Table 7-2 100-Year Design Freeboard Requirements on Buried Structures

Structure Bankfull Width	Required Freeboard
Less than 8-foot BFW	1 foot above 100-year flow event
8- to 15-foot BFW	2 feet above 100-year flow event
Greater than 15-foot BFW	3 feet above 100-year flow event (bridge)

In areas that are tidally influenced, the impacts of 2 feet of sea level rise shall be considered for the project. For all projects, the stream designer shall consider providing the clearances in Table 7-2 above the 100-year projected 2080 water surface elevation.

The required minimum 100-year design freeboard shall be maintained across the entire minimum hydraulic opening, as shown in the SFZ figures in the Standard Plans (WSDOT 2021d). If aggradation is expected to occur, additional freeboard shall be given above the 100-year design freeboard equal to the anticipated aggradation.

If the 100-year design freeboard requirements listed above cannot be met, a deviation will be required in the specialty report and approval from the HQ Hydraulics Section is required. At a minimum, the stream designer shall demonstrate the following:

- The proposed freeboard will pass all expected debris, water, and sediment
- There is no history of repetitive maintenance at the crossing location
- Providing the required freeboard would cause adverse environmental impacts, roadway geometric impacts, or other unacceptable impacts
- Efforts have been made to maximize the freeboard to the extent practicable

Approval from the HQ Hydraulics Section does not guarantee that permitting agencies will approve the proposed 100-year design freeboard.

7-4.5.2 Maintenance Clearance

Maintenance clearance is the vertical dimension added to the height to allow for monitoring, maintenance, or wildlife. The HQ Hydraulics Section determines the maintenance clearance required if there is a height required to maintain habitat elements. If no habitat elements need to be maintained, the PEO determines the maintenance clearance required. The initial maintenance clearance target is 6 feet; however, if it is expected that machinery will need to access and operate under the structure, 10 feet may be necessary. More guidance on maintenance clearance can be found as design instructions on the WSDOT Design website and Chapter 720 of the WSDOT *Design Manual* (WSDOT 2020).

7-4.6 *Buried Structures*

Buried structures for WSDOT projects can follow either the bridge design or stream simulation design criteria. When a buried structure is used as the crossing structure, wing walls shall be used to minimize the overall length of the buried structure. Wing walls can also increase the efficiency of the crossing structure. Wing walls shall be a minimum of 10 feet in length and shall be increased based on the potential impacts of lateral migration as assessed by the hydraulics engineer of record. If a buried structure is used, a few additional criteria apply.

If a structure length is more than 10 times its width, then a meander amplitude assessment shall be conducted per Section 7-4.4.4. A meander amplitude assessment may also be warranted in crossings that are greater than 200 feet in length, multiple crossings in a short length (interchange, divided highway, etc.), or in other situations as described in Section 7-4.4.4.

The WCDG and WAC require that all stream simulation culverts be countersunk a minimum of 30 percent and a maximum of 50 percent, but not less than 2 feet overall. Alternative depths of culvert fill may be acceptable with engineering justification that considers channel degradation, aggradation, and total scour. Scour analyses are considered acceptable engineering justification.

Four-sided buried structures shall be countersunk a minimum of 2 feet below total scour at the design flood, regardless of span width. If this requirement cannot be met, approval from the HQ Hydraulics Section is required. It is understood that four-sided structures are created in whole-foot increments because of construction practices, so if the countersink is slightly below 2 feet, contact the HQ Hydraulics Section to verify if additional depth is required.

The footings of three-sided buried structures shall be countersunk as described in the WSDOT *Bridge Design Manual*.

In some cases, constructibility is easier if the structure is placed flat or the stream designer may recommend that the structure be placed at a different slope from that of the streambed. Buried structures may be placed at a different slope from the prevailing stream gradient so long as the minimum freeboard is met throughout the structure, the minimum required countersink is met throughout the structure, and justification is provided and approved by the HQ Hydraulics Section. In some cases, this may require a slightly taller structure. The reasoning for placing the culvert at a different slope shall be described in the specialty report.

7-4.7 *Sediment*

WAC dictates allowable sediment sizes in a fish-bearing stream. Stream simulation design aims to mimic natural conditions to the extent possible, but sometimes stream conditions have been altered, reaches have been sediment starved, or adjacent infrastructure (constraints) do not allow for bed mobility into adjacent reaches.

Apply the stream simulation requirement of a D_{50} that is within 20 percent of the reference reach unless constraints prevent this. A Streambed Material Decision Tree to further assist stream designers in determining which methodology to use for streambed sediment sizing in these special cases is shown in Appendix 7A.

For sediment sizing, WSDOT uses the Modified Critical Shear Stress Approach, as described in Appendix E from the 2008 United States Forest Service (USFS) Guidelines for all systems under 4 percent and the Unit-Discharge Bed Design as described by the 2013 WCDG for systems greater than 4 percent. A system is considered stable if the D_{84} is stable at the design flow event.

7-4.7.1 No Constraints

As previously described, apply the stream simulation requirement of a D_{50} that is within 20 percent of the reference reach unless prevented by constraints. Most systems fall into this scenario. The design process for sediment sizing under these conditions is to match the reference reach material to the extent possible using the materials available from WSDOT's Standard Specifications (WSDOT 2021c).

Stability of the bed mix shall still be evaluated and documented in the specialty report.

7-4.7.2 Constraints

If constraints in the systems, as described in Section 7-4.1, could have an impact on the stream design, the risk of the stream not being stable will need to be evaluated.

In some cases, a bed design based on the pebble count from the existing reference reach will meet the requirements for stability. The existing pebble count will first need to be evaluated for stability, using the appropriate methodology from Section 7-4.7. If the D_{84} is not stable at the design flood, then a risk assessment will need to be conducted to determine the next steps. The HQ Hydraulics Section and RHE shall be a part of the risk assessment process.

7-4.7.2.1 Risk Assessment

To complete a risk assessment for the site, the constraints must be identified and what the potential impact to those constraints would be if natural processes were to occur. If the constraints are private or public infrastructure not owned by WSDOT, the owners of the infrastructure should be consulted. The Streambed Material Decision Tree in Appendix 7A can be helpful in determining the level of risk; however, the ultimate decision on constraints and risks to constraints is made by the project team.

If it is determined that the project is high risk and cannot be allowed to regrade, a roughened channel must be constructed. A roughened channel is designed to be completely non-deformable up to the design discharge. If a roughened channel is built, any habitat features must be installed at the time of construction, as they are unlikely to form themselves. A roughened channel will likely have additional permit requirements (and possibly long-term commitments) associated with it.

If a project is considered medium risk, an alternatives analysis needs to be conducted. The stream designer needs to describe the constraint, describe the impact of meeting the requirements for sediment size, identify and evaluate any alternatives, and describe the preferred alternative. When describing the preferred alternative, the stream designer must also describe how the preferred alternative reduces the risk to an acceptable level and what potential impact to fish life this alternative may have. In cases where coarser sediment is necessary on a medium-risk project, an overcoarsened channel with habitat complexity features may be constructed. This channel is subject to agreements between WSDOT and permitting agencies. An overcoarsened channel has a $D_{84,}$ which is stable at the Design Flood.

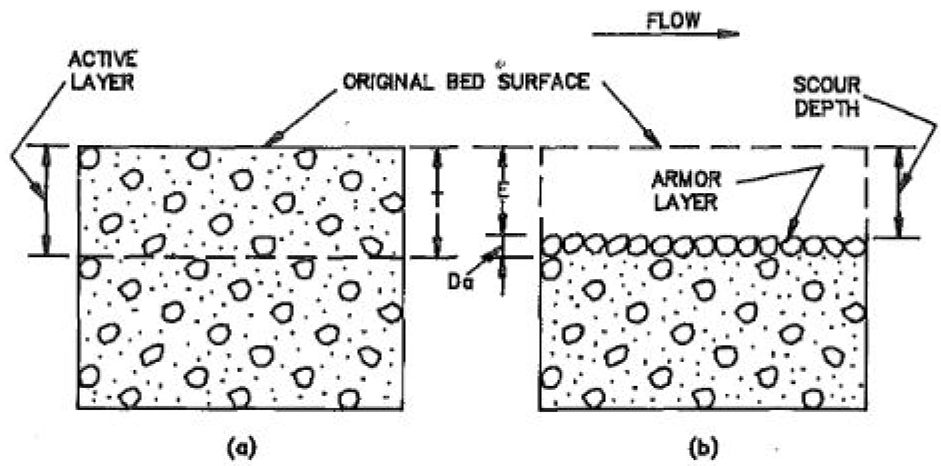
If a project is determined to be low risk, then the bed material should match the pebble count in the reference reach and the process described in Section 7-4.7.1 applies.

7-4.7.3 Natural Streambed Armor Layer Design

Streambed material that is designed and placed in a WSDOT channel follows a well-graded specification that results in a highly homogeneous mixture of streambed sediment and streambed cobbles lining the newly constructed and/or restored channel. This homogenous mix attempts to mimic the site-specific gradation of stream particles (sediment), normally prescribed via pebble count data, but also contains a large volume of fine-grained and highly mobile material with a desired outcome of bed sealing and relative bed stability. Streambed sediment can have as much as 16 percent by weight passing the No. 40 sieve, which is medium sand. In a gravel bed stream much of this finer material may be transported away from the active sediment layer during bed-forming discharges. This will be variable depending on sediment transported from upstream reaches. The bed will ultimately end at a state of dynamic equilibrium—a natural bed armor layer. The natural armor layer protects the integrity of the bed, adds stability, and renders the finer particles below it relatively immobile. However, a large volume of fine, highly mobile sediment must be "worked" by the stream to achieve this more stable state. The result is material transported downstream and likely lost within the reach. Figure 7-5 depicts formation of an armor layer.

Figure 7-5 Formation of an Armor Layer

(a) Well-Mixed Original Bed Material (b) Armor Layer with Underlying Bed Material



Source: Borah 1989.

To prevent this loss, an active layer that matches the reference reach pebble count, but with no fines below a calculated surface layer particle size, could be designed. If the stream designer is in a system in which this may be appropriate and wants to pursue this design, approval from the HQ Hydraulics Section is required.

7-4.7.3.1 Construction Requirements

The final streambed material shall be placed in lifts no thicker than 12 inches. Placement of streambed material shall be constructed to ensure that stream low flow rate is conveyed above each channel layer. The contractor shall apply water and 0.5 to 1.0 inch of streambed sand to each layer to facilitate filling the interstitial voids of the streambed materials. The voids are satisfactorily filled when water equivalent to the low flow rate of the stream does not go subsurface and there is no perceivable difference in the low flow rate from upstream of the project limits to the downstream of the project limits.

7-4.7.4 Step-Pool Design

Step-pool systems occur naturally, between 3 and 8 percent slopes, and occur through natural material sorting or are forced through LWM. Many Washington streams are above this gradient and special consideration is required for their design.

If the system's reference reach is step-pool in nature or the stream designer has other reason to believe that a step-pool system is most appropriate for the site, the stream designer shall contact the HQ Hydraulics Section for any additional guidance that has been developed. The design of a step-pool system may require stability features that are larger than typical habitat structures or sediment size, channel-spanning wood, higher than normally recommended drop heights, etc. Closely working with the HQ Hydraulics Section will also help expedite any deviations from this *Hydraulics Manual* that are necessary to ensure a successful step-pool design.

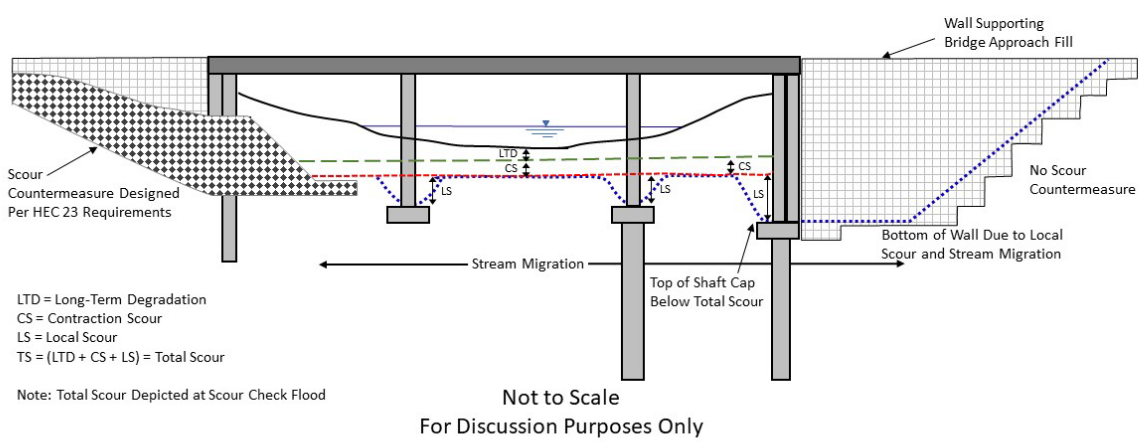
7-4.8 *Total Scour*

All structures shall be designed for total scour, as defined by HEC-18, regardless of structure span. Figure 7-6 illustrates the various total scour components—specifically, long-term degradation, contraction scour, and local scour for a water crossing that has likelihood of channel migration over the life of the structure. If no channel migration were expected to occur over the life of the structure, long-term degradation and contraction scour would be a uniform offset from the existing channel section. Methodology used for determining total scour shall follow the methods described in HEC-18. All four-sided buried structures shall be countersunk a minimum of 2 feet below the total scour depth at the scour design flood and shall be countersunk deep enough for the bottom to not become exposed during the scour check flood. Foundation depth for three-sided buried structures/traditional bridge structures with abutments and piers shall be determined by the bridge and geotechnical office.

7-4.9 *Channel Migration for Structural Design*

All structures shall be designed to account for the channel migration expected over the life of the structure. If there is an opportunity for channel migration to occur over the design life of the structure, the stream designer shall document in the specialty report the risk of channel migration at each pier and/or abutment and whether any scour countermeasures or increase in structure size are recommended. See HEC-20 and Sections 7-2.5.4 and 7-4.4.4 for additional guidance on assessing channel migration and maintaining continuity of channel processes, respectively. Figure 7-6 provides an example for a water crossing with deep foundations, channel migration, and abutments. On the left side of Figure 7-6 a scour countermeasure designed meeting HEC-23 Volume 1 and Volume 2 requirements, specifically the use of an apron below long-term degradation and contraction scour at the scour check flood, is used to mitigate abutment scour. On the right side of Figure 7-6, no scour countermeasure was used, resulting in a greater depth of scour because of the requirement to account for abutment scour at the foundation. See HEC-23 Volume 1 and Volume 2 and the FHWA *TechBrief Hydraulic Considerations for Shallow Abutment Foundations* for additional guidance for the proper design of scour countermeasures.

Figure 7-6 Total Scour Components with Channel Migration and Abutments



7-4.10 *Channel Complexity*

Chapter 10 covers the requirements for channel complexity when LWM is used.

Channel complexities are obstructions within the stream channel that manipulate the flow to promote channel shape and stability and diversify flow velocities, which contributes to sediment sorting and supports diverse habitat for fish. Channel complexities are used to mimic natural characteristics in a stream. They are more important through water-crossing structures where vegetation and bank stability are absent or reduced. Mimicking bank strength and structure inside of a structure is difficult without soil cohesion and root strength, which is found outside of structures. Instability of the material being placed can create a situation where the channel shape deteriorates over time. Aggradation inside of the structure can also cause the channel to lose its shape over time. It is critical to consider the longevity of the channel complexity design: how it may change over time, its sustainability, and fish passability throughout the life of the crossing.

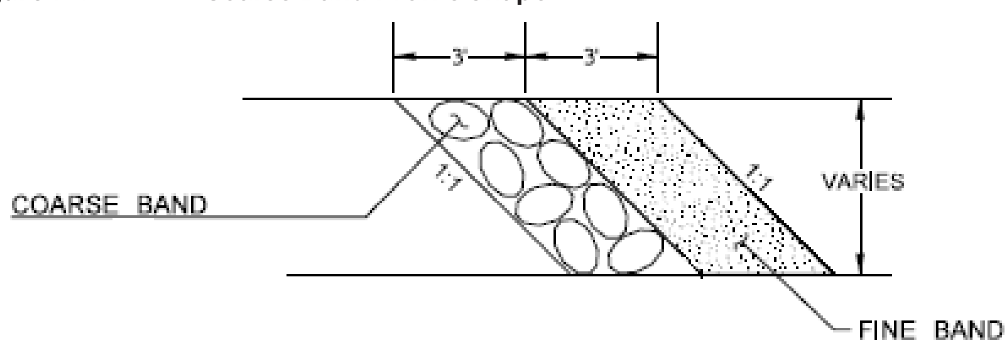
Channel complexities can be made up of coarser aggregate (cobbles and boulders) that is sized to be stable at the design flow events. Woody material can be used in conjunction with coarse aggregate but should not be used by itself inside of a crossing structure as its life span will not exceed the life of the crossing. Subsurface flow through channel complexities has been a concern in recent projects as voids in the coarser mixes allow low flows to penetrate below the stream profile. Streambed fine sediment bands have been installed upstream of complexity features that can help seal the streambed mix. In addition, layering and watering in streambed fine sediment in layers has also shown to help seal the complexity features.

WSDOT has used channel complexity features such as coarse bands, bars, barbs, and clusters. Additional guidance will be provided in future revisions to the *Hydraulics Manual*.

7-4.10.1 Coarse Bands

Coarse bands are bands of material that are coarser than the overall bed design material. They are meant to keep the stream centered in the culvert, should be partially deformable, and are not intended to be used for grade control. As a result of project monitoring and repair, it was determined that the use of a streambed fine sediment band of material upstream of a coarse band can help seal the streambed mix. Coarse bands shall be constructed to ensure that stream low-flow rate is conveyed above each channel layer. Streambed fine sediment shall consist of a natural material unless otherwise approved by HQ Hydraulics Section. The typical profile shape used for coarse and fine bands can be seen in Figure 7-7. More information on coarse bands, including spacing, can be found in the 2013 WCDG.

Figure 7-7 Coarse Band Profile Shape



Coarse bands can be used within all structures that are four-sided and that have a stream slope of 2 percent or less. Coarse bands shall not be used within structures that have a stream slope greater than 4 percent. Coarse bands are sized for the D_{84} to be stable at the 100-year flow event and shall not have material that is larger than twice the D_{100} of the design bed mix.

7-4.10.2 Bars, Barbs, and Clusters

It may be necessary to have bars, barbs, or clusters of coarser material beneath/inside of structures to support channel complexity. In these cases, the stream designer must use engineering judgment to determine what this will look like and how it will tie into the upstream and downstream planform.

If used in the system, bars should be sized and spaced to mimic the expected sinuosity and consist of well-graded streambed cobbles.

If used in the system, clusters and barbs should be sized large enough to remain stable, be placed in a way that they promote localized scour/pool development, do not create a low-flow barrier risk, and engage in the active channel. In addition to being stable during flow events, consideration should be given for the stream's location and whether vandalism could be an issue. If the location is in an area where there may be human activity, larger, heavier boulders may help keep the structures in place.

It may be necessary to install barbs to direct flows where site constraints exist. Barbs are considered a channel complexity feature but with a hydraulic intention to direct flows away from a bank or structure where bank stability is critical.

7-4.10.3 Construction Requirements

A channel takes a few large flows to have habitat elements form. In cases where a fish barrier is replaced, if these habitat elements are not formed during construction, the first migration of fish may be left with a long, straight channel that makes passage difficult. Leaving scour pools at the LWM and other complexity elements at locations where a pool would naturally form is recommended. A low-flow pilot channel is also required to be installed that connects the habitat complexity elements immediately after construction, unless otherwise approved by HQ Hydraulics Section.

7-4.11 *Scour Countermeasures*

Scour countermeasures are not always avoidable, whether it is to protect the structure itself or to protect other elements of the roadway adjacent to a water body. When a scour countermeasure is necessary, the specialty report shall document the risk to the infrastructure asset and rationale for the protection, any current evidence of erosion, and the countermeasure design standard. HEC-23 Volume 1 and Volume 2, and Chapter 10 provide additional guidance on the implementation of scour countermeasures. The ISPG can be used for bank stabilization protection and in combination with HEC-23 Volume 1 and Volume 2 but cannot be considered a scour countermeasure alone for structural protection.

For new structures, scour countermeasures shall not encroach within the minimum hydraulic opening. The design of scour countermeasures first relies on an understanding and agreement of the element they intend to protect and the required design standard for the asset. Elements of a water crossing that may need a scour countermeasure include but are not limited to the bridge substructure, walls, and the roadway embankment. Each of these elements can have varying levels of acceptable risk and thus different design standards. Figure 7-8 and Figure 7-9 provide conceptual sketches for where a scour countermeasure can be placed in relation to the minimum hydraulic opening and depth of scour for a water crossing in a fish-bearing stream with and without abutment scour, respectively. In these examples, the bridge is founded on deep foundations, which are designed to meet HEC-18 requirements and do not rely on the integrity of the scour countermeasure. Also depicted in Figure 7-8 is a very important but often overlooked scour countermeasure feature for water crossings with abutment scour, the apron. Guidance for design of the apron can be found in HEC 23, Volume 1 and Volume 2 and the FHWA *TechBrief Hydraulic Considerations for Shallow Abutment Foundations*. The example figures also contain curtain walls, which assist to retain the roadway embankment fill and were decided by the PEO, for this specific crossing, to rely on the integrity of the scour countermeasure for their design. Because of the site-specific nature of water crossings, the HQ Hydraulics Section shall be contacted to assist in coordinating with the appropriate subject matter experts to determine the design standards for the scour countermeasure and the level of protection they can assume to provide for a given asset.

Figure 7-8 Scour Countermeasure Design for Water Crossing Structures with Deep Foundation and Calculated Abutment Scour

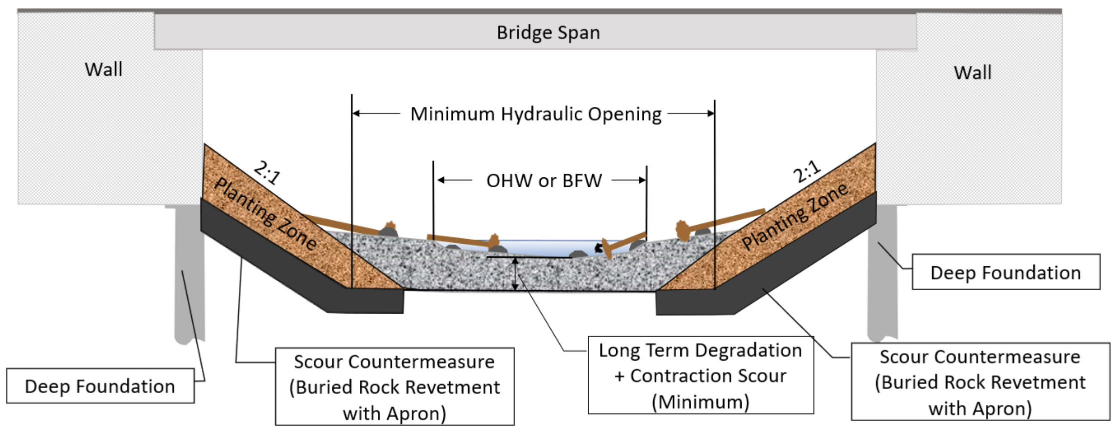
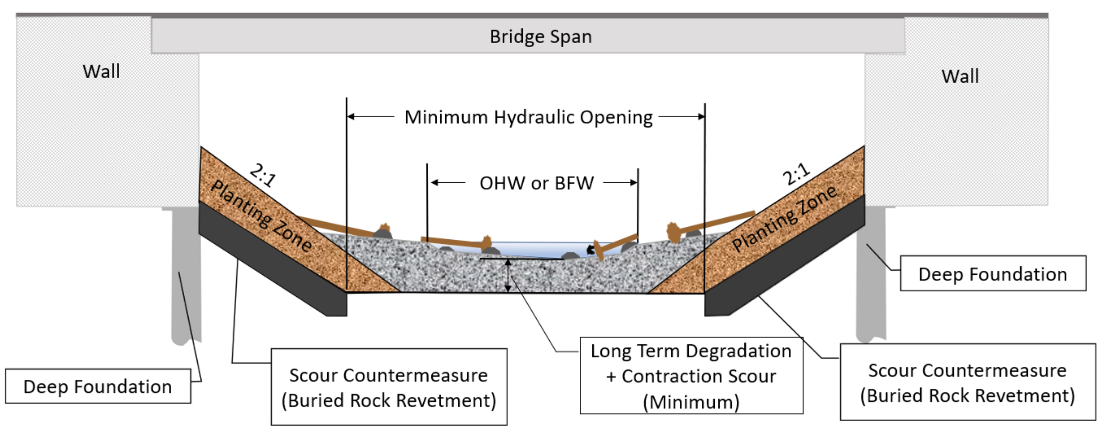


Figure 7-9 Scour Countermeasure Design for Water Crossing Structures with Deep Foundation and No Calculated Abutment Scour



7-4.12 *Landscaping/Planting*

The landscape architect will follow guidance for planting near streams located in WSDOT's *Roadside Manual* Chapter 830 for all projects located near streams. It is also beneficial for the stream designer to review this chapter. The stream designer shall collaborate with the landscape architect and provide input on the need for bank stabilization countermeasures, habitat complexity, riparian restoration, and any planting that needs to be done prior to the first storm event of the year. The planting windows for WSDOT projects that do not install irrigation are October 1 to March 1 west of the Cascade Crest and October 1 to November 15 east of the Cascade Crest, per the WSDOT Standard Specifications (WSDOT 2021c). If planting needs to occur before the end of these windows for stability reasons, the contract will need to be updated to reflect the timeline.

7-4.13 *Determining Crossing Design Methodology for Documentation*

The three most used design methodologies by WSDOT from WDFW's 2013 WCDG are the Unconfined Bridge, Confined Bridge, and Stream Simulation methodologies. For all unconfined systems, the design methodology shall be described as Unconfined Bridge. For all confined systems over 20 feet, those expecting 1 foot or more of channel regrade, or slopes that are outside of the slope ratio, the methodology shall be described as Confined Bridge unless otherwise approved by the HQ Hydraulics Section. For all structures under 20 feet that do not fall into the categories described for Unconfined Bridge or Confined Bridge, the design methodology shall be Stream Simulation unless otherwise approved. If a different methodology was approved by the HQ Hydraulics Section, the design process shall be documented as the process that was approved. See Section 7-5 for some other available methods.

7-5 Other Design Methods

It is recognized that not all stream crossings will be able to meet stream simulation or either bridge design methodologies. As described in Section 7-4, other available design methodologies can be accepted on a case-by-case basis with the approval of the HQ Hydraulics Section. This section briefly describes some of the other methodologies available.

Some of these design methodologies may need to include project objectives with performance measures, inspection schedules, maintenance triggers, and a contingency plan should the project fail to meet performance measures with permitting applications.

7-5.1 *No-Slope Design*

No-slope design recommendations can be found in the 2013 WCDG and WAC. The no-slope designs are performed on BFWs of less than 10 feet, low gradients (less than 3 percent), and short culvert lengths (less than 75 feet). This design methodology is not preferred because it has a higher risk of becoming a barrier in the future, does not give the stream much room for natural processes, and has a lower capacity than stream simulation culverts and bridges.

7-5.2 *Fish Passage Improvement Structures*

Fish passage improvement structures are any structures that facilitate the passage of fish either through or around the fish barrier that do not necessarily mimic natural channel processes. Structures such as roughened channels, roughened rock ramps, structure retrofit designs, and hydraulic culvert designs are examples of fish passage improvement structures. Fish passage improvement structures are allowed only by prior approval from the HQ Hydraulics Section. Additional information about roughened channels, roughened rock ramps, and structural retrofits is included below. Other fish passage improvement structures exist but are not covered here.

A fish passage improvement structure may be necessary to facilitate fish passage through an existing structure, allow for a transition between a newly constructed fish-passable structure and an upstream fishway, or as a means of grade control when deemed necessary. All fish passage improvement structures must meet WAC 220-660-200.

7-5.2.1 Roughened Channel Design Methodology

A roughened channel is a constructed channel with a streambed material and configuration designed to be non-deformable up to the design discharge. A roughened channel can help dissipate energy from an adjacent fishway into a newly constructed channel or may be necessary to prevent a channel from degrading over time.

7-5.2.2 Roughened Rock Ramp Design Methodology

Roughened rock ramps are similar to roughened channels except a roughened rock ramp uses large boulders to dissipate energy.

7-5.2.3 Structure Retrofit Design Methodology

An existing structure that currently does not provide fish passage can be authorized to remain in place until the end of its useful life by retrofitting the culvert to make it fish passable. It must be demonstrated that the culvert will comply with WAC 220-660-200(11). It is unlikely that a structure retrofit will be allowed within WRIAs 1 through 23 because of the Injunction.

7-6 Structure-Free Zone

The SFZ is an imaginary prism of infinite length both upstream and downstream that is horizontally centered on the stream and represents the minimum boundary within which no part of the fish passage structure, including footings, shall be allowed.

The components of the SFZ that determine the boundaries are width, height, and length. The specialty report documents the minimums for stream processes for hydraulic opening (width and height including freeboard, scour, and bed thickness), and length of the structure. However, there may be other reasons to increase the width and height of a structure that are not hydraulic related, such as constructibility, maintenance access, wildlife connectivity, or cost, and the specialty report does not document justification for additional width or height outside of what is necessary to allow for stream processes.

7-7 Temporary Stream Diversions

Temporary stream diversions shall be designed following the methodology described in Chapter 3 using the flow rates determined by this section. All other temporary culvert designs should follow the requirements of Chapter 3. Under most circumstances, determination of the design and configuration of temporary culverts for streams is left to the contractor. This allows the contractor to create the most efficient work plan for its construction method. If the PEO wishes to design the temporary culverts, the reason shall be discussed with the HQ Hydraulics Section, and approval will be required.

For design-build projects, the design and flow rate are determined by the design-builder based on the requirements of project permits.

For design-bid-build projects on fish-bearing streams, the HQ Hydraulics Section calculates the flow rates necessary for temporary culverts and that value is part of the special provisions. A conceptual-level plan is required for permits, but no plans for the temporary culvert system should be put into the final plan set and should not be documented in the specialty report, unless otherwise approved.

Temporary culverts for streams shall be designed for the following storm events:

- **Single season:** For a temporary culvert expected to be in place for a single fish window, the design flow rate shall be, at a minimum, equal to the expected 50 percent exceedance flow rate during the window when the temporary culvert is in place with a contingency plan that shall be in place within 2 hours or less to bring the system to meet the expected 10 percent exceedance flow rate during the window when the temporary culvert is in place. The expected flow rates during the window when the temporary culvert is in place can be determined through stream gage data (if available) or through an MGSFlood seasonal flow analysis (western Washington only). The flows can also be measured in the previous fish window years to get a base flow followed by an analysis for a 2-year storm based on rainfall for that fish window. If there are no data to calculate the flows during the construction window, then the expected 2-year flow rate shall be used for the design flow (contingency not necessary in this case) unless the PEO can justify a different flow if approved by the HQ Hydraulics Section.
- **Multiple season:** The flow rate used for a temporary stream bypass expected to remain in place through a winter is to be the 10-year flow event as determined by the same hydrologic methodologies as those for the 2-year event.

The design flood for temporary structures over water bodies shall be determined on a case-by-case basis by the HQ Hydraulics Section.

7-8 Monitoring

In September 2015, as part of the Injunction, state agencies and tribal nations agreed upon and finalized a set of Monitoring Implementation Guidelines. Those guidelines are the basis of WSDOT's current fish passage monitoring plan. Some elements of the monitoring plan apply to all statewide fish passage projects, not just those within the case area. Some projects have monitoring requirements as part of a state or federal permit. The monitoring plan, based on the agreed-upon guidelines, provides protocols that can be applied to those special monitoring requirements and will ensure a consistent and efficient process.

There are three basic types of monitoring inspections:

- **Post-construction compliance inspection:** WSDOT evaluates all fish passage projects to ensure that they are constructed as designed and permitted. Sites are also evaluated for their ability to pass fish using WDFW barrier assessment methods.
- **Overwinter inspection:** WSDOT inspects sites corrected under the Injunction after the first full winter to evaluate the impact of high seasonal flows on fish passage at the new structure.
- **Long-term evaluations:** Sites corrected under the Injunction are evaluated 5 and 10 years after construction to determine if they still provide fish passage and to determine if the structures still conform to the fish passage standards under which they were constructed.

The results of the monitoring effort are summarized each year in the Fish Passage Annual Report, which can be found on the WSDOT Fish Passage Program website. WSDOT uses the information from the monitoring efforts to work with WDFW and the tribes to improve upon the design and construction processes and will update this chapter as needed to reflect current practices and best available science.

7-9 Additional Resources

The stream designer may find the following manuals helpful for additional information:

- HEC-17: Highways in the River Environment - Floodplains, Extreme Events, Risk, and Resilience
- HEC-18: Evaluating Scour at Bridges
- HEC-20: Stream Stability at Highway Structures Fourth Edition
- HEC-23: Bridge Scour and Stream Instability Countermeasures Experience, Selection, and Design Guidance Third Edition, Volume 1 and Volume 2
- HEC-25: Highways in the Coastal Environment
- 2013 WDFW WCDG
- 2008 USFS Manual: *Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings*
- WDFW ISPG

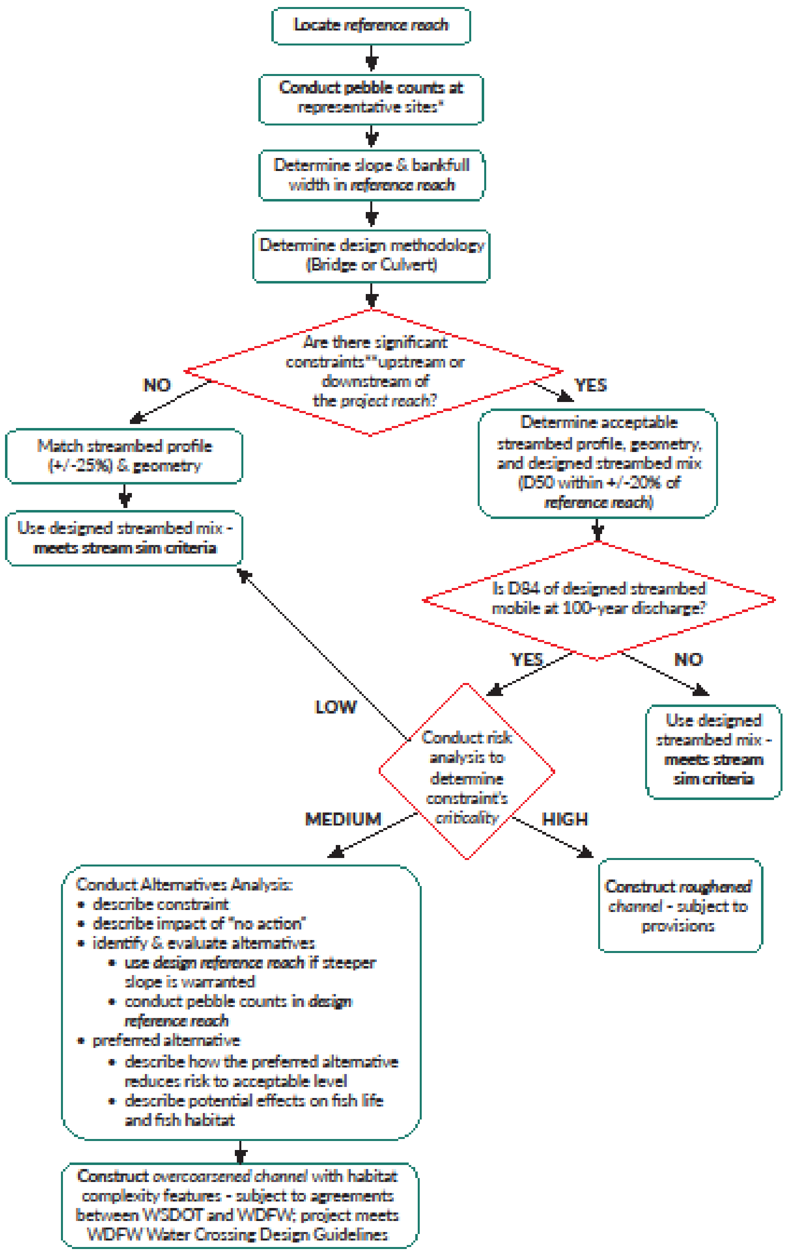
7-10 Appendices

Appendix 7A	Streambed Material Decision Tree
Appendix 7B	Design Methodology Requirements for Bridges and Stream Simulation Culverts

Appendix 7A Streambed Material Decision Tree

OCTOBER 2016

Streambed Material Decision Tree



* Select representative sites that:
- are away from recent or chronic sediment sources
- are in riffles
- avoid pools
- outside of the influence of man-made or natural structures such as LWM, eroding banks

** Constraints on channel regrading (including but not limited to):
- upstream/downstream infrastructure: culverts/bridges, pipelines, etc.
- water intakes/diversions
- groundwater wells
- upstream/downstream wetlands/habitat
- non-WSDOT property
- roadway geometry

DEFINITIONS

Criticality: the combination of probability of an effect to a structure, and the level of impact that the effect would have; see example chart on back.

Designed streambed mix: sediment size distribution that uses pebble counts from the reference reach for the D50 and D84, and an even, designed distribution of sizes for finer classes (USFS, 2008)

Design reference reach: is a reach of stream, preferably within the same watershed, that is relatively stable

Overcoarsened Channel: a constructed channel with a median particle size that is greater than 20% larger than the median particle size of the design reference reach; is deformable at discharges below the 100-year discharge.

Project reach: the segment of stream in which the fish passage is located

Reference reach: A stable segment of stream with consistent slope, geometry, planform, and sediment load that represents, to the best available knowledge, background condition of the project reach. (Rosgen, D.H., 1989)

Roughened Channel: a constructed channel with streambed material and configuration designed to be non-deformable up to the design discharge

Stable stream: A stream, over time (in the present climate), that transports the flows and sediment produced by its watershed in such a manner that the dimension, pattern and profile are maintained without either aggrading, nor degrading (Rosgen, 1996)

This document is intended to guide fish passage restoration design in cases where there are site constraints that are either too costly to resolve, or would take too long to resolve. In these cases, the regraded reach may be steeper than the initially identified reference reach. The reach assessment is an essential part of the process, but this document's scope is limited to the decisions that affect the design of streambed materials which may be larger than what would normally be indicated by stream simulation-based design.

		Impact			
		Minor	Moderate	Major	Extreme
Risk	Unlikely	Low	Low	Medium	Medium
	Moderate	Low	Medium	Medium	High
	Likely	Medium	Medium	High	High
	Very likely	Medium	High	High	High

Table 1. Criticality Matrix. Risk is the probability of an effect on a constraint. Impact is the level of effect that damage to the constraint would have.

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Appendix 7B Design Methodology Requirements for Bridges and Stream Simulation Culverts

WSDOT

BRIDGE AND LARGE BOTTOMLESS CULVERT DESIGN METHODOLOGY

Stream Crossing Element	Goals	Summary of relevant Washington Administrative Code (WAC)	Summary of relevant WDFW Water Crossing Guidelines	Supplemental Guidance
Bankfull/Bed Width	Determine accurate bankfull width relative to site conditions. Design teams will reach agreement in the field where possible. If hydraulic modeling is necessary, meet after to discuss results.	A person must measure at least 3 widths that describe prevailing conditions at straight channel sections and outside the influence of any culvert, bridge, or other artificial or unique channel constriction [220-660-190(3)(e)]	Page 222–243. (Appendix C) Provides recommended methods to determine bankfull width.	Bankfull in highly modified (urban/agricultural) determined by hydraulic modelling, reference reach or comparative analysis. See also WSDOT Hydraulic Manual, Chapter 7 Fish Passage.
Channel Slope/ Gradient	For culvert, the slope of the bed in the project reach is within 25% of the prevailing slope upstream and downstream.	The slope of the bed inside a stream-simulation culvert must not exceed the slope of the upstream channel by more than twenty-five percent. [220-660-190(6)(a)(iv)] If the channel is heavily degraded, the slope should be that of a stable channel that would fit within the geomorphic context of the reach. [220-660-190(3)(c)(ii)]	Page 87. If channel is considered unconfined, channel gradient is indirectly accounted for in the velocity ratio. Where the velocity ratio is defined by the average velocity within the main channel of the proposed crossing divided by the average velocity in the main channel of the unobstructed river channel. For confined channels, there is no guidance for acceptable channel gradients.	Slope ratio greater than 1.25 or more than 1' of uncontrolled regrade needs formal reach analysis. In low gradient systems provide explanation of analysis if gradient is outside stream ratio. See also WSDOT Hydraulic Manual, Chapter 7 Fish Passage.
Countersink/ Scour	Culvert bottom or bridge foundation does not become exposed for life of structure and substrate size is similar to adjacent channel.	The bridge design must minimize the need for scour protection. Where mid-channel piers are necessary, design them so no additional scour protection is required. If scour protection is unavoidable, the design must minimize the scour protection to the amount needed to protect piers and abutments. The design must specify the size and placement of the scour protection so it withstands expected peak flows. [220-660-190 (4)(g)]	Page 70–72. Follow AASHTO and FHWA Guidelines. Prevent or limit local scour and coarsening of the stream substrate.	WSDOT designs bridges for the 500-year event. See also WSDOT Hydraulic Manual, Chapter 7 Fish Passage.
Channel Geometry	Continuity of channel planform and cross-section maintained throughout reach; address channel complexity, large woody material, and meander bends.	Must design water crossing structures in fish-bearing streams to allow fish to move freely through them at all flows when fish are expected to move. All water crossings must retain upstream and downstream connection in order to maintain expected channel processes. These processes include the movement and distribution of wood and sediment and shifting channel patterns. Water crossings that are too small in relation to the stream can block or alter these processes, although some encroachment of the flood plain and channel migration zone will be approved when it can be shown that such encroachment has minimal impacts to fish life and habitat that supports fish life. [WAC 220-660-190(2)(a)]	Page 72–73. The stream channel created or restored near the bridge should have a gradient and cross-section similar to the existing morphology upstream and downstream adjacent channel.	See also WSDOT Hydraulic Manual, Chapter 7 Fish Passage.
Floodplain Continuity	Constructed channel mimics adjacent floodplain habitat conditions and allows for floodplain connectivity.	All water crossings must retain upstream and downstream connection in order to maintain expected channel processes. These processes include the movement and distribution of wood and sediment and shifting channel patterns. Some encroach is allowed as long as proven to have minimal impacts to fish life and habitat [220-660-190(2)(a)]. A bridge over a watercourse with an active flood plain must be designed to prevent a significant increase in the main channel average velocity. The bridge is defined as the main bridge span(s) plus flood plain relief structures and approach road overtopping. This velocity must be determined at the 100-year flood flow or the design flood flow approved by the department. The significance threshold should be determined by considering bed coarsening, scour, backwater, flood plain flow, and related biological and geomorphological effects typically evaluated in a reach analysis. [220-660-190(4)(c)]	Page 70–72, 78–89. Allow continued down-valley flow of water on the floodplain. The bridge/culvert design must comply with legislation governing development within floodplains.	If the ratio V2/V1 is less than 1.1, no additional justification is needed. If V2/V1 is greater than 1.1, must explain how there is no significant effect. V2 = design velocity V1 = existing velocity
Freeboard	Maintain structural integrity of the crossing for the duration of the design life.	The design must have at least three feet of clearance between the bottom of the bridge structure and the water surface at the 100-year peak flow unless engineering justification shows a lower clearance will allow the free passage of anticipated debris. [220-660-190 (4) (f)]	Page 15, 81. Culverts shall be installed to an approved design to maintain structural integrity to the 100-year peak flow with consideration of the debris loading likely to be encountered. A table of estimating clearance is provided, although are not based on hydraulic modeling or empirical studies and therefore should be used caution.	See also WSDOT Hydraulic Manual, Chapter 7 Fish Passage. Additional justification possible when recommended freeboard is not achievable.
Substrate	Channel substrate mimics reference reach.	The water crossing design must provide unimpeded passage for all species of adult and juvenile fishes. Passage is assumed when there are no barriers due to behavioral impediments, excessive water slope, drop or velocity, shallow flow, lack of surface flow, uncharacteristically coarse bed material, and other related conditions. [220-660-190(2)(a)], [220-660-190(3)(a)]	Page 44–52, 80. A reference reach approach to sizing sediment is preferred. Substrate should be designed to address bed stability at high flows and must be well-graded to prevent loss of significant surface flow.	See also WSDOT Hydraulic Manual, Chapter 7 Fish Passage.
Structure Span	Crossing width (span) allows for geomorphic processes to occur including 100 year flood flows; Minimize the need for scour protection; maintain structural integrity for the duration of the design life.	The bridge must pass water, ice, large wood and associated woody material, and sediment likely to move under the bridge during the 100-year flood flows or the design flood flow approved by the department. The waterward face of all bridge elements must be landward of the Ordinary High Water Line (OHWL), except for mid-channel piers and protection required at the toe of embankment in confined channels. The span must be sized to prevent a significant increase in the main channel average velocity. The significance threshold should be determined by considering bed coarsening, scour, backwater, flood plain flow, and related biological and geomorphological effects. The span must account for channel migration during the bridge's lifespan. If there are levees or other infrastructure that constrains bridge design, WDFW may approve a shorter bridge span than would otherwise be required. [220-660-190(4)]	Page 70, 83–90 Existing bridges with a good performance rating can be replaced in kind. Confined channels, distance between bridge abutments should be bankfull width plus a safety factor. Unconfined channels with flood plain and overbank flow should be designed such that the velocity in the main channel under the bridge should be close to the prevailing velocity in the main channel of the river.	See also WSDOT Hydraulic Manual, Chapter 7 Fish Passage.
Coarse Bands	For culverts: help form structure and maintain gradient; to keep the thalweg off the culvert wall, not intended to be grade control or rigid structures that do not deform over time.	N/A	Page 42–46 Helps form channel complexity where LWM can't be installed. Less important in steep streams.	Use for channel slopes less than 2%. Evaluate for slopes between 2% to 4%. Use material between the D84 and two times the D100 of the streambed design mix.
Crossing Length	Minimize confined length of channel and riparian impacts, increase width for long crossings. Skew also needs to be considered - crossing should use skew to avoid abrupt bends leading to the culvert inlet and from the culvert outlet.	N/A	Page 70, 83–84.	See also WSDOT Hydraulic Manual, Chapter 7 Fish Passage.
Floodplain Utilization Ratio (FUR)	To determine if unconfined bridge design criteria are adequate for the bridge or buried structure.	N/A	N/A	Measure FUR outside the influence of any crossing structures.
Streambank Protection/ stabilization	Minimize armoring (use of rip rap or concrete) and use bio-engineering techniques where appropriate.	Any proposed bank hardening must include: (i) An analysis performed by a qualified professional assessing the level of risk to existing buildings, roads, or services being threatened by the erosion; (ii) Technical rationale specific to the project design, such as a reach and site assessment (iii) Evidence of erosion and/or slope instability to warrant the work. Any bank hardening must protect fish life and habitat by using the least-impacting technically feasible alternative. The common alternatives below are in order from most to the least preferred: (i) No action – Natural channel processes to occur; (ii) Biotechnical techniques; (iii) Combination of biotechnical and structural techniques; and (iv) Structural techniques Streambank stabilization should be limited to the least amount needed to protect eroding banks. The project must be designed to withstand the maximum selected design flow. Use natural materials whenever feasible, including large wood and vegetation; protect existing spawning and rearing habitat. [WAC 220-660-130]	N/A	See Integrated Streambank Protection Guidelines
Hydrology	Correlate to watershed conditions and land use, while avoiding over-engineered channels and banks.	N/A	Page 101. Page 282-287 (Appendix G) Design Flows for Fish Passage	Address potential effects of extreme events (e.g., 500-year); use of best available science.

Washington Department of Fish and Wildlife, 2016, Incorporating Climate Change into Design of Water Crossing Structures

WSDOT

STREAM SIMULATION CULVERT DESIGN METHODOLOGY

Stream Crossing Element	Goals	Summary of relevant Washington Administrative Code (WAC)	Summary of relevant WDFW Water Crossing Guidelines	Supplemental Guidance
Bankfull/Bed Width	Determine accurate bankfull width relative to site conditions. Design teams will reach agreement in the field where possible. If hydraulic modeling is necessary, meet after to discuss results.	A person must measure at least 3 widths that describe prevailing conditions at straight channel sections and outside the influence of any culvert, bridge, or other artificial or unique channel constriction. [220-660-190(3)(e)]	Page 222–243. (Appendix C) Provides recommended methods to determine bankfull width.	Bankfull in highly modified (urban/agricultural) determined by hydraulic modelling, reference reach or comparative analysis. See also WSDOT Hydraulic Manual, Chapter 7 Fish Passage.
Culvert Gradient	The culvert is set at an elevation below total scour and provides adequate freeboard.	The culvert gradient must be set at the prevailing stream gradient unless an alternative slope is approved by the department. [220-660-190 (6)(a)(iii)]	p. 34. While no specific minimum slope ratio is suggested, the goal is to place the bed in the culvert at the same gradient as the stream – not to over- or under-steepen it.	In cases where placing the culvert at the same gradient as the stream would cause constructability issues, placing the culvert at a zero slope is acceptable as aslong as the necessary embedment depth adn freeboard are met and the engineering justification is provided.
Channel Slope/ Gradient	The slope of the bed inside the culvert is within 25% of the slope of the upstream channel.	The slope of the bed inside a stream-simulation culvert must not exceed the slope of the upstream channel by more than twenty-five percent. [220-660-190(6)(a)(iv)] If the channel is heavily degraded, the slope should be that of a stable channel that would fit within the geomorphic context of the reach. [220-660-190(3)(c)(ii)]	Page 32–34. The slope of the bed inside a stream-simulation culvert must not exceed the slope of the upstream channel by more than twenty-five percent. ($S_{culvert}/S_{upstream\ ch}$) < 1.25	Slope ratio greater than 1.25 or more than 1' of uncontrolled regrade needs formal reach analysis. In low gradient systems, provide explanation if designed gradient is outside slope ratio. See also WSDOT Hydraulic Manual, Chapter 7 Fish Passage.
Channel Geometry	Continuity of channel shape maintained throughout reach [channel complexity].	All water crossings must retain upstream and downstream connection in order to maintain expected channel processes. WAC 220-660-190(2)(a)	Page 172–73. The natural channel cross-section and the cross-section constructed through the crossing should be the same (at least up to bank full) so that material that is moving in the natural channel will also pass through the constructed channel in the crossing.	See WSDOT Hydraulics Manual, Chapter 7 supplement
Countersink/ Scour	Culvert bottom does not become exposed for life of structure and substrate size is similar to adjacent channel.	Must be countersunk a minimum of 30% and a maximum of 50% of the culvert rise, but not less than two feet. Alternative depths of culvert fill may be accepted with engineering justification [220-660-190 (6)(a)(v)].	Page 207. 30% to 50%, not less than 2 feet unless justified by analysis.	WSDOT uses 100-year scour depth plus 2 feet. See WSDOT Hydraulics Manual, Chapter 7 supplement.
Cross Section	Adjacent channel shape is continuous through crossing.	If the channel is heavily degraded, the cross section must match expected stream measurements in order to limit main channel velocity and scour to prevailing conditions. [220-660-190(3)(c)(ii)]	Page 37–43, 53–64, 207–208. Bed cross section should be similar to the adjacent stream cross section.	
Floodplain Continuity	Constructed channel mimics adjacent channel habitat conditions.	Fish must be able to move freely at all flows when fish are expected to move. All water crossings must retain upstream and downstream channel processes. Floodplain encroachments may be approved if it can be shown that there are minimal impacts to fish life and habitat [220-660-190 (2) (a)]	N/A	
Freeboard	Crossing provides unimpeded passage of fish, 100-year flood flows, LWD, and sediment.	N/A	Page 15. Culverts shall be installed to an approved design to maintain structural integrity to the 100-year peak flow with consideration of the debris loading likely to be encountered. A table of estimating clearance is provided, although are not based on hydraulic modeling or empirical studies and therefore should be used caution.	See also WSDOT Hydraulic Manual, Chapter 7 Fish Passage.
Substrate	Channel substrate mimics reference reach.	D50 must be +/- 20% of the D50 of the reference reach. The department may approve exceptions if the proposed alternative sediment is appropriate for the circumstances. [220-660-190 (6) (vi)].	Page 44–52. A reference reach approach to sizing sediment is preferred. Substrate should be designed to address bed stability at high flows and must be well-graded to prevent loss of significant surface flow.	Streambed Material Decision Tree & WSDOT Hydraulic Manual, Ch. 7
Culvert size	Culvert opening should be wide enough to maintain water and sediment transport continuity.	Bed width inside a culvert may be calculated by using any published stream simulation design methodology approved by the department, or may be determined on a case-by-case basis with an approved alternative plan that includes project objectives, inspection, maintenance, and contingency components. [220-660-190 (6)(a)(ii)]	Page 37–40. Typically culvert bed is, 1.2*BFW+2 (in alluvial systems), note examples of exceptions for deviating. The structure span should span the calculated bed width.	
Coarse Bands	Help form structure and maintain gradient; to keep the thalweg off the culvert wall, not intended to be grade control or rigid structures that do not deform over time.	N/A	Page 29, 42–44. Coarse bands should be used on channel slopes less than 4%.	Use for channel slopes less than 2%. Evaluate for slopes between 2% to 4%. Use material between the D84 and two times the D100 of the streambed design mix.
Crossing Length	Minimize confined length of channel and riparian impacts, increase width for long crossings. Skew also needs to be considered - crossing should use skew to avoid abrupt bends leading to the culvert inlet and from the culvert outlet.	N/A	Page 70, 83–84. Bridge length in this section should be referred as "bridge span." See "structure span" in cell H13.	See also WSDOT Hydraulic Manual, Chapter 7 Fish Passage.
Floodplain Utilization Ratio (FUR)	Determine if a channel is confined (FUR < 3) or unconfined (FUR > 3). Look for frequent out of bank flows and/or high flows away from channel.	N/A	Page 19, 36, 75. FUR < 3 indicates a confined channel where a culvert is better suited. FUR is defined as the flood-prone (FPW) width divided by the bankfull width (BFW).	When FUR>3, use unconfined bridge method for minimum channel span. Measure FUR outside the influence of any crossing structures.
Streambank Protection/ stabilization	Minimize armoring (use of rip rap or concrete) and use bio-engineering techniques where appropriate.	Any proposed bank hardening must include: (i) An analysis performed by a qualified professional assessing the level of risk to existing buildings, roads, or services being threatened by the erosion; (ii) Technical rationale specific to the project design, such as a reach and site assessment (iii) Evidence of erosion and/or slope instability to warrant the work. Any bank hardening must protect fish life and habitat by using the least-impacting technically feasible alternative. The common alternatives below are in order from most to the least preferred: (i) No action – Natural channel processes to occur; (ii) Biotechnical techniques; (iii) Combination of biotechnical and structural techniques; and (iv) Structural techniques - Streambank stabilization should be limited to the least amount needed to protect eroding banks. The project must be designed to withstand the maximum selected design flow. Use natural materials whenever feasible, including large wood and vegetation; protect existing spawning and rearing habitat. [WAC 220-660-130]	N/A	
Hydrology/ Design Flows	Develop design flows that accurately reflect watershed conditions, including future conditions	N/A	Page 101. Page 282–287 (Appendix G) Design Flows for Fish Passage	Address potential effects of extreme events (e.g., 500-year); use of best available science.

Washington Department of Fish and Wildlife, 2016, Incorporating Climate Change into Design of Water Crossing Structures

19-01-0038

Chapter 8 Pipe Classifications and Materials

8-1 Introduction

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

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

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

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

The type of material that is appropriate for a project is dependent on several factors including, but not limited to, pipe strength and corrosion and abrasion potential (Sections 8-4, 8-5, and 8-6); fill height (Section 8-12); the required pipe size, debris passage, and necessary end treatments (Chapter 3); and ease of fish passage (Chapter 7). Except for sizing the pipe, end treatments, and fish passage, each of these issues is further discussed in this chapter along with guidelines to assist the PEO in selecting the appropriate pipe material for a project site and application (Section 8-4).

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

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

Pipe materials and installation methods shall conform with WSDOT's Standard Specifications (WSDOT 2021c) and Standard Plans (WSDOT 2021d) whenever possible. Other specifications may be used when the Standard Specifications (WSDOT 2021c) and Standard Plans (WSDOT 2021d) are not applicable.

8-2 Pipe Classifications

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

8-2.1 Drain Pipe

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

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

Drain pipe smaller than 12 inches in diameter can withstand fill heights of 30 feet or more without experiencing structural failure. All of the materials listed in WSDOT’s Standard Specifications are adequate under these conditions (WSDOT 2021c). For drain pipe applications using pipe diameters 12 inches or larger, or with fill heights greater than 30 feet, the PEO shall specify only those materials listed in both the Standard Specifications (WSDOT 2021c) and the fill height tables in Section 8-12.

8-2.2 Underdrain Pipe

Underdrain pipe is small-diameter perforated pipe intended to intercept groundwater and convey it away from areas such as roadbeds or retaining walls. Underdrain applications use 6- to 8-inch-diameter pipe, but larger diameters can be specified. The minimum design life expectancy is 25 years, and no protective treatment is required. The Standard Specifications list applicable materials for underdrain pipe (WSDOT 2021c).

Underdrain pipe is generally used in conjunction with well-draining backfill material and a construction geotextile. Details regarding the various applications of underdrain pipe are described in WSDOT’s *Design Manual* (WSDOT 2020), the WSDOT Plan Sheet Library, and the Standard Plans (WSDOT 2021d). The hydraulic design of underdrain pipe is discussed in Chapter 6.

8-2.3 Culvert Pipe

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

The maximum and minimum fill heights over a pipe material are provided in Section 8-12. For materials or sizes not provided in Section 8-12, contact the HQ Hydraulics Section or review the Standard Specifications (WSDOT 2021c).

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

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

8-2.3.1 Circular and Schedule Culvert Pipe

Circular culvert pipe measuring 12 to 48 inches in diameter is designated as "schedule pipe" and shall be selected unless a pipe material is excluded for engineering reasons. The pipe schedule table listed in Section 7-02 of the Standard Specifications includes the structurally suitable pipe alternatives available for a given culvert diameter and fill height (WSDOT 2021c). Additionally, 8-8, Figure 8-10, and Figure 8-12 provide the PEO with a list of pipe alternatives and protective treatment depending on the corrosion zone. All schedule pipe shall be installed in accordance with Section 8-10.4.

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

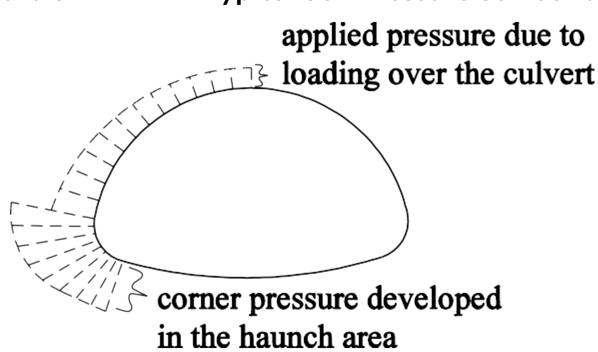
The type of material for circular culvert pipe measuring 54 to 120 inches in diameter shall be designated on the plan sheets. The structure notes sheet should include any acceptable alternative material for that particular installation. A schedule table for these large sizes has not been developed because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

8-2.3.2 Pipe Arches

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

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

Figure **8-1** **Typical Soil Pressure Surrounding a Pipe Arch**



8-2.3.3 Structural Plate Culverts

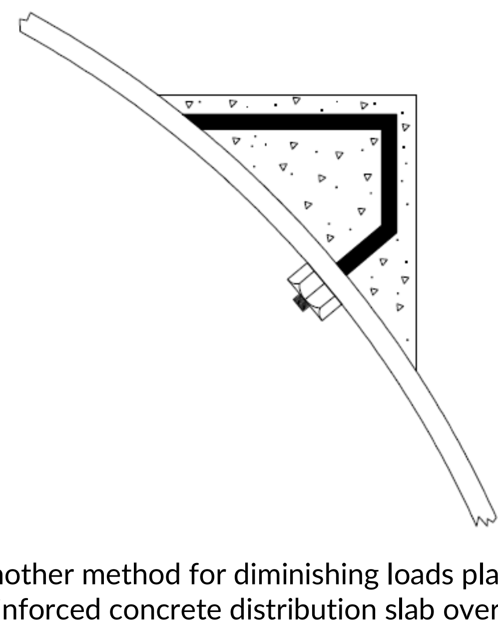
Structural plate culverts are steel or aluminum structures delivered to the project site as unassembled plates of material and bolted together. Structural plate culverts are large diameter—from 10 to 40 feet or more—and are available in several different shapes including circular, pipe arch, elliptical,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

The material requirements for structural plate culverts are described in the Standard Specifications (WSDOT 2021c). Aluminum structural plate culverts can be used anywhere in the state, regardless of the corrosion zone. Steel structure plate culverts are not permitted in salt water or Corrosion Zone III, as described in Section 8-4. The protective coatings described in Section 8-5.3.1 shall not be specified for use on these types of culverts because the coatings interfere with the bolted seam process.

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

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

Figure **8-2** **Concrete Thrust Beams Used as Longitudinal Stiffeners**



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

8-2.3.4 Private Road Approach and Driveway Culverts

The requirements for culverts placed under private road approaches and driveways are less stringent than the requirements for culverts placed under roadways. Private road approaches and driveway culverts are off of the main line of the highway, so minimal hazard is presented to the traveling public if a failure occurs. Also, it is difficult to provide a minimum 2-foot cover over the top of these culverts. Therefore, private road approaches and driveway culverts can be specified without the protective treatments described in Section 8-5.3.1, and the minimum fill heights listed in Section 8-12 can be reduced to 1 foot. Concrete pipe of the class described in Table 8-3 shall be specified for fill heights less than 1 foot. The PEO shall follow the same guidelines for material and design life as noted in Section 8-2.1.

The PEO 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 AASHTO HS 25 loading will consistently be traveling over the culvert and if the fill height is less than 2 feet, only pipes meeting the minimum fill height described in Table 8-3 shall be specified.

8-2.3.5 Concrete Box Culverts

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

All precast box culverts shall be installed in accordance with the manufacturer's recommendations. Design and submittal requirements are listed in the Standard Specifications (WSDOT 2021c). For extending or new construction of cast-in-place box culverts, contact the HQ Hydraulics Section.

The dimensions and reinforcement requirements for precast box culverts are described by AASHTO. AASHTO M 259 describes precast box culverts with fill heights ranging from 2 to less than 20 feet. Refer to Section 8-12.2 for additional guidance on the use of concrete structures in shallow cover applications. If a precast box culvert is specified on a contract, the appropriate AASHTO specification 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.

8-2.3.6 Three-Sided Concrete Box Culverts

Three-sided concrete box culverts 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 shall not be greater than 4 percent in the direction parallel to the channel.

The structures are well suited for low cover applications where a wide hydraulic opening must be provided. They can be specified with as little as zero cover and span lengths up to less than 20 feet. It is possible to use 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 quickly, often within 1 to 2 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 Section should be contacted to perform the necessary scour analysis.

8-2.4 *Storm Sewer Pipe*

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

The pipe schedule table in the Standard Specifications lists all of the structurally suitable pipe alternatives available for a given culvert diameter and fill height (WSDOT 2021c). Additionally, 8-8, Figure 8-10, and Figure 8-12 provide the PEO with a list of pipe alternatives and protective treatments depending on the corrosion zone. All schedule pipe shall be installed in accordance with Section 8-10.4.

All storm sewer pipes, unless indicated otherwise on the plans, must be pressure tested. Pressure testing indicates the presence of leaking seams or joints or other structural failures that may have occurred during the manufacturing or installation of the pipe. The Standard Specifications describe three types of pressure tests that are available (WSDOT 2021c). The contractor generally has the option of choosing which pressure test to perform. Pressure tests include the following:

- **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 6 additional feet of water column is placed on the test section. The pipe leakage is measured and must be less than the allowable leakage described in the Standard Specifications (WSDOT 2021c).
- **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, water leaking into the pipe is collected and measured and must be less than the allowable leakage rate described in the Standard Specifications (WSDOT 2021c).
- **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 pound per square inch (psi) (7 kilopascals). The measured time must be equal to or greater than the required time described in the Standard Specifications (WSDOT 2021c).

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

8-2.5 *Sanitary Sewer Pipe*

Sanitary sewers and side sewers consist of pipes and manholes intended to carry either domestic or industrial sanitary wastewater. Any sanitary sewer work on WSDOT projects will likely consist of replacement or relocation of existing sanitary sewers for a municipal sewer system. Therefore, the pipe materials will be in accordance with the requirements of the local health department, sewer district, and the Standard Specifications (WSDOT 2021c).

8-3 Pipe Materials

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

Several pipe materials are acceptable to WSDOT, depending on the pipe classification (see the Standard Specifications [WSDOT 2021c]). WSDOT's policy is to allow and encourage all schedule pipe alternatives that will function properly at a reasonable cost.

If one or more of the schedule pipe alternatives at any location are not satisfactory, or if the project has been designed for a specific pipe material, the schedule alternate or alternates shall be so stated on the plans, usually on the structure note sheet. Pipe materials shall conform to the *Hydraulics Manual*, the Standard Specifications (WSDOT 2021c), and the Standard Plans (WSDOT 2021d).

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

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

8-3.1 *Concrete Pipe*

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

8-3.1.1 Concrete Drain Pipe

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

8-3.1.2 Concrete Underdrain Pipe

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

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

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

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

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

Concrete pipe is permitted anywhere in the state, regardless of corrosion zone, pH, or resistivity. It has a smooth interior surface, which gives it a relatively low Manning's roughness coefficient (Appendix 4A). The maximum fill height for concrete pipe is limited to about 30 feet or less. However, concrete pipe is structurally superior for carrying wheel loads with shallow cover. For installations with less than 2 feet of cover, concrete pipe is an acceptable alternative. Table 8-3 lists the class of pipe that 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 provided in Section 8-10.3. During the installation process, pipe should be uniformly supported to prevent point load concentrations from occurring along the barrel or at the joints.

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

8-3.2 *Metal Pipe: General*

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

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

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