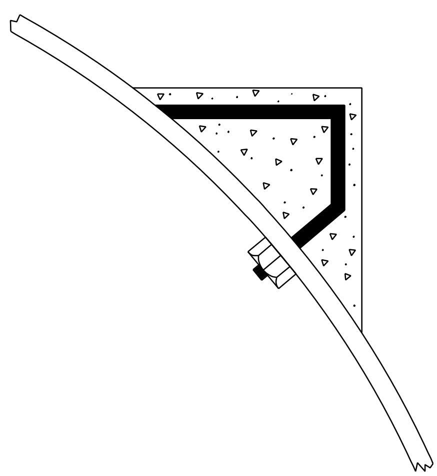
Figure 8-1-3.2

8-1.3.3 Structural Plate Culverts

Structural plate culverts are steel or aluminum structures that are delivered to the project site as unassembled plates of material and are then bolted together. Structural plate culverts are typically large diameter (from 10 feet (3 meters) to 40 feet (12 meters) or more) and are available in a number of different shapes including circular, pipe-arch, elliptical, and bottomless arch with footings. These structures are generally 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 Division 7-03 of 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 should not be specified for use on these types of culverts because the coatings interfere with the bolted seam process. In order to compensate for the lack of protective treatment, structural plate furnished in galvanized steel shall be specified with 1.5 oz/ft^2 (460 g/m^2) of galvanized coating on each surface of the plate (typical galvanized culvert pipe is manufactured with 1 oz/ft^2 (305 g/m^2) of galvanized coating on each surface of the pipe). The designer 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 gauge thickness in this manner can provide a service life of 50 years or more for a very small increase in cost.

To prevent excessive deflection due to dead and/or live loads on larger structural plate culverts, longitudinal or circumferential stiffeners are sometimes added. 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 8-1.3.3. The thrust beams are added to the structure prior to backfill. Concrete thrust beams provide some circumferential stiffening as well as longitudinal stiffening. They also provide a solid vertical surface for soil pressures to act on and a surface, which is easier to backfill against.



Concrete Thrust Beams Used as Longitudinal Stiffeners

Figure 8-1.3.3

Another method that can be used to diminish the 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 generally used in low-cover applications and serves to distribute live loads out into the soil column adjacent to the culvert. The HQ Hydraulics Office should be consulted to assist in the design of this type of structure.

8-1.3.4 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. Private road approach and driveway culverts are off of the main line of the highway, so very little hazard is presented to the traveling public if a failure occurs. Also, in many instances it is difficult to provide a minimum 2 feet (0.6 m) of 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 8-11 can be reduced to 1 foot (0.3 m). If fill heights less than 1 foot (0.3 m) are expected, concrete pipe of the class described in Fill Height Table 8-11.2 should be specified. Designers should follow the same recommendations for material and design life as noted in Section 8-1.1, Drain Pipe.

The designer is cautioned that structural failure may occur on some private road approaches or driveways if the right combination of fill height, live load, soil conditions, and pipe material are present. If live loads approaching the AASHTO HS-25 loading will consistently be traveling over the culvert and if the fill height is less than 2 feet (0.6 m), it is highly recommended that only concrete pipe of the class described in Fill Height table 8-11.2 be specified.

8-1.3.5 Concrete Box Culverts

Concrete box culverts are either cast-in-place or precast. All precast box culverts shall be installed in accordance with the manufacturer's recommendations. For extending or new construction of cast-in-place box culverts, please contact HQ Hydraulics. The dimensions and reinforcement requirements for precast box culverts are described in one of two specifications produced by the Association of State Highway and Transportation Officials (AASHTO). AASHTO M 259 describes precast box culverts with fill heights ranging from 2 feet to 20 feet (0.6 to 6 meters). AASHTO M 259 describes precast box culverts with fill heights less than 2 feet (0.6 m). See Section 8-11.2 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 should 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.

8-1.3.6 Concrete Three-sided Box Culverts

Concrete three-sided structures refer to either rectangular or arch shaped structures that are precast with reinforced concrete. The structures are generally supported by concrete footings, but can be fabricated with a full floor section if necessary. When footings are used, the footing slope should not be greater than 4% in the direction parallel to the channel. The structures are well suited for low cover applications where a relatively wide hydraulic opening must be provided. They can be specified with as little as zero cover and span lengths up to 26 feet (8 meters). It is possible to utilize structures with greater span lengths, but the design for those structures must be coordinated with the Bridge and Structures Office. The structures can be installed very quickly, often within one to two days, which can significantly decrease road closures or traffic delays. 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. The HQ Hydraulics Office should be contacted to perform the necessary scour analysis.

8-1.4 Storm Sewer Pipe

A storm sewer (also referred to as a storm drain in this manual) is defined as two 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 very costly to replace. The minimum design life of a storm sewer pipe is 50 years.

Storm sewer pipe from 12 inch (300 mm) to 48 inch (1200 mm) in diameter is designated as "schedule pipe" and should be selected unless a pipe material is excluded for engineering reasons. The pipe schedule table is listed in Division 7-04 and section 9-05 the *Standard Specifications and* lists all of the structurally suitable pipe alternates available for a given culvert diameter and fill height. Additionally, Figures 8-4.1B, .2B, and .3B provide the designer 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, unless indicated otherwise on the plans, must be pressure tested. Pressure testing is required primarily to indicate the presence of leaking seams or joints or other structural failures that may have occurred during the manufacturing or installation of the pipe. Division 7-04 of the *Standard Specifications* describes three types of pressure tests that are available. The contractor generally has the option of choosing which pressure test to perform. The tests include:

Exfiltration: The section of pipe to be tested is filled with water, and an apparatus is connected to the upper end of the pipe so that an additional 6 feet (2 m) of water column is placed on the test section. The leakage out of the pipe is measured, and must be less than the allowable leakage described in the Standard Specifications.

Infiltration: This test is intended for situations where the groundwater table is above the crown of the upper end of the pipe test section. Once the pipe has been installed, the amount of water leaking into the pipe is collected and measured, and must be less than the allowable leakage rate described in the Standard Specifications.

Low Pressure Air: The section of pipe to be tested is plugged on both ends and compressed air is added until the pipe reaches a certain pressure. The test consists of measuring the time required for the pressure in the test section to drop approximately 1 psi (7 kilopascals). The measured time must be equal to or greater than the required time described in the Standard Specifications.

Metal storm sewer pipe will require the same protective coating to resist corrosion as required for culvert pipe. In addition, coatings may also be required for ungasketed helical seam metal pipes to enable them to pass one of the pressure tests described above. For example, Treatment 1, as described in Section 8-5.3.1 is needed to satisfy the pressure test for an ungasketed helical lock seam pipe. Gasketed helical lock seams, and welded and remetalized 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 8-11.

8-1.5 Sanitary Sewer Pipe

Sanitary sewers consist of pipes and manholes intended to carry either domestic or industrial sanitary wastewater. Any sanitary sewer work on WSDOT projects will usually be a replacement or relocation of existing sanitary sewers for a municipal sewer system. Because of this the pipe materials will usually be in accordance with the requirements of the local sewer district and or Section 7-17 of the *Standard Specifications*. Sanitary wastewater is fairly corrosive regardless of location and therefore pipe materials and treatments should be chosen accordingly.

Pressure testing is always required on sanitary sewers to minimize groundwater infiltration or sewer water exfiltration. The testing is performed in accordance with Division 7-17 of the *Standard Specifications*. As with storm sewers, the contractor has the option of conducting an exfiltration, infiltration, or low-pressure air test. The primary difference between the tests for storm sewers versus the tests for sanitary sewers is that the allowable leakage rate for sanitary sewers is less than the allowable leakage rate for storm sewers.

8-2 Pipe Materials

Various types of pipe material are available for each of the classifications described in Section 8-1. Each type of material has unique properties for structural design, corrosion/ abrasion resistance, and hydraulic characteristics which are further discussed throughout this section to assist the designer in selecting the appropriate pipe materials.

A number of pipe materials are acceptable on WSDOT projects depending on the pipe classification; see section 7 of the Standard Specifications. It is WSDOT's policy is to allow and encourage all schedule pipe alternates that will ensure a properly functioning pipe at a reasonable cost. If at any specific location one or more of the schedule pipe alternates 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 should conform to this manual, the *Standard Specifications*, and WSDOT's *Standard Plans for Road, Bridge, and Municipal Construction.*

Justification for not providing a pipe material, as limited by the allowable fill heights, corrosion zones, soil resistivity, and the limitations of pH for steel and aluminum pipe shall be justified in the Hydraulic Report (see Appendix 1-3) 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 will 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 designer may specify a particular type without alternates; however, the city or county must submit a letter stating their justification. Existing culverts should be extended with the same pipe material and no alternates are required.

8-2.1 Concrete Pipe

8-2.1.1 Concrete Drain Pipe

Concrete drain pipe is non-reinforced and meets the requirements of ASTM C 118. 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 the joints.

8-2.1.2 Concrete Underdrain Pipe

Concrete underdrain pipe is perforated, non-reinforced, and meets the requirements of AASHTO M 175. The strength requirements for concrete underdrain pipe are the same as the strength requirements for plain concrete culvert pipe.

8-2.1.3 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 and meets the requirements of AASHTO M 86, Class 2 only. Reinforced concrete pipe meets the requirements of AASHTO M 170, 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. Due to its lack of strength, Class I reinforced concrete pipe is rarely used and is not listed in the fill height tables of Section 8-11.

The reinforcement placed in concrete pipe can be either circular or elliptical in shape. 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 8-10.3, 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, and it is extremely important that the pipe be handled and installed with the axis placed in the vertical position.

Concrete joints utilize 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 is not recommended for use 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 listed in Appendix 4-1. The maximum fill height for concrete pipe is limited to about 30 feet (10 m) or less. However, concrete pipe is structurally superior for carrying wheel loads with very shallow cover.
For installations with less than 2 feet (0.6 m) of cover, concrete pipe is an acceptable alternative. Fill Height Table 8-11.2 lists the appropriate class of pipe that should 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 discussed in Section 8-10.3. It is important during the installation process to insure that the pipe is uniformly supported, in order to prevent point load concentrations from occurring along the barrel or at the joints.

The weight of concrete pipe sometimes makes it difficult to handle during installation and this should be considered on certain sites. Also, in sanitary sewer applications, the build up of hydrogen sulfide could be a concern. The designer should follow the recommendations of the local sewer district or municipality when deciding if concrete pipe is an acceptable alternate at a given location.

An estimate of wall thickness for concrete pipe can be found using a simple rule of thumb. Take the inside diameter in feet and add 1 inch. For example, lets assume we have a 24-inch (2 foot) diameter culvert. Add 1 inch to 2 feet and the estimated wall thickness is 3 inches.

8-2.2 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. Galvanized and aluminized steel pipe conform the requirements of AASHTO M 36, while aluminum alloy pipe conforms to the requirements of AASHTO M 196.

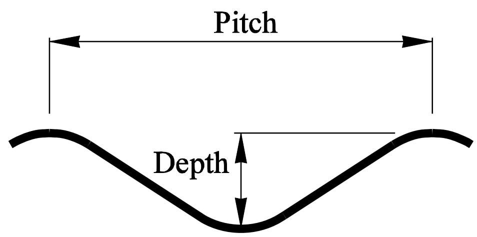
Metal pipe is classified as a flexible pipe, which means that applied loads are resisted primarily by the strength of the bedding and backfill surrounding the pipe, with some additional support given by the pipe material itself. Because of the dependence upon the strength of the bedding and backfill 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, and can be used with fill heights up to 100 feet (30 m) or more. Metal pipe is susceptible to both corrosion and abrasion; methods for limiting these issues are covered in Section 8-5.3 and Section 8-6.

8-2.2.1 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) in order for the pipe to pass the pressure testing requirements.

Helically wound corrugations are available in several standard sizes, including 2-⅔ inch pitch by ½ inch depth (68 mm pitch by 13 mm depth), 3 inch by 1 inch (75 mm by 25 mm), and 5 inch by 1 inch (125 mm by 25 mm). The corrugation sizes are available in several different gauge thicknesses, depending on the pipe diameter and the height of fill. The larger corrugation sizes tend to be utilized as the pipe diameter exceeds about 60 inch (1500 mm). A typical corrugation section is shown in Figure 8-2.2.1.



Typical Corrugation Section

Figure 8-2.2.1

As a result of the helical manufacturing process, the Manning's roughness coefficient for smaller diameter (less than 24 inch (600 mm)) 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 the need to increase 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 600 mm (24 in.), the designer should use the Manning's roughness coefficient specified in Appendix 4-1 to determine if a larger diameter metal pipe alternate is required.

8-2.2.2 Annular Corrugations

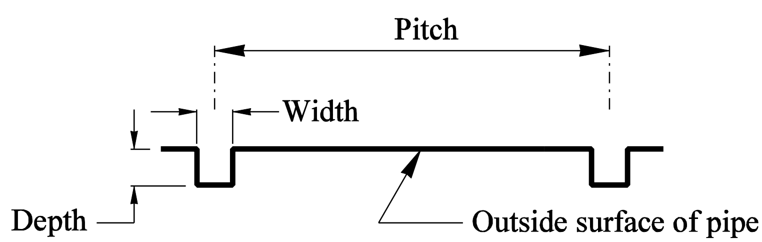
Metal pipe can be produced with annular corrugations, where the corrugations are perpendicular to the flow line of the pipe. The seams for this type of pipe are both circumferential and longitudinal, and are joined by rivets. The Manning's roughness coefficient for all annularly corrugated metal pipes is specified in Appendix 4-1. The fill heights shown in Section 8-11 apply to both helical and annular corrugated metal pipe.

The typical corrugation section shown in Figure 8-2.2.1 is the same for annular corrugations, except that annular corrugations are available only in 2-⅔ inch by ½ inch (68 mm by 13 mm) and 3 inch by 1-inch (75 mm by 25 mm) sizes.

8-2.2.3 Spiral Rib

Spiral rib pipe utilizes the same manufacturing process as helically wound pipe, but instead of using a standard corrugation pitch and depth; spiral rib pipe is comprised of rectangular ribs between flat wall areas. A typical spiral rib section is shown in Figure 8-2.2.3. Two profile configurations are available: ¾inch width by ¾inch depth by 7-½inch pitch (19 mm by 19 mm by 190 mm) or 1 inch by 1 inch by 11 inch (19 mm by 25 mm by 292 mm). 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) in order 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 Appendix 4-1.



Typical Spiral Rib Section

Figure 8-2.2.3

8-2.2.4 Galvanized Steel

Galvanized steel consists of corrugated or spiral rib steel pipe with 1 oz.ft^2 (305 g/m^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 or greater than 8.5. It is also not permitted if the soil resistivity is less than 1,000 ohm-cm. It 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 in order for the pipe to attain the required 50-year service life.

8-2.2.5 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 Zone I and II without the use of protective coatings.

Aluminized steel is not permitted when the pH is less than 5 or greater than 8.5. It is also not permitted if the soil resistivity is less than 1,000 ohm-cm.

8-2.2.6 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 is considered to meet the 50-year life expectancy for both Corrosion Zone 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 is not recommended when backfill material has a very 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, it is generally not recommended that aluminum pipe be coated with the protective treatments discussed in Section 8-5.3.1

8-2.3 Thermoplastic Pipe — General

Thermoplastic pipe is a term used to describe a number of different types of polyethylene (PE, HDPE) and polyvinyl chloride (PVC) pipes that are allowed for use in drain, underdrain, culvert, storm sewer, and sanitary sewer applications. Not all types of thermoplastic pipe are allowed for use in all applications. The designer must reference the appropriate section of Division 9-05 of the *Standard Specifications to* determine the allowable thermoplastic pipe for a given application.

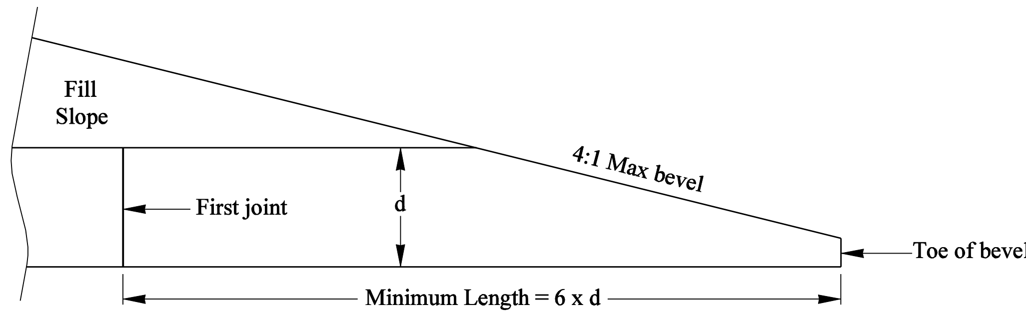
Thermoplastic pipe is classified as a flexible pipe, which means that applied loads are resisted primarily by the strength of the bedding and backfill surrounding the pipe, with some additional support given by the pipe material itself. Because of the dependence upon the strength of the bedding and backfill 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 very resistant to both pH and resistivity. As a result, thermoplastic pipe is an acceptable alternate 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 is not recommended for severely abrasive conditions as described in Figure 8.6.

The weight of thermoplastic pipe is relatively light when compared to other pipe alternatives. This can simplify handling of the pipe because large equipment may not be necessary during installation. However, the lightweight of the pipe can also lead to soil or water floatation 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 is 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 should be beveled to match the surrounding embankment or ditch slope. The ends should be beveled no flatter than 4:1, 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 beveled pipe shall be at least 6 times the diameter of the pipe, measured from the toe of the bevel to the first joint under the fill slope (see Figure 8-2.3). 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 inch (900 mm) in diameter and larger, it is recommended that a Standard Plan B-75.20 headwall be used in conjunction with a beveled end.



Minimum Length for Thermoplastic Pipe Beveled Ends

Figure 8-2.3

8-2.3.1 Corrugated PE Tubing for Drains and Underdrains

Corrugated PE tubing used for drains and underdrains is a single wall, corrugated interior pipe conforming to the requirements of AASHTO M 252. It is available in diameters up to 10 inches (250 mm). This type of pipe is extremely flexible and be manipulated easily on the job site should it become necessary to bypass obstructions during installation. See Section 8-1.1 for treating the exposed end for floatation.

8-2.3.2 PVC Drain and Underdrain Pipe

PVC drain and underdrain pipe is a solid wall, smooth interior pipe conforming to the requirements of AASHTO M 278. It is available in diameters up to 200 mm (8 in.). This type of pipe is typically delivered to the job site in 6 m (20 ft) 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 Section 8-1.1 for treating the exposed end for floatation.

8-2.3.3 Corrugated PE Culvert and Storm Sewer Pipe

Corrugated PE used for culverts and storm sewers is a double-wall, smooth interior pipe conforming to the requirements of AASHTO M 294 Type S or D. This type of pipe can be used under all state highways, subject to the fill height and diameter limits described in Section 8-11 of this manual and Division 7-02.2 of the *Standard Specifications*.

The primary difference between PE used for culvert applications and PE 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 to occur. 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 in situations where a combination of a high water table and fine-grained soils near the trench are expected, it is recommended that the joint used for storm sewer applications 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.

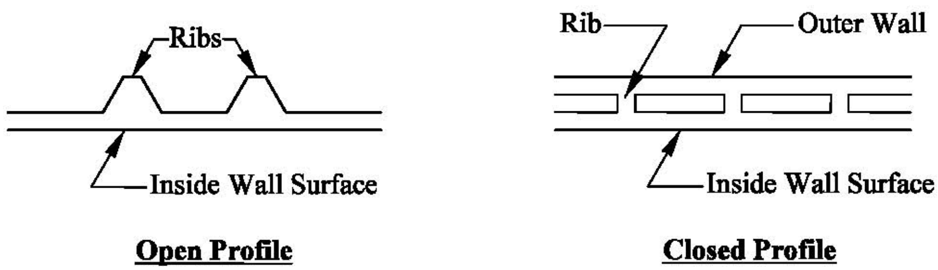
In storm sewer applications, all joints must be capable of passing WSDOT's pressure test requirements. Because of this requirement, it may be possible that the allowable pipe diameter for storm sewer applications may be less than the allowable diameter for culvert applications. The designer should consult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

8-2.3.4 Solid Wall PVC Culvert, Storm, and Sanitary Sewer Pipe

Solid wall PVC culvert, storm, and sanitary sewer pipe is a solid wall, smooth interior pipe conforming to the requirements of ASTM D 3034 SDR 35 for pipes up to 15 inches (375 mm) in diameter and ASTM F 679, Type 1 only, for pipe sizes 18 to 27 inch (450 to 625 mm). This type of pipe can be used under all state highways, subject to the fill height and diameter limits described in Section 8-11 of this manual and Divisions 7-02.2 of 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 Division 9-05.12(1) of the *Standard Specifications*.

8-2.3.5 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 8-2.3.5. 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. Profile wall PVC culvert and storm sewer pipe must conform to the requirements of AASHTO M 304 or ASTM F794, Series 46. This pipe can be used under all state highways, subject to the fill height and diameter limits described in Section 8-11 of this manual and Divisions 7-02.2 of 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 Division 9-05.12(2) of the *Standard Specifications*.



Typical Profile Wall PVC Cross Sections

Figure 8-2.3.5

8-2.4 Ductile Iron Pipe

Ductile iron pipe is an extremely strong, durable pipe primarily designed for use in high-pressure water distribution and sanitary sewer systems. It is acceptable to use ductile iron for culvert and storm sewers, but it is generally not a cost-effective option. Fill heights for ductile iron can be obtained from various manufacturers or by contacting the HQ Hydraulics Office.

8-2.5 Solid Wall HDPE

Solid wall high density polyethylene pipe has many uses, it is used primarily for trenchless applications but occasionally this type of pipe is used for specific applications including bridge drainage, drains or outfalls on very steep sloes, waterline installations and sanitary sewer lines. 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 leak proof connection that is as strong as the pipe itself. There are a wide variety of grades and cell classifications for this pipe, contact HQ Hydraulics Branch for specific pipe information.

8-3 Vacant

8-4 Pipe Corrosion Zones and Pipe Alternate Selection

Once a designer has determined the pipe classification needed for an application, the next step is to ensure 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.

In order to simplify this process, the state of Washington 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 8-4. A flow chart and corresponding acceptable pipe alternate list have been developed for each of the corrosion zones and are shown in Figures 8-4.1 to 8-4.3. The flow chart and pipe alternate list summarize the information discussed in Section 8-5 related to corrosion, pH, resistivity, and protective treatments and can be used to easily develop all of the acceptable pipe alternates for a given location.

The flow charts and pipe alternate 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 Figure 8-6 should be followed.

When selecting a pipe alternative, the designer should always keep in mind the degree of difficulty that will be encountered in replacing a pipe at a future date. Drain pipes are placed relatively shallow and are easy to replace. Culverts tend to have more depth of cover and pass under the highway alignment making them more difficult to replace. Storm sewers are generally utilized 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. These are generalities that will serve as guidelines to the designer.

When special circumstances exist (i.e., extremely high fills or extremely expensive structure excavation) the designer should 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 Figures 8.4.1A and B for a complete listing of all acceptable pipe alternates for culvert and storm sewer applications. Treatment 1, 2 or 5 is required for all storm sewers if the seams are not pressure testable (ungasketed lock seam).

Parts of Eastern Washington, which are not in Corrosion Zone I are placed into Corrosion Zone II. They include:

Okanogan Valley

Pend Oreille Valley

Disautel — Nespelem Vicinity

8-4.2 Corrosion Zone II

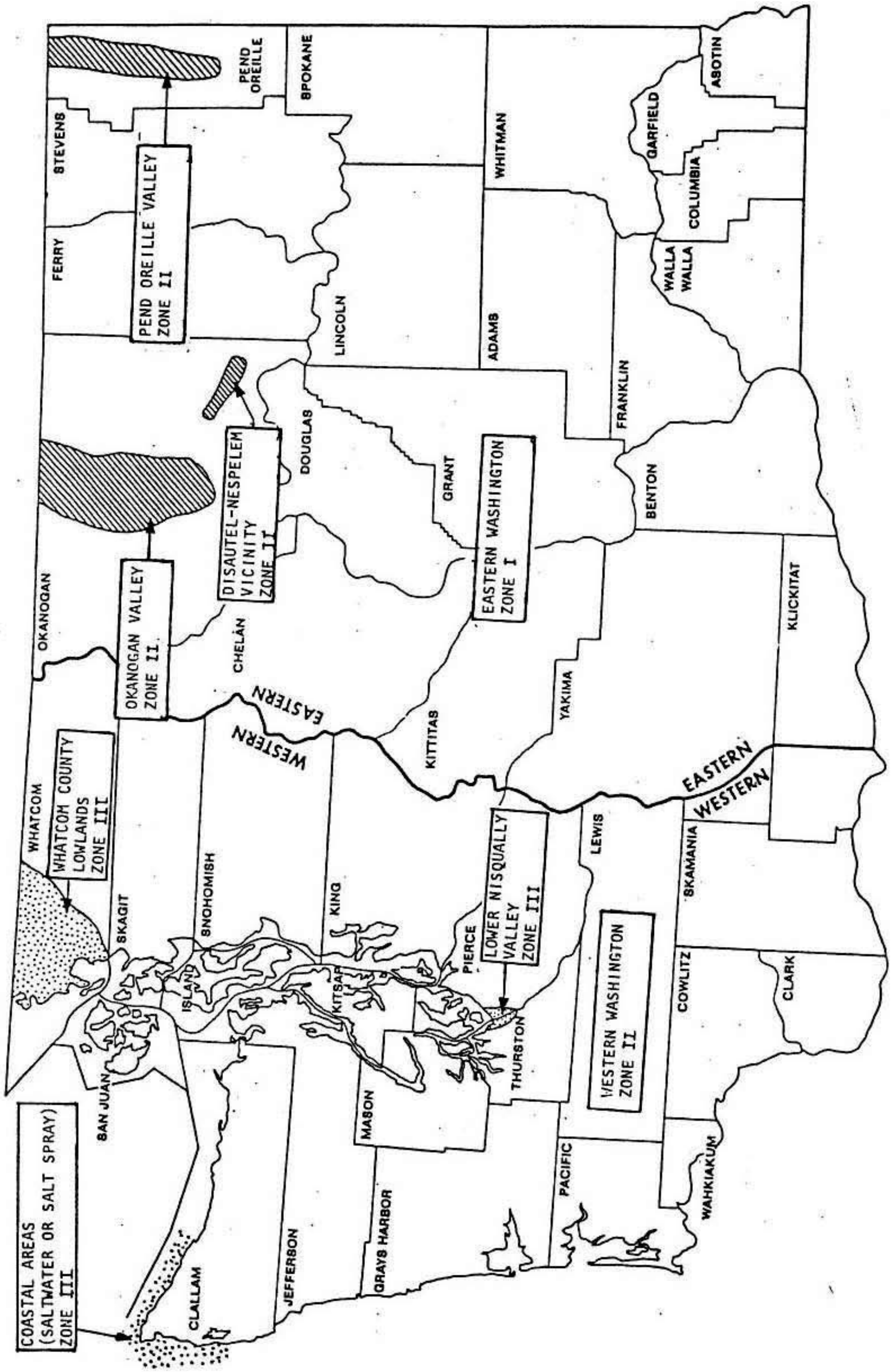
Most of Western Washington, with the exceptions noted below, along with the three areas of Eastern Washington identified above make up Corrosion Zone II. This is an area of moderate corrosion activity. Generally, Treatment 2 is the minimum needed to provide corrosion protection for galvanized steel culverts and storm sewers. Untreated aluminized steel, aluminum alloy, thermoplastic, and concrete pipe may be used in Corrosion Zone II. See Figures 8.4.2A and B for a complete listing of all acceptable pipe alternates for culvert and storm sewer applications.

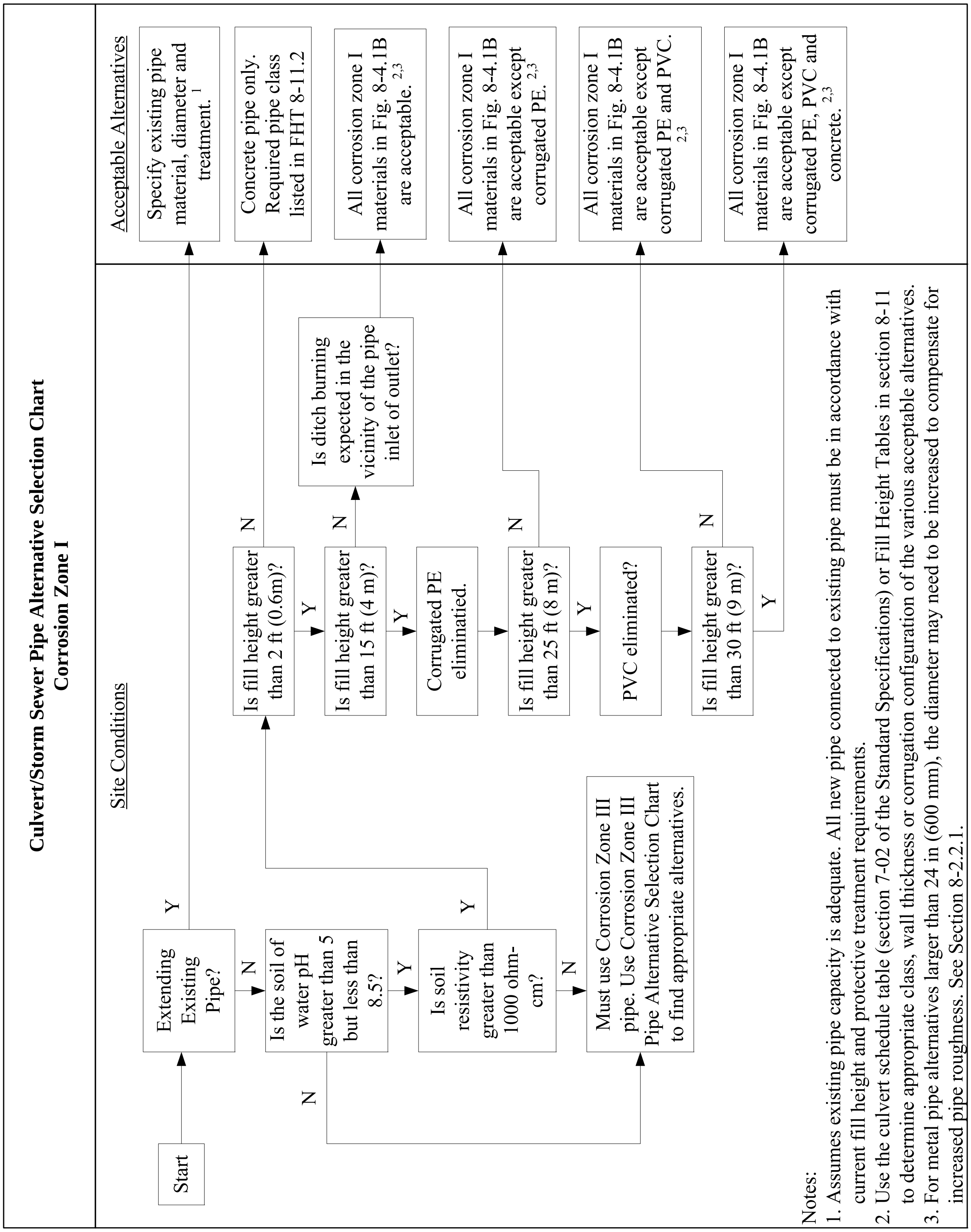
Parts of western Washington, which are not located in Corrosion Zone II, are placed into Corrosion Zone III. They include:

1. **Whatcom County Lowlands, described by the following:**
   a. 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; and
   c. All other roads and areas lying northerly and westerly of the above described 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 should include areas with elevations less than 20 feet (6 meters) above the average high tide elevation. Along the Pacific coast and the Straits of Juan de Fuca, areas within 300 to 600 feet (100 to 200 meters) of the edge of the average high tide can be influenced by salt spray and should be classified as Corrosion Zone III. However, this influence can vary significantly from location to location, depending on the roadway elevation and the presence of protective bluffs or vegetation. In these situations, the designer is encouraged to evaluate existing pipes in the vicinity of 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 8-2.2.6. See Figures 8.4.3A and B for a complete listing of all acceptable pipe alternates for culvert and storm sewer applications.


COASTAL AREAS
(SALTWATER OR SALT SPRAY)
ZONE III
WHATCOM COUNTY
LOWLANDS
ZONE III
OKANOGAN VALLEY
ZONE II
DISAUTEL-NESPELEM
VICINITY
ZONE II
PEND OREILLE VALLEY
ZONE II
EASTERN WASHINGTON
ZONE I
LOWER NISQUALLY
VALLEY
ZONE III
WESTERN WASHINGTON
ZONE II
EASTERN
WESTERN
EASTERN
WESTERN
CLALLAM
JEFFERSON
GRAYS HARBOR
PACIFIC
WAHKIAKUM
SAN JUAN
MASON
THURSTON
WHATCOM
SKAGIT
SNOHOMISH
ISLAND
KING
KITSAP
PIERCE
LEWIS
SKAMANIA
COWLITZ
CLARK
OKANOGAN
CHELAN
KITTITAS
YAKIMA
KLICKITAT
FERRY
STEVENS
PEND OREILLE
SPOKANE
LINCOLN
DOUGLAS
GRANT
ADAMS
WHITMAN
FRANKLIN
BENTON
WALLA WALLA
COLUMBIA
GARFIELD
ASOTIN



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 in section 8-11 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.

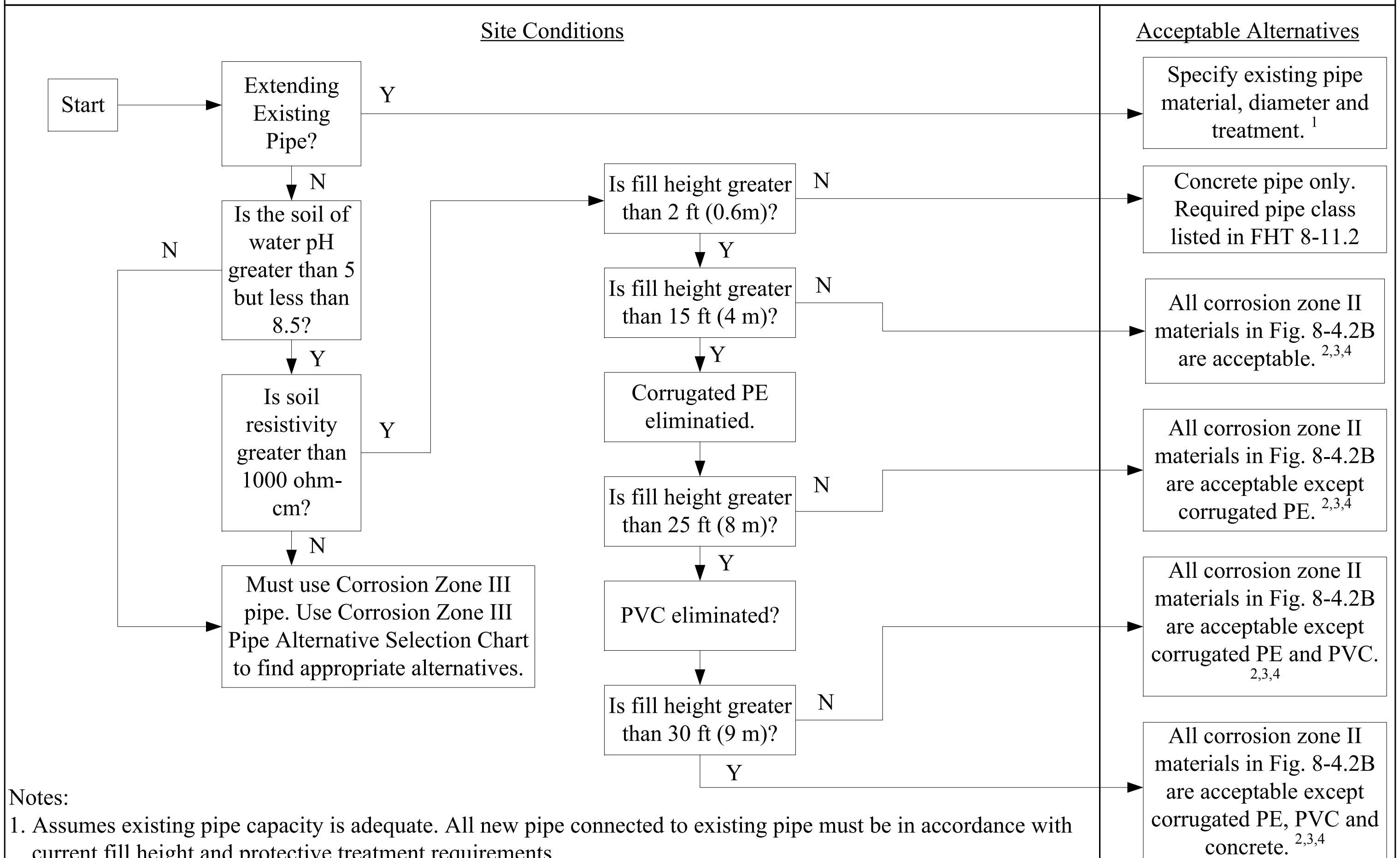
Culverts	Storm Sewers
Schedule Pipe: Schedule _____Culvert Pipe If Schedule pipe not selected then: **Concrete:** • Plain Concrete Culvert Pipe • Cl___Reinf. Concrete Culvert Pipe **PVC:** • Solid Wall PVC Culvert Pipe • Profile Wall PVC Culvert Pipe **Polyethylene** • Corrugated Polyethylene Culvert Pipe • Plain Aluminized Steel 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.___Reinf. Concrete Storm Sewer Pipe **PVC:** Solid Wall PVC Storm Sewer Pipe Profile Wall PVC Storm Sewer Pipe **Polyethylene:** • Corrugated Polyetheylene Storm Sewer Pipe **Steel:** • Plain Galvanized Steel Storm Sewer Pipe with gasketed or welded and remetalized seams • Treatment 1, 2, or 5 Gavanized Steel Storm Sewer Pipe • Plain aluminized Steel Storm Sewer Pipe with gasketed or welded and remetalized seams • Treatment 1, 2, or 5 Aluminized Steel Storm Sewer Pipe **Steel Spiral Rib:** • Plain Galvanized Steel Spiral Rib Storm Sewer Pipe with gaketed or welded and remetalized seams • Treatment 1, 2, or 5 galvanized steel spiral rib storm sewer pipe • Plain Aluminized Steel Spiral Rib Storm Sewer with gasketed or welded or welded and remetalized seams • Treatment 1, 2 or 5 Aluminum Steel Spiral Rib Storm Sewer Pipe **Aluminum:** • Plain Aluminum Spiral Rib Storm Sewer Pipe with gasketed seams • Treatment 1, 2, or 5 aluminum storm sewer pipe. **Aluminum Spiral Rib:** • Plain Aluminum Spiral Rib Storm Sewer Pipe with gasketed seams • Treatment 1, 2, or 5 Aluminum Spiral Rib Storm Sewer Pipe

Corrosion Zone I

Acceptable Pipe Alternates and Protective Treatments

Figure 8-4.1B

Culvert/Storm Sewer Pipe Alternative Selection Chart
Corrosion Zone II



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 in section 8-11 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.

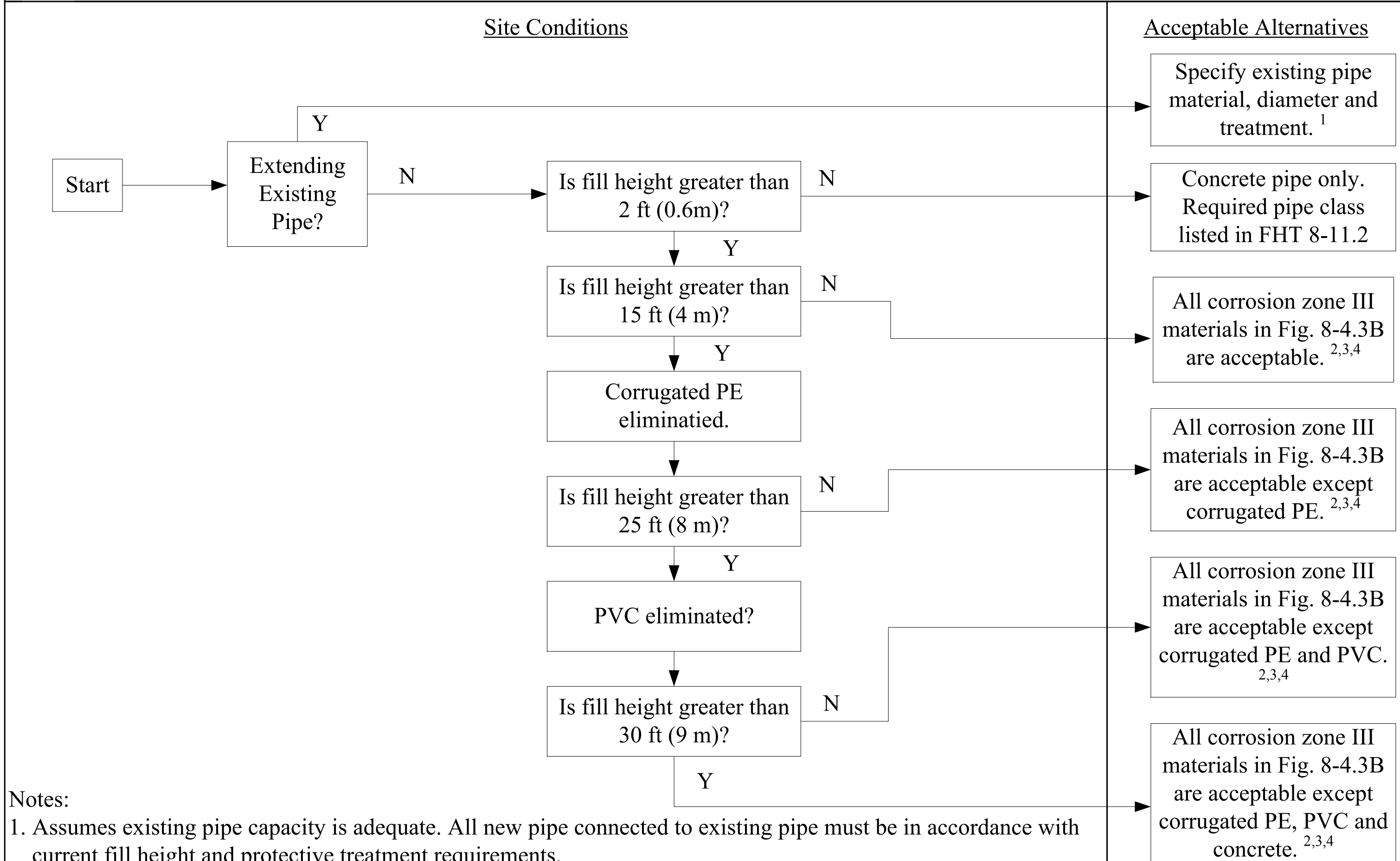
Culverts	Storm Sewers
Schedule Pipe: Schedule _____Culvert Pipe Galvanized Steel alternate shall have TR. 2 If Schedule pipe not selected then: **Concrete:** • Plain Concrete Culvert Pipe • Cl___Reinf. Concrete Culvert Pipe **PVC:** • Solid Wall PVC Culvert Pipe • Profile Wall PVC Culvert Pipe **Polyethylene** • Corrugated Polyethylene Culvert Pipe **Steel** • Treatment 2 Galvanized Steel Culvert Pipe • Plain Aluminized Steel Culvert Pipe **Aluminum:** • Plain Aluminum Culvert Pipe	**Concrete:** • Plain Concrete Storm Sewer Pipe • Cl.___Reinf. Concrete Storm Sewer Pipe **PVC:** • Solid Wall PVC Storm Sewer Pipe • Profile Wall PVC Storm Sewer Pipe **Polyethylene:** • Corrugated Polyetheylene Storm Sewer Pipe **Steel:** • Treatment 1, 2, or 5 Galvanized Steel Storm Sewer Pipe • Treatment 1, 2, or 5 Galvanized Steel Storm Sewer Pipe with gasketed or welded and remetalized seams • Plain Aluminized Steel Spiral Rib Storm Sewer Pipe with gasketed or welded and remetalized seams • Treatment 1, 2, or 5 Aluminized Steel Storm Sewer Pipe **Steel Spiral Rib:** • Treatment 1, 2, or 5 Galvanized Steel Spiral Rib Storm Sewer Pipe • Treatment 1, 2, or 5 Galvanized Steel Spiral Rib Storm Sewer Pipe with gasketed or welded and remetalized seams • Plain Aluminized Steel Spiral Rib Storm Sewer with gasketed or welded or welded and remetalized seams • Treatment 1, 2, or 5 Aluminum Steel Spiral Rib Storm Sewer Pipe **Aluminum:** • Plain Aluminum Storm Sewer Pipe with gasketed seams • Treatment 1, 2, or 5 Aluminum Storm Sewer Pipe **Aluminum Spiral Rib:** • Plain Aluminum Spiral Rib Storm Sewer Pipe with gasketed seams • Treatment 1, 2, or 5 Aluminum Spiral Rib Storm Sewer Pipe

Corrosion Zone II

Acceptable pipe Alternates and Protective Treatments

Figure 8-4.2B

Culvert/Storm Sewer Pipe Alternative Selection Chart
Corrosion Zone III



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 in section 8-11 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.

Culverts	Storm Sewers
Schedule Pipe: Schedule _____Culvert Pipe_____In. Diam. If Schedule pipe not selected then: **Concrete:** • Plain Concrete Culvert Pipe • Cl___Reinf. Concrete Culvert Pipe **PVC:** • Solid Wall PVC Culvert Pipe • Profile Wall PVC Culvert Pipe **Polyethylene** • Corrugated Polyethylene Culvert Pipe **Aluminum:** • Plain Aluminum Culvert Pipe[1]	**Concrete:** • Plain Concrete Storm Sewer Pipe • Cl.___Reinf. Concrete Storm Sewer Pipe **PVC:** • Solid Wall PVC Storm Sewer Pipe • Profile Wall PVC Storm Sewer Pipe **Polyethylene:** • Corrugated Polyetheylene Storm Sewer Pipe **Aluminum:** • Plain Aluminum Storm Sewer Pipe with gasketed seams[1] **Aluminum Spiral Rib:** • Plain Aluminum Spiral Rib Storm Sewer Pipe with gasketed seams[1]

1. Can be used if the requirements of Section 8-2.2.6 are met

Corrosion Zone III

Acceptable Pipe Alternates and Protective Treatments

Figure 8-4.3B

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 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 a number of 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 serves as minimum guidelines for determining the appropriate number of tests for a project.

1. **Size and importance of the drainage structure -** A project comprised of large culverts or storm sewers under an interstate or other major arterial warrant testing at each culvert or storm sewer location, while a project comprised of small culverts under a secondary highway may only need a few tests for the entire length of 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 different soil types and geologic conditions, increasing the likelihood of variable pH readings. Tests should 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 should 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 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, 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 Region III pipe materials are the only acceptable alternates. Resistivity test 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 Methods for Controlling Corrosion

8-5.3.1 Protective Treatments

Metal pipe, depending on the material and the geographical location, may require a protective asphalt coating to insure corrosion resistance throughout the pipe design life. As a general guideline, research has shown that asphalt coatings can typically add 15 to 35 years of life to metal pipes. Listed below are three different protective asphalt treatments available for use. The material specifications for the protective asphalt treatments are described in Division 9-05.4(3), (4) and (6) of the *Standard Specifications*.

Treatment 1: Coated uniformly inside and out with asphalt. This treatment will protect the soil side of the pipe from corrosion but will only protect the waterside of the pipe from corrosion in environments that have little or no bed load moving through the pipe. Most culverts and storm sewers experience some degree of bed load, whether it is native upstream material or roadway sanding debris. The abrasive characteristics of the bed load can remove the asphalt coating relatively quickly, eliminating any corrosion resistance benefit. Consequently, this treatment is rarely specified.

As an alternative to Treatment 1 – 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.

Treatment 2: Coated uniformly inside and out with asphalt and with an asphalt paved invert. This treatment differs from Treatment 1 in that the invert of the pipe is paved with asphalt. Normal water levels within a pipe generally encompass about 40 percent of the circumference of the pipe, and this is where most of the corrosion takes place. The inside coating of the pipe above the normal watermark is not usually attacked by corrosion. Below the normal watermark, the protective coating suffers from wet and dry cycles and is also exposed to abrasion. For these reasons, the bottom 40 percent of the pipe is most critical and, therefore, paved with asphalt.

As an alternative to Treatment 2 – 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.

Treatment 3: No longer available.

Treatment 4: No longer available.

Treatment 5: Coated uniformly inside and out with asphalt and a 100 percent periphery inside spun asphalt lining. This treatment coats the entire inside circumference of the pipe with a thick layer of asphalt, covering the inside corrugations and creating a hydraulically smooth (see Manning's value in Appendix 4-1) interior. The coating also provides invert protection similar to Treatment 2. Treatment 5 can be used on ungasketed lock seam pipe to seal the seam and allow the pipe to pass a pressure test in storm sewer applications.

Treatment 6: No longer available.

The protective treatments, when required, shall be placed on circular pipe as well as pipe arch culverts. Structural plate pipes do not require protective treatment as described in Section 8-1.3.3. 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 designers discretion. When unusual abrasive or corrosive conditions are anticipated and it is difficult to determine which treatment would be adequate, it is recommended that either the HQ Materials Laboratory or HQ Hydraulics Office be consulted.

8-5.3.2 Increased Gauge 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. A methodology has been developed by California Transportation Department (Caltrans) to estimate the expected service life of untreated corrugated steel pipes. The method utilizes 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 Regional Hydraulics Section/Contact or from the HQ 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 designer in quantifying the abrasion potential of a site. The abrasion levels are identified in Figure 8-6. The descriptions of abrasion levels are intended to serve as general guidance only, and 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 designer is encouraged to use those guidelines in conjunction with the abrasion history of a site to achieve the desired design life of a pipe.

Sampling of the streambed materials is generally not necessary, but visual examination and documentation of the size of the materials in the stream bed and the average stream slopes will give the designer guidance on the expected level of abrasion. Where existing culverts are in place in the same drainage, the condition of the inverts should also be used as guidance. The stream velocity should be based on typical flows, such as a 6-month event, and not a 10- or 50-year event. This is because most of the abrasion will occur during those smaller events.

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 should be increased two or more standard sizes over the required hydraulic opening in situations where abrasion and bed load concerns have been identified.

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 (1m/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% to 2% • Velocities less than 6 ft/s (2 m/s)	For metal pipes, an additional gage thickness may be specified if existing pipes in the vicinity show a susceptibility to abrasion, or any of the protective treatments specified in Section 8-5.3.1 would be adequate.
Moderate Abrasive	• Moderate bed loads of sands and gravels, with stone sizes up to about 3 inches (75 mm) • Slopes 2% to 4% • Velocities from 6 to 15 ft/s (2 to 4.5m/s)	Metal pipes shall be specified with asphalt paved inverts and the pipe thickness shall be increased one or two standard gauges. The designer may want to consider a concrete-lined alternative. Concrete pipe and box culverts should be specified with an increased wall thickness or an increased concrete compressive strength. Thermoplastic pipe may be used without additional treatments.
Severe Abrasive	• Heavy bed loads of sands, gravel and rocks, with stones sizes up to 12 inch (300 mm) or larger • Slopes steeper than 4% • Velocities greater then 15 ft/s (4.5 m/s)	Asphalt protective treatments will have extremely short life expectancies, sometimes lasting only a few months to a few years. Metal pipe thickness should be increased at least two standard gages, or the pipe invert should be lined with concrete. Box culverts should 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 is not recommended in this condition.

Pipe Abrasion Levels

Figure 8.6

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 Specifications* should 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 from manufacturer to manufacturer, but are generally similar in performance to either the corrugated metal pipe joint or the concrete pipe joint described above. There are currently three types of joints available for thermoplastic pipe. They include:

- Integral 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.

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

Solid wall HDPE pipe is joined using either a mechanical fitting or more commonly the pipe is welded together using a fusion machine. Both types of joint create a water tight, positive connection that will pass the pressure test requirements for storm sewer applications.

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 (15-20% grade) or highly erosive slope. In these cases, the pipe diameter is relatively small, 10 inch (250 mm), continuous polyethylene tubing may be used without the need for anchors since there are no joints in the pipe. On larger pipes, HDPE pipe with fused joints may be used without the use of pipe anchors. For further design guidance contact HQ.

8-8.1 Thrust Blocks

Thrust blocks should be designed to help stabilize fitting (tees, valves, bends, etc.) from movement by increasing the soil bearing area. The key to sizing a thrust block is a correct determination of the soil bearing value. Values can range from less than 1000 lb/ft^2 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 action of the thrust. See standard plan B-90.50 (Concrete Thrust Block) for details on placement and sizing of a thrust block for various fittings.

8-9 Pipe Rehabilitation and Abandonment

Pipes that have deteriorated over time due to either corrosion or abrasion can significantly affect the structural integrity of the roadway embankment. Once identified, these pipes should be repaired in a timely manner, as failure of the pipe could ultimately result in failure of the roadway. The first two sections describe methods for repairing pipe and the third section provides guidance for pipe abandonment. Before selecting a Trenchless Technique or abandoning a pipe, the Regional Hydraulics Engineer or the HQ Hydraulics Office should be consulted for additional information.

8-9.1 Pipe Replacement

The most common pipe repair method is to remove and replace an existing culvert, which generally requires that all or part of the roadway be closed during construction. Before deciding to replace a pipe, several factors should be considered including the; roadway ADT, size of the pipe structure involved, depth of the fill, width of the workable roadway prism, and length of detour required during construction. Pipe replacement is best suited for projects with lower ADT, shallow cover, smaller pipes, and shorter detour routes.

8-9.2 Trenchless Techniques for Pipe Replacement

Trenchless techniques for pipe replacement have become increasingly popular on Interstate and other high ADT roadways. As the name implies these methods have the ability to retrofit or completely replace a pipe with minimal trenching, and therefore minimal affect to the roadway traffic. Project sites that favor trenchless technology for a pipe rehabilitation include sites with: higher ADT, deeper cover, larger pipes, and longer detour routes.

Prior to selecting a trenchless technology, the designer should investigate the feasibility of a pipe to be rehabilitated and provide a long term repair. The investigation should include: the condition of the pipe bedding and backfill, the hydraulic capacity of the pipe, and the structural integrity of the pipe. Each of these items is summarized below:

1. Evaluate cracks in the pipe to determine if water is leak through the pipe wall, eroding the bedding material. If erosion is presence, the voids may need to be grouted to provide proper support of the rehabilitated pipe.
2. The structural integrity of the host pipe should be evaluated to determine which trenchless technology is appropriate.
3. Finally, the hydraulic analysis for a rehabilitated pipe should be the same as required for a new pipe or culvert. . Any type of liner used to rehabilitate a pipe will reduce the diameter of the pipe, thus reducing capacity. However, due to the smoothness of the new liner, the improved efficiency of the pipe may compensate for the lost capacity.

A number of rehabilitation methods are available which can restore structural integrity to the pipe including: fold and form, slip lining, pipe bursting, tunneling, horizontal directional drilling, and pipe jacking. Each of these methods is further summarized below.

Various types of liners can retrofit the pipe interior and provide additional structural support. One of these techniques is called ‘fold and form’ and involves pulling a folded HDPE pipe through the existing (host) pipe, the liner pipe is then inflated with hot air or water so the liner molds itself to the host pipe, sealing cracks and creating a new pipe within a pipe. The same procedure can be followed using a felt material impregnated with resins.

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 typically much more expensive than the other methods, this may be the only feasible option for placing large diameter pipes under interstates or major arterials.

Horizontal Directional drilling (HDD) is a technique, which 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: drilling a pilot hole, pilot whole enlargement, and pullback installation of the carrier pipe.

Pipe jacking or ramming is probably the most widely known and most commonly used method. This method advances pipe through the ground with thrust from hydraulic jacks. 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 Treatments are not required on smooth-walled steel pipe used for jacking installations; however jacked pipes may require extra wall thickness to accommodate the expected jacking stresses.

8-9.3 Abandoned Pipe Guidelines

Whenever possible, abandoned pipes should be removed. However, if it is not practical to remove the pipe it may be abandoned in place with the inlet plugged following section 7-08.3(4) of the *Standard Specifications*. All pipes should be evaluated prior to abandonment by either the project PE, Region Hydraulic Engineer, or HQ Hydraulic Engineer to determine any potential hazards associated with a failure of the pipe. If a pipe failure could cause a collapse of the roadway prism, the pipe should either be removed or completely sealed with a Controlled Density Fill (CDF) that meets the section 2-09.3(1)E of the *Standard Specifications*.

8-10 Pipe Design

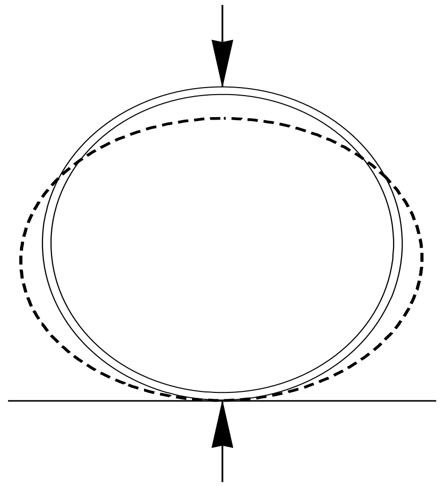
8-10.1 Categories of Structural Materials

Based upon material type, pipes can be divided into two broad structural categories: flexible and rigid. Alone, flexible pipes have little structural bending strength. The material, from which they are made, such as corrugated metal or thermoplastic, can be flexed or distorted significantly without cracking. Consequently, flexible pipes depend on support from the backfill to resist bending. Rigid pipes, however, are stiff and do not deflect appreciably. The material, from which they are made, 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 the 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 8-10.2. When good backfill material is 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. 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.

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.



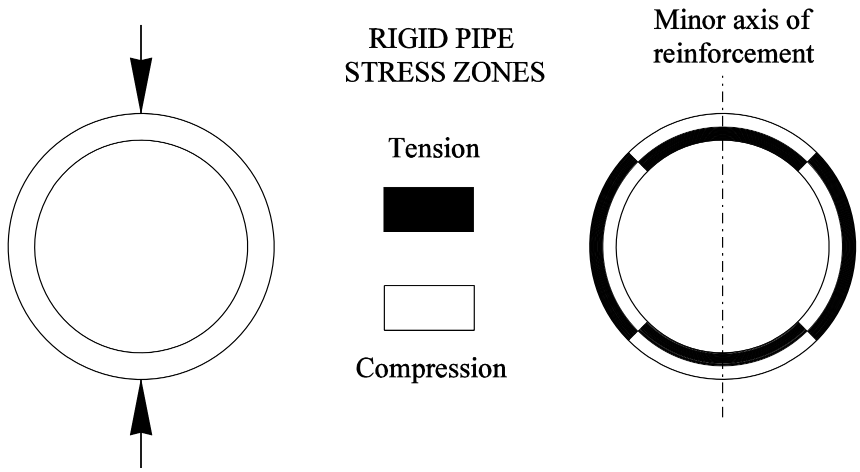
Deflection of Flexible Pipes

Figure 8-10.2

A flexible pipe will be stable as long as adequate soil support is achieved around the pipe. 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.

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 8-10.3. 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 8-2.1.



Zones of Tension and Compression in Rigid Pipes

Figure 8-10.3

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 and Division 7-08 of 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 8-11 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 insure adequate compaction of the backfill material. See Standard Plan B-55.20 for Pipe Zone

Bedding and Backfill and *Stand Specifications* Section 7-08.3(3) Backfilling for guidelines. Any trenching conditions not described in the *Standard Plans or Specifications* should receive prior approval from HQ Hydraulics. When using flexible pipes, the bedding should be shaped to provide support under the haunches of the pipe. When using rigid pipe, the bedding should be shaped to provide uniform support under the haunches and also shaped to provide clearance for the bell ends on bell and spigot type pipe. The importance of proper backfill for flexible and rigid pipe is discussed in Section 8-10.2 and 8-10.3 respectively. In addition to providing structural support for a pipe, the bedding and backfill must 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 Section 3-4.4 and dikes and plugs are discussed in Division 7-02.3(1) of the *Standard Specifications*.

In order 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 Structural Analysis and Fill Height Tables

The HQ 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. The fill height tables demonstrate the maximum and minimum amounts of cover that can be placed over a 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 designer shall specify the same wall thickness or class of material for the entire length of a given pipe, and that 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 designer should review all of the tables in Section 8-11.3 and select the most efficient corrugation thickness for the pipe diameter. For fill heights in excess of 100 feet (30 m), special designs by the HQ Hydraulics Office will be required.

8-11.1 Pipe Cover

Pipe systems should be designed to provide at least 2 feet (0.6 m) of cover over the pipe measured from the outside diameter of the pipe to the bottom of pavement. This measurement does not include any asphalt or concrete paving above the top course. This depth tends to provide adequate structural distribution of the live load and also allows a significant number of pipe alternatives to be specified on a contract. Unless the contract plans specify a specific pipe material, the designer should design for the schedule pipe fill heights as described in Division 7 of the *Standard Specifications*. If there is no possibility of a wheel load over the pipe, a designer may request using non-scheduled pipe with approval from the HQ Hydraulics Office. Approval will be contingent on no possibility that an errant vehicle could pass over pipe.

During construction, more restrictive fill heights are required, and are specified in Division 1-07.7 of the *Standard Specifications*. The restrictive fill heights are intended to protect pipe from construction loads that can exceed typical highway design loads.

8-11.2 Shallow Cover Installation

In some cases, it is not possible to lower a pipe profile to obtain the necessary minimum cover. In those cases, concrete pipe of the class shown in Fill Height Table 8-11.3 may be specified. Included in that table are typical pipe wall thicknesses for a given diameter. The pipe thickness must be taken into consideration in low cover applications. Justification must also be included in the hydraulic report describing why it was not possible to lower the pipe profile to obtain the preferred 2 feet (0.6 m) of cover.

In addition to circular pipe, concrete box culverts and concrete arches are also available for use in shallow cover installations. For concrete three sided or box culverts, designers need to verify that the shallow cover will still provide HS 25 loading. Other options include ductile iron pipe, plain steel pipe, or the placement of a concrete distribution slab. The designer should consult with either the Regional Hydraulics Section/Contract or the HQ Hydraulics Engineer for additional guidance on the use of these structures in this application.

8-11.3 Fill Height Tables

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	10	14	21	26
18	18	11	14	22	28
24	16	11	15	22	28
30		11	15	23	29
36		11	15	23	29
48		12	15	23	29
60		12	16	24	30
72		12	16	24	30
84		12	16	24	30

Minimum Cover: 2 feet

Concrete Pipe

Fill Height Table 8-11.1 (English)

Pipe Diameter mm	Maximum Cover in Meters				
	Plain AASHTO M 86M	**Class II AASHTO M 170M**	**Class III AASHTO M 170M**	**Class IV AASHTO M 170M**	**Class V AASHTO M 170M**
300	5.5	3.0	4.3	6.5	7.9
450	5.5	3.4	4.3	6.5	8.5
600	5.0	3.4	4.6	6.5	8.5
750		3.4	4.6	7.0	9.0
900		3.4	4.6	7.0	9.0
1200		3.7	4.6	7.0	9.0
1500		3.7	4.9	7.5	9.0
1800		3.7	4.9	7.5	9.0
2100		3.7	4.9	7.5	9.0

Minimum Cover: 0.6 meters

Concrete Pipe

Fill Height Table 8-11.1 (Metric)

Pipe Diameter in.	Pipe Wall Thick. 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	1.5	1.0	0.5
48	5		1.5	1.0	0.5
60	6		1.5	1.0	0.5
72	7		1.5	1.0	0.5
84	8		1.5	1.0	0.5

Concrete Pipe for Shallow Cover Installations

Fill Height Table 8-11.2 (English)

Pipe Diameter mm	Pipe Wall Thick. mm	Minimum Cover in Meters			
		Plain AASHTO M 86M	Class III AASHTO M 170M	Class IV AASHTO M 170M	Class V AASHTO M 170M
300	50	0.45	0.45	0.30	0.15
450	63	0.45	0.45	0.30	0.15
600	75	0.45	0.45	0.30	0.15
750	88	0.45	0.45	0.30	0.15
900	100	0.45	0.45	0.30	0.15
1200	125		0.45	0.30	0.15
1500	150		0.45	0.30	0.15
1800	175		0.45	0.30	0.15
2100	200		0.45	0.30	0.15

Concrete Pipe for Shallow Cover Installations

Fill Height Table 8-11.2 (Metric)

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
36*	65	81	100	100	100
42*	56	70	98	100	100
48*	49	61	86	100	100
54*		54	76	98	100
60*			68	88	100
66*				80	98
72*				73	90
78*					80
84*					69

* Designers should consider the most efficient corrugation for the pipe diameter.

Minimum Cover: 2 feet

Corrugated Steel Pipe 2⅔ in. × ½ in. Corrugations AASHTO M 36

Fill Height Table 8-11.3 (English)

Pipe Diameter mm	Maximum Cover in Meters				
	1.6 mm 16 ga	**2.0 mm 14 ga**	**2.8 mm 12 ga**	**3.5 mm 10 ga**	**4.2 mm 8 ga**
300	30.5	30.5	30.5	30.5	
450	30.5	30.5	30.5	30.5	
600	30	30.5	30.5	30.5	30.5
750	24	30	30.5	30.5	30.5
900	20	24.5	30.5	30.5	30.5
1050	17	21.5	30	30.5	30.5
1200	15	18.5	26	30.5	30.5
1350		16.5	23	30	30.5
1500			21	27	30.5
1650				24.5	30
1800				22.5	27.5
1950					24.5
2100					21

Minimum Cover: 0.6 meters

Corrugated Steel Pipe 68 mm × 13 mm Corrugations AASHTO M 36M

Fill Height Table 8-11.3 (Metric)

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
108			44	56	69
114			41	53	65
120			39	50	62

* Designers should consider the most efficient corrugation for the pipe diameter.

Minimum Cover: 2 feet

Corrugated Steel Pipe 3 in. × 1 in. Corrugations AASHTO M 36

Fill Height Table 8-11.4 (English)

Pipe Diameter mm	Maximum Cover in Meters				
	1.6 mm 16 ga	**2.0 mm 14 ga**	**2.8 mm 12 ga**	**3.5 mm 10 ga**	**4.3 mm 8 ga**
900	23	28.5	30.5	30.5	30.5
1050	19.5	24.5	30.5	30.5	30.5
1200	17	21.5	30	30.5	30.5
1350	15	19	27	30.5	30.5
1500	13.5	17	24	30.5	30.5
1650	12.5	15.5	22	28	30.5
1800	11.5	14.5	20	25.5	30.5
1950	10.5	13	18.5	24	29
2100	10	12	17	22	27
2250	9	11.5	16	20.5	25.5
2400		10.5	15	19	23.5
2550		10	14	18	22.5
2700			13.5	17	21
2850			12.5	16	20
3000			12	15	19

Minimum Cover: 0.6 meters

Corrugated Steel Pipe 75 mm × 25 mm Corrugations AASHTO M 36M

Fill Height Table 8-11.4 (Metric)

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

Minimum Cover: 2 feet

Corrugated Steel Pipe

5 in. × 1 in. Corrugations AASHTO M 36

Fill Height Table 8-11.5 (English)

Pipe Diameter mm	Maximum Cover in Meters				
	1.6 mm 16 ga	2.0 mm 14 ga	2.8 mm 12 ga	3.5 mm 10 ga	4.3 mm 8 ga
750	24.5	30.5	30.5	30.5	30.5
900	20.5	25.5	30.5	30.5	30.5
1050	17.5	21.5	30.5	30.5	30.5
1200	15	19	27	30.5	30.5
1350	13.5	17	24	30.5	30.5
1500	12	15	21.5	27.5	30.5
1650	11	13.5	19.5	25	30.5
1800	10	12.5	17.5	23	28
1950	9.5	11.5	16.5	21	26
2100	8.5	10.5	15	19.5	24
2250	8	10	14.5	18.5	22.5
2400		9.5	13.5	17	21

Minimum Cover: 0.6 meters

Corrugated Steel Pipe 125 mm × 25 mm Corrugations AASHTO M 36M

Fill Height Table 8-11.5 (Metric)

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
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

* 6 in. × 2 in. corrugations require field assembly for multi-plate, diameter is too large to ship in full section.

Corrugated Steel Structural Plate Circular Pipe 6 in. × 2 in. Corrugations

Fill Height Table 8-11.6 (English)

Pipe Diameter Mm	Minimum Cover m	Maximum Cover in Meters						
		2.8 mm 12 ga	3.5 mm 10 ga	4.5 mm 8 ga	4.8 mm 7 ga	5.5 mm 5 ga	6.5 mm 3 ga	7.0 mm 1 ga
1500	0.6	13	19	25.5	28	30.5	30.5	30.5
1800	0.6	10.5	16	21	24	28.5	30.5	30.5
2100	0.6	9	13.5	18	20.5	24.5	29	30.5
2400	0.6	8	12	16	18	21.5	22.5	28
2700	0.6	7	10.5	14	16	19.5	23	24.5
3000	0.6	6.5	9.5	13	14.5	17.8	20.5	22.5
3300	0.6	6	9	11.5	13	16	18.5	20
3600	0.6	5.5	8	11.5	12	14.5	17	18.5
3900	0.6	5	7	9.5	11	13	16	17
4200	0.6	4.5	6.5	9	10	12.5	14.5	16
4500	0.6	4.3	6	8.5	9.5	11.5	13.5	15
4800	0.6		6	8	9	10.5	13	14
5100	0.9		5.5	7	8.5	10	12	13
5400	0.9			7	8	9.5	11.5	12.5
5700	0.9				7.5	9	10.5	12
6000	0.9				7	9	10	11.5

Corrugated Steel Structural Plate Circular Pipe 152 mm × 51 mm Corrugations

Fill Height Table 8-11.6 (Metric)

Span × Rise in. × in.	Min. Corner Radius in.	Thickness		Minimum Cover Feet	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

NS = Not Suitable

***Corrugated Steel Pipe Arch* 2⅔ in. × ½ in. Corrugations AASHTO M 36**

Fill Height Table 8-11.7 (English)

Span × Rise mm × mm	Min. Corner Radius mm	Thickness		Min. Cover M	Maximum Cover in Meters for Soil Bearing Capacity of:	
		Mm	Gage		191 kPa	290 kPa
430 × 330	75	1.6	16 ga	0.6	3.7	5.5
530 × 380	75	1.6	16 ga	0.6	3	4.3
610 × 460	75	1.6	16 ga	0.6	2.1	4.0
710 × 510	75	1.6	16 ga	0.6	1.5	3.4
885 × 610	75	1.6	16 ga	0.8	NS	2.1
1060 × 740	88	1.6	16 ga	0.8	NS	2.1
1240 × 840	100	2.0	14 ga	0.8	NS	1.8
1440 × 970	125	2.8	12 ga	0.8	NS	2.4
1620 × 1100	150	2.8	12 ga	0.8	NS	2.7
1800 × 1200	175	3.5	10 ga	0.6	NS	3
1950 × 1320	200	4.3	8 ga	0.6	1.5	3
2100 × 1450	225	4.3	8 ga	0.6	1.5	3

NS = Not Suitable

Corrugated Steel Pipe Arch 68 mm × 13 mm Corrugations AASHTO M 36M

Fill Height Table 8-11.7 (Metric)

Span × Rise in. × in.	Corner Radius in.	Thickness		Min. Cover Feet	Maximum Cover in Ft 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

Corrugated Steel Pipe Arch 3 in. × 1 in. Corrugations AASHTO M36

Fill Height Table 8-11.8 (English)

Span × Rise mm × mm	Corner Radius mm	Thickness		Min. Cover Mm	Maximum Cover in m for Soil Bearing Capacity of:	
		mm	Gage		190 kPa	290 kPa
1010 × 790	125	2.0	14 ga	0.8	2.4	3.7
1160 × 920	150	2.0	14 ga	0.6	2.4	4
1340 × 1050	175	2.0	14 ga	0.6	2.4	4
1520 × 1170	200	2.0	14 ga	0.6	2.4	4
1670 × 1300	225	2.0	14 ga	0.6	2.7	4
1850 × 1400	300	2.0	14 ga	0.6	3.4	4.9
2050 ×1500	350	2.0	14 ga	0.6	3.4	5.2
2200× 1620	350	2.0	14 ga	0.6	3	4.9
2400 × 1720	400	2.0	14 ga	0.6	3.4	5.2
2600 × 1820	400	2.8	12 ga	0.6	3	4.5
2840 × 1920	450	2.8	12 ga	0.6	3	4.9
2970 × 2020	450	2.8	12 ga	0.6	3	4.5
3240 × 2120	450	3.5	10 ga	0.6	2.7	4.3
3470 × 2220	450	3.5	10 ga	0.6	2.4	4
3600 × 2320	450	4.3	8 ga	0.6	2.1	3.7

Corrugated Steel Pipe Arch 75 mm × 25 mm Corrugations AASHTO M-36M

Fill Height Table 8-11.8 (Metric)

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*
14 – 2 × 9 - 10	31	0.111	12 ga	2	12	2	16*
15 – 4 × 10 - 4	31	0.140	10 ga	2	11	2	15*
16 – 3 × 10 - 10	31	0.140	10 ga	2	11	2	14*
17 – 2 × 11 - 4	31	0.140	10 ga	2.5	10	2.5	13*
18 – 1 × 11 - 10	31	0.168	8 ga	2.5	10	2.5	12*
19 – 3 × 12 - 4	31	0.168	8 ga	2.5	9	2.5	13
19 – 11 × 12 - 10	31	0.188	6 ga	2.5	9	2.5	13
20 – 7 × 13 - 2	31	0.188	6 ga	3	7	3	13

* Fill limited by the seam strength of the bolts. TSF: tons per square foot

Additional sizes are available. Contact the OSC Hydraulics Office for more information.

Corrugated Steel Structural Plate Pipe Arch 6 in. × 2 in. Corrugations

Fill Height Table 8-11.9 (English)

Span × Rise Mm × mm	Corner Radius mm	Thickness		190 kPa Soil Bearing Capacity		290 kPa Soil Bearing Capacity	
		mm	Gage	Min. Cover m	Max. Cover m	Min. Cover m	Max. Cover m
1850 × 1400	457	2.8	12 ga	0.6	5	0.6	7
2130 × 550	457	2.8	12 ga	0.6	4.3	0.6	6.5
2410 × 1700	457	2.8	12 ga	0.6	4	0.6	6
2690 × 1850	457	2.8	12 ga	0.6	3.4	0.6	5
2970 × 2010	457	2.8	12 ga	0.6	3	0.6	4.5
3330 × 2160	457	2.8	12 ga	0.6	2.7	0.6	4.3
3610 × 2310	457	2.8	12 ga	0.6	2.1	0.6	4
3910 × 2540	457	2.8	12 ga	0.8	1.8	0.6	3.7
4040 × 2840	787	2.8	12 ga	0.6	4	0.6	5
4320 × 3000	787	2.8	12 ga	0.6	3.7	0.6	5
4670 × 3150	787	3.5	10 ga	0.6	3.4	0.6	4.5
4950 × 3300	787	3.5	10 ga	0.6	3.4	0.6	4.3
5230 × 3450	787	3.5	10 ga	0.8	3	0.8	4
5510 × 3610	787	4.5	8 ga	0.8	3	0.8	3.7
5870 × 3760	787	4.5	8 ga	0.8	2.7	0.8	4
6070 × 3910	787	4.8	6 ga	0.8	2.7	0.8	4
6270 × 4010	787	4.8	6 ga	0.9	2.1	0.9	4

* Fill limited by the seam strength of the bolts.

Additional sizes are available. Contact the OSC Hydraulics Office for more information.

Corrugated Steel Structural Plate Pipe Arch 152 mm × 51 mm Corrugations

Fill Height Table 8-11.9 (Metric)

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

Minimum Cover: 2 Feet

Aluminum Pipe 2⅔ in. × ½ in. Corrugations AASHTO M 196

Fill Height Table 8-11.10 (English)

Pipe Diameter mm	Maximum Cover in Meters				
	1.5 mm (16 ga)	**1.9 mm (14 ga)**	**2.7 mm (12 ga)**	**3.4 mm (10 ga)**	**4.2 mm (8 ga)**
300	30.5	30.5			
450	23	28.5	30.5		
600	17	21.5	30		
750		56	24		
900		14.5	20	26	
1050			17	22	
1200			15	19	24
1350			13	17	21
1500				15	19
1650					17
1800					13.5

Minimum Cover: 0.6 meters

Aluminum Pipe 68 mm × 13 mm Corrugations AASHTO M 196M

Fill Height Table 8-11.10 (Metric)

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

Minimum Cover: 2 Feet

Aluminum Pipe 3 in. × 1 in. Corrugations AASHTO M 196

Fill Height Table 8-11.11 (English)

Pipe Diameter mm	Maximum Cover in Meters				
	1.5 mm (16 ga)	**1.9 mm (14 ga)**	**2.7 mm (12 ga)**	**3.4 mm (10 ga)**	**4.2 mm (8 ga)**
900	13	20	23	30	
1050	11	14	20	25.5	
1200	9.5	12	17.5	22	27.5
1350	8.5	10.5	15	20	24.5
1500		9.5	13.5	17.5	22
1650		8.5	12.5	16	20
1800		8.0	11.5	14.5	18
1950		7.5	10.5	13.5	17
2100			9.5	12.5	15.5
2250			9.0	11.5	14.5
2400			8.0	11	13.5
2550				10	12.5
2700				9.5	12
2850					11.5
3000					10.5

Minimum Cover: 0.6 meters

Aluminum Pipe 75 mm × 25 mm Corrugations

Fill Height Table 8-11.11 (metric)

Pipe Dia. 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

Minimum Cover: 2 feet

Aluminum Structural Plate

9 in. × 2 in. Corrugations With Galvanized Steel Bolts

Fill Height Table 8-11.12 (English)

Pipe Dia. mm.	Maximum Cover in Meters						
	2.5 mm	**3.2 mm**	**3.8 mm**	**4.4 mm**	**5.1 mm**	**5.7 mm**	**6.4 mm**
1500	9.5	13.5	18.5	21.5	24.5	28	30.5
1800	7.5	11.5	15	17.5	20.5	23.5	26
2100	6.5	10	13	15	17.5	20	22.5
2400	6	8.5	11.5	13.5	15	17.5	19.5
2700	5	7.5	10	12	13.5	15.5	17.5
3000	4.5	6.5	9	10.5	12	14	15.5
3300	4.3	6	8	10	11.5	13	14.5
3600	3.7	5.5	7.5	9	10	11.5	13
3900		5	7	8	9.5	10.5	12
4200			6.5	7.5	9	10	11
4500				7	8	9	10.5

Minimum Cover: 0.6 meters

Aluminum Structural Plate

230 mm × 64 mm Corrugations With Galvanized Steel Bolts

Fill Height Table 8-11.12 (Metric)

Span × Rise in. × in .	Corner Radius In.	Thickness		Min. Cover Feet	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

NS = Not Suitable

Aluminum Pipe Arch

2⅔ × ½ Corrugations

Fill Height Table 8-11.13 (English)

Span × Rise mm × mm	Corner Radius mm	Thickness		Min. Cover m	Maximum Cover in Meters for Soil Bearing Capacity of:	
		mm	Gage		190 kPa	290 kPa
430 × 330	75	1.5	16 ga	0.6	3.7	5.5
530 × 380	75	1.5	16 ga	0.6	3	4.3
610 × 460	75	1.5	16 ga	0.6	2.1	4
710 × 510	75	1.9	14 ga	0.6	1.5	3.4
885 × 610	75	1.9	14 ga	0.8	NS	2.1
1060 × 740	89	2.7	12 ga	0.8	NS	2.1
1240 × 840	102	2.7	12 ga	0.8	NS	1.8
1440 × 970	127	3.4	10 ga	0.8	NS	2.4
1620 × 1100	152	3.4	10 ga	0.8	NS	2.7
1800 × 1200	178	4.2	8 ga	0.6	NS	3.0

NS = Not Suitable

Aluminum Pipe Arch

68 mm × 13 mm Corrugations AASHTO M 196M

Fill Height Table 8-11.13 (Metric)

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

*Fill limited by the seam strength of the bolts.

(1) Additional sizes and varying cover heights are available, depending on gage thickness and reinforcement spacing. Contact the OSC Hydraulics Office for more information.

Aluminum Structural Plate Pipe

Arch 9 in. × 2⅔ in. Corrugations,

¼ in. Steel Bolts, 4 Bolts/Corrugation

Fill Height Table 8-11.15 (English)

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

Minimum Cover: 2 feet

Steel and Aluminized Steel Spiral Rib Pipe

¾ × 1 × 11½ in. or ¾ × ¾ × 7½ in.

Corrugations AASHTO M 36

Fill Height Table 8-11.16 (English)

Diameter mm	Maximum Cover in Meters		
	1.6 mm 16 ga	**2.0 mm 14 ga**	**2.8 mm 12 ga**
450	15	22	
600	15	22	30.5
750	12.5	17.5	29.5
900	10.5	14.5	24.5
1050	9	12.5	21
1200	8	11	18.5
1350	7	10	16.5
1500	6	9	15

Minimum Cover: 0.6 meters

Steel and Aluminized Steel Spiral Rib Pipe

19 × 25 × 292 mm r 19 × 19 × 191 mm

Corrugations AASHTO M 36M

Fill Height Table 8-11.16 (Metric)

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

Minimum Cover: 2 feet

Aluminum Alloy Spiral Rib Pipe

¾ × 1 × 11½ in. or ¾ × ¾ × 7½ in.

Corrugations AASHTO M 196

Fill Height Table 8-11.17 (English)

Diameter mm	Maximum Cover in Meters			
	1.5 mm 16 ga	1.9 mm 14 ga	2.7 mm 12 ga	3.4 mm 10 ga
300	11	15		
450	10.5	14.5		
600	7.5	11	19	25
750	6	8.5	15	20
900	4.5	7.5	12.5	16.5
1050		6	10.5	14
1200		5	9	12
1350		4.3	8	10.5
1500		3.7	7.5	9

Minimum Cover: 0.6 meters

Aluminum Alloy Spiral Rib Pipe

19 × 25 × 292 mm or 19 × 19 × 190 mm Corrugations

AASHTO M 196M

Fill Height Table 8-11.17 (Metric)

	Span × Rise mm × mm	Corner Radius mm	Minimum Gage Thickness mm	Min. Cover m	Maximum Cover (1) in Feet for Soil Bearing Capacity of:	
					190 kPa	290 kPa
a	1800 × 1650	808	2.5	0.6	7*	7*
b	2100 × 1750	808	2.5	0.6	6.5*	6.5*
c	2210 × 1800	808	2.5	0.6	6*	6*
d	2360 × 1830	808	2.5	0.6	5.5*	5.5*
e	2570 × 1910	808	2.5	0.6	5*	5*
f	2820 × 1960	808	2.5	0.6	4.5*	4.5*
g	3120 × 2060	808	2.5	0.6	4.3*	4.3*
h	3280 × 2080	808	2.5	0.6	4*	4*
i	3480 × 2160	808	2.5	0.6	3.7*	3.7*
j	3840 × 2260	808	3.2	0.6	4.3	5*
k	3940 × 2290	808	3.8	0.6	4	4.3*
l	3990 × 2490	808	3.8	0.6	4	5.5*
m	4240 × 2570	808	3.8	0.6	3.7	5*
n	4470 × 2950	808	4.4	0.6	3.7	5.5
o	4670 × 3050	808	4.4	0.6	3.4	5
p	4900 × 3150	808	5.1	0.6	3	5
q	5110 × 3250	808	5.1	0.67	3	4.5
r	5260 × 3350	808	5.7	0.69	3	4.5
s	5490 × 3450	808	6.4	0.69	2.7	4.3
t	5690 × 3560	808	6.4	0.71	2.7	4.3

*Fill limited by the seam strength of the bolts.

(1) Additional sizes and varying cover heights are available, depending on gage thickness and reinforcement spacing. Contact the OSC Hydraulics Office for more information.

Aluminum Structural Plate Pipe

Arch 230 mm × 64 mm Corrugations,

19 mm Steel Bolts, 4 Bolts/Corrugation

Fill Height Table 8-11.15 (Metric)

Span × Rise in. × in.	Corner Radius in.	Thickness		Min. Cover Feet	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

Aluminum Pipe Arch 3 × 1

Corrugations AASHTO M 196

Fill Height Table 8-11.14 (English)

Span × Rise mm × mm	Corner Radius mm	Thickness		Min. Cover m	Maximum Cover in Feet for Soil Bearing Capacity of:	
		mm	Gage		190 kPa	290 kPa
1010 × 790	127	1.9	14 ga	0.8	2.4	3.7
1160 × 920	152	1.9	14 ga	0.6	2.4	4
1340 × 1050	178	1.9	14 ga	0.6	2.4	4
1520 × 1170	203	1.9	14 ga	0.6	2.4	4
1670 × 1300	229	1.9	14 ga	0.6	2.7	4
1850 × 1400	305	1.9	14 ga	0.6	3.4	5
2050 × 1500	356	1.7	12 ga	0.6	3.4	5
2200 × 1620	356	2.7	12 ga	0.6	3	5
2400 × 1720	406	2.7	12 ga	0.6	3.4	5
2600 × 1820	406	3.4	10 ga	0.6	3	4.5
2840 × 1920	457	4.2	8 ga	0.6	3	5

Aluminum Pipe Arch 75 mm × 25 mm

Corrugations AASHTO M 196M

Fill Height Table 8-11.14 (Metric)

Solid Wall PVC	Profile Wall PVC	Corrugated Polyethylene
ASTM D 3034 SDR 35 3 in. to 15 in. dia. ASTM F 679 Type 1 18 in. to 48 in. dia.	AASHTO M 304 or ASTM F 794 Series 46 4 in. to 48 in. dia.	AASHTO M 294 Type S 12 in. to 60 in. dia.
25 feet All diameters	25 feet All diameters	25 feet All diameters

Minimum Cover: 2 feet

Thermoplastic Pipe (English)

Fill Height Table 8-11.18

Solid Wall PVC	Profile Wall PVC	Corrugated Polyethylene
ASTM D 3034 SDR 35 75 mm to 375 mm dia. ASTM F 679 Type 1 450 mm to 1200 mm dia.	AASHTO M 304 or ASTM F 794 Series 46 100 mm to 1200 mm dia.	AASHTO M 294 Type S 300 mm to 1500 mm dia.
8 meters All diameters	8 meters All diameters	4 meters All diameters

Minimum Cover: 0.6 meters

Thermoplastic Pipe (Metric)

Fill Height Table 8-11.18