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Chapter 14 - Culverts

14.1 Purpose and Definition of a Culvert

Culverts, previously introduced in Section 3.1.5, may have a span long enough to be considered a bridge. For the purposes of this discussion, a culvert will be defined not by span length but by construction. Regardless of span, a culvert is normally designed hydraulically for fully submerged conditions (excluding bottomless) and have earth fill on top. Therefore their hydraulic and structural design methodology often differs from a typical bridge.

Some culverts have a long enough span to be classified as bridges, while others are no more than pipes under a road or driveway. The commonality is construction below and independent of the roadway surface. Culverts typically do not have a deck, superstructure, or substructure, with the exception of the bottomless culverts which have a substructure. As previously discussed in Section 3.1.5, a culvert is primarily a hydraulic structure, and its main purpose is to transport water flow efficiently. A culvert takes advantage of submergence to increase water carrying capacity. The most common materials used in the construction of culverts:

- Concrete (Pre-Cast and Cast-in-Place)
- Metal (Steel and Aluminum)
- Plastic (HDPE)
- Masonry

14.2 Components of Culverts

The nomenclature for the components of Culverts is included below.

- Apron – Area that is intended to reduce the potential for scour as water enters and exits the culvert
- Barrel – The opening that allows the water to pass under the roadway
- Crown – The top, or uppermost part, of the culvert
- End Section – An appurtenance attached to the end of a culvert to improve hydraulic efficiency, and anchorage
- Haunch – The area outside the pipe, and below the Spring line and the bottom of the pipe
- Headwall – A structure placed at the inlet or outlet of a culvert to protect the embankment slopes, anchor the culvert, and retain soil around the culvert opening
- Invert—The inside bottom of the culvert in cross section, which serves as the flow line of the culvert
- Joint - the location where two sections of material that the culvert is composed of are mated.
- Nosing—Location between culverts in a multiple culvert crossing which is often protected with concrete or riprap

- Parapet – A type of head wall above the opening of the culvert which not only retains fill, but projects above the roadway surface and acts as either a traffic barrier or a foundation for guard rail.
- Spring line — A line extending parallel to the invert along the length of the culvert at its widest point.
- Toe wall/Cutoff Wall – A full width wall which extends downward from the invert of the culvert at the inlet or outlet end to prevent piping and undermining
- Wingwall – A tapering wall the originates from the top of the culvert and is intended to retain soil under the roadway

14.3 Common Types of Culverts

14.3.1 Corrugated Metal Pipe/Pipe Arch

A corrugated metal pipe or pipe arch is typically constructed of steel or aluminum, with corrugations in the pipe to provide enhanced structural stability. Spans for preformed round pipe can extend up to approximately 12 feet in diameter, where spans of round corrugated plate structures can extend up to 50 feet. Corrugations typically vary from 2-2/3 inches x 1/2 inch to 5 inches x 1 inch. Some deep corrugation structures may have 15-1/2 inches x 5-1/2 inches or 16 inches x 6 inches corrugations.

Because corrugated metal pipes are flexible, meaning that the pipe has relatively little resistance to bending, they are highly dependent on the integrity of their surrounding backfill for their structural stability. Preformed corrugated metal pipe sections are typically delivered in 20 foot sections which require a joint every 20 feet. Joints are typically held together with bands that have indentations to engage the first one or two corrugations from each pipe at the joint, and the band is then bolted to tension it around the pipe. These type joints may be subject to leaking and misalignment if not carefully installed. Careful alignment and installation of the joint combined with adequate compaction of bedding and backfill will minimize the probability of joint problems developing.

Corrugated metal plate pipes/arches are composed of individual corrugated metal plates that are bolted together in the field to construct the culvert. These corrugated plates are often of heavier gauge metal than the pre-formed pipes, and are delivered in smaller sized pieces. Because each plate typically has multiple bolts fastening it to adjacent plates, the joints between aren’t typically misaligned, and so leak less frequently. An example of a twin corrugated metal plate pipe arch culvert is shown in Figure 14.1.

Figure 14.1 Twin Corrugated Metal Plate Pipe Arches

14.3.2 Rigid Concrete Pipe

Rigid concrete pipe is made of reinforced Portland cement concrete. The pipe sizes may range up to 15 feet in diameter, with roughly equivalent waterway openings in oval and arched pipe. Concrete pipe is typically precast and delivered in 8 foot lengths, meaning there will be a joint every 8 feet along the length of the culvert. Concrete pipe is rigid, which has a high resistance to bending, making soil stability around the pipe less critical than with metal pipe, but still important. Concrete pipe is highly dependent on the stability of the soils beneath the pipe to maintain the alignment and the integrity of the joints. Should the bedding move, the joints are likely to separate.

14.3.3 Corrugated Polyethylene Pipe

Corrugated high density polyethylene pipe is typically used for culverts with spans of up to 8 feet. Often the culverts are double walled, with a corrugated exterior wall and a smooth interior wall. The culverts are typically delivered in 20 foot sections, requiring joints every 20 feet. Joints are typically bands that engage the first corrugations adjacent to the joint or bell and spigot type joints which snap together. In rare cases, the joints may be welded.

14.3.4 Precast Concrete Box /Arch

Precast concrete box culverts can be designed for various depths of cover and live loads. Standard concrete boxes are available with spans up to 12 feet with wall thicknesses from 4 to 12 inches, where precast arches may span up to 100 feet. Because the precast sections are being transported to the construction site, the size of the sections used to construct the culvert varies to control the size and weight for transportation. Precast culverts will typically have a joint every 6 feet to 8 feet.

14.3.5 Cast-in-Place Concrete Box or Arch

Because cast in place box culverts and arches are not limited by the transportation constraints that limit precast culverts, they may have longer spans or different configurations. It is not uncommon for cast in place boxes to have multiple barrels to provide additional span or waterway openings, as shown in Figure 14.2. Cast-in-place concrete culverts and arches can be designed and constructed to meet specific site conditions.

Figure 14.2 Twin Barrel Cast-in-Place Concrete Box Culvert

14.3.6 Corrugated Metal Box

Corrugated metal box culverts may be constructed of either galvanized steel or aluminum and typically range in span from 9 feet to 25 feet. Vertical openings range from 3 feet to 13 feet. They are usually constructed of corrugated structural plate with the corrugation size depending on the span and configuration of the box.

14.3.7 Masonry

Masonry culverts are typically constructed of stone, brick or concrete block, an example of which is shown in Figure 14.3. This type of culvert was commonly built prior to the 1920's because these relatively durable materials were readily available for construction. The masonry units may be held together with mortar, or they may be dry (no mortar). Dry masonry relies on the friction/compression of well fit masonry units to hold the culvert together. Since the 1920's, the use of masonry in culvert applications has largely been limited to headwalls.

Figure 14.3 Masonry Culvert

14.3.8 Bottomless Pre-Cast Concrete Box or Arch

Precast 3-sided concrete culverts or arches can be designed for various depths of cover and live loads. Unlike other culverts, the natural stream bottom serves as the invert, and the legs of the box or arch are founded on concrete footings. Spans can be up to 100 feet for arches. As with the other precast culverts, size and weight for transportation will often govern the size of the precast pieces and the number of joints. An example of a bottomless pre-cast arch is shown in Figure 14.4.

Figure 14.4 Bottomless Precast Concrete Arch

14.3.9 Bottomless Cast-in-Place Concrete Box or Arch

Because bottomless cast in place box culverts and arches are not limited by the transportation constraints that limit precast culverts, they may have longer spans or different configurations. Like their precast counterparts, cast-in-place bottomless structures are founded on concrete footings, and the invert is the natural stream bottom. Cast-in-place concrete culverts and arches can be designed and constructed to meet specific site conditions.

14.3.10 Bottomless Corrugated Metal Box or Arch

Bottomless corrugated metal box culverts and arches may be constructed of either galvanized steel or aluminum and typically range in span up to 40 feet. Unlike the corrugated metal structures with a bottom, the legs of a bottomless corrugated metal box or arch are founded on concrete footings, and the invert is the natural stream bed. They are usually constructed of corrugated structural plate, with the corrugation size depending on the span and configuration of the box. An example of a bottomless corrugated metal arch culvert is shown in Figure 14.5.

Figure 14.5 Bottomless Corrugated Metal Arch Culvert

14.3.11 Bottomless Masonry Culvert (Masonry Arch)

Bottomless Masonry Culverts (masonry arches) are typically constructed of stone or brick, and were more commonly built the prior to the 1920’s. Stone and brick are relatively durable materials that were readily available for construction. Similar to the previously discussed bottomless culvert structures, the bottomless masonry culverts also used the natural stream bottom as the invert and were founded on either concrete or masonry footings. More recently, the use of masonry in culvert applications has largely been limited to headwalls.

14.4 Culvert Defects

14.4.1 Debris

Debris inside culverts, as well as at inlet and outlet ends, can degrade the hydraulic capacity and performance of culverts. An example of debris and silt buildup in a corrugated culvert is shown in Figure 14.6. Accumulations of debris can re-direct the flow of water causing scour of the stream banks, road embankment, or stream bed. Debris can also cause standing water in culverts, or conditions where material stays in contact with the culvert keeping it wet, and accelerating deterioration of the culvert materials. This is of particular concern in applications with galvanized steel. The debris may be large such as trees, limbs, woody vegetation, tires, shopping carts, or naturally occurring objects such as cobbles and boulders that have been washed down stream into or around the culvert. The debris may also be smaller grained soils, such as gravel, sand or silt. Vegetation growing at the inlet may also restrict the waterway opening.

Figure 14.6 Debris and Silt in Corrugated Culvert

14.4.2 Siltation

Similar to debris, siltation inside culverts, as well as at inlet and outlet ends, can degrade the hydraulic capacity and performance of culverts, as shown in the examples in Figure 14.6 and Figure 14.7. Accumulations of silt can re-direct the flow of water causing scour of the stream banks, road embankment, or stream bed. Silt can also cause standing water in culverts or conditions where material stays in contact with the culvert keeping it wet. These situations can accelerate deterioration of the culvert materials. This is of particular concern in applications with galvanized steel. The siltation may be caused, or at least exacerbated, by larger debris, such as trees, limbs, cobbles and boulders, or vegetation. Removal of larger debris should be done in conjunction with siltation removal to reduce the potential for deposition of more silt.

Figure 14.7 Silt and Vegetation Blocking Corrugated Metal Culvert

14.4.3 Scour

Scour is the lowering of the stream bed due to the removal and transportation of stream bed material by flowing water. Scour can occur at the inlet end, outlet end, or both ends of a culvert. Scour holes may form near the culvert inlet due to the flow striking against the upstream embankment prior to entering the culvert, or as the flow accelerates upon entering the culvert if the culvert is forming a constriction in the stream. Local scour at the outlet may occur when high velocity water exits the culvert.

The stream may also be subject to general scour. General scour is the gradual degrading or lowering of the stream bed over all, or part of its length. General scour can be a concern if the area of degradation is migrating upstream toward the outlet of the culvert. This can ultimately lead to the culvert being undermined. Conversely, general scour upstream of the culvert can subject the culvert to siltation and debris accumulation.

14.4.4 Leaking Joints

Joints serve several purposes, including:

- Maintaining the flow of water through the culvert
- Keeping soil, and water from infiltrating into the culvert
- Maintaining alignment
- Preventing the sections from pulling apart

Evidence of poor joint performance includes:

- Separated or misaligned joints
- Evidence of water infiltration or exfiltration
- Soil infiltration
- Seepage at joints
- Open joints
- Sink holes in the embankment/pavement surface over the joints

14.4.5 Corrugated Metal Culvert Defects

14.4.5.1 Damaged Coatings

Steel culverts are typically coated to protect the steel from corrosion. The coatings routinely used include galvanizing (zinc) or aluminizing (aluminum). In addition, galvanized pipe can be coated with polymer or asphalt to extend its life. In all cases, damage to the coatings will accelerate the onset of corrosion at the damaged coating location, which will reduce the lifespan of the culvert as corrosion advances.

Aluminum alloy culverts are typically uncoated, because aluminum alloys develop a protective oxide barrier layer when installed in environments where pH is between 4.0 and 9.0. For comparison purposes, distilled water has a pH of 7.0, baking soda has a pH of approximately 9, and tomatoes have a pH of around 4.

14.4.5.2 Dents and Localized Damage

Pipe wall damage such as dents, bulges, cracks, tears, and creases can occur during installation and backfill of culvert. If the damage is extensive the structural integrity of the culvert may be compromised, requiring rehabilitation or replacement. In many cases, localized damaged is not critical to the long term durability of the culvert.

14.4.5.3 Corrosion

Corrosion occurs in soils or waters that have corrosive properties (high or low pH) or an abrasive environment (where abrasion removes the protective coatings on the culvert increasing vulnerability to corrosion). Acidity or Alkalinity can occur from pollutants, such as acid rain, but more typically it is due to the underlying geology of the area. Corrosion can lead to section loss, perforation, and ultimately structural failure. Some agencies may choose to utilize culvert materials of heavier gauge, or with additional coatings to obtain the necessary design life given a more corrosive environment. However, when corrosion progresses to the point where the culvert is failing (leaks, perforations, structural deformations) repairs, rehabilitation, or replacement options should be explored. During selection of the repair option, the pH of the environment should be considered. Examples of culvert corrosion are shown in Figure 14.8 and Figure 14.9.

Figure 14.8 Corrosion in Plate Arch

Figure 14.9 Corrosion Failure of Culvert Invert

14.4.6 Concrete Culvert Defects

14.4.6.1 Cracks

Cracks in concrete culverts may occur due to a number of factors. The contributing factors can often be identified by the type of crack in the concrete culvert. Types of cracks occurring in concrete culverts include:

- Circumferential cracks near joints of round concrete culverts. These cracks usually indicate that there has either been some movement or settlement of the pipe sections, the gaskets were improperly installed, or the pipe was damaged during installation.
- Longitudinal Cracking of round culverts at the invert, crown and spring line .These cracks are usually flexural cracks caused by loss of side support (Figure 14.10 left).
- Longitudinal Cracking of round or pipe arch culverts parallel to the invert. These cracks are usually shear cracks due to loss of support at the haunches (Figure 14.10 middle).
- An example of good side support is shown in Figure 14.10 (right).

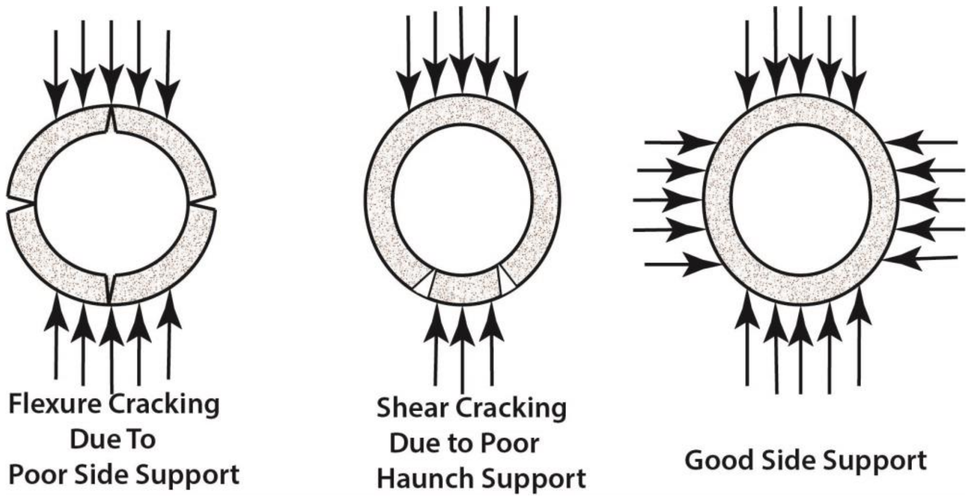

Figure 14.10 Longitudinal Cracks in Concrete Pipe

Transverse, or circumferential, cracks in round or pipe arch culverts often indicate that the pipe is in flexure. Cracks in the bottom of the pipe indicate a loss of support at midsection, whereas cracks in the top of the pipe indicate a point load was applied to the pipe at or near the location of the crack.

Cracks in box culvert and arch concrete can indicate differential settlement in the case of transverse cracks in the top, or invert and differential earth pressures in the case of the walls. Longitudinal cracks in box culverts that are not a result of reinforcing corrosion can often be attributed to flexural or shear distress in the concrete.

14.4.6.2 Spalls

A spall is a fracture of the concrete parallel to or inclined to the surface of the concrete. Spalls often occur along the edges of cracks, near joints and corners, and above reinforcing steel that has corroded.

14.4.7 Polyethylene Culvert Defects

14.4.7.1 Cracks

Polyethylene culvert pipes can sometimes develop cracks due to improper installation procedures, impacts, or stresses. Large cracks could compromise the structural integrity of the pipe, or cause soil infiltration, while small cracks may not be severe enough to need repair.

14.4.7.2 Minor Damage

Minor damage may be smaller than the width of one corrugation. Minor damage that perforates the pipe wall may cause infiltration/exfiltration of water as well as infiltration of soil. If left unchecked, this could lead to loss of soil support for the pipe.

14.4.8 Masonry Culvert Defects

14.4.8.1 Cracks

Individual bricks, stones, or blocks may be cracked, broken, crushed, or missing. Sometimes a seam or crack will follow a mortar line through a masonry unit, which then opens up a seam or crack in the individual unit. Cracks may also develop parallel to the surface of the masonry unit resulting in spalls or loss of section. Cracks may also be caused by thermal movement, or moisture related causes such as water infiltration. Cracks may also indicate that the culvert is subject to differential loading or stresses, or the loss of foundation support.

14.4.8.2 Loss of Mortar

In most masonry construction, mortar is used to cement the masonry units together. Loss of mortar may lead to displacement or loss of masonry units which can compromise the structural integrity of the culvert (Figure 14.11). Loss of mortar may be caused by moisture, thermal expansion and contraction, or loss of soil support. Loss of mortar may lead to water and soil infiltration.

Figure 14.11 Mortar Loss in Bottomless Masonry Arch

14.4.8.3 Soil and Water Infiltration

Cracking or loss of mortar may lead to water and soil infiltrating into the culvert. This can lead to the loss of soil covering the culvert, distresses in the surfaces above, and potential structural failure of the culvert from the loss of uniform soil cover. Loss of mortar may be caused by moisture, thermal expansion and contraction, or loss of soil support. In cold climates, water infiltration can also lead to freeze thaw damage to the mortar and masonry units.

14.4.8.4 Frost Action

Distress due to frost action is may take the form of uniform or differential heaving of the culvert, deformation of the culvert shape, or displacement of masonry units. After the frozen soils surrounding the culvert thaw, additional damage may occur resulting from loss of soil support, or differential loading from the soils.

In order for frost action occur, the environment around the culvert must be subject to freezing temperatures, frost susceptible soils, and a source of water. Because there is no effective way to control the temperature, and culverts are often crossing waterways, the feasible solution to prevent frost action is typically to bed and backfill the culvert on granular soils that are not frost susceptible.

14.4.8.5 Loss of Foundation Support

Like any other type of culvert construction, support from the surrounding soil is important to the proper structural performance of the culvert. Loss of soil support may be caused by weak soils, inadequate compaction of bedding or back fill, erosion or scour, moisture infiltration or frost action. Indications of foundation support loss include cracking, deformation, loss of mortar, settlement, or uplift.

For additional information about maintenance and repair of masonry structures, see Chapter 16.

14.4.9 Bottomless Culvert Defects

14.4.9.1 Scour/Undermining

Solid foundations are essential to the continued performance of bottomless culverts. Unlike culverts with bottoms, where scour begins at the inlet and outlet ends of the culvert, scour (or undermining) can begin at any point along the footings of a bottomless culvert and extend or migrate from there. Loss of support for the footings can lead to footing failure and, in turn, overall structural failure of the culvert.

14.4.9.3 Section Loss/ Spalls in Substructure

Loss of section in the footings of bottomless culverts can lead to loss of support for the structural elements of the culverts. An example of footing section loss in a bottomless culvert is presented in Figure 14.12.

Figure 14.12 Footing Section Loss in Bottomless Culvert

When to Call the Engineer

The Engineer should be notified if loss of section in footing or loss of bottom support in culvert appears to be causing distress such as cracks, bending deformation, etc.

14.5 Preventive and Basic Maintenance of Culverts

In this section, preventive maintenance refers to the on-going scheduled activities aimed at maintaining and extending the service life of culverts. Scheduled maintenance activities become important to proper culverts performance. Many agencies have a culvert inspection program, which assesses conditions and identifies maintenance and repair needs. The inspection cycle for culverts is based on the agency, but can range from 1 to 10 years. The level of detail can vary from inspection-to-inspection and can also vary within various agencies. Often culverts are checked for debris or scour issues annually, or after major storm events, whereas in-depth structural inspections happen less frequently.

14.5.1 Removal of Debris

Before beginning any debris removal work, it is essential to determine the environmental regulations that govern the water body that the culvert is carrying. The debris removal operations should be performed in compliance with local environmental regulations, such that:

- Debris is not displaced downstream where it could degrade water quality.
- A debris problem at another structure is not created.
- The spread of an invasive species is not accelerated.
- Removal of debris, such as a beaver dam, does not cause a sudden release of impounded water that would cause damage downstream.

14.5.1.1 Debris Removal

Removal of large debris at the inlet and outlet ends of a culvert is often most effectively performed with an excavator or other large equipment. Removal of large debris inside the culvert may require the use of cables, mandrels, or manned entry. If the debris blocking the entrance or exit of the culvert is a beaver dam, the appropriate permit from the state environmental agency may be required.

14.5.1.2 Silt Removal

Several methods may be employed for silt removal, included vacuuming with a vacuum truck, flushing with a water or sewer jet, flushing with a fire hose, or collection with a bucket line. Details of these methods are discussed below.

Vacuum Truck- A vacuum may be used to remove sediment and relatively small diameter debris from culverts including stones, leaves, bricks, litter and sediment. The vacuum apparatus is typically truck mounted with a holding tank ranging in size from 200 to 3500 gallons. The vacuum hose diameters range from 4 inches to 10 inches and are equipped with a metal end for breaking up sediment.

Water jet/Sewer Jet – A water or sewer jet can be either a truck or trailer mounted piece of equipment used to flush sediment and debris from culverts. The equipment consists of a high pressure pump and water supply. A hose with a nozzle is inserted into the culvert, using the high pressure water to dislodge debris and wash it to the downstream outlet of the culvert, where it is collected and removed. Nozzle configurations and water pressures can vary depending on the type of equipment used and the type of debris and culvert being cleaned. The maintenance staff should exercise caution using high pressure water nozzles to remove silt and debris in culverts with open joints, or masonry culverts with loose masonry or open joints. In these instances, the high pressure water may remove even more material from existing open joints.

Fire Hose Flushing – This equipment consists of various types of nozzles that can be placed on the end of a fire hose that is drawn through a culvert to flush or clean it. Silt/Debris is flushed to the downstream outlet, where it is collected and removed.

Bucket Line – This equipment is a cable that pulls a clam-shell-type bucket through a larger diameter culvert (greater than 48 inches). The bucket collects debris and removes it from the culvert. The full bucket is typically pulled through the culvert in the direction of flow, and is removed and emptied at the downstream end.

14.5.1.3 Vegetation Removal

The condition of the vegetation and surroundings should be evaluated to determine the appropriate method and degree of vegetation removal. Depending on the type of channel and the conditions, the vegetation removal may be as simple as mowing the areas adjacent to the inlet or outlets to keep them clear, without increasing erosion potential.

In areas where fast growing vegetation is a concern, or obstruction of the culvert with vegetation has been a recurring problem, mechanical removal (excavation of the roots) or use of herbicides may be appropriate. Use of herbicides will be governed by local environmental regulations.

14.5.2 Scour Repair

Local scour occurs at the inlet and outlet ends of culverts due to changes in water velocity as water enters and exits the culvert. The strategies for repair vary depending on the severity of the scour, the likelihood of continued scour, and the risk of damage caused by scour.

In the case of a scour hole at the outlet of a culvert which is not threatening the culvert, its appurtenances, or adjacent properties, no action may be warranted.

In the case of scour holes that could potentially threaten the culvert, filling the scour hole with riprap (i.e., stone fill) of the appropriate size based on stream flows and velocities is an appropriate option. An example drawing for scour repair using riprap is shown in Figure 14.13. See Chapter 15 for additional information about maintaining the waterway.

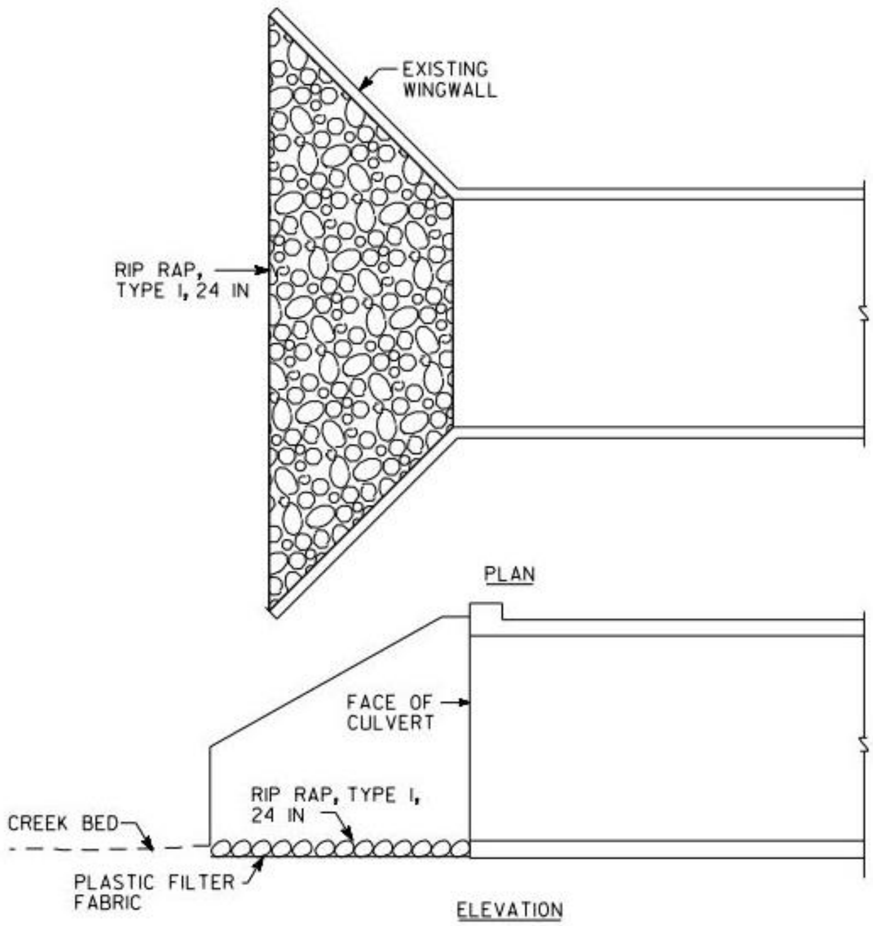

Figure 14.13 Riprap at Culvert Entrance/Exit for Scour Repair (Courtesy of GADOT)

In cases where scour has advanced underneath the culvert, a repair will not only need to be made to the scour hole outside the culvert, but also to the undermined area. One method of repairing the undermining uses self-leveling concrete (flowable fill). An example of this technique is shown below in Figure 14.14, with cross section views shown (left), plan views shown (right), existing condition(top) and final condition (bottom).

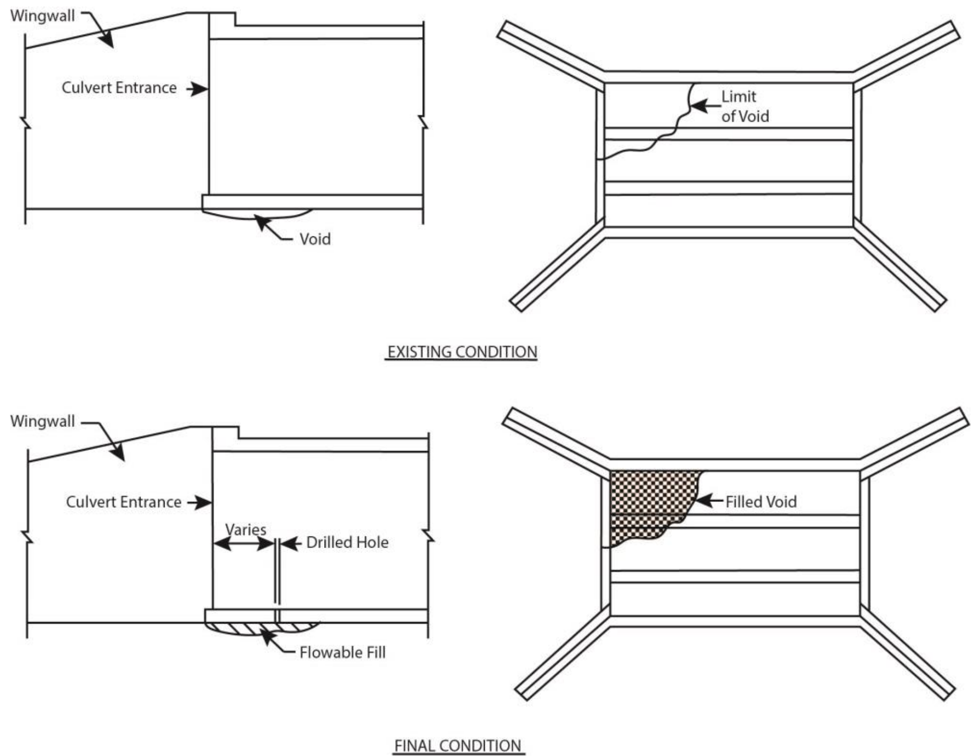

Figure 14.14 Void Repair.

It may be necessary to perform this repair technique in conjunction with either the construction of a cutoff wall, the placement of riprap, or both.

Grout bags can also be used for foundation undermining repair. For more information, see 15.2.3 Grout Bag Placement.

14.6 Repair and Rehabilitation of Culverts

A bridge maintenance crew will often be called upon to repair and rehabilitate culverts. This will go beyond simply cleaning debris and patching damaged areas.

14.6.1 Repair of Damaged Invert

14.6.1.1 Concrete Paved Invert

When the invert of a culvert has deteriorated, and the culvert is large enough for workers to enter the culvert, a new concrete invert may be cast in the culvert. Prior to relining, or as part of the new invert installation, any voids beneath the invert should be filled with concrete. An example of a repair of a damaged invert by using a concrete paved invert is shown in Figure 14.15.

Figure 14.15 Concrete Paved Invert

14.6.1.2 Saddle Plates

When corrugated metal culverts have deterioration limited to the invert or other isolated areas, another method of repair is to attach new plates of the same corrugation spacing to the invert or other location in need of repair. Prior to placing the new plates, any perforations or voids beneath the invert should be filled.

14.6.2 Relining Culverts

In the relining cases below, the result is a new structural interior to the existing pipe.

14.6.2.1 Slip Lining

By this method, the pipe is slip lined by pulling sections of the liner pipe through the existing pipe and then grouting the annular space between the existing pipe and the liner in accordance with the liner pipe manufacturer's recommendation.

When to Call the Engineer

Call an engineer to determine if the reduced waterway area will have adequate capacity to pass the design flow.

One concern with slip lining is the reduction of hydraulic opening, and therefore hydraulic capacity. Prior to undertaking a lining project, an engineer should be consulted to determine if the reduced waterway area of the lined culvert will have adequate capacity to pass the design flow. If the capacity of the lined pipe will be inadequate, other rehab/repair options should be explored.

Slip lining a culvert requires sections of liner pipe to be staged adjacent to the inlet or outlet of the culvert prior to insertion into the existing culvert. With liner pipe sections routinely being 20 feet or longer, the work area could extend off the right of way. Prior to selection of lining as a repair option, the limits of the right of way should be established, and a determination made if the proposed liner pipes will cause encroachment on adjoining lands during installation. If encroachment is likely to occur, options such as temporary or permanent right of way acquisition or working with the supplier reduce the length of the liner pipes should be explored.

A variety of different pipe materials are used for slip lining. The process of installing each of them is essentially the same with some minor variations based on the material. Some materials that are commonly used to slip line culverts are:

- Corrugated Metal Pipe
- Corrugated Metal Plate Pipe/Plate Arch
- Smooth Interior Metal Pipe
- High Density Polyethylene Pipe

In cases the where inlet or outlet are not controlling the hydraulic capacity, the installation of a liner with a smoother interior than the original culvert can mitigate the reduction capacity caused by the smaller waterway opening, however it may increase water velocities at the culvert outlet. Some examples of smooth interior pipe include HDPE, smooth metal, Spin Cast and Cured in Place Pipe. Corrugated metal pipes are not smooth and should not be used for this purpose.

Figure 14.16 shows the steps involved to line a corrugated metal plate pipe arch. If the existing footing is adequate, it can be used as the footing for the liner arch. If not, repairs to the existing footing will be necessary as described in Section 14.6.6 Footing Repair of Bottomless Culverts. In the case of a round pipe, perforations in the invert and voids below it must be filled, and blocking beneath the invert of the liner pipe is typically provided to maintain an annular space between the existing pipe and the liner pipe.

The pipe or arch sections are then assembled outside the culvert and slid into place using winches, jacks or heavy equipment. Following placement of the liner, the ends are formed in preparation for grouting.

A sequence of photos showing replacement of an existing corrugated metal arch with a new corrugated metal arch in shown in Figure 14.16. The figure shows several steps, including (a) Assembly of plate arch outside existing culvert from interior of existing culvert, (b) Assembly of plate arch liner from outside existing culvert, (c) Plate arch liner in place prior to forming and grouting, (d) Exterior formwork for placing grout between liner and existing arches, (e) Formwork for grouting annular space between existing arch and liner from interior of liner, and (f) Interior close up showing how skewed end of corrugated arch was formed. For the installation shown in Figure 14.16, the grout was placed from the roadway surface by excavating to the top of the existing corrugated arch and cutting holes for grout placement (see Figure 14.17). Specifically in Figure 14.17, the liner arch and hole cut in existing arch visible in bottom of hole is shown (left) and placement of grout is shown (right). The completed lined arch is shown in Figure 14.18.

Figure 14.16 Sequence of Culvert Lining Replacement in Corrugated Metal Arch (Courtesy of Washington County NY DPW)

Figure 14.17 Grout Placement Hole Excavated in Road Surface (Courtesy of Washington County NY DPW)

Figure 14.18 Completed Lined Arch (Courtesy of Washington County NY DPW)

Figure 14.19 and Figure 14.20 show slip lining installations using smooth interior metal pipe. In Figure 14.19, the external view is shown (left) and internal view showing grout ports is shown (right). While the pipe in Figure 14.19 does have ribs, they are flat enough that the pipe is considered smooth for hydraulic purposed. In the installation of the metal pipe shown in Figure 14.20, grouting occurred from the interior using the grout ports shown in the photo. Following curing of the grout, the forms were removed and the stream was restored.

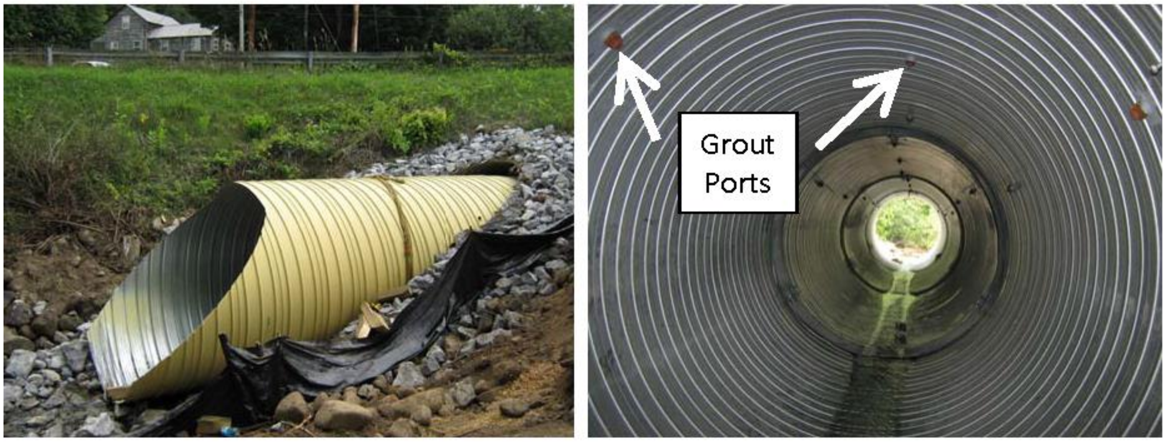

Figure 14.19 Smooth Interior Metal Pipe Slip Liner
(Courtesy of Saratoga County NY DPW)

Figure 14.20. Smooth Wall Steel Culvert Liners (Courtesy of Virginia DOT)

14.6.2.2 Shotcrete/Spin cast Concrete Liner

A deteriorated culvert may be relined with pneumatically projected concrete (Shotcrete) or spin cast concrete. Both methods provide a new concrete liner to the culvert which can be structural if designed correctly.

Pneumatically projected concrete is most often used in culverts that are large enough for workers to enter. It consists of a dry concrete mix that is pneumatically applied, typically 2 inches to 4 inches thick on the interior surfaces of the culvert. An example of shotcrete placement for culvert lining is shown in Figure 5.42. If necessary, reinforcing steel or sheer studs can be placed. Alternatively, steel or polypropylene fibers can be included in the concrete for added strength.

Spin cast concrete is typically used for smaller diameter culverts that are not feasible for workers to enter. The spin casting process uses a centrifugal device to cast a cement/mortar mix against the walls of the culvert to form a new concrete liner inside the existing culvert.

14.6.2.3 Cured In Place Pipe (CIPP)

Cured In Place Pipe (CIPP) may be used for reconstruction of culverts up to 108 inches diameter. The method installs a resin-impregnated, flexible tube which is inverted into the existing culvert by use of a hydrostatic head or air pressure. The resin is cured by circulating hot water, steam, or hot air within the tube. When cured, the finished pipe will be continuous and tight-fitting. This technique requires taking the culvert out of service for the duration of installation and curing.

An example of the steps for installation of an inversion liner is shown in Figure 14.21, showing (a) Incisions are cut in sides of liner to facilitate inversion, (b) Sides of liner fastened to installation scaffolding, while first portion of liner is inverted, (c) Water is added to inverted liner to advance it toward installation manhole (d) Inverted liner being lined up and advanced into the installation manhole.

A completed installation of cured in place pipe is shown in Figure 14.22.

(a)

(b)

(c)

(d)

Figure 14.21 Inversion Liner Installation

Figure 14.22 A Completed Installation of Cured in Place Pipe (Courtesy of Insituform USA)

For information regarding spall and delamination repair, please see Chapter 5.

14.6.3 Joint Repair

Methods for joint repair include:

- Internal bands
- Internal joint seals
- Flexible chemical grout injection
- Concrete collars

These methods are described below.

Internal bands can be used for metal pipes where water tightness is not critical, but a soil tight mechanical connection is desired. Internal expanding metal bands are placed over the joint, and the bolts/threaded rod assembly is tightened forcing the bands against the surface of the pipe.

Suggested Procedure

Installation of Internal Expanding Bands

1. The area to be repaired is first cleaned.
2. The pipe is marked on either side of the joint or damaged area to ensure proper alignment.
3. The expanding band is placed over the center of the joint or damaged area.
4. The internal expanding metal bands are tightened, pressing the seal against the pipe.

Internal joint seals are comprised of an Ethylene Propylene Diene Monomer (EPDM) rubber gasket and metal band which expands to conform to the inner wall of the pipe. They can be used for both High Density PolyEthylene (HDPE) and metal pipes.

Suggested Procedure

Installation of Internal Joint Seals

1. The area to be repaired is first cleaned.
2. The pipe is marked on either side of the joint or damaged area to ensure proper alignment.
3. The seal is placed over the center of the joint or damaged area.
4. The expanding band is placed over the center of the seal.
5. The internal expanding metal bands are tightened, pressing the seal against the pipe.

Injection of flexible chemical grout creates a collar around leaking pipe and joints. Grouting chemicals are forced into the joint and the surrounding soil where they activate, sealing the joint. To inject the chemical grout:

Suggested Procedure

Injection of Chemical Grout

1. The culvert is first cleaned.
2. The equipment containing the grout is inserted into the pipe and positioned over the joint.
3. The grout is forced through the joint from the inside of the pipe and then gels when it comes in contact with water to form a waterproof collar.

Concrete collar installation involves building a form around the area to be repaired and encasing it in concrete.

Suggested Procedure

Construction of a Reinforced Concrete Collar

1. Excavate bedding from under and around the existing pipe to a width at least 12 inches from either side of the joint.
2. Encase the damaged joint with a concrete collar a minimum of 24 inches wide and at least 6 inches thick around the culvert.
3. Carefully replace and compact bedding.
4. Then backfill to provide proper support for pipe and collar.

An example of a concrete installation procedure is shown in Figure 14.23.

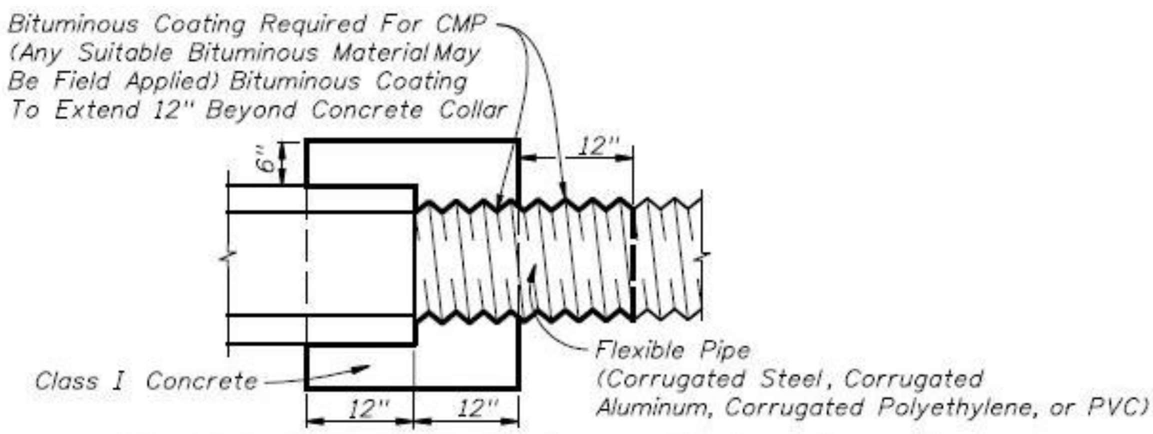

Figure 14.23 Concrete Collar Detail (Courtesy of Florida DOT)

14.6.4 Rehabilitating/Installing Toe Walls

In some cases, installation of toe walls can serve to create a permanent repair in areas where there is a tendency for scour holes to develop at either the inlet or outlet of a culvert. If sized correctly, toe walls prevent scour from undermining the culvert, but toe walls will not prevent scour holes from forming. The toe wall should extend to at least 6 inches below the depth of expected scour to protect the culvert from undermining. After the stream flow is diverted around the work area, the toe wall is formed and poured. The toe wall should be adequately anchored to the culvert with rebar, bolts, shear studs or other appropriate means. On completion of the wall, the scour hole is backfilled with either riprap, or native stream bed material to conform to the natural stream bed. An example of a toe wall and its associated detail are presented Figure 14.24 and Figure 14.25, respectively.

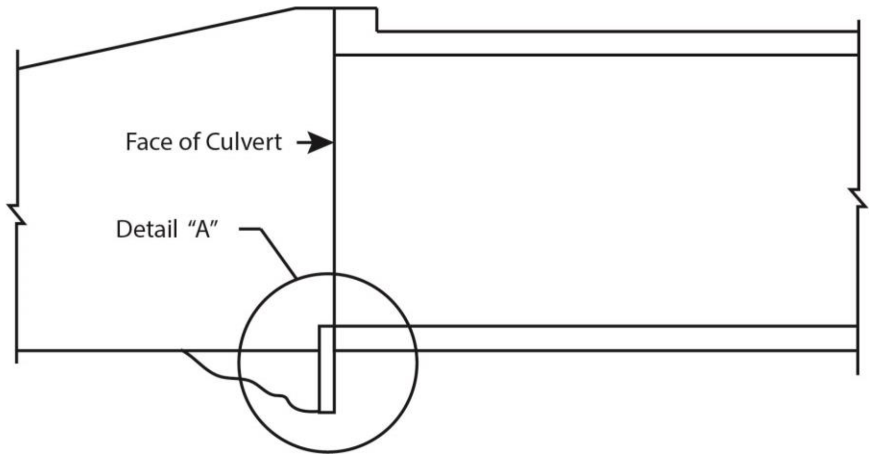

Figure 14.24 Toe Wall. Detail "A" Shown in Figure 14.25

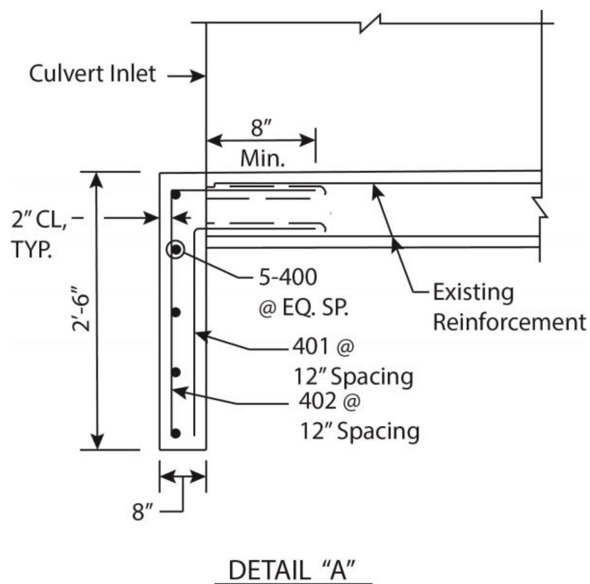

Figure 14.25 Toe Wall Detail at Concrete Box Culvert (Courtesy of GA DOT)

14.6.5 Repointing Masonry

Repointing of masonry is necessary when the mortar has deteriorated to the point that it is either missing or has loosened to the point where bonding and support are no longer provided.

Hand pointing is appropriate if the loss of mortar is less that the full depth of the masonry units, and the new mortar is primarily serving to protect and retain the original mortar. In the cases where the joint mortar is completely missing or deteriorated to the point where it is providing no support, pressure mortaring is a more appropriate technique. Pressure mortaring will provide full penetration of the joints to restore structural strength of the mortar.

Prior to repointing existing masonry, the existing mortar should be carefully evaluated, and a new mortar selected that will provide a similar strength to the existing mortar. A mixture of mortar strengths in the culvert could cause cracking of existing mortar joints, or cracks to propagate through masonry units where they had previously been in mortar joints.

Because of the age of many masonry structures, they may be eligible for the National Register of Historic Places, either alone or as part of a grouping, district, or larger feature. If state or federal funds are being used for the work, the State Historic Preservation office should be consulted before initiating any work. For more information on repointing masonry, please see Chapter 16 on Masonry Arch Bridges.

Suggested Procedure

Repointing Masonry

1. The masonry should be carefully evaluated to determine the extent and types of repairs.
2. A grout placement plan that also identifies any reinforcement is developed.
3. Necessary water diversions/cofferdams are deployed to permit grouting and repointing to occur in a dry environment.
4. Joints to be repaired are cleaned with low pressure water.
5. Cleaned joints are blown clean with compressed air.
6. Any reinforcement required is installed (See Figure 14.26).
7. Masonry is pre-wet to Saturated Surface Dry (SSD) prior to grouting or hand pointing.
8. Pointing and grouting is performed maintaining the moisture and temperature necessary to provide adequate curing of mortar or grout.
9. Face of masonry units is cleaned prior to set up of mortar or grout.

Figure 14.26 Reinforcing Steel Installed Prior to Grouting Stone Masonry

14.6.6 Footing Repair of Bottomless Culverts

In bottomless culverts, repair of the footing is similar to repair of concrete in piers or abutments (see Chapters 5 and 13). However, culvert footing repair often entails tight spaces that make use of heavy equipment difficult or impossible, and diversion of stream flows where conventional cofferdams are not feasible.

The repair to a bottomless culvert footing requires assessing the extent of the repair by determining the limits of sound concrete and determining the design scour elevation. Aside from simple repairs to above water cracks and spalls, more extensive concrete repairs should extend below design scour depth if feasible.

To excavate, form, and pour in dry conditions the stream will need to be diverted. In Figure 14.27, the owner is using twin HDPE culverts to divert flow during a low flow period. Other diversion methods could include sandbagging, bypass pumping, cofferdams or Aqua dams.

Figure 14.27 Preparation for Footing Repair on Corrugated Plate Arch

Once the water has been diverted, the existing footing surface should be removed to sound concrete, and the soil at the toe of the footing should be excavated to the design repair depth.

As part of the forming process, provision should be made for adequately connecting the repair concrete to the existing footing. Typically, reinforcing bar is drilled and grouted into the existing concrete. Some agencies will treat the face of the existing concrete with epoxy or another bonding agent to strengthen the bond between the new concrete and the old concrete.

The concrete is placed and cured, forms removed, and the stream restored to its original course. The completed repaired footing is shown in Figure 14.28.

Figure 14.28 Repaired Footing for Corrugated Plate Arch

14.7 Chapter 14 Reference List

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