An Overview of Culvert Design

By Bernie Roseke, P.Eng., PMP
CulvertDesign.com

Culverts are a small, low cost installation that if designed incorrectly, can have significant impacts on the channel, the road, and the upstream landowners. Small variations in design criteria and/or methods can result in major ramifications to stakeholders which are many times the cost of the culvert installation.

A culvert needs to:

- Convey water
- Support the embankment and/or roadway above it
- Protect adjacent property from flood damage
- Be economical

Conveying Water

Normally the governing road authority has standards for design flow selection, usually stated as a return period, for example the 1:25 year flood. Often there are standards for a check flow as well. This is usually found using hydrology software, which uses the Rational or SCS Method together with stream flow routing.

For culvert design criteria, the road authority will usually provide the design criteria as one or more of the following:

- Minimum freeboard (headwater elevation in relation to the culvert crown)
- Maximum velocities
- Maximum head loss

Using culvert design software or a manning's equation on average stream channel properties, the designer will find the "tailwater" or normal running depth of the channel at the design flow as measured from the lowest channel point. This tailwater, together with the flow, is entered into culvert design software which determines the "headwater," as well as inlet and outlet velocities, and the head loss.

The calculation for these values comes from the American Federal Highway Administration through Hydraulic Design System #5 (HDS-5) and it is not easily done by hand. Basically, the designer must calculate a headwater using two methods, inlet control and outlet control, and select the higher value.

If using a round culvert, it is usually advantageous to bury the inverts slightly (to a maximum of a quarter diameter). This allows the culvert to silt in over time and creates provides more conformity to the stream channel.

Supporting the Embankment

Structural design of culverts with diameters 3.0 m and greater is governed by the Canadian Highway Bridge Design Code, section 7, Buried Structures. In the United States, the equivalent is the AASHTO LRFD Bridge Design Specifications, section 12, however the Canadian structural design calculations have been based on more research and are more thorough. You might also find references to design methods from the American Iron and Steel Institute (AISI) or American Society for Testing of Materials (ASTM), but these have been superseded by AASHTO (although not substantially different).

Like the culvert hydraulic calculations, structural calculations are difficult to perform by hand. It is recommended that the designer obtain structural design software for this purpose. The AASHTO method is simple and can serve as a more intuitive design check.

The structural integrity of the culvert is determined by the backfill. The culvert itself simply transmits dead and live loads from above into the surrounding backfill. When the fill above the culvert is above roughly 6 – 8 m, additional precautions are required such as culvert thickness, or using a structural plate pipe instead of regular CSP.

The Corrugated Steel Pipe Institute (CSPI) assists designers by providing tables which aid in selection of culvert thicknesses and corrugation profiles under specified live load and height of cover situations. These are published in section 6, “Structural Design” of the Handbook of Steel Drainage and Highway Construction Products.

Protecting Adjacent Property

Adjacent property should be surveyed to determine the stage at which flooding occurs. The return periods used in the design flow selection should be used to compare calculated headwaters with adjacent land elevations. Sometimes the analysis will need to be run with multiple flow depths to get an overall picture of the circumstances under which flooding will occur, and its severity.

If head losses are significant this is a red flag, even if the headwater elevations are not above threshold levels. Head losses are a sign that the pipe is inadequate for the flow and a small increase in flow above the design flow can result in a large increase in headwater elevation, and thus flooding.

Being Economical

Culvert structures come in many shapes and sizes.

- Corrugated Steel Pipe (CSP): Round CSP is generally the most economical and should be investigated first. It can be coated with galvanizing or polymer for added corrosion protection. It ranges in size up to 3.6 m in diameter, after which the pipe deflects under its own weight and becomes difficult to install adequately. You can place two side by side, or as many as you like, to carry the required flow. If there is too much fill above the culvert, or the flow is too high, you must move toward a “structural plate” CSP.
- Structural place CSP (SPCSP) is similar to CSP except it is manufactured in sections and bolted together in the field. Because it is not rolled in one single piece, it can be designed and constructed in much larger sizes and corrugation profiles. Currently the Handbook of Steel

Drainage and Highway Construction Products contains data for up to 16 m diameter culverts, but greater sizes have been constructed. Clearly, once your culvert is this big, structural design becomes a major factor.

- Horizontally Ellipsed CSP: When you don't have much embankment to work with over the pipe, or the hydraulic advantages are worth the extra money, you can get structural plate CSP's in an oval shape. Obviously, the structural design considerations are important here and the designer should investigate the need for a concrete slab above the culvert. Without any concrete reinforcement, however, the cost of a horizontally ellipsed structure is not much different than the equivalent round SPCSP. The designer must choose a "side radius" and a "top and bottom radius" and the plates are configured (usually by the manufacturer) so that one of the bolted seams runs in each of the corners where the radius change occurs.
- Pipe Arches are flat bottomed culverts which provide better hydraulic characteristics but contain a high stress zone in the bottom corners where the radii are low.
- Arches, or open bottom arch culverts, are the most expensive option but they are sometimes necessitated by geometric constraints. For these types of culverts, protecting the footings from erosion is a primary concern.

Naturally, CSP's are the cheapest alternative, but if flows dictate something larger, the designer must price out each of the above options, calculating their length, size, fill required, and other parameters to arrive at a decision as to which is the most cost effective option.

CulvertDesign.com contains many resources for culvert designers, including checklists, cost estimates, design guides, codes, ASTM standards, and others. Our online web based culvert design software, CulvertPro, contains all of the calculations needed for the design of a culvert, including hydrology (Rational and SCS Methods), culvert hydraulics, and culvert length calculations.

Bernie Roseke, P.Eng., PMP is the owner of CulvertDesign.com, the online culvert design resource for engineers and design professionals.