7.0 CHAPTER 7 - CULVERTS

7.1 GENERAL

For the purpose of this manual, culverts are defined as structures that are completely surrounded by soil and located below the surface of the roadway parallel to the general direction of the stream flow. A bridge-size culvert is defined as a culvert having equivalent flow area of 1500 mm diameter or greater. Bridge-size culverts receive Level 1 BIM inspections at regular intervals as outlined in the Level 1 BIM Manual.

Culverts can be timber, concrete or metal. Timber and concrete culverts are classified as "rigid culverts" and are designed to carry external loads without significant deflection. Metal culverts are classified as "flexible culverts". They consist of relatively thin corrugated metal which has low bending strength and they are dependent on the surrounding backfill for load carrying capacity.

Bridge-size culverts have proven to be an efficient and economical alternative to conventional bridge structures for small stream crossings and have been widely used in Alberta for the past 45 years. Approximately 52% of all stream crossings in the Province are bridge-size culverts. Of these, less than 1% are timber, less than 5% are concrete, and more than 94% are metal culverts.

7.2 TYPES OF CULVERTS

7.2.1 TIMBER CULVERTS

Before the development of the corrugated metal culverts, timber was commonly used for smaller culverts. However, timber culverts have not been used in Alberta for over 40 years and there are only a small number still in service. These culverts are box shape structures consisting of heavy timber members. They are fairly small compared to the large concrete and metal culverts used today. These culverts have performed fairly well over the years with rotting of the timber being the major defect.

7.2.2 CONCRETE CULVERTS

There are two main types of concrete culverts – concrete boxes and concrete arches. Concrete box culverts can be single or multi-cell consisting of rectangle shapes with a roof, sidewall and a floor (see picture Figure7.1). The concrete box culvert can be cast-in-place or precast. Concrete arch culverts consist of a concrete arch shape supported on a concrete footing (see picture Figure 7.2) and are normally cast-in-place but can be precast in segments. The footing is normally supported on the soil but can be supported on piles. The arch culvert may or may not have a concrete floor. If it does not have a concrete floor, there is generally some type of protection (e.g. large rocks) to prevent erosion of the stream bed through the culvert. The concrete arch culverts are normally larger than concrete box culverts.

Figure 7-1 Concrete Box Culvert

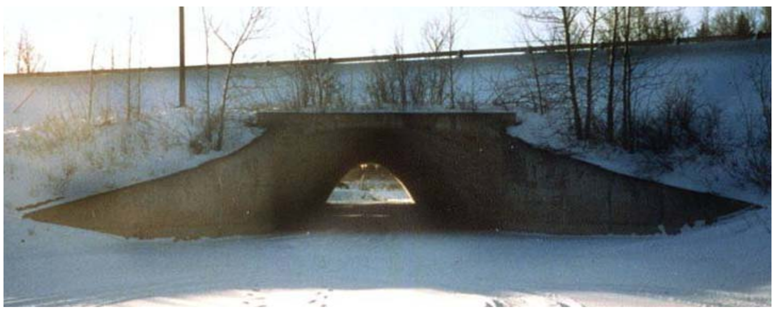

Figure 7-2 Concrete Arch Culvert

Before the development of large corrugated metal culverts, concrete culverts were commonly used for culverts beyond the size of timber culverts. The corrugated metal culverts are generally more economical to construct than concrete culverts and the number of concrete culverts constructed in Alberta in the past 40 years has been relatively small. Concrete culverts are still used where geotechnical problems prevent the use of metal culverts and for very large culverts that are beyond the normal limits for metal culverts. Concrete is also sometimes used in very corrosive environments where metal culverts would have a significantly shorter life.

Concrete culverts have proven to be very durable and do not have many maintenance problems. One of the main areas of defects in these culverts has been the culvert floor. They are often fairly thin and not well reinforced and they tend to crack and heave. They can be undermined and removed by high flows. With the floor removed the streambed can be eroded during flood conditions and this can lead to the failure of the culvert.

7.2.3 FLEXIBLE METAL CULVERTS (CSP/SPCSP)

These are by far the most common bridge-size culverts found in Alberta. Flexible culverts are constructed of thin metal plate (normally steel) that has been corrugated to increase its stiffness. However, these structures are still very flexible and depend on the soil surrounding the culverts to maintain their shape. These culverts fall into two main types: The Corrugated Steel Pipe (CSP) culvert and the Structural Plate Corrugated Steel Pipe (SPCSP) culvert. The CSP culvert is manufactured and installed in complete rings joined together by some type of coupler. The culverts are normally round but can be manufactured in arch shapes. The SPCSP culvert is constructed from segments of corrugated steel plate bent to various radii. These plates are bolted together along longitudinal and circumferential seams. Since the plates can be different radii, these culverts can be round, arch or elliptical in shape. They also do not have to be complete rings and can have open bottoms with the culvert wall supported by concrete footings (pictures of a SPCSP culvert can be seen in Figures 13.1 and 13.2 of the Level 1 BIM Manual).

Corrugated Profile & Plate Thickness
There are a number of different profiles for corrugated steel plate. The corrugation profile is defined by the pitch (the distance between two valleys or crests of the corrugation) and the depth (the distance between the valley and the crest of the corrugation). Also there are a number of different thicknesses of corrugated steel plates. Table 7.1 & 7.2 below shows the available profiles and plate thicknesses of corrugated steel plate. CSP culverts have four different corrugation profiles ranging from 38 x 6.5 mm to 125 x 26 mm and plate thicknesses of 1.0 mm to 4.3 mm. The smaller profiles and thicknesses are used for small drainage ditch and non bridge-size culverts with the larger profiles and thicknesses being used for the larger bridge-size culverts. CSP culverts are available up to approximately 3 metres diameter.

	Corrugated Steel Pipe (CSP/CMP)	**Structural Plate Corrugated Steel Pipe (SPCSP/SPCMP)**
Corrugation Profiles (pitch x depth)	38 X 6.5 mm	152 x 51 mm
	68 x 13 mm	380 x 140 mm
	76 x 25 mm	400 x 150 mm
	125 x 26 mm	

Table 7.1 Corrugation Profile

Corrugated Steel Pipe (CSP)		**Structural Plate Corrugated Steel Pipe (SPCSP)**
Gauge	Nominal mm	Nominal mm
20	1.0	3
18	1.3	4
16	1.6	5
14	2.0	6
12	2.8	7
10	3.5	8
8	4.3	

Table 7.2 Plate Thickness for CSP and SPCSP

Until fairly recently SPCSP profiles were manufactured with only one profile (152 x 51 mm) with plate thicknesses up to 7 mm. This SPCSP profile could be used for construction of culverts up to approximately 6 metres diameter. About 10 years ago corrugated metal culvert manufacturers developed larger corrugation profiles (380 x 140 mm and 400 x 150 mm) with plate thicknesses up to 8 mm. These profiles allowed the construction of much larger culverts with spans up to 25 metres. These larger corrugation profiles are commonly referred to by the different manufacturer's trade names of Super-Cor and Bridge-Plate.

The Super-Cor and Bridge-Plate profiles have become popular for open bottom type culverts. These larger profiles have permitted these open bottom culverts with fairly long spans to be used for roadway and animal underpasses as well as stream crossings. There are a number of different shapes for these open bottom culverts and some of these shapes are illustrated in Figure 7.3. below.

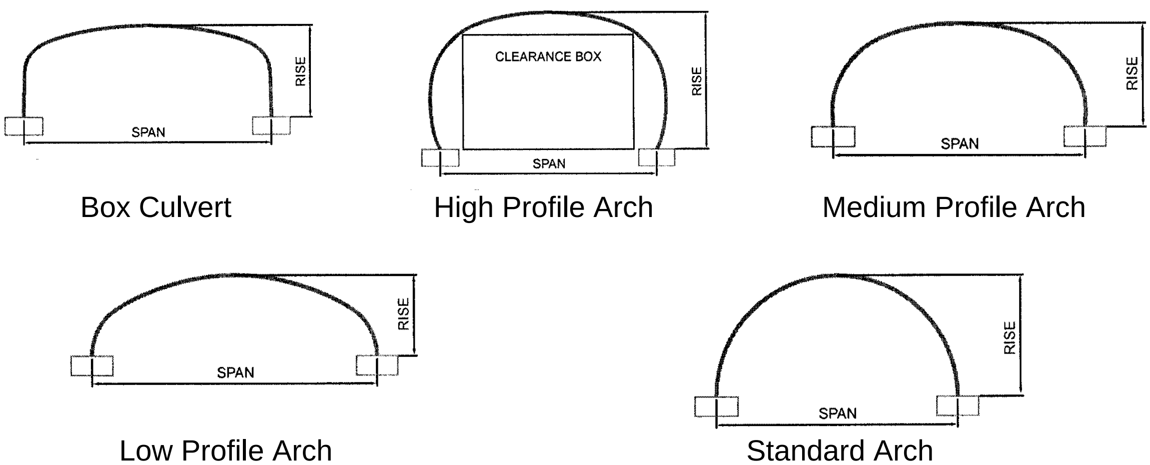

Figure 7-3 Open Bottom Culvert Shapes

7.2.4 ARCH BEAM CULVERT (ABC) AND CULVERT ARCH BEAM (CAB)

There are two hybrid type culverts which are sometimes used in Alberta. They are both corrugated metal culverts that use a composite concrete slab for part of the structure. The Arch Beam Culvert (ABC) is a horizontal elliptical structural plate culvert with a composite concrete slab which extends over the sidewall backfill (see Figure 7.4). This culvert is used for situations with low fill cover where the composite concrete slab is required to carry live load stresses. These types of culverts are common on irrigation canal crossings. The Culvert Arch Beam (CAB) is a vertical arch shape with a composite concrete slab on the top portion of the arch which has a slotted angle iron joint along each spring line to allow for a small amount of differential movement between the composite top arch and the bottom section of the culvert to avoid cracking of the seams at the spring line.

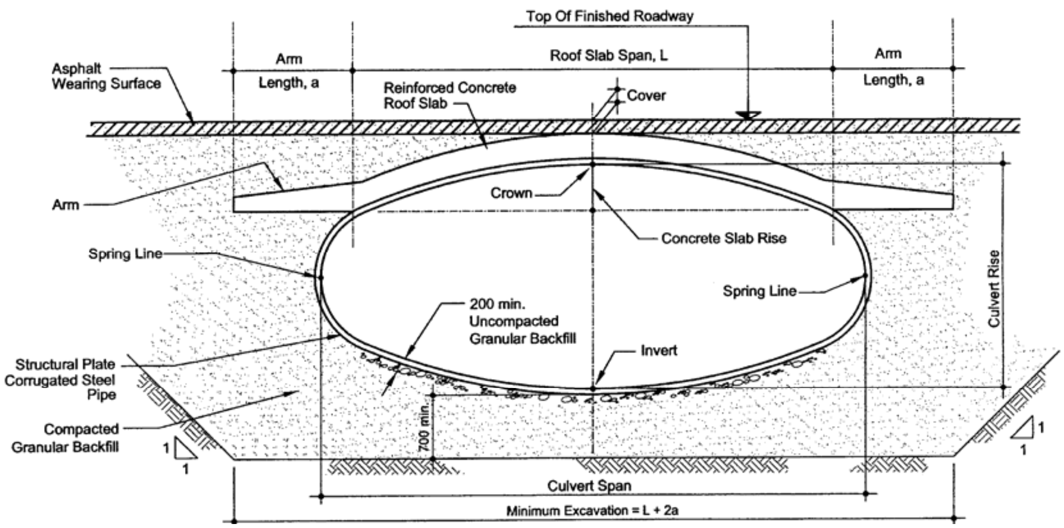

Figure 7-4 Arch Beam Culvert (ABC)

7.3 CULVERT CORROSION PROTECTION

7.3.1 CULVERT COATINGS

All corrugated steel culverts have some type of coating to protect the steel from corrosion. The available coatings for corrugated steel (in order of increasing cost) are galvanized, double galvanized, aluminized or polymer coating. The corrosion of a steel culvert is a function of the pH and the conductivity of the soil and water at the culvert site. Lower pH (more acidity) and higher conductivity (lower resistivity) are more corrosive for the culvert. The normal expected life for coatings of a culvert plate is a 50 year life to first perforation of the culvert plate. The Department has developed a best practice guideline for selection of steel culvert coatings based on this 50 year life and this guideline can be found on the Department's website.

Normal galvanizing (610g/m^2) will give a 50 year perforation life for most site conditions found in Alberta and is by far the most common coating used for steel culverts. Double galvanizing (1220g/m^2) increases the amount of zinc coating on the metal surface and can be used in conditions of lower resistivity and lower pH than normal galvanizing. In the field a bridge inspector will normally not be able to distinguish between galvanized and double galvanized plate. Aluminum coating gives very good protection to the steel in areas of low resistivity but in not recommended for conditions of pH<5.0. Polymer coated culverts are the most resistant to corrosion in areas of low pH and low resistivity. It would normally only be used in very aggressive environments and is not commonly used for metal culverts in Alberta. Also, in very aggressive corrosion environments, concrete pipe culverts are sometimes used.

7.3.2 CATHODIC PROTECTION

Another method of protecting metal culverts from corrosion is a cathodic protection system. Corrosion of metal is an electro-chemical process which involves the creation of small electric cells with flow of electrons from one area (the anode) to the other area (the cathode). Corrosion or loss of section occurs at the anode. A cathodic protection system involves the establishment of an anode external to the structure being protected making the structure the cathode. There are two types of cathodic protection systems. There are passive systems in which a sacrificial anode of metal with high corrosion potential is electrically connected to the structure (the cathode) and there are impressed current systems in which an external power source is used to impose a current from an inert (low dissolution) anode to the structure (the cathode).

The zinc and aluminum coatings used for corrugated steel culverts are really a form of a sacrificial anode system in that the zinc and aluminum will sacrifice itself to protect the steel. However, this is not normally thought of as a cathodic protection system. Cathodic protection systems are commonly used to protect oil and gas pipelines. These systems are not commonly used for large culverts. However, cathodic protection systems have been used for a small number of culverts in Alberta. These have been at sites where the normal coatings have shown premature failure due to an aggressive corrosion environment and the cathodic protection systems have been installed to extend the life of the culverts.

Most of the cathodic protection systems used for bridge-size culverts in Alberta are impressed current systems. Where there has been a power source fairly close to the culvert site, these systems have been fairly economical to install. However, the systems require regular maintenance and monitoring to assure that the system is working properly.

7.4 COMMON PROBLEMS/DEFECTS

Deformation

For flexible culverts, deformation of the designed shape of the culvert is a common problem (see picture Figure 7.5). Corrugated metal culverts are fairly weak in bending and depend on the soil around the culverts to maintain their shape. It is very important that the backfill around the culvert is properly compacted. Poor backfill practices have lead to deformations of the roof and the sidewalls of the culvert. Major deformations, especially with the roof of the culvert, can lead to collapse of the culvert (see picture Figure 7.6).

Figure 7-5 Deformation of culvert shape

Figure 7-6 Collapsed culvert

Cracked Longitudinal Seams

The SPCSP culverts have longitudinal seams between segments where the corrugated plates are lapped and bolted. A common defect of these seams is cracking of the plate between the bolt holes (see picture Figure 7.7). These cracks are due to bending stresses that are induced into the joint. In theory there are no bending moments at these joints and the forces are carried across the joint in ring compression. However, in practice, for various reasons these longitudinal joints are often subject to bending stresses. Some causes are:

- The lapped plates may not rest properly due to improper fabrication or assembly of the plates.
- The soil at the joint may not provide proper support due to improper backfill.
- The bolts at the joint may be over-torqued.

The bending capacity of the joint is dependent on the lap of the plates. A joint (seam) that has the plates lapped so that the bolts in the valley are nearer the visible edge of the plates has significantly greater bending capacity than a joint (seam) that has a lap with the bolts on the crest nearer the visible edge. Therefore, seams with improper laps are much more likely to crack from bending stresses induced into the seam.

Figure 7-7 Cracking of plate between bolt holes

Separated Circumferential Seams
The CSP culverts are manufactured in complete rings which are joined at circumferential seams generally with some type of coupler. These circumferential seams can sometimes become separated due to movement of the surrounding soil allowing fill material into the culvert.

Corrosion
Corrosion is a common problem with metal culverts. The corrosion can be due to the water or the soil or both. Corrosion due to water can be easily seen during an inspection (see picture Figure 7.8). However, corrosion due to the soil is harder to detect but is sometimes noticeable by rust staining coming through the bolt holes above the waterline (see picture Figure 7.9).

Figure 7-8 Corrosion due to water

Figure 7-9 Corrosion due to soil

Cracking of Concrete Floors
Cracking and heaving of the floor of concrete culverts is a common problem. This can be a serious defect since severe cracking and heaving of the floor can lead to its removal during high flows and possible undermining and failure of the culvert.

Scour and Other Hydraulic Problems
Scour is a common problem for both concrete and metal culverts (see picture Figure 7.10). Culverts normally restrict the stream flow at their location and cause higher velocities of the water

particularly in flood situations. Since the stream is being restricted, improper transition between the stream and the culvert section may cause scour. Also the alignment of the stream at either end of the culvert may cause scour problems.

Figure 7-10 Culvert scour

The restriction in stream opening at the culvert can also cause problems with debris catching at the ends and partially or completely blocking the stream flow. Removal of debris accumulation is a regular maintenance item for culverts.

7.5 REPAIR OF CULVERTS

Strutting

Strutting is one of the most common repair procedures used for metal culverts. Timber or steel struts are installed inside the culvert. The struts are supported on the top and bottom by longitudinal beams (see picture Figure 7.11). Strutting is used for problems with deformation and/or cracking of longitudinal seams. It is generally considered a temporary repair which is used to prevent a complete collapse of the culvert. It is often used to keep a culvert in service for a number of years until it can be replaced. However, struts have been used successfully in some culverts for long periods of time. The main problem with this type of a repair is that the struts can be removed by the force of debris during floods or the debris can catch on the struts and completely block the culvert.

Figure 7-11 Strutting

Shotcrete/Concrete Beams

Shotcrete beams are used to repair cracked longitudinal seams on culverts that have serious cracks of longitudinal seams but do not have other significant defects such as deformation or corrosion. The repair method consists of attaching anchors to the culvert plate on each side of the seam, placing reinforcing steel, and covering the anchors and reinforcing steel with shotcrete concrete (see picture Figure 7.12). The shotcrete beam helps transmit the ring compression forces in the culvert across the longitudinal seam. It also holds the plates at the seam in place so that they cannot slide past each other if the plate cracks completely between the bolt holes. The shotcrete beam is normally an economical repair if there is only one or two cracked longitudinal seams in a culvert ring. . If there are more than two cracked seams in a ring, a culvert liner maybe more cost effective. Recently, cast-in-place concrete beams have been used in place of shotcrete beams.

Figure 7-12 Shotcrete beam

Culvert Liners

Culvert liner repairs involve the placing of another culvert inside the existing culvert and grouting the space between the two culverts with concrete. The culvert liner can be a complete culvert that is dragged inside the existing culvert (see pictures Figure 7.13) or it can be assembled from culvert liner plates inside the culvert. Culvert liners can be used for culverts with a number of different problems, eg. corrosion, cracked or separated culvert seams, and moderate deformations. The culvert liner reduces the size and the hydraulic capacity of the culvert. If the culvert has some excess hydraulic capacity or if the culvert site allows for the culvert to operate under a head, this type of repair is feasible. Sometimes smooth wall pipe can be used for the culvert liner which can restore some or all of the hydraulic capacity lost with decreased size. Culvert liners can be used for only part of the length of the culvert (if defects are only in that part) or for the whole length of the culvert. A culvert liner can be an expensive method of repair especially for the entire length of the culvert. If the culvert is in a relatively shallow fill, it is generally more economical to completely replace the culvert. However, under high fills or for high volume roadways, culvert liners can be very cost effective.

Figure 7-13 Culvert liner

Concrete Floors

Concrete culverts often have problems with cracking and heaving of their concrete floors. Replacement of these floors in low flow conditions can be a cost effective repair. Also for metal culverts that have problems with corrosion from the water at the bottom of the culvert placing a concrete floor can be an economical repair. Metal arch culverts often have problems with cracking at the haunches of the arch, and corrosion and heaving problems with the floor. A reinforced concrete floor with partial height concrete walls up the sides of the culvert can be used to repair these problems (see picture Figure 7.14).

Figure 7-14 Concrete floor with partial concrete walls

Rock Rip Rap/Scour Repair

Scour and erosion are common problems with culverts and placement of rock rip rap is the most common method for repair of these problems. Rock rip rap is classified by size of the rock and range from Class 1M (average size 200 mm) to Class lll (average size 900 mm). Large rock is used for larger culverts with higher stream flows. Class lll rock rip rap would only be used for very large culverts. For repair of scour problems it is generally necessary to place fill in the scour holes before placing the rock rip rap. Filter cloth is placed on the fill material before placing the rock to prevent this material from being undermined by the stream flow. Filter cloth is also now normally placed under all rock rip rap. Below are some pictures of rock rip rap repairs of culverts (Figures 7.15 to 7.17).

Figure 7-15 Rock Rip Rap at culvert outlet

Figure 7-16 Scour repair

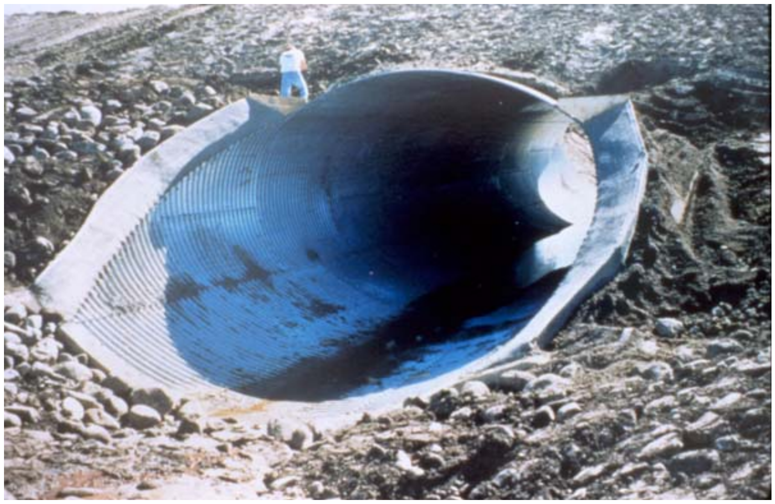

Figure 7-17 Rock Rip Rap being placed at new culvert

7.6 CULVERT SIZE/HYDRAULIC CAPACITY

A culvert must be capable of accommodating the flow of the stream in flood conditions without causing significant damage to the land and property surrounding the culvert. Culverts may sometimes run under a head backing up the water levels and causing some upstream flooding. If the culvert is located in an area where this flooding does not have significant impact it may be acceptable. Also many streams will have debris during flood conditions and culverts are designed to have some free board during flood conditions to pass this debris. Determining the volume of water a culvert may need to accommodate during a flood event can be difficult and there is a whole area of hydrotechnical engineering devoted to this field. There are statistical methods available to predict flood flows based on previously recorded flood events. These predicted flows are assigned probabilities of occurring e.g. 1 in 25 years, 1 in 100 years, etc. and depending on the importance of the crossing, a culvert would be designed for a particular return period. Most major streams have gauge stations where flood flows have been recorded for many years and significant data is available. However, for most small streams where culverts are used, there are few if any records. Therefore, using conventional statistical methods to predict flood flows can be very inaccurate.

The Department has recently developed a new approach to determine culvert design flows which is commonly referred to as the Run-Off Depth Method. This method uses historical rainfall records and the drainage area of the culvert to determine a maximum flow for the culvert. Environment Canada has very old and detailed records of rainfall and it is believed that this approach to determining the flood design flow will give better results than earlier methods. Details on the Department's Run-Off Depth Methods can be found on the Department's website. There are sometimes other factors besides accommodation of extreme floods that need to be considered when determining the size of a culvert. Fish passage will be a requirement in most streams and this may require low culvert velocity at regular flood events which may govern the size of the culvert. Also for navigable streams the ability to accommodate watercraft may govern the size of the culvert.

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