







Chapter 5: Environmental Guidelines for Culverts

Water Resources Management Division
Water Rights, Investigations, and Modelling Section
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Chapter 5

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CULVERTS

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5.l General

Culverts are often used to provide access across drainage ditches, intermittent streams and small watercourses. Culverts can provide an efficient and inexpensive means of crossing provided they are properly designed and properly installed at suitable locations. Often culverts are also necessary to provide drainage where roads or other structures would interfere with the otherwise normal flow of surface runoff. Temporary or permanent culvert stream crossings are preferred to fording of small watercourses where extensive fording may give rise to channel destabilization.

On some streams it is environmentally desirable to construct bridges instead of culvert crossings because bridge installations can avoid extensive alteration of the flow regime which is inherent with most culvert installations. Bridges are also preferred to culverts in crossing all streams which support fish populations. Culvert installations usually result in more substantial alteration or loss of sections of the natural channel bed and can cause a partial or total barrier to fish migration. Installation of culverts in major watercourses and rivers, instead of bridges, is not considered a good environmental practice.

Many types of culverts are available from suppliers, the most popular being corrugated steel pipe. Reinforced concrete culverts, and plastic pipe culverts, are usually available in round sections only. Examples of corrugated steel and plastic culverts can be seen in **Figure 5.1**. Corrugated steel culverts are available in a large variety of cross sectional shapes and sizes to suit varying stream conditions or requirements, the most popular shape being round or arched.

All culvert installations of significant size, including multiple or gang culvert installation, should undergo thorough hydraulic and hydrologic analysis. Factors such as channel gradient, flow velocity, channel cross section, channel roughness, discharge patterns, peak water levels, quantity of flow, and ice formation must be considered.

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Figure 5.1 A Corrugated Steel Culvert Mitred to the Face of a Wall (Top), and a Small Plastic Culvert with a Masonry Headwall (Bottom)

The completed culvert installation should safely accommodate reasonably predictable levels of flow and adequately resist the erosive action of moving water without creating any adverse environmental impact at the crossing or in upstream or downstream areas. Flow quantity may be predicted through a variety of methods including the rational method, unit hydrograph, SCS Method, or Regional Flood Frequency Analysis. In addition to utilizing any of these methods a relevant amount of data must be collected on the stream and its watershed such as:

- historical streamflows
- velocity distribution in stream
- high water marks
- ice shove marks
- precipitation data
- potential river scour data
- ice formation and ice jamming areas
- rating of erosion hazard
- surface drainage patterns
- floodplains
- surface area of rivers, lakes, bays, wetlands

While it is not always necessary or possible to determine all of the source data listed above it is generally advisable to have sufficient data to check expected flood flow by at least two independent methods.

The following sections of this chapter provide helpful information for culvert design and installation to ensure that the width and depth of flow expected in the stream under natural conditions is not significantly altered by the installation of culverts. Construction procedures should follow these guidelines with the primary objective being to prevent environmental damage such as pollution and siltation. These guidelines are intended to provide explanatory information and guiding principles but do not provide a complete code for design because certain design criteria such as load bearing capacity should be derived from appropriate texts. Engineering advice should be sought by lay people who wish to purchase and install their own culverts.

5.2 Culvert Location and Shape

The location of culverts is perhaps the most important consideration in installing an environmentally satisfactory culvert crossing. While the location of the road will probably be the primary consideration, it is important to realize that minor changes in road alignment may be necessary to avoid problem areas as far as culvert installations are concerned.

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5.2.1 Select a Stable Location

Avoid locations where there are abrupt or short radius bends in the stream channel and areas where erosion, undercutting, or fine soils are evident. These areas are often subject to greater erosive force which could create problems for a culvert installation.

Heavy erosive action can lead to undercutting of the culvert and structural damage. In addition, these areas are often unstable and the channel may be shifting. If the stream bed is mobile it may eventually bypass the culvert, rendering the installation useless. Culvert crossings should be located on straight, stable channel segments with no evidence of heavy erosive action.

5.2.2 Select a Site With Uniform Channel Gradient

Select a culvert site where the channel gradient is uniform for a distance upstream and downstream in the channel. This will avoid areas where there may be sudden increases in water velocity immediately upstream or downstream of the installation. The gradient must be constant at the crossing itself. Culverts should never be installed with bends in them.

Steeper channel gradients result in higher flow velocity. This could mean that the installation would be subject to greater risk of erosion and washout caused by the momentum of water striking the culvert inlet area. Areas of low gradient should therefore be given preference.

5.2.3 Location With Regard to Ice

A culvert should not be located where large quantities of solid sheet ice are formed upstream. During spring runoff such ice may break loose and block the culvert. Outlet areas of small pools or ponds should therefore not be culverted.

5.2.4 Culvert Shape

The shape of a culvert should conform to the site conditions and to the flow regime at that location. While round culverts are the most popular, a variety of shapes are available (see **Figure 5.2**). Design options are limited by flow characteristics and highway alignment. Where elevation is restricted the designer may select a shape which is horizontally elongated to produce the same cross sectional area with less height.

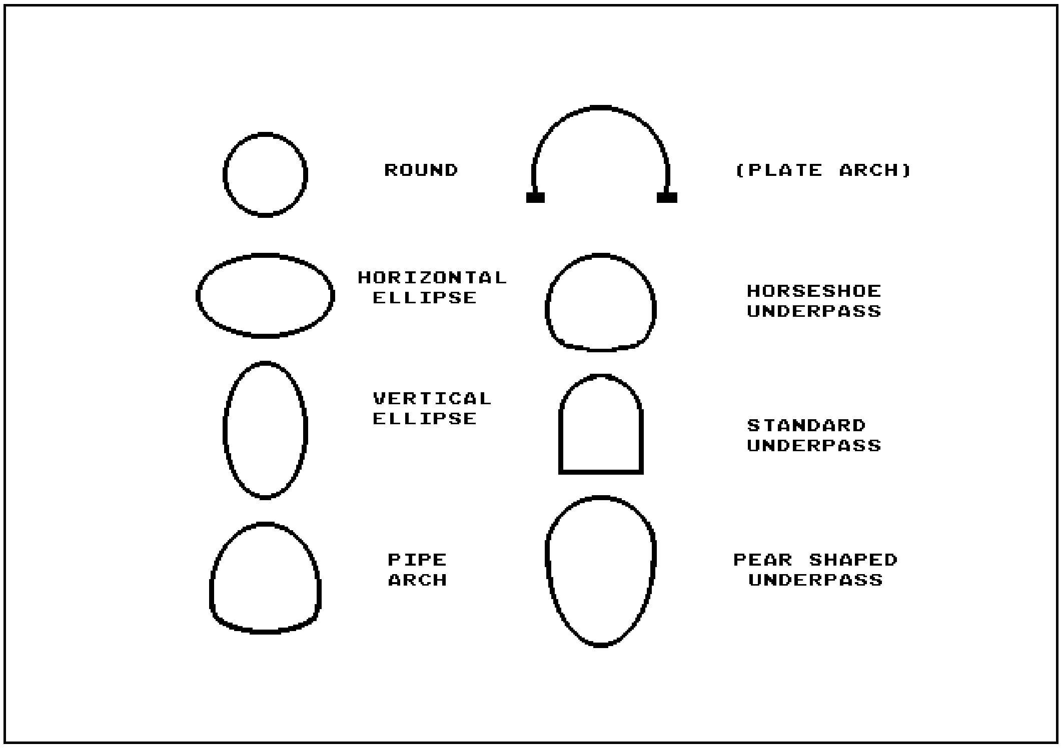

Figure 5.2 Common Shapes for Corrugated Steel Culverts

Although an open bottom arch is shown in **Figure 5.2**, arch "culverts" can be treated as bridges and are discussed in *Chapter 4, "Bridges"*. A photo of an arch culvert can be seen in **Figure 5.3**.

Figure 5.3 Corrugated Steel Arch Culvert

Wider culverts result in lower flow velocity. At low flows wider culverts may have insufficient water depth to allow fish passage.

Generally, arch shapes are useful to reduce the elevation of fill, but they are more difficult to install. Elliptical shapes provide better low flow characteristics. Multiple barrels of the same size or different sizes may be easier to install and conform to the stream shape, but these installations are generally less efficient hydraulically when compared to larger single size pipes.

5.3 Culvert Capacity

All culvert installations should be designed to safely accommodate peak flow volumes estimated for that section of channel during the expected life of the culvert. This means that the size or capacity of a culvert should be commensurate with its expected serviceability. For instance a culvert installed under an infrequently used forest access road would not be expected to give the same degree of performance as a culvert installed under a major highway. Nevertheless all culverts must be installed in a manner which is acceptable from an environmental standpoint. When culvert capacity is exceeded by a very large volume of flow or the capacity is reduced by blockage, there is a danger of:

- overtopping, damage to the roadway and traffic interruption
- consequential threats to human safety
- damage to adjacent property or the environment
- unsafe outlet velocities
- injurious deposition of bed load

Excessive headwater depth can contribute to a "piping effect" through the backfill material surrounding culverts. This can undermine culverts and result in a major washout.

Surcharge conditions can cause flooding upstream of the culvert and/or scour and erosion at the culvert inlet.

5.3.1 Provide Adequate Capacity to Prevent Surcharge

Culverts should be designed with adequate capacity to carry maximum design flows without creating surcharge or backwater conditions. In this regard culverts should be designed to carry the design flow with a headwater depth not greater than the vertical dimension of the pipe. Large culverts (over 2.0 m) should have a freeboard.

Small culverts under 2.0 m can use the California Balanced Design Method (see **Figure 5.4)**, which specifies (1) a 10 year return flood can be carried without static head at the inlet, and (2) a 100 year return flood will be carried utilizing the full head available at the inlet.

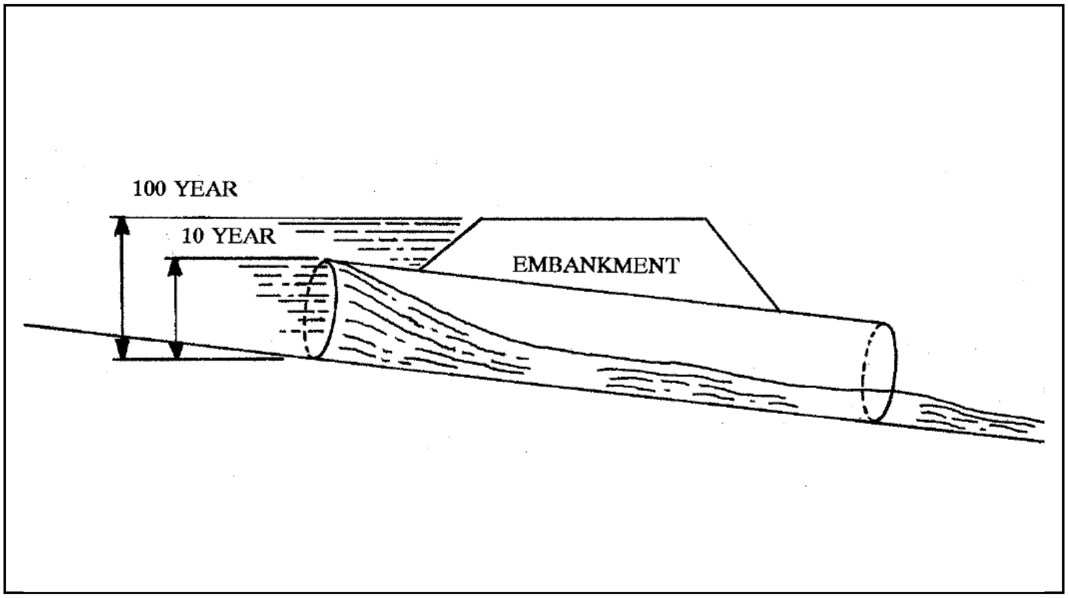

Figure 5.4 California Balanced Design Method

Where overtopping can be tolerated (ie. if none of the previously mentioned consequences of inadequate capacity apply except overtopping itself), the 100 year return period can be reduced to:

Freeways	50 year
Arterials	50
Urban local and collector streets	25
Rural and forest areas	20
Driveways and farm lanes	10

Typically, in Newfoundland, stream widths are greater than the culvert opening. The flow may become constricted, causing critical conditions at the inlet, a case called inlet control. The discharge of the culvert is controlled by the entrance conditions, which are:

- headwater depth
- cross sectional area
- type of inlet edge

The roughness, length, and outlet conditions of the culvert do not influence culvert performance. The entrance of the pipe acts as an orifice and is governed by the equation:

$$Q = C_d * A_o * (2gh)^{0.5}$$

where

Q = flow
C_d= experimental coefficient
A_o= area of orifice
h = height from centre of orifice to headwater surface
g = gravity constant (9.81 m/s^2)

C_d has a wide range and is primarily an indicator of the roughness of the opening. The influence of the edge roughness of the culvert decreases as the culvert diameter increases.

It is important to remember that under inlet control, the slope of the culvert does not affect the flow capacity. However, at high slopes the flow velocity in the pipe will be increased and may result in undermining at the outlet, downstream bed scour and damage to control structures.

5.3.2 Allowance for Limited Gravel Deposition

Culvert capacity should be designed to include provision for limited gravel deposition within the culvert if required for fish habitat reasons. (See **Figure 5.5**). This gravel should be sufficient to mimic a natural type of stream bed within the culvert, if the stream is a natural habitat for fish. Typically, the depth of allowable gravel deposition is 1/3 of the diameter for culverts under 0.75 m diameter, and 0.3 m for culverts over 0.75 m diameter. Because the gravel deposition reduces the cross sectional area of the pipe, the diameter of the culvert must be selected to produce sufficient flow capacity even with gravel deposition.

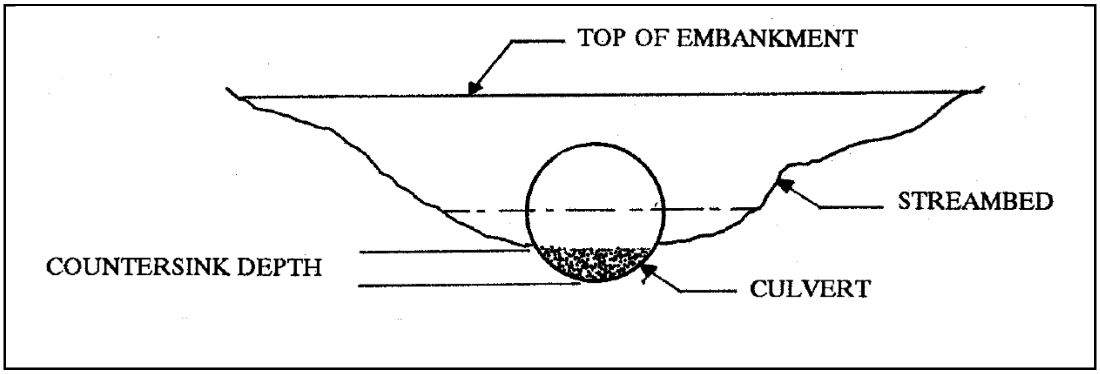

Figure 5.5 Countersunk Culvert

Size selection is further complicated because the flow actually has three distinct hydraulic stages:

1.	Weir or open channel flow	H = 0 to D/2
2.	Flow known experimentally	H = D/2 to D
3.	Orifice flow	H > D

where

H = depth of water at inlet
D = diameter of culvert

Gravel deposition affects channel roughness, orifice roughness, and opening size. Consequently, in sizing a culvert allowance must be made for the reduced capacity resulting from this installation feature. Having used normal culvert design methods to estimate the appropriate size of culvert, **Figure 5.6** may be used to select the proper larger sized culvert to provide for countersunk installation.

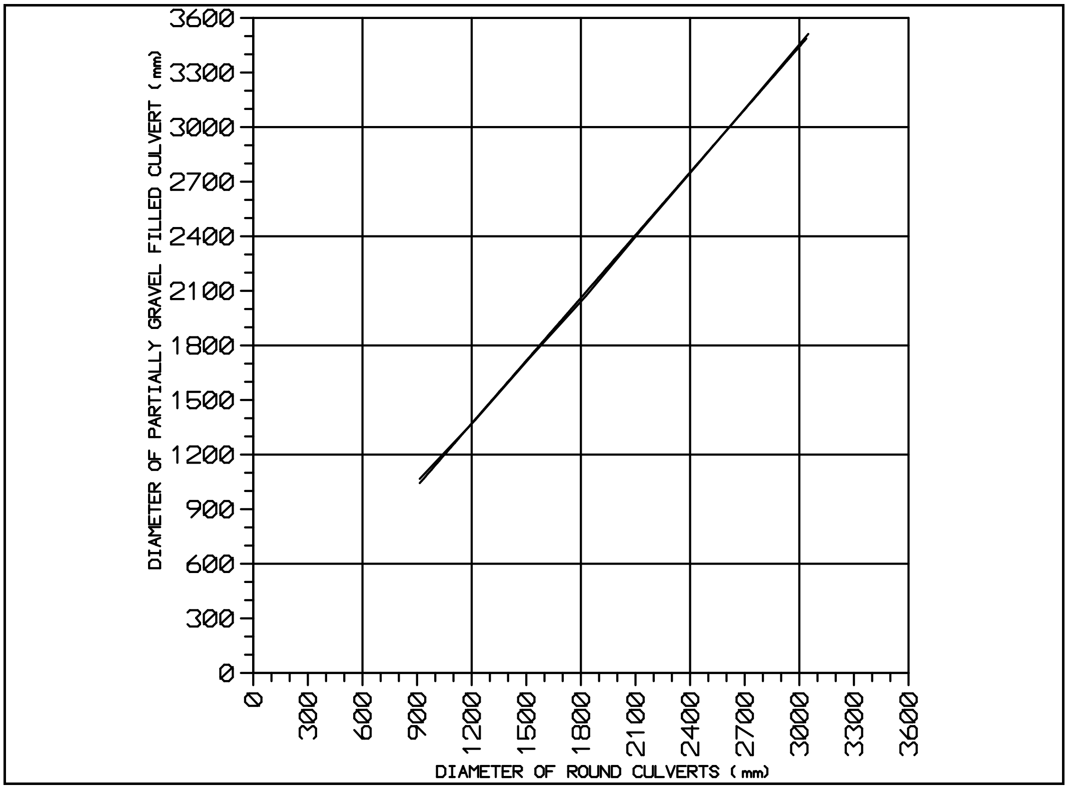

Figure 5.6 Conversion of Normal Round Culvert to Countersunk

5.3.3 Maintain Natural Stream Channel Capacity

Culvert installations should provide capacity equivalent to that of the existing natural channel. In this regard infilling of the channel or reduction of the natural cross sectional area of the channel due to the culvert placement and backfilling should be avoided. Pipe arches are a preferred shape over circular pipe in wide and flat bottomed streams.

5.3.4 Debris Control Structures and Culvert Capacity Should Address Maintenance Requirements

Many debris barriers or trash racks require cleaning after every storm. The expected frequency of debris removal should be considered in selecting the debris control structure. If a low standard of maintenance is anticipated, the designer should choose to pass the debris through the structure by ensuring adequate capacity.

5.3.5 Anticipate Reduced Capacity

Whereas the design capacity for a culvert installation may indicate an adequate installation purely from a hydrologic point of view, the possibility of reduced capacity must be anticipated. This is particularly important where there is ice, debris from logging or other forestry operations or debris from vandalism and littering. A culvert may require dramatic over sizing to allow passage of debris.

5.4 Flow Velocities in Culverts

5.4.1 Choose Design Velocities to Suit Existing Flow Conditions

The design flow velocity in culverts should be chosen to conform with existing natural upstream and downstream flow velocities. All factors which determine flow velocity through a culvert should be examined. These include:

- The slope of the culvert (grade on which it is placed),
- the roughness of the inside of the culvert,
- the design of the culvert inlet and outlet,
- the flow volume,
- the level or head of water at the inlet,
- backwater effects from downstream controls, and,
- the culvert type or more specifically the cross sectional shape which determines the perimeter in contact with the flowing water.

Low inlet and outlet flow velocities are preferred for all culvert installations. High velocity flow can result in undermining, erosion, and washouts of culverts and can also create an impasse to migrating fish. The flow velocity at times of normal flow conditions should not exceed 0.9 m/s except in instances where very steep natural channel grade and high velocity flow in the channel dictate a high flow velocity through the culvert.

5.4.2 Results of High Velocities

The downstream results of higher velocities may involve:

- bed scour
- bank erosion
- structural damage or overtopping of control structures
- undercutting of culvert.

If the velocity is dissipated quickly by the stream the main problems will be bed scour and undercutting in the immediate vicinity of the culvert. The flow velocity causes sufficient shear force to overcome the gravitational and frictional forces holding bed material in place. Transport velocities for streambed materials are given in **Table 5.1**.

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Table 5.1: Transport velocity for various sizes of streambed materials		
MATERIAL	PARTICLE SIZE mm	VELOCITY m/s
silt	0.005 - 0.05	0.15 - 0.30
sand	0.25 - 2.5	0.30 - 0.65
gravel	5.0 -15	0.80 - 1.20
pebble	25 - 75	1.40 - 2.40
cobble	100 - 200	2.70 - 3.90

5.4.3 Choose Correct Gradient

In most cases, culverts should be installed such that the gradeline coincides with the average streambed gradeline. Attempts to control flow velocity by changing the grade will have the following consequences:

a) Culvert grade greater than stream; inlet will be elevated causing upstream ponding or outlet will be submerged and the barrel will act as a silt and gravel trap, eventually becoming blocked.

b) Culvert grade less than stream; inlet will have a drop or outlet will be hanging.

Both cases will act as an obstruction for fish passage.

While some deviation from the stream grade may serve to decrease flow velocity in a culvert, calculations justifying this deviation must be performed. If the desired flow velocity cannot be achieved this way, then it is obvious that a bridge, rather than a culvert, is required.

5.5 Culvert Installation and Construction Practices

Improperly installed culverts are a waste of the owner’s money, a threat to aquatic life, and may be a threat to the users of any structure built over or adjacent to them. A photograph of a poor culvert installation is shown in **Figure 5.7**.

Figure 5.7 Poorly Installed Culverts

Figure 5.7 illustrates several obvious problems encountered with culvert installation. The pieces of corrugated metal lying in the water indicate that sections of culvert have failed under load and collapsed onto the stream bed. The culverts are projecting from the fill. There is no end protection to resist erosive action. It appears that the culverts have been placed haphazardly with very little concern for hydraulics, aesthetics, fish passage, or embankment protection. The embankment is poorly constructed and unstable.

Hopefully these guidelines will help installers avoid situations like the one pictured above.

5.5.1 Installation to Manufacturer's Specifications

The installation of all culverts should comply with the specifications prescribed by the manufacturer of that product, particularly in regard to pipe zone bedding material quality, degree of compaction, and minimum or maximum pipe cover for design loadings.

5.5.2 Operation of Heavy Equipment

The use of heavy equipment in waterbodies should be avoided. The operation of heavy equipment should be confined to dry stable areas.

5.5.3 Work During Times of Low Flow

All work involving minor alterations to the stream channel to permit culvert placement should be carried out at a time of low flow conditions. It is prudent however to be prepared for increased flows by scheduling work according to the weather forecast and to have a contingency plan for unexpectedly large runoff from a sudden storm.

5.5.4 Avoid In-Stream Excavation, Work in the Dry

In-stream excavation can cause considerable siltation and pollution of watercourses. If excavation of bed material or other extensive in-stream work is necessary, to make a level bed for the culvert for example, all flow should be diverted or confined to a section to allow the work to be carried out in the dry.

5.5.5 Control of Stream Flow for Culvert Placement

Streamflow may be controlled in any of a number of ways in order to provide a dry working area. Four methods which may be used include the following:

l. A temporary diversion channel. (See *Chapter 7, "Diversions, New Channels, Major Alterations"*).

2. A temporary culvert(s).

3. Pumping. (See *Chapter 10, "General Construction Practices"*).

4. Confining flow to a channel section by use of cofferdams. (See *Chapter 10, "General Construction Practices"*).

5.5.6 Culvert Gradient to Follow Stream Gradient

The gradient of all culverts as far as possible should follow the stream channel gradient and should be placed in line with the direction of the main flow.

5.5.7 Multiple Culvert Installations

In multiple (gang) culvert installations, one culvert should be set at an elevation lower than the others to provide adequate flow depth and velocity for fish passage during low flow conditions. **Figure 5.8** shows an example of culverts from two separate crossings having outlets at the same point. The elevation is not as much of a factor here since it is not a true gang culvert.

Figure 5.8 Two Culverts with a Shared Outlet Location

5.5.8 Place Culvert at Correct Elevation

Culverts should be placed at such an elevation that there is no ponding of water at the upstream inlet of the culvert and there is drop or hydraulic jump created at the outlet of the culvert. Similarly, outlets should not be submerged.

Large culverts may be countersunk into the channel bed. This also permits some gravel deposition in the culvert which creates a natural type of bed within the culvert.

5.5.9 Quality of Bedding and Backfill Material for Culverts

Suitable material of good quality should be used in backfilling culverts to ensure a good culvert installation. A compactable granular material "Granular Class B" quality or better is suitable for most installations. Cohesive soils or material containing large amounts of sand, fine silt or clay should not be used, because erosion of the material may result. Well graded granular material also provides better load carrying capability than poorly graded material or cohesive soils. Small culverts may be backfilled with the same material used to construct the road, provided that the material meets road construction standards. Larger culverts should be backfilled more carefully, using select material if necessary.

5.5.10 Procedure for Backfilling Culverts

Backfill material placed under the haunches of the pipe should be in intimate contact with the entire bottom surface of the structure. Pre-shaping the bedding material to match the culvert curvature may assist in this regard. Backfill material should be placed in layers not exceeding 300 mm in thickness and compacted with suitable hand operated compacting equipment. Backfilling should be done in a manner that will prevent any deformation or displacement of the culvert. Proper compaction is necessary to provide adequate load bearing capacity above the culvert, and is necessary to reduce the voids which can cause "piping effect". The soil compaction around the culvert should achieve 90% standard Proctor density or better. The major factors which influence soil compaction and which should be taken into consideration include the following:

- moisture content of the soil,
- nature of the soil, its gradation and physical properties,
- type and amount of compaction effort required.

Granular soil types are best compacted by applying a continuous vibratory action.

5.5.11 Removal of Shipping Supports

Large diameter culverts are often shipped with bracing to prevent deformation of the culvert during transport and installation. These braces should be removed upon completion of the work as they may contribute to blockages by debris or ice.

5.6 Culvert Inlet and Outlet Structures

Culvert end structures, pre-built or constructed in place are attached to the ends of culverts to reduce erosion, retain the fill, inhibit seepage, improve the aesthetics and hydraulic characteristics and make the ends structurally stable.

Headwalls may be made of concrete, lumber, steel sheet piling or rock either grouted or cemented or simply left plain. Headwalls are sometimes skewed relative to the culvert to fit the angle of crossing. Wingwalls may be used to aid in funnelling the approaching flow of water directly into the inlet and to prevent erosion on the stream banks adjacent to the culvert. **Figure 5.9** shows a masonry headwall and wingwalls.

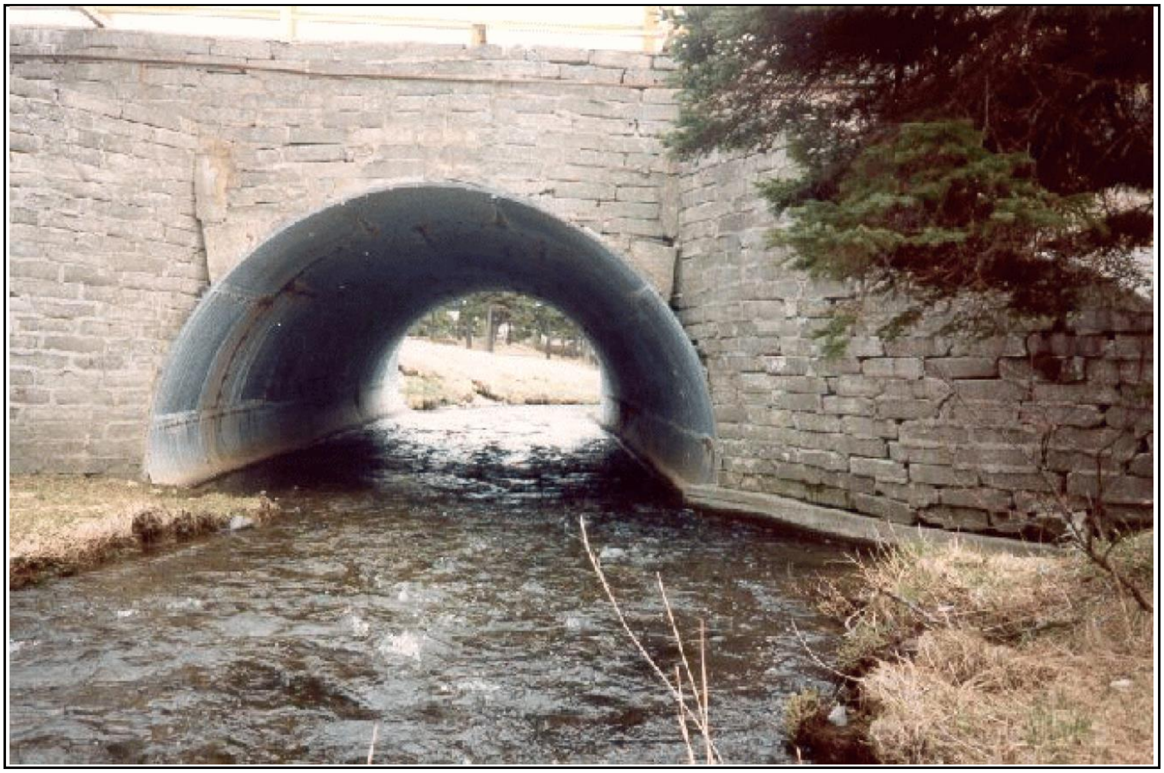

Figure 5.9 Pipe Arch Culvert with Masonry Headwall and Wingwalls

Larger culverts may be provided with specially shaped inlets. These inlets provide a smooth transition from a wide channel to a slightly narrower culvert barrel with the result that entrance losses are reduced and the culvert will effectively be able to carry a larger quantity of flow.

Special outlets or spill aprons are used to prevent erosion where high velocity flow re-enters the channel downstream. Trash Racks are optional end structures which serve to remove debris and also prevent unauthorized access.

5.6.1 Headwalls Required

Small sized culvert installations such as drainage culverts do not always require headwalls provided the fill is stable and is placed at a very mild slope. The necessity of providing headwalls generally increases with the culvert size.

5.6.2 Use of Armour Rock

Attractive, long term, economical and efficient protection of culvert inlet and outlet areas can be provided with rock when properly installed. Rock of sufficient size to form a permanent stable structure should be used. The foundation rocks should be set below the bed of the watercourse to prevent undermining. Wingwalls and headwalls of fitted rock should be leaned into the embankment at an inclination of at least 1/6 from the vertical axis to ensure stability. Joints can be pointed with concrete or mortar to provide a more uniform or water tight surface but the structure should not be dependent on the jointing material for structural stability. Where irregular or rubble rock is used to protect inlet and outlet areas, the rock should form a slope no steeper than one horizontal to one vertical and it should be well consolidated.

5.6.3 Use of Slope-Tapered Inlets

A tapered inlet slope provides less inlet head loss and thus can provide greater capacity and efficiency for culverts installations. Projecting culvert ends can be cut with a tapered slope to conform to the finished embankment slope and provides a neater and more aesthetically pleasing installation. Slope tapered inlets also provide less likelihood of serious blockage of the inlet by debris. However, special measures must be employed to prevent uplift of the projecting lip.

5.6.4 Use of Steel End Sections

A variety of steel end sections which are shop fabricated for assembly in the field, are available for attachment to corrugated steel pipe. These can provide better hydraulic inlet and outlet conditions and protection from erosion or scour of the road embankment and bed material, and can provide protection to the culvert ends as well.

5.6.5 Use of Concrete

Headwalls, wingwalls, spill aprons or other end structures constructed of cast in place concrete should be installed in accordance with the guidelines on use of concrete in *Chapter 10, "General Construction Practices"*.

5.6.6 Trash Racks Should be Sloped

Where a trash rack is used to catch debris and prevent it from entering a culvert, the rack should be installed with a low incline to prevent floating debris from being held against the rack by the flow (as with vertical trash racks) as this can cause serious flow constriction flooding, or washouts. An inclined rack allows debris to be pushed up to the top of the inlet structure where it will not seriously constrict flow and where it can be easily removed.

5.6.7 Use of Spill Aprons for Scour Protection

An apron of fitted rock or rip-rap can be installed at the outlet of a culvert to provide protection to the stream bed and prevent scour or undermining. Such a structure can also provide a sufficient roughness factor to reduce the velocity at the outlet thus providing further protection from erosion or scour. This is preferred to concrete or steel aprons which do not significantly reduce outlet velocities and which often cause scour of the bed material at the apron lip.

5.7 Inspection and Maintenance

5.7.1 Inspect Culverts Regularly

Culvert installations should be inspected regularly so that immediate action can be taken to clear blockages caused by ice or debris and to identify any apparent problems, such as erosion, which may require remedial action.

5.7.2 Inspect Culverts During and After Major Floods

An inspection of culverts should be made during and after major floods to observe the culvert operation and record high water marks. Conditions which require corrective maintenance should be noted including debris accumulations, silting, erosion, piping, scour, and structural damage. Performance information that reflects a need for design or construction changes due to unexpected large flood peaks should be submitted to the regulatory authority or owner for further action.

5.7.3 Establish a Culvert Maintenance Program

Culvert failures can be both disastrous and expensive. A comprehensive program for maintaining culverts in good repair and operating condition will reduce the probability of failures and prove to be cost effective. The program should include periodic inspections with supplemental inspections following flood events.

5.7.4 Mark Culvert Inlets and Outlets for Identification

All culvert inlets and outlets should be clearly marked so as to be identified during snow clearing and road grading operations.

5.7.5 Protect Inlets and Outlets

Inlet and outlet areas of culvert installations must be adequately protected by placing rip-rap, or fitted stone, or concrete headwalls to prevent bank had channel erosion.

5.7.6 Replace Damaged Culverts

Culverts which have been damaged by ice or debris, by improper installation or construction procedures, or are in a condition which could impair their proper functioning should be replaced immediately to prevent overtopping, erosion, or flooding.

5.7.7 Maintenance Access

Provisions for maintenance access are necessary especially where debris control structures are installed. A parking area for equipment such as a crane may be necessary in order to remove debris without disrupting traffic. Also such access should not disrupt the site rehabilitation efforts.