Chapter 6: OPEN BOTTOM STRUCTURES

This chapter presents design criterion for open bottom structures such as Arch culverts and three-sided concrete structures they both have a natural bottom and are supported on footings.

The most common types of structures are open bottom arches (pipes with metal or concrete footings) and concrete three-sided box structures with concrete footings. These structures historically have had their footings installed on bedrock to prevent scouring and for bearing pressure concerns.

Open Bottom Flow Model

The flow model and design of these structures is similar to those for designing pipe arches and culverts. Charts solutions are available in most design manuals. Roughness is a consideration when the structure is designed for outlet control but is not a concern when the culvert is designed for inlet control.

Fish passage through the structures assumes stream simulation. Fish will move between the rocks which provide protection and points of low velocity.

An outlet control boulder weir is recommended for arches for the same reason as we recommend them for culverts. That control weir creates an energy dissipation pool to prevent the stream down cutting at the culvert outlet, and will backwater flow to the top of the riprap at the outlet to the arch. The weir should be designed to backwater to the top of the riprap placed inside the arch for scour protection.

If the structures are placed on bedrock, boulder clusters should be placed inside the structure to capture substrate and provide low velocity areas.

Structures at the Confluence of two streams

A special case exists when open bottom structures outlet into a main channel. The footings on these structures often need to be taller at the outlet. Gravel deposition will occur at the outlet. That deposition may rise to the level of the main stem depth during peak flows. Adding extra height to the footing will prevent the outlet from becoming restricted or blocked. Bridge options may be required.

Design the top of footing at the outlet to the level that the mainstream may cause sediment to aggrade too. That level is estimated as the bank full elevation of the main channel. The riprap level, or top of the rock in the structure should be designed for back-watering from the lowest possible level. Taper the footing for these contingencies. See the diagram below.

Design of Open Bottom Structures

The design process is fairly well documented in the Handbook of Steel drainage and highway Construction Products and AASHTO specifications for Highway Bridges.

1. Given the Design Flow-normally Q100 and slope, select a culvert size that pass that flow from nomograph or programs.

2. Add freeboard height to structure for debris flow movement during peak events. Bridge structures often have 4 feet of freeboard to allow floating debris to pass under the superstructures. Major arches should have at least 3 feet of freeboard.

3. Check the outlet velocity for peak flows' events. If these velocities are excessive than design an outlet dissipation basin or widen the culvert. The width of the structure will be most likely influenced by the depth and velocity of flow at peak flows. To prevent scouring to footings, install riprap for the full width of the footings. The riprap size is a function of flow depth and velocity.

4. Check the backwater height during peak flows events. Verify that the backwater will not extend beyond road right of way limits or damage property. Consider enlarging structure to lower backwater.

5. Check Steel Design for safety against structural Failure. On large structure the calculations below are recommended. On smaller structures the manufacturers' recommendations are adequate. The following methods have customarily been used Service Load Design, Load Factor Design, and the LFRD design method. These calculations should be documented in the preconstruction file.

(1) Wall Area of pipe

(2) Buckling strength
(3) Seam resistance for structures with longitudinal seams
(4) Check design for Flexibility, minimum cover and maximum cover in accordance with the appropriate AASHTO specifications.

Footing and Foundation Design

A. Erodible Foundations:

When open bottom structures are placed in an erodible foundation the usual practice is ripraping the entire area between the footings. The size of the riprap is a function of water depth and velocity of flow. On steeper grades the velocities will increase potentially causing the rock works to scour out. Increasing the culvert width will reduce the flow width and velocity. This relationship will usually establish the span or width of an open bottom structure span on steep grades.

B. Bearing Capacity and Settlement

Open bottom structures should be placed on foundations that have high bearing capacity and low potential for settlement. In general open bottom structures can be safely placed on gravel or rock foundations. If the foundation is on soil other than a gravel or rock foundation, a geo-technical report with recommendations for the design is an absolute necessity. Special construction details are required for those designs. Drilling is recommended for verifying soil and rock conditions on open bottom structures.

C. Riprap

1. Place a continuous riprap blanket between the footings to collect substrates. The riprap must be sized to prevent movement during high flows. The size of the riprap is a function of the peak flow and gradient of the channel. On steeper grades the footings may need to be deeper to accommodate the larger riprap and prevent the footings from scouring. If the footings are on natural rock the requirement for a riprap blanket is still recommended to collect substrates and provide roughness for fish passage. Fabric should be placed under the riprap to prevent fines from being washed out under the rock.

2. Size riprap to provide protection from 100 year events. A typical design on a low gradient structure requires well-graded rock designed to handle the design velocity and depth. See Appendix D for design criterion and examples. The rock should be angular and interlocked to prevent movement during high flows. Use fabric under rock to prevent fines from moving from under and around footings.

3. Provide sufficient head for movement of debris through the structure. Metal arch structures will normally not survive an overtopping event. Concrete structures will handle greater debris loads and often can be salvaged after a debris torrent.

Positive advantages of arch structures.

1. Meet a total passage criterion except large woody debris

2. When installed correctly will minimally change channel characteristics.

3. Are often the only way to achieve passage for full stream simulation for grades greater than 5%.

4. Allow passage of fish for grades greater than 13%.

5. Concrete arch structures are often preferred to metal arch structure for the following reasons. They resemble bridges in their construction and have higher clearance for debris flow than arches of the same width. They have a greater likely-hood of resisting a debris flow and are preferred at sites with overtopping risks. They need less cover than arches.

6. May be only design that allows for fluctuations of gravel bars at the confluence of smaller streams with larger streams.

7. Use open bottom structures with grades at or near bedrock at slopes. The load-bearing pier design can be used when bedrock is at greater depth. If engineered and designed carefully these structures can be placed on the fill.

Negative aspects of arch structures

1. A metal arch will cost more than a baffled culvert. A concrete arch will cost approximately more than the culvert or arch.

2. More complex structure requires additional time to construct with resultant concerns in seasonal restrictions, weather, and traffic delays.

3. May be a barrier to movement of large woody debris.

4. Metal arches have limitation on minimum cover. Maximum cover is normally not an issue.

5. Should not be placed in areas where footings are questionable. Bearing pressure concerns are a significant design issue. If bedrock or geology conditions are not obvious drilling should be considered as part of preconstruction design.
6. Footings must be protected from scouring. Those calculations are crucial to the success of the structure.

Open bottom Arch with Concrete Footings

This is the most common design and standard drawings are available for most details. Photos of a typical installation are shown below. Typical drawings are included in appendix C.

Installing multi plate pipe on concrete footings

The riprap inside is a critical design element and requires special inspection.

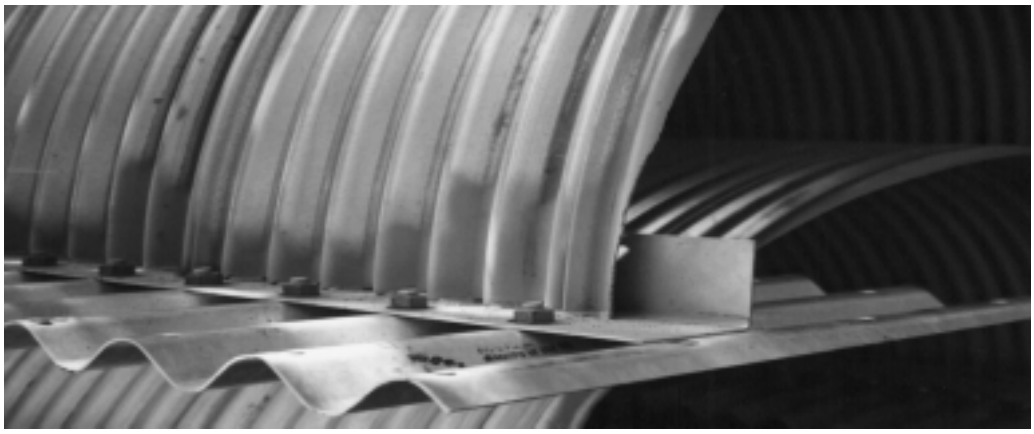
Open Bottom Arch Culverts with Metal Footings

This past summer we installed an open bottom arch culvert with metal footings. The pipe was placed on a riprap foundation. The pipe was 8 feet in width constructed by slicing an 8-foot diameter culvert lengthwise. The metal shoes are typical shoes provided for multi-plate structures.

This concept has future applications but needs some design adjustments.

1. The footings were excessively wide and costly. A design needs to be developed which will allow the fabricator to construct his own steel footing plates in house.

2. The bands were cumbersome to install. Future installations will use a different band detail wherein the band is bolted to the footing and than tightened around the top as in the case of a plate band.

3. Leveling the riprap was more difficult than anticipated. A leveling course was placed on the riprap of smaller aggregate. During the first flood event that rock washed out. Future projects will need to use larger rock for leveling or a grouted riprap along the sides.

Looking at the inside of Frenchie Creek Culvert. The riprap was placed full length on a geotextile to prevent scouring of the foundation. See Base plate detail below.