

## **4.4 Culvert Materials**

### **4.4.1 General**



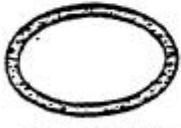





Culverts are primarily made with reinforced concrete, corrugated metal, and more recently, solid-wall, profile wall, and reinforced plastic. The strength and physical characteristics of the materials depend upon their chemistry and the interrelationship between the constituent materials. Metals and plastic are homogeneous isotropic materials whereas concrete and masonry is a mixture or combination of materials. The method by which the materials are connected significantly influences whether the strength of the materials may be utilized structurally.

### **4.4.2 Concrete**

Culverts may be made with either precast or cast-in-place reinforced concrete. This selection depends on the size and complexity of the culvert design. Precast sections are uniform in size and shape and are made in sections that can easily be transported, lifted, and installed. Cast-in-place concrete construction is often used when ready-mix concrete is available and when the culvert should be constructed without joints. Precast concrete culverts may be made with high strength concrete, whereas cast-in-place concrete culverts may have special reinforcement at critical locations to resist high loads and stresses.

- **Precast** – Precast concrete pipe is manufactured in eight standard shapes: circular, arch, horizontal elliptical, vertical elliptical, pipe arch, box sections, three-sided arch top, and flat top sections, as shown in Table 4-1. With the exception of box culverts, concrete culvert pipe is manufactured in up to five standard strength classifications. The higher the classification number the higher the strength. Box culverts are designed for various depths of cover and live loads. All of the standard shapes are manufactured in a wide range of sizes. Circular and elliptical pipes are available with standard sizes as large as 3600 mm (144 inches) in diameter, with larger sizes available as special designs. Standard box sections are also available with spans as large as 3600 mm (144 inches). Precast concrete arches on cast-in-place footings are available with spans up to 12.2 m (40 feet).
- **Cast-in-place** – Reinforced culverts that are cast-in-place are typically either rectangular or arch-shaped. The rectangular or box shape is more common and is usually constructed with multiple cells (barrels) to accommodate longer spans. One advantage of cast-in-place construction is that the culvert can be designed to meet the specific requirements of a site. Due to the longer construction time of cast-in-place culverts, precast concrete or corrugated metal culverts are often selected. However, in many areas cast-in-place culverts may be more practical.
- **Shapes** – By the very nature of it, reinforced concrete may be used to make virtually any structural shape desired. Thus, if necessary and feasible, it is possible to make almost any shaped culvert with either precast or cast-in-place reinforced concrete.

Table 4-1 Standard concrete pipe shapes

SHAPE	RANGE OF SIZES	COMMON USES
<p>CIRCULAR</p> 	<p>300 to 400mm (12 to 180 in) reinforced 100 to 900mm (4 to 36 in) non-reinforced</p>	<p>Culverts, storm drains, and sewers.</p>
<p>PIPE ARCH</p> 	<p>375 to 3300 mm (15 to 132 in) equivalent diameter</p>	<p>Culverts, storm drains, and sewers. Used where head is limited.</p>
<p>HORIZONTAL ELLIPSE</p> 	<p>Span X Rise 450 to 3600 mm (18 to 144 in) equivalent diameter</p>	<p>Culverts, storm drains, and sewers. Used where head is limited.</p>
<p>VERTICAL ELLIPSE</p> 	<p>Span X Rise 900 to 3600 mm (36 to 144 in) equivalent diameter</p>	<p>Used where lateral clearance is limited.</p>
<p>RECTANGULAR (box sections)</p> 	<p>Span 0.9 to 3.6 m (3 to 12 ft)</p>	<p>Culverts, storm drains, and sewers. Used for wide openings with limited head.</p>
<p>ARCH</p> 	<p>Span 7.2 to 12.3 m (24 to 41 ft)</p>	<p>Culverts and storm drains. For low, Wide waterway enclosures.</p>
<p>FLAT TOP 3-SIDED</p> 	<p>Span 4.2 to 10.5 m (14 to 35 ft)</p>	<p>Culverts and storm drains. For low, Wide waterway enclosures.</p>
<p>ARCH TOP 3-SIDED</p> 	<p>Span 4.8 to 10.8 m (16 to 36 ft)</p>	<p>Culverts and storm drains. For low, Wide waterway enclosures.</p>

### 4.4.3 Corrugated Steel

Corrugated steel culverts are made with factory-produced corrugated sheet steel. Corrugated pipe culverts are made with factory-produced corrugated pipe sections. Large corrugated culverts are normally field-assembled using structural plate products. Structural plate steel products are available as structural plate pipes, box culverts, or long span structures. Standard shapes for corrugated steel culverts are shown on Table 4-2.

- **Material** – Corrugated steel pipe is fabricated from sheets coated with zinc or aluminum. It is reasonably lightweight for shipping and comes in a large range of thicknesses and corrugations to provide the appropriate strength. However, it requires controlled backfill for proper soil support. Other options include various coatings and/or pavings for added protection.
- **Shapes** – Corrugated steel may be used for a wide variety of shapes, sizes, and lengths of culverts. The culverts may be made from prefabricated sections that are factory produced or assembled in the field from specially fabricated plates. The shapes may be made from various thicknesses of plate stock.

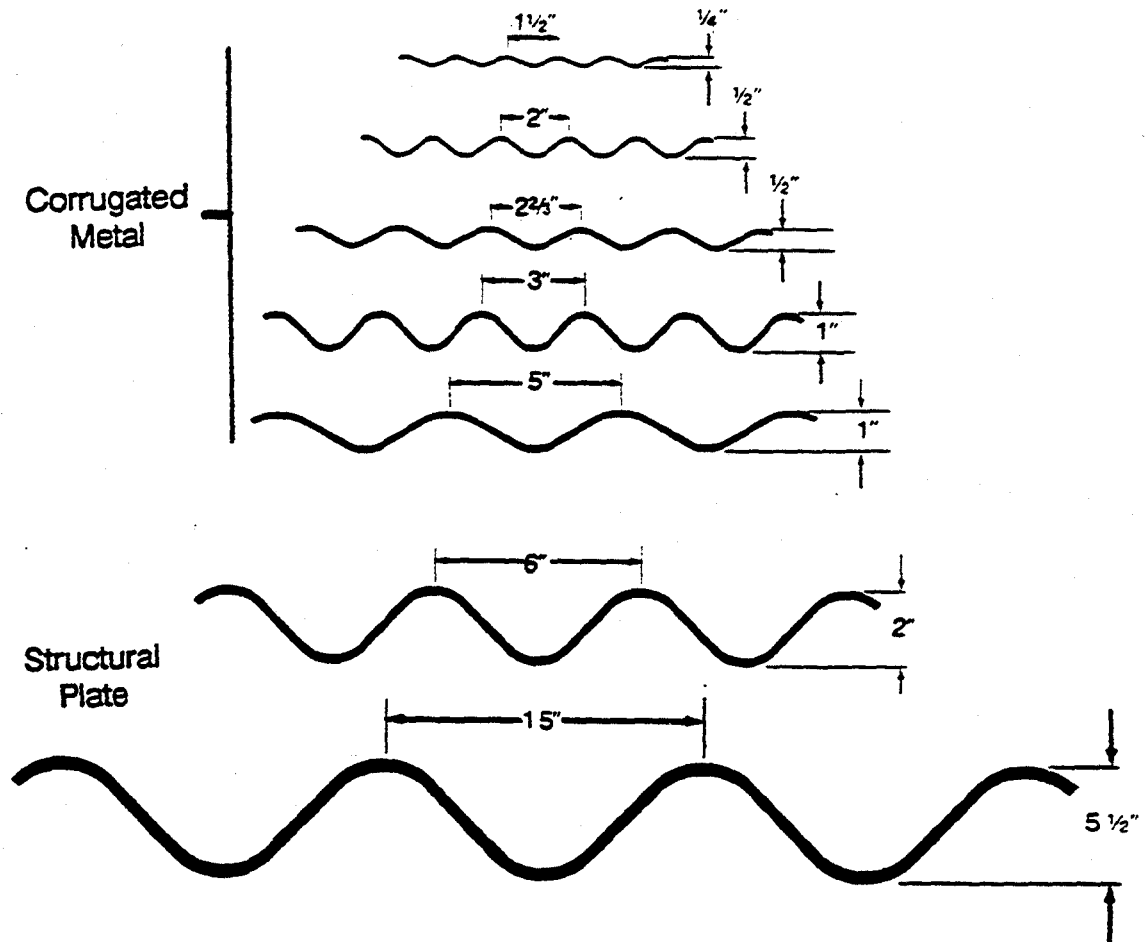
**Pipe** – Corrugated steel pipe is factory made in two basic shapes: round and pipe arch. Both round and arch shapes are available in a wide range of standard sizes. Round pipe is available in standard sizes up to 3600 mm (144 inches) in diameter. Standard sizes for pipe arch are available in sizes up to the equivalent of 3000 mm (120 inch) diameter round pipe. Both shapes are produced in several wall thicknesses, several corrugation sizes, as shown in Figure 4-10 and with annular (circumferential) or helical (spiral) corrugations.

Pipes with annular corrugations have riveted, spot welded, or bolted seams. Pipes with helical corrugations have continuously welded seams or lock seams. Corrugated steel pipe and pipe arch are usually coated with zinc (galvanized) or aluminum. Additional protective coatings are used with the metallic coating when there are potential corrosion or abrasion problems.

**Structural plate** – Structural plate steel pipes are field assembled from standard corrugated galvanized steel plates. Standard plates have corrugations with a 150mm (6-inch) pitch and a depth of 50 mm (2 inches). Plates are manufactured in a variety of thicknesses and are pre-curved for the size and shape of the structure to be erected. Standard plates have a nominal length of either 3 m or 3.7m (10 or 12 feet) and are produced in standard widths of 3N, 5N, 6N, 7N, and 8N, where N equals 3 pi or 244 mm (9.6 inches). Widths are measured along the circumference of the structure. Since the circumference of a circle equals pi times the diameter, the use of dimensions expressed in N or pi permits easy conversion from pipe circumference of 60 pi or 20N and would normally be assembled from four 5N plates. Structural plate pipes are available in six basic shapes: round, pipe arch, arch, vertical ellipse, horizontal ellipse, and underpass. The standard sizes available range in span from 1.5 m to 7.9m (5 feet to 26 feet).

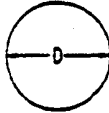
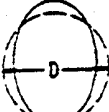
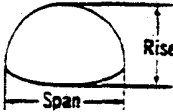
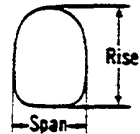


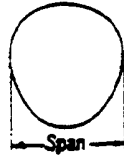
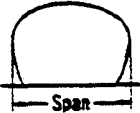


**Box** – Steel box sections use standard 150 by 50 mm (6 by 2 inch) corrugated galvanized steel plates with special reinforcing elements applied to the areas of maximum moment or 375 by 140 mm (15 by 5 1/2 inches) corrugated plate without ribs. Steel box culverts are available with spans that range from 3m (9 feet 8 inches) to 6.3m (20 feet 9 inches).

**Long span** – Long span steel structures are assembled using conventional 150 by 50 mm (6 by 2 inch) corrugated galvanized steel plates with longitudinal or circumferential stiffening members or 375 by 140 mm (15 by 5 ½ inch) corrugated plate without ribs. There are five standard shapes for long span structures: horizontal elliptical, pipe arch, low profile arch, high profile arch, and pear shape. The long span pipe arch is not commonly used. The span lengths of typical sections range from 5.9m (19 feet 4 inches) to 12.2 m (40 feet). Longer spans are available for some shapes as special designs.



**Figure 4-10 Common corrugated patterns (not to scale) (English only)**

Table 4-2 Standard corrugated steel culvert shapes (English only)

Shape	Range of Sizes	Common Uses
Round 	6 in. - 26 ft.	Culverts, subdrains, sewers, service tunnels, etc. All plates same radius. For medium and high fills (or trenches).
Vertically-elongated (ellipse) 5% is common 	4 - 21 ft. nominal; before elongating	Culverts, sewers, service tunnels, recovery tunnels. Plates of varying radii; shop fabrication. For appearance and where backfill compaction is only moderate.
Pipe-arch 	Span x Rise 17 in. x 13 in. to 20 ft. 7 in. x 13 ft. 2 in.	Where headroom is limited. Has hydraulic advantages at low flows. Corner plate radius. 18 inches or 31 inches for structural plate.
Underpass* 	Span x Rise 5 ft. 8 in. x 5 ft. 9 in. to 20 ft. 4 in. x 17 ft. 9 in.	For pedestrians, livestock or vehicles (structural plate).
Arch 	Span x Rise 6 ft. x 1 ft. 9 1/2 in. to 25 ft. x 12 ft. 6 in.	For low clearance large waterway opening, and aesthetics (structural plate).
Horizontal Ellipse 	Span 7 - 40 ft.	Culverts, grade separations, storm sewers, tunnels.
Pear 	Span 25 - 30 ft.	Grade separations, culverts, storm sewers, tunnels.
High Profile Arch 	Span 20 - 45 ft.	Grade separations, culverts, storm sewers, tunnels, ammo ammunition magazines, earth covered storage.
Low Profile Arch 	Span 20 - 50 ft.	Low-Wide waterway enclosures, culverts, storm sewers.
Box Culverts 	Span 10 - 26 ft.	Low-Wide waterway enclosures, culverts, storm sewers.
Specials	Various	For lining old structures or other special purposes. Special fabrication.

\*For equal area or clearance, the round shape is generally more economical and simpler to assemble.

#### 4.4.4 Corrugated Aluminum

Corrugated aluminum culverts are constructed from factory assembled corrugated aluminum pipe or field assembled from structural plates. Structural plate aluminum culverts are available as conventional structural plate structures, box culverts, or long span structures.

- **Material** – Corrugated aluminum pipe is fabricated from aluminum-alloy sheets. It is very lightweight for shipping and handling. It has good resistance to corrosion, especially in brackish waters but is subject to abrasion in fast-flowing streams with a significant load of sand or rock. It is generally more flexible than steel, requires greater care in installation, and is less tolerant of less-than-normal cover.

- **Shapes** – Corrugated aluminum may be used for a wide variety of shapes, sizes, and lengths of culverts. The culverts may be made from prefabricated sections that are factory produced or assembled in the field from specially fabricated plates. The shapes may be made from various thickness of plate stock.

**Pipe** - Factory assembled aluminum pipe is available in two basic shapes: round and pipe arch. Both shapes are produced with several different wall thicknesses, several corrugation patterns, and with annular (circumferential) or helical (spiral) corrugations. Round aluminum pipe is available in standard sizes up to 3000 mm (120 inches) in nominal diameter. Aluminum arch pipe is available in sizes up to the equivalent of a 2400 mm (96-inch) diameter round pipe.

**Structural plate** - Structural plate aluminum pipes are field assembled with 228 mm (9-inch)-pitch by 64 mm (2.5-inch)-depth corrugations. Plates are manufactured in a variety of plate thicknesses and are pre-curved for the specific size and shape of the structure to be erected. Plates are manufactured in lengths of SN through 18N, where N equals 3 pi or 244 mm (9.625 inches). Plate length is measured along the circumference of the structure. Standard plates have a net width of 1.4 m (4.5 ft.). Structural plate aluminum pipes are produced in five basic shapes: round, pipe arch, arch, pedestrian/animal underpass, and vehicle underpass. A wide range of standard sizes is available for each shape. Spans as large as 7.9 m (26 feet) can be obtained for the arch shape.

**Box** - The aluminum box culvert utilizes standard aluminum structural plates with aluminum rib reinforcing added in the areas of maximum moments. Ribs are bolted to the exterior of the aluminum shell during installation. Aluminum box culverts are suitable for shallow depths of fill and are available with spans ranging from 2.7 m (8 feet 9 inches) to 7.7m (25 feet 5 inches).

**Long Span** - Long span aluminum structures are assembled using conventional 225 by 64 mm (9- by 2.5-inch) corrugated aluminum plates and aluminum rib stiffeners. Long span aluminum structures are available in the same five basic shapes as steel long spans: including horizontal ellipse, pipe arch, low profile arch, high profile arch, and pear shape. The typical sizes for aluminum spans are essentially the same as the typical sizes available for steel long span structures. Spans range from 5.9 m (19 feet 4 inches) to 12.2 m (40 feet).

#### 4.4.5 Plastic

“Plastic” pipe is as unspecified a term as is “metal” pipe. There are many types of materials that may be used to produce plastic pipe, and the resulting pipe will have strength and other properties that vary accordingly. The properties of the plastic will depend primarily on the type of base resin that is used as well as the blend (or formulation) of chemicals in the final resin material that is used to produce the pipe. Just as with the design of concrete mixes, it is a common practice to use special additives with the basic resin to facilitate the production process and/or to alter the resulting physical and chemical properties of the finished product.

In general, plastics may be divided into two basic groups: (1) thermoplastics and (2) thermosetting plastics. The primary difference between these classes of material is that thermoplastics may be remelted and reshaped whereas thermosetting plastic cannot be remelted. Thus, the strength and other properties of thermoplastics will depend on the ambient temperature, and thermosetting plastics will retain their strength properties under a wide range of temperatures. The strength of these plastics will depend more on the types of resins that are used than on whether they are thermoplastics or thermosetting plastics.

Although both types of plastic may be used for culvert and drainage products, they are usually constructed from thermoplastic-type materials, which are less expensive and more easily used to manufacture. Two of the most popular types of material that are used are polyvinyl chloride (PVC) and polyethylene (PE). Thermosetting type resins are commonly used for pipe that must handle fluids at high temperatures.

Plastic drainage products may also be classified according to whether they are made just of plastic or whether the plastic is reinforced with fibers, typically glass fibers. The latter may be called “fiberglass” pipe. Since glass fibers have a filament strength of over 2067 n/mm<sup>2</sup> (300,000 psi), pipe products that are made with long continuous glass fibers will have greater strength properties over unreinforced plastic pipe.

- Polyvinyl Chloride (PVC) - Polyvinyl Chloride piping is made only from compounds that do not contain plasticizers and minimal quantities of other ingredients. It has been labeled as rigid PVC in the United States to distinguish it from flexible or plasticized PVCs from which such items as laboratory tubing, luggage, and upholstery are made. This pipe exhibits good long-term strength with high stiffness. It is for this reason that PVC has become an important material for both pressure and nonpressure pipe applications. There is a much broader range of PVC fittings, valves, and appurtenances available than in any other plastic. The pipe is manufactured in both solid wall and profile wall in sizes up to 1200 mm (48 inches).

- Polyethylene (PE) - Polyethylene is perhaps the most well known of the plastics in the polyolefin group. These are plastics that are formed by the polymerization of straight chain hydrocarbons that are known as olefins. They include ethylene, propylene, and butylene. PE piping is tough and flexible, even at subfreezing temperatures. PE pipe has good abrasion resistance and is available in solid wall and profile wall with diameters up to 2400 mm (96 inches). It is often used to slipline deteriorating pipes.

#### 4.4.6 Other Materials

- Masonry - Stone and brick are durable, low maintenance materials. Prior to the 1920's, both were used frequently in railroad and road construction projects because they were readily available from rock cuts or local brickyards. Although stone and brick are seldom used for

constructing culvert barrels, stone is used occasionally for this purpose in locations that have very acid runoff. The most common use of stone is for headwalls where a rustic or scenic appearance is desired. Brick is frequently used in the construction of manholes and inlets in storm drainage systems, because it may easily be built up without the need for formwork.

- **Vitrified Clay Pipe** - Vitrified clay pipe is manufactured from clays and shales that are the mineral aggregates remaining after the weathering process of nature. This weathering process leaches out the soluble and reactive minerals from the rock and soil, leaving an inert material. This chemically inert material is then burned in kilns at 1000-2100 degrees Fahrenheit at which "vitrification" occurs and the clay particles become fused into an inert chemically stable compound.

Vitrified clay pipe is resistant to internal and external attack from acids, alkalies, gases, and solvents. It is resistant to abrasion and scour and will not corrode.

- **Cast Iron** - Cast iron is iron in which carbon has been dissolved. It is generally no longer used for culvert construction. It has poor tensile strength and is brittle and susceptible to cracking. The shapes are cast and are bulky in comparison to steel. Cast iron does, however, exhibit good corrosion resistance.

#### 4.4.7 Coatings for Culvert Materials

A variety of types of coatings may be used either singularly or in a combination of layers to protect culverts from chemical and/or abrasion attack. The type(s) of coatings will depend upon the type of culvert material and the types of deterioration or distress they incur. The necessity for protective coatings depends upon a number of factors, including:

- Chemistry and acidity (pH) of the adjacent soil
- Chemistry and acidity (pH) of the water passing through the culvert
- Particle size and velocity of the solid material being transported through the culvert
- Environmental effects including freezing and thawing

- **Coatings for metal culverts** - Corrugated steel culverts are protected with metallic coatings of zinc (galvanized) or aluminum. Protective coatings for metal culverts also include bituminous coatings, bituminous paving, fiber-bonded bituminous coatings, polymer, concrete paving, and concrete coatings. Additional protective coatings are used with the metallic coating when there are serious corrosion or abrasion problems.

Bituminous - This is the most common material used to protect corrugated steel pipe against corrosion. This procedure can also increase the resistance of metal pipe to acidic conditions if the coating is properly applied and it remains in place. Careful handling during transportation, storage, and installation is required to avoid damage to the coating. Bituminous coatings can also be damaged by abrasion. Field repairs should be made when bare metal has been exposed. Inert fibers may be embedded in the zinc coating to improve the adherence to metallic-coated bituminous material pipe. It should be noted that the durability of bituminous coatings is dependent on strict adherence by the fabricator to proper coating procedures.

Polymer - There are several types of polymer coatings that may be applied for corrosion and/or abrasion protection. The term polymer generally refers to a variety of types of plastic that



may be used either plain "neat" or as a matrix for binding aggregates together, much the same as portland cement or asphaltic cement are used to make those respective types of concrete. Plain plastic coatings, often epoxies, may be applied directly to the metal or to other surface coatings. Culverts may also be coated with a polymer concrete, which is a mixture of plastic and aggregate. There have also been recent developments for coating metal culverts with fiberglass, which are (for these types of applications) short glass fibers held in a resin matrix. However, the 10 mil thick PVC and polyolefin plastic coatings that may be used to coat metal culverts do not provide increased resistance to abrasion, although polyethylene will to some extent.

Concrete/mortar - Metal culverts may be coated with a Portland Cement mortar or concrete for corrosion and abrasion resistance. Concrete of good quality is resistant to many corrosive agents. When the effluent has a pH of 5.0 or less, protective measures are generally required. One problem with using this type of coating is getting a good bond or connection between the metal pipe and the mortar or concrete lining.

Galvanizing - Galvanizing refers to the process of coating steel with a layer of zinc. Bare, uncoated, galvanized steel pipe generally performs well when the pH of the soil immediately adjacent to the pipe and the pH of the flow that the pipe will carry are between 6 and 10 and when the electrical resistivity of the soil is 2,000 ohm-cm or greater. Bare galvanized steel pipe should not be used in salt or brackish environments.

Aluminum coating Type 2 - Steel may also be coated with aluminum for corrosion protection. Aluminum generally performs adequately when the pH of the soil immediately adjacent to the pipe and the pH of the flow that the culvert will carry are between 5 and 9, and when the electrical resistivity of the flow and the minimum electrical resistivity of the soil is 1500 ohm-cm or greater. When backfilled with a clean, granular, well-drained soil, aluminum coated pipe has shown excellent resistance to corrosion, except when exposed to seawater and tidal flow. Aluminum coatings may not perform well in very acid or heavy metal (copper, iron, etc.) environments. If the pH is between 6.0 and 8.0, aluminum coated Type 2 is acceptable with resistivity of 100 ohm-cm or greater.

Type 1 aluminum coatings are inappropriate for drainage applications.

- **Coatings for concrete culverts** - Concrete culverts are rarely coated when they are constructed. However, when they are installed in particularly aggressive chemical environments, they may be coated with epoxy resins or special high density, low porosity concrete materials that have a high resistance to chemicals and chemical attack.

- **Invert protection** - The inverts of corrugated metal culverts are frequently paved to extend the life of the culvert by protecting the invert against corrosion and abrasion. The paving also smoothes the inside of the culvert, which improves the hydraulic capacity of such culverts.

Bituminous paving - Paving of CMP inverts with bituminous materials has been a common practice for many years. The bituminous coating is usually at least 3 mm (1/8-inch) thick over the inner crest of the corrugations. Generally only the lower quadrant of the pipe interior is paved. Fiber binding is sometimes used to improve the adherence of bituminous material to the metallic-coated pipe. Although bituminous paving has been widely used, it has been found that the coating may deteriorate and spall off after a number of years, particularly in some environments. After the coating starts to deteriorate, corrosion of the culvert will begin.

Concrete paving - The invert of culverts may also be paved with plain or reinforced Portland Cement concrete. For both new and repair situations this type of paving would normally be applied after the culvert is installed. Although this would normally be done only for corrugated metal pipe culverts, it is occasionally used for precast concrete culverts, to provide additional thickness to resist abrasion and/or corrosion. Metal culvert sections may also be factory produced with a complete concrete lining.