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Chapter 14

Characteristics, Inspection and Evaluation of Culverts

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Topic 14.1 Culvert Characteristics

14.1.1 Introduction

A culvert is a structure designed hydraulically to take advantage of submergence to increase water carrying capacity. Culverts, as distinguished from bridges, are usually covered with embankment and are composed of structural material around the entire perimeter. Some culverts are supported on spread footings with the streambed serving as the bottom of the culvert. If culverts satisfy NBIS bridge length requirements of 20 feet or greater, they may be classified as bridges in the National Bridge Inventory (NBI).

Over the years, culverts have traditionally received less attention than bridges. Since culverts are less visible it is easy to put them out of mind, particularly when they are performing adequately. Additionally, a culvert usually represents a significantly smaller investment than a bridge.

Since 1967 there has been an increased emphasis on bridge safety and on bridge rehabilitation and replacement programs. In many cases small bridges have been replaced with multiple barrel culverts, box culverts, or long span culverts (see Figure 14.1.1). There have also been recent advances in culvert design and analysis techniques. Long span corrugated metal culverts with spans in excess of 40 feet were introduced in the late 1960's.

Figure 14.1.1 Culvert Structure

As a result of these developments, the number, size, complexity, and cost of culvert installations have increased. The failure of a culvert may be more than a mere driving inconvenience. Failure of a major culvert may be both costly and hazardous.

Bridge-size culverts are inspected regularly to identify potential safety problems and maintenance needs. Culverts smaller than bridges may or may not be inspected, depending on the state. Preserving the investment in the structure and minimizing property damage due to improper hydraulic functioning are also key reasons for regular inspections and other maintenance actions.

Purpose of Culvert Inspection

The National Bridge Inspection Program (NBIP) was designed to insure the safe passage of vehicles and other traffic. The inspection program provides a uniform database from which nationwide statistics on the structural and functional safety of bridges and large culvert-type structures are derived. Although these bridge inspections are essentially for safety purposes, the data collected is also used to develop rehabilitation and replacement priorities.

Bridges with spans over 20 feet in length are inspected on a two-year cycle in accordance with the National Bridge Inspection Standards (NBIS). According to the American Association of State Highway and Transportation Officials (AASHTO) the definition of bridges includes culverts with openings measuring more than 20 feet along the centerline of the road and also includes multiple pipes where the distance between openings is less than or equal to half of the pipe opening. Multiple barrel culvert installations with relatively small pipes can therefore meet the definition of a bridge.

Structures included in the NBIS are evaluated by utilizing a standardized inventory appraisal process that is based on rating certain structural and functional features. The data obtained is recorded on standardized inspection forms. The minimum data required for bridge length culverts is shown on the Structure Inventory and

Appraisal Sheet (SI&A). Procedures for coding these items are provided in the *FHWA Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (*Coding Guide*)

While the importance of the NBIS inspection program cannot be overemphasized, the SI&A data sheets are oriented toward bridges rather than culverts; thus, they do not allow an inspector to collect either detailed condition data or maintenance data for culverts. Additionally, the NBIS program does not specifically address structures where the total opening length is less than 20 feet. However, some type of formal inventory and inspection is needed for culverts that are not bridge length. In many cases, the failure of a culvert or other structure with openings less than 20 feet long can present a life threatening hazard. Although the primary purpose of this and other sections relating to culverts is to provide inspection guidelines for culverts included in the NBIS program, the guidelines are also generally applicable to culverts with openings which are less than 20 feet long. For culverts (and span-type structures) less than 20 feet in length, the state in which the structure is located will incorporate it into their inventory and inspection program. In this case, the state defines the criteria whereby culverts are to be included in the their inventory and inspection program.

Ideally, all culverts are inventoried and periodically inspected. Some limitations may be necessary because a considerable effort is required to establish a current and complete culvert inventory. Small culverts may not warrant the same rigorous level of inspection as large culverts. Each agency defines its culvert inspection program in terms of inspection frequency, size, and type of culverts to be inventoried and inspected, and the information to be collected. Culverts larger than 20 feet are inspected every two years under the NBIS program. If possible, all culverts are inventoried and inspected to establish a structural adequacy and to evaluate the potential for roadway overtopping or flooding.

The types and amount of condition information to be collected is based on the purpose for which the information will be used. For example, if small pipes are not repaired but are replaced after failures occur, then the periodic collection of detailed condition data may not be warranted. Documentation of failures as well as the causes of failures may be all the condition data that is needed. However, the inventory is updated whenever a replacement is accomplished.

Safety

Safety is the most important reason why culverts as well as bridges are inspected. To ensure that a culvert is functioning safely, the inspector evaluates the structural integrity, hydraulic performance, and roadside compatibility of the culvert.

- Structural Integrity - The failure of major culverts can present a life threatening safety hazard. The identification of potential structural and material problems requires a careful evaluation of indirect evidence of structural distress as well as actual deterioration and distress in the culvert material.

- Hydraulic Performance - When a culvert's hydraulic performance is inadequate, potential safety hazards may result. The flooding of adjacent properties from unexpected headwater depth may occur. Downstream areas may be flooded by failure of the embankment. The roadway embankment or culvert may be damaged due to scour or undermining.

- Roadside Compatibility - Many culverts, like older bridges, present roadside hazards. Headwalls and wingwalls higher than the road or embankment surface may constitute a fixed obstacle hazard. Headwalls and wingwalls are presented in detail in Topic 14.1.6. Abrupt drop-offs over the end of a culvert or steep embankments may represent rollover hazards to vehicles that leave the roadway.

- Hazards of Culvert Inspection – Presented in Topic 2.2, Safety Fundamentals for Bridge Inspectors.

Maintenance Needs

Lack of maintenance is a prime cause of improper functioning of culverts and other drainage structures. Regular periodic inspections allow minor problems to be spotted and corrected before they become serious.

Outcomes

The primary outcome of this topic as well as Topics 2.1, 2.2, 3.1, 4.2, 4.3, 7.6, 13.2, 14.2, and 14.3 is to provide information that will enable bridge inspectors to perform the following tasks:

- Properly inspect an existing culvert.
- Evaluate structural adequacy.
- Evaluate hydraulic adequacy and recognize potential flood hazards.
- Correctly document and evaluate the findings of a culvert inspection using the appropriate FHWA and AASHTO criteria.
- Recognize and document traffic safety conditions.
- Recommend corrective actions/maintenance needs.

To meet the primary outcome, the topics in this reference manual provide general procedures for conducting, reporting, and documenting a culvert inspection, and guidelines for evaluating specific hydraulic and structural culvert components.

A second outcome of these sections is to provide inspectors with the information necessary to understand and evaluate the significance of defects and their effect on hydraulic and structural performance. Topics 14.2 and 14.3 present information on rigid and flexible culverts. Durability concepts are also reviewed in these topics.

14.1.2 Differentiation Between Culverts and Bridges

Traditional definitions of culverts are based on the span length rather than function or structure type. For example, the NBIS bridge length definition included in the *FHWA Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* states:

"A structure including supports erected over a depression or a obstruction, such as water, highway, or railway, and having a track or passageway for carrying traffic or other moving loads, and having an opening measured along the center of the roadway of more than 20 feet between undercopings of abutments or spring lines of arches, or extreme ends of openings for multiple boxes."

Therefore, structures that are less than 20 feet may be known as culverts.

Many structures that measure more than 20 feet along the centerline of the roadway have been designed hydraulically and structurally as culverts. The structural and hydraulic design of culverts is substantially different from bridges, as are construction methods, maintenance requirements, and inspection procedures. A few of the more significant differences between bridges and culverts are:

Hydraulic

Culverts are usually designed to operate at peak flows with a submerged inlet to improve hydraulic efficiency. The culvert constricts the flow of the stream to cause ponding at the upstream or inlet end. The resulting rise in elevation of the water surface produces a head at the inlet that increases the hydraulic capacity of the culvert. Bridges may constrict flow to increase hydraulic efficiency or be designed to permit water to flow over the bridge or approach roadways during peak flows. However, bridges are generally not designed to take advantage of inlet submergence to the degree that is commonly used for culverts. The effects of localized flooding on appurtenant structures, embankments, and abutting properties are important considerations in the design and inspection of culverts.

Structural

Culverts are usually covered by embankment material. Culverts are designed to support the permanent load of the soil over the culvert as well as transient loads including vehicular traffic. Either transient loads or permanent loads may be the most significant load element depending on the type of culvert, type and depth of cover, and amount of live load. However, transient live loads on culverts are generally not as significant as the permanent loads unless the cover is shallow. Box culverts with shallow cover are examples of the type of installation where transient live loads may be significant. Permanent and transient loading is presented in detail in Topic 14.1.3.

Figure 14.1.2 Box Culvert with Shallow Cover

In most culvert designs the soil or embankment material surrounding the culvert plays an important structural role. Lateral soil pressures enhance the culverts ability to support vertical loads. The stability of the surrounding soil is important to the structural performance of most culverts.

Maintenance

Because culverts usually constrict flow, there is an increased potential for waterway blockage by debris and sediment, especially for culverts subject to seasonal flow. Multiple barrel culverts may also be particularly susceptible to debris accumulation. Scour caused by high outlet velocity and turbulence at inlet end is a concern. As a result of these factors, routine maintenance for culverts primarily involves the removal of obstructions and the repair of scour and undermining. Prevention of joint leakage may be critical in culverts bedded in pipeable soils to prevent undermining and loss of support.

Traffic Safety

A significant safety advantage of many culverts is the elimination of bridge parapets and railings. Culverts can usually be extended so that the standard roadway cross section can be carried over the culvert to provide a vehicle recovery area. However, when culvert ends are located near travel lanes or adjacent to shoulders, guardrails may be used to protect the traffic. Another safety advantage of culverts is that less differential icing occurs. Differential icing is the tendency of water on the bridge deck to freeze prior to water on the approaching roadway. Since culverts are under fill material and do not have a bridge deck, the temperature of the roadway over the culvert is at or near the temperature of the roadway approaching the culvert.

Construction

Careful attention to construction details such as bedding, compaction, and trench width during installation is important to the structural integrity of the culvert. Poor compaction or poor quality backfill around culverts may result in uneven or differential settlement over the culvert and possibly structural distress of the culvert.

Durability

Durability of material is a significant problem in culverts and other drainage structures. In very hostile environments such as acid mine drainage and chemical discharge, corrosion and abrasion can cause deterioration of all commonly available culvert materials.

Inspection

The inspection and assessment of the structural condition of culverts requires an evaluation of not only actual distress but circumstantial evidence such as roadway settlement, pavement patches, and embankment condition.

14.1.3 Structural Characteristics of Culverts

Loads on Culverts

In addition to their hydraulic functions, culverts also support the weight of the embankment or fill covering the culvert and any load on the embankment. There are two general types of loads that are carried by culverts: permanent loads and transient loads.

Permanent Loads

Permanent loads include the earth load or weight of the soil over the culvert and any added surcharge loads such as buildings or additional earth fill placed over an existing culvert. If the actual weight of earth is not known, 120 pounds per cubic foot is generally assumed.

Transient Loads

The vehicular live loads and live load surcharge on a culvert include the loads and forces, which act upon the culvert due to vehicular or pedestrian traffic. The highway wheel loads (as part of the AASHTO HL-93 design load) used for design and analysis are shown in Figure 14.1.3. The effect of live loads decreases as the height of cover over the culvert increases. When the cover is less than two feet, concentrated loads may be considered as being spread uniformly over a rectangle with sides 1.15 times the depth of cover plus the initial footprint. This concept is illustrated in Figures 14.1.4 and 14.1.5. In addition to the truck load, the HL-93 is also comprised of a 640 pound lane load. This load converts into an additional 64 pounds per square foot, but may be ignored if the depth of the cover is greater than 8 feet.

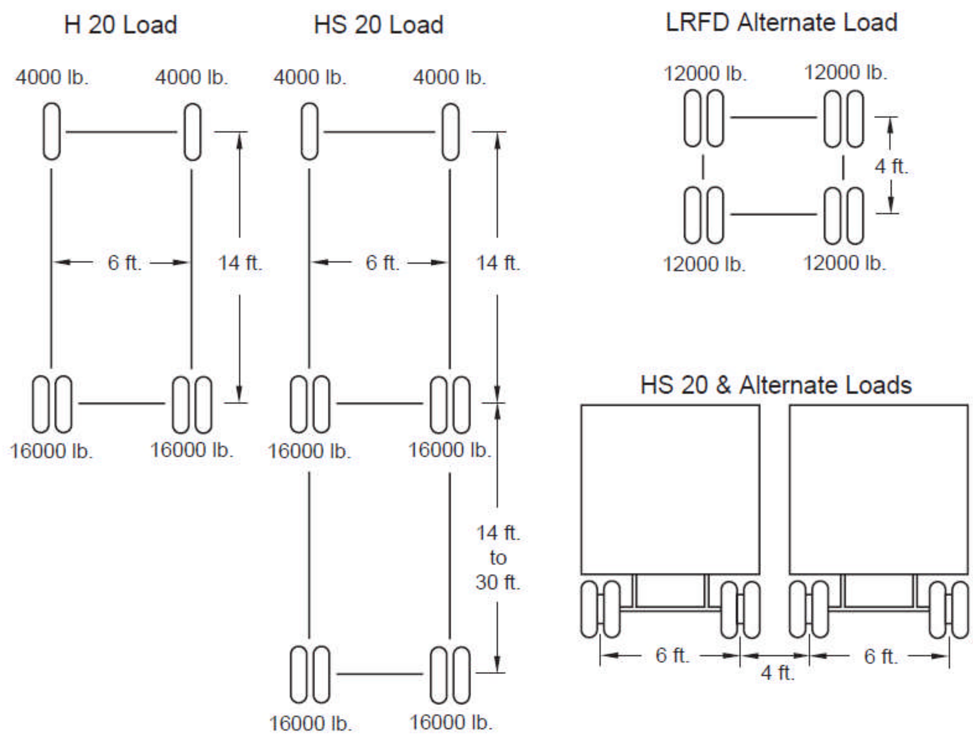


Figure 14.1.3 AASHTO Wheel Loads and Wheel Spacings

(Source: *Concrete Pipe Design Manual*, American Concrete Pipe Association, April 2007)

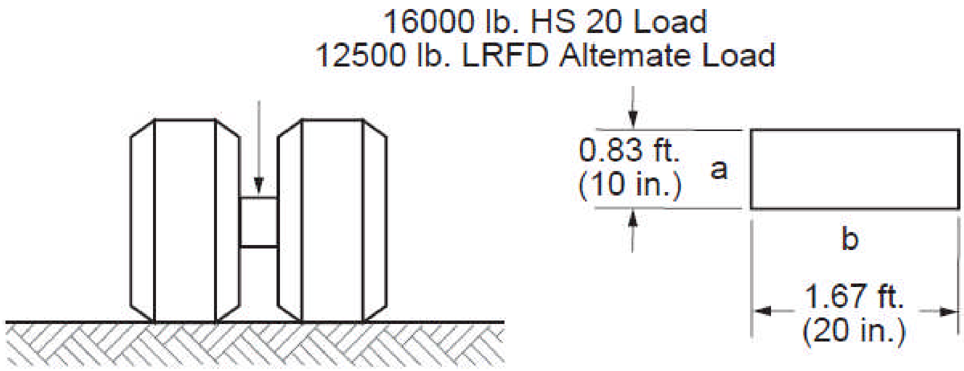
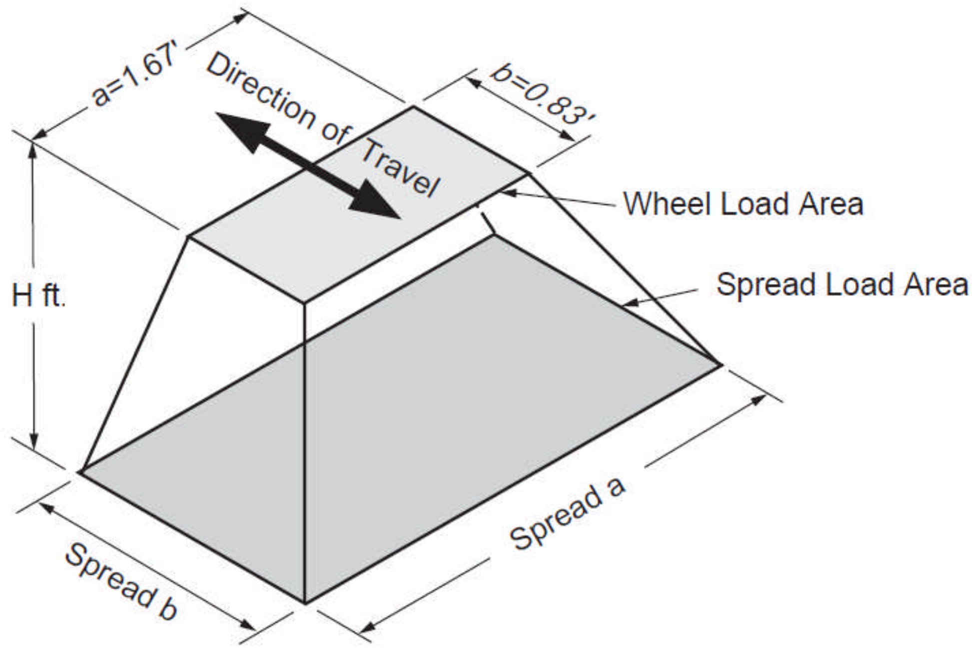


Figure 14.1.4 AASHTO Wheel Load Surface Contact Area (Foot Print)

(Source: *Concrete Pipe Design Manual*, American Concrete Pipe Association, April 2007)



Soil Type	H, ft	P, lbs	Spread a, ft	Spread b, ft
Select Granular Soil Fill	H < 2.03	16,000	a + 1.15H	b + 1.15H
Other Soils	H < 2.33	16,000	a + 1.00H	b + 1.00H

Figure 14.1.5 Spread Load Area (Single Dual Wheel)

(Source: *Concrete Pipe Design Manual*, American Concrete Pipe Association, April 2007)

Categories of Structural Materials

Based upon material type, culverts are divided into two broad structural categories: rigid and flexible.

Rigid Culverts

Culverts made from materials such as reinforced concrete or stone masonry are very stiff and do not deflect appreciably. The culvert material itself provides the needed stiffness to resist loads. In doing this, zones of tension and compression are created. The culvert material is designed to resist the corresponding stresses.

Rigid Culverts are presented in detail in Topic 14.2.

Flexible Culverts

Flexible culverts are commonly made from steel or aluminum. In some states composite materials are used. Flexible culverts rely on the surrounding backfill material to maintain their structural shape. Since they are flexible, they can be deformed significantly with no cracks occurring.

As vertical loads are applied, a flexible culvert will deflect if the surrounding fill material is loose. The vertical diameter decreases while the horizontal diameter increases. Soil pressures resist the increase in horizontal diameter.

For flexible culverts with large openings, sometimes longitudinal and/or circumferential stiffeners are used to prevent excessive deflection. Circumferential stiffeners are usually metal ribs bolted around the circumference of the culvert. Longitudinal stiffeners may be metal or reinforced concrete. This type of stiffener is sometimes called a thrust beam.

Flexible culverts are presented in detail in Topic 14.3.

Construction and Installation Requirements

The structural behavior of flexible and rigid culverts is often dependent on construction practices during installation (see Figure 14.1.6). Items, which require particular attention during construction, are discussed briefly in the following text. This information is provided so that the bridge inspector may gain insight on why certain structural defects are found when inspecting a culvert.

- Compaction and Side Support - Good backfill material and adequate compaction are of critical importance to flexible culverts. A well-compacted soil envelope is needed to develop the lateral pressures required to maintain the shape of flexible culverts. Well-compacted backfill is also important to the performance of rigid culverts. Poorly compacted soils do not provide the intended lateral support.
- Trench Width - Trench width can significantly affect the earth loads on rigid culverts. It is therefore important that trench widths be specified on the plans and that the specified width not be exceeded without authorization from the design engineer.
- Foundations and Bedding - A foundation capable of providing uniform and stable support is important for both flexible and rigid culverts. The foundation must be able to support the structure at the proposed grade and elevation without concentration of foundation pressures. Foundations are relatively yielding when compared to side fill. Establishing a suitable

foundation requires removal and replacement of any hard spots or soft spots. Bedding is needed to level out any irregularities in the foundation and to insure uniform support. When using flexible culverts, bedding is shaped to a sufficient width to permit compaction of the remainder of the backfill, and enough loose material is placed on top of the bedding to fill the corrugations. When using rigid culverts, the bedding conforms to the conditions specified in the plans and is shaped to allow compaction and to provide clearance for the bell ends on bell and spigot type rigid pipes. Adequate support is critical in rigid pipe installations, or shear stress may become a problem.

- Construction Loads - Culverts are generally designed for the loads they carry after construction is completed. Construction loads may exceed design loads. These heavy loads can cause damage if construction equipment crosses over the culvert installation before adequate fill has been placed or moves too close to the walls, creating unbalanced loading. Additional protective fill may be needed for equipment crossing points.

- Camber - In high fills the center of the embankment tends to settle more than the areas under the embankment side slopes. In such cases it may be necessary to camber the foundation slightly. This is accomplished by using a flat grade on the upstream half of the culvert and a steeper grade on the downstream half of the culvert. The initial grades are set to prevent waterponding or pocketing.

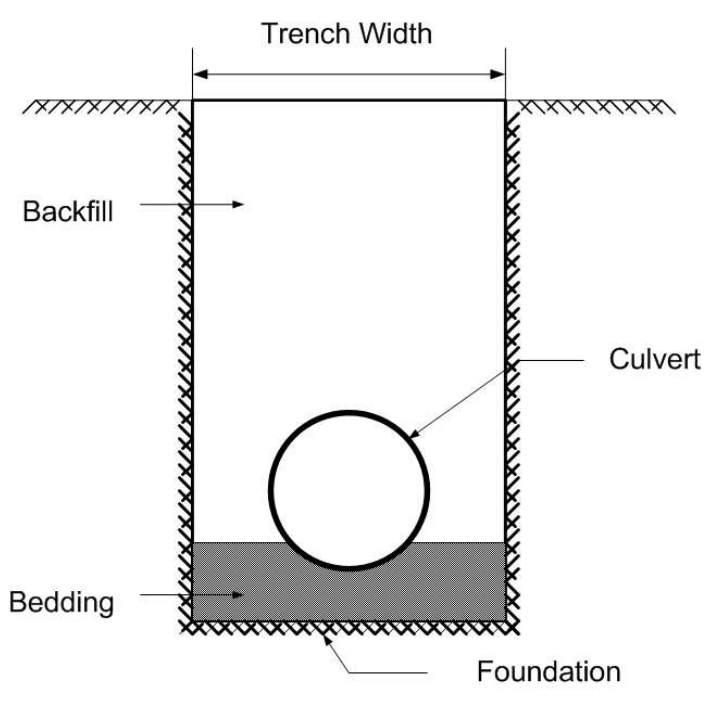


Figure 14.1.6 Culvert Construction and Installation Requirements

14.1.4 Culvert Shapes

A wide variety of standard shapes and sizes are available for most culvert materials. Since equivalent openings can be provided by a number of standard shapes, the selection of shape may not be critical in terms of hydraulic performance. Shape selection is often governed by factors such as depth of cover or limited headwater elevation. In such cases a low profile shape may be needed. Other factors such as the potential for clogging by debris, the need for a natural stream bottom, or structural and hydraulic requirements may influence the selection of culvert shape. Each of the common culvert shapes are discussed in the following paragraphs.

Circular

The circular shape is the most common shape manufactured for pipe culverts (see Figure 14.1.7). It is hydraulically and structurally efficient under most conditions. Possible hydraulic drawbacks are that circular pipe generally causes some reduction in stream width during low flows. It may also be more prone to clogging than some other shapes due to the diminishing free surface as the pipe fills beyond the midpoint. With very large diameter corrugated metal pipes, the flexibility of the sidewalls dictates that special care be taken during backfill construction to maintain uniform curvature.

Figure 14.1.7 Circular Culvert Structure

Pipe Arch and Elliptical Shapes

Pipe arch and elliptical shapes are often used instead of circular pipe when the distance from channel invert to pavement surface is limited or when a wider section is desirable for low flow levels (see Figure 14.1.8). These shapes may also be prone to clogging as the depth of flow increases and the free surface diminishes. Pipe arch and elliptical shapes are not as structurally efficient as a circular shape.

Figure 14.1.8 Pipe Arch Culvert

Arches

Arch culverts offer less of an obstruction to the waterway than pipe arches and can be used to provide a natural stream bottom where the stream bottom is naturally erosion resistant (see Figure 14.1.9). Foundation conditions must be adequate to support the footings. Riprap is frequently used for scour protection.

Figure 14.1.9 Arch Culvert

Box Sections

Rectangular cross-section culverts are easily adaptable to a wide range of site conditions including sites that require low profile structures (see Figure 14.1.10). Due to the flat sides and top, rectangular shapes are not as structurally efficient as other culvert shapes. In addition, box sections have an integral floor.

Figure 14.1.10 Concrete Box Culvert

Multiple Barrels

Multiple barrels are used to obtain adequate hydraulic capacity under low embankments or for wide waterways (see Figure 14.1.11). In some locations they may be prone to clogging as the area between the barrels tends to catch debris and sediment. When a channel is artificially widened or when a culvert is constructed, excessive sedimentation is more likely to occur in any or all of the barrels based upon the conditions. The span or opening length of multiple barrel culverts includes the distance between barrels as long as that distance is less than half the opening length of the adjacent barrels.

Figure 14.1.11 Multiple Cell Concrete Culvert

Frame Culverts

Frame culverts are constructed of cast-in-place (see Figure 14.1.12) or precast reinforced concrete. This type of culvert has no floor (concrete bottom) and fill material is placed over the structure.

Figure 14.1.12 Frame Culvert

14.1.5 Culvert Materials

Precast Concrete

Precast concrete culverts are manufactured in six standard shapes:

- Circular
- Pipe arch
- Horizontal elliptical
- Vertical elliptical
- Rectangular
- Arch

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 180 inches in diameter, with larger sizes available as special designs. Standard box sections are also available with spans as large as 144 inches. Precast concrete arches on cast-in-place footings are available with spans up to 41 feet. A listing of standard sizes is provided in Topic 14.2. Refer to Topic 14.2 for a detailed discussion of precast concrete culverts.

Cast-in-Place Concrete

Culverts that are reinforced cast-in-place concrete are typically either rectangular or arch-shaped. The rectangular 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 long construction time of cast-in-place culverts, precast concrete or corrugated metal culverts are sometimes selected. However, in many areas, cast-in-place culverts are more practical and represent a significant number of installations. Refer to Topic 14.2 for a detailed discussion of cast-in-place concrete culverts.

Metal Culverts

Flexible culverts are typically either steel or aluminum and are constructed from factory-made corrugated metal pipe or field assembled from structural plates. Structural plate products are available as plate pipes, box culverts, or long span structures (see Figures 14.1.13 and 14.1.14). Several factors such as span length, vertical and horizontal clearance, peak stream flow and terrain determine which flexible culvert shape is used. Refer to Topic 14.3 for a detailed discussion of metal culverts.

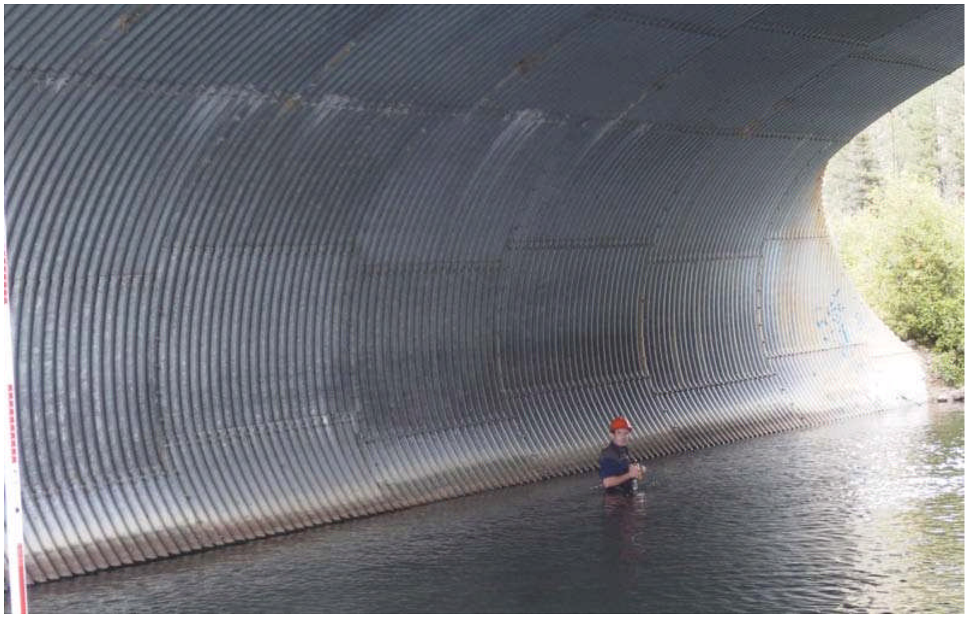


Figure 14.1.13 Large Structural Plate Pipe Arch Culvert

Figure 14.1.14 Large Structural Plate Box Culvert

Masonry

Stone and brick are durable, low maintenance materials. Prior to the 1920's, both stone and brick were used frequently in railroad and road construction projects because they were readily available from rock cuts or local brickyards. Currently stone and brick are seldom used for constructing culvert barrels. Stone is used occasionally for this purpose in locations which have very acidic runoff, but the most common use of stone is for headwalls where a rustic or scenic appearance is desired. A stone masonry arch culvert is shown in Figure 14.1.13. Refer to Topic 14.2 for a detailed discussion of stone masonry.

Figure 14.1.15 Stone Masonry Arch Culvert

Timber

There are a limited amount of timber culverts throughout the nation.

Timber culverts are generally box culverts and are constructed from individual timbers similar to railroad ties. Timber culverts are also analogous to a short span timber bridge on timber abutments (see Figure 14.1.14). Refer to Topic 14.2 for a detailed discussion of timber culverts.

Figure 14.1.16 Timber Box Culvert

Plastic

Plastic culverts are relatively new and are not as common. They are round in shape, similar to corrugated metal culverts (see Figure14.1.17). Refer to Topic 14.3 for a detailed description of plastic culverts.

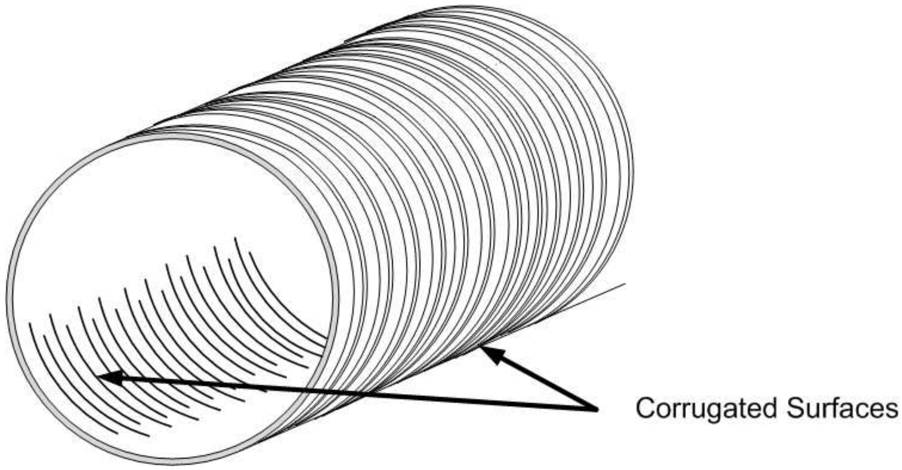


Figure 14.1.17 Schematic of a Single Walled Plastic Culvert

Other Materials

Aluminum, steel, concrete, and stone masonry are the most commonly found materials for existing culverts. There are several other materials which may be encountered during culvert inspections, including cast iron, stainless steel, terra cotta, and asbestos cement. These materials are not commonly found because they are either labor intensive (terra cotta) or used for specialized situations (stainless steel and cast iron).

14.1.6 Culvert End Treatments

Culverts may have end treatments or end structures. End structures are used to control scour, support backfill, retain the embankment, improve hydraulic efficiency, protect the culvert barrel, and provide additional stability to the culvert ends.

The most common types of end treatments are:

- Projecting - The barrel simply extends beyond the embankment. No additional support is used (see Figure 14.1.18).
- Mitered - The end of the culvert is cut to match the slope of the embankment. This is commonly used when the embankment has some sort of slope paving (see Figure 14.1.18).
- Skewed - Culverts, which are not perpendicular to the roadway, may have their ends cut parallel to the roadway (see Figure 14.1.20).
- Pipe end section - A section of pipe is added to the ends of the culvert barrel. These are typically used on smaller culverts.
- Headwalls - Used along with wingwalls to retain the fill, resist scour, and improve the hydraulic capacity of the culvert. Headwalls are usually reinforced concrete (see Figure 14.1.21), but can be constructed of timber or masonry. Metal headwalls are usually found on metal box culverts.

Figure 14.1.18 Culvert End Projection

Figure 14.1.19 Culvert Mitered End

Figure 14.1.20 Culvert Skewed End

Figure 14.1.21 Culvert Headwall and Wingwalls

Miscellaneous Appurtenance Structures may also be used with end treatments to improve hydraulic efficiency and reduce scour. Typical appurtenances include:

- Aprons - Used to reduce streambed scour at the inlets and outlets of culverts. Aprons are typically concrete slabs, but they may also be riprap (see Figure 14.1.22). Most aprons include an upstream cutoff wall (also known as a toe wall) to protect against undermining.

- Energy Dissipators - Used when outlet velocities are likely to cause streambed scour downstream from the culvert. Stilling basins, riprap or other devices that reduce flow velocity can be considered energy dissipators (see Figure 14.1.23).

  Appurtenances such as aprons and energy dissipaters are subject to fast flowing water. Inspect these appurtenances to determine they are in condition to perform their intended duties. For concrete appurtenances, look for material deteriorations such as cracking, spalling, chloride contamination, abrasion and reinforcing steel corrosion. See Topic 6.2 for anticipated modes of concrete deterioration and inspection procedures for concrete.

Figure 14.1.22 Apron

Figure 14.1.23 Riprap Basin

14.1.7 Hydraulics of Culverts

Culverts are primarily constructed to convey water under a highway, railroad, or other embankment. A culvert which does not perform this function properly may jeopardize the throughway, cause excessive property damage, or even loss of life. The hydraulic requirements of a culvert usually determine the size, shape, slope, and inlet and outlet treatments. Culvert hydraulics can be divided into two general design elements:

- Hydrologic Analysis
- Hydraulic Analysis

A hydrologic analysis is the evaluation of the watershed area for a stream and is used to determine the design discharges or the amount of runoff the culvert is designed to convey.

A hydraulic analysis is used to select a culvert, or evaluate whether an existing culvert is capable of adequately conveying the design discharge. To recognize whether a culvert is performing adequately, it is important for the inspector to understand the factors that influence the amount of runoff to be handled by the culvert as well as the factors which influence the culvert's hydraulic capacity.

Hydrologic Analysis

Most culverts are designed to carry the surface runoff from a specific drainage area. While the selection and use of appropriate methods of estimating runoff requires a person experienced in hydrologic analysis and would usually not be performed by the inspector, it is helpful to understand how changes in the topography of the drainage area can cause major changes in runoff. Climatic and topographic factors are briefly presented:

Climatic Factors

Climatic factors that may influence the amount of runoff include:

- Rainfall intensity
- Storm duration
- Rainfall distribution within the drainage area
- Soil moisture
- Snow melt
- Rain-on-snow
- Other factors

Topographic Factors

Topographic factors that may influence runoff include:

- The land use within the drainage area
- The size, shape, and slope of the drainage area
- Water regulation features such as dams and irrigation canals
- Other factors such as the type of soil and elevation

Land use is the most likely characteristic to change significantly during the service life of a culvert. Changes in land use may have a considerable effect on the amount and type of runoff. Some surface types will permit more infiltration than other surface types. Practically all of the rain falling on paved surfaces will drain off while much less runoff will result from undeveloped land. If changes in land use were not planned during the design of a culvert, increased runoff may exceed the capacity of an existing culvert when the land use does change.

The size, shape, and slope of a culvert's drainage area influence the amount of runoff that may be collected and the speed with which it will reach the culvert. The amount of time required for water to flow to the culvert from the most remote part of a drainage area is referred to as the time of concentration. Changes within the drainage area may influence the time of concentration.

Straightening or enclosing streams and eliminating temporary storage by replacing undersized upstream pipes are examples of changes which may decrease time of concentration. Land use changes may also decrease time of concentration since water will flow more quickly over paved surfaces. Since higher rainfall intensities occur for shorter storm durations, changes in time of concentration can have a significant impact on runoff. Drainage areas are sometimes altered and flow diverted from one watershed to another.

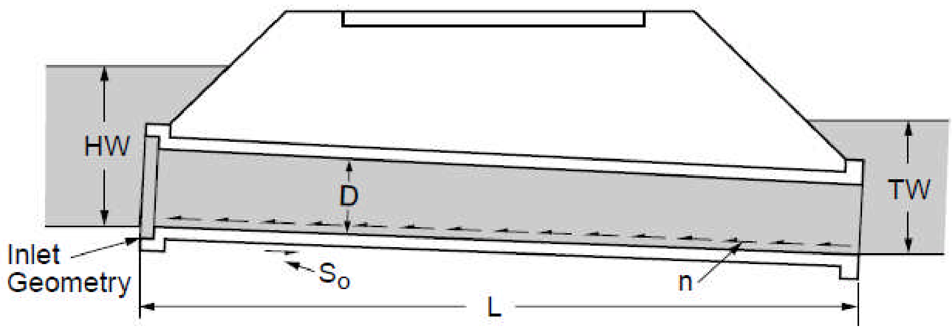
Hydraulic Analysis

The factors within a hydraulic analysis affecting a culvert's capacity may include headwater depth (see Figure 14.1.24), tailwater depth, inlet geometry, the slope of the culvert barrel, barrel area, barrel length, and the roughness of the culvert barrel. The various combinations of the factors affecting flow can be grouped into two types of conditions in culverts:

- Inlet control
- Outlet control

Inlet Control

Under inlet control the discharge from the culvert is controlled at the entrance of the culvert by headwater depth and inlet geometry (see Figure 14.1.24). Inlet geometry includes the cross-sectional area, shape, and type of inlet edge. Inlet control governs the discharge as long as water can flow out of the culvert faster than it can enter the culvert.



D = Inside diameter for a circular pipe
HW = Headwater depth at culvert entrance
L = Length of culvert
n = Surface roughness of the pipe wall, usually expressed in terms of Manning's n
S_o = Slope of the culvert pipe
TW = Tailwater depth at culvert outlet

Figure 14.1.24 Factors Affecting Culvert Discharge (Source: Concrete Pipe Design Manual, American Concrete Pipe Association, April 2007

Most culverts, except those in flat terrain, operate under inlet control during peak flows. Since the entrance characteristics govern, minor modifications at the culvert inlet can significantly affect hydraulic capacity. For example, change in the approach alignment of the stream may reduce capacity, while the improvement of the inlet edge condition, or addition of properly designed headwalls and wingwalls, may increase the capacity.

Outlet Control

Under outlet control water can enter the culvert faster than water can flow through the culvert. The discharge is influenced by the same factors as inlet control plus the tailwater depth and barrel characteristics (slope, length, and roughness). Culverts operating with outlet control usually lie on flat slopes or have high tailwater.

When culverts are operating with outlet control, changes in barrel characteristics or tailwater depth may affect capacity. For example, increased tailwater depth or debris in the culvert barrel may reduce the capacity.

Special Hydraulic Considerations

Inlet and Outlet Protection

The inlets and outlets of culverts may require protection to withstand the hydraulic forces exerted during peak flows. Inlet ends of flexible pipe culverts, which are not adequately protected or anchored, may be subject to entrance failures due to buoyant forces. The outlet may require energy dissipators to control erosion and scour and to protect downstream properties. High outlet velocities may cause scour which undermines the headwall, wingwalls, and culvert barrel. This erosion can cause end-section drop-off in rigid sectional pipe culverts.

Protection Against Piping

Seepage along the outside of the culvert barrel may remove supporting material. This process is referred to as “piping”, since a hollow cavity similar to a pipe is often formed. Piping can also occur through open joints. Piping is controlled by reducing the amount and velocity of water seeping along the outside of the culvert barrel. This may require watertight joints and in some cases anti-seep collars. Good backfill material and adequate compaction of that material are also important.

14.1.8 Factors Affecting Culvert Performance

Some of the common factors that can affect the performance of a culvert include the following:

- Construction Techniques - Specifically, how well the foundation was prepared, the bedding placed, and the backfill compacted.
- The characteristics of the stream flow - water depth, velocity, turbulence.
- Structural Integrity - how well the structure can withstand the loads to which it is subjected, especially after experiencing substantial deterioration and section loss.
- Suitability of the Foundation - Can the foundation material provide adequate support?
- Stability of the embankment in relationship to other structures on the upstream or downstream side.
- Hydraulic capacity - if the culvert cross section is insufficient for flow, upstream ponding could result and damage the embankment.
- The presence of vegetation, debris and sedimentation buildup - can greatly affect the means and efficiency of the flow through the culvert.
- The possibility of abrasion and corrosion caused by substances in the water, the surrounding soil or atmosphere.

14.1.9 Types and Locations of Culvert Distress

Types of Distress

The combination of high earth loads, long pipe-like structures and running water tends to produce the following types of distress:

- Structural - High embankments may impose very high permanent loads on all sides of a culvert and can cause shear or bending failure (see Figure 14.1.25).
- Foundation - Either a smooth sag or differential vertical displacement at construction or expansion joints (settlement). Tipping of wingwalls. Lateral movement of precast or cast-in-place box sections (see Figure 14.1.26).
- Hydraulic - Full flow design conditions result in accelerated scour and undermining at culvert ends as well as at any irregularities within the culvert due to foundation problems (see Figure 14.1.27).
- Debris accumulation - Branches, sediment and trash can often be trapped at the culvert entrance restricting the channel flow and causing scour (see Figure 14.1.28).

Figure 14.1.25 Bending or Shear Failure

Figure 14.1.26 Cracking of Culvert End Treatment Due to Foundation Settlement

Figure 14.1.27 Scour and Undermining at Culvert Inlet

Figure 14.1.28 Debris and Sediment Buildup

Inspection Locations

A logical sequence for inspecting culverts helps ensure that a thorough and complete inspection will be conducted. In addition to the culvert components, look for high water marks, changes in the drainage area, and other indications of potential problems. In this regard, the inspection of culverts is similar to the inspection of bridges.

For typical installations, it is usually convenient to begin the field inspection with general observations of the overall condition of the structure and inspection of the approach roadway. Select one end of the culvert and inspect the embankment, waterway, headwalls, wingwalls, and culvert barrel. Progress to the other end of the culvert. The following sequence is applicable to all culvert inspections:

- Overall condition
- Approach roadway and embankment settlement
- Waterway (see in Topic 13.2)
- End treatments
- Appurtenance structures
- Culvert barrel

Overall Condition

General observations of the condition of the culvert are made while approaching the culvert area. The purpose of these initial observations is to familiarize the inspector with the structure. They may also point out a need to modify the inspection sequence or indicate areas requiring special attention. Remain observant for changes in the drainage area that might affect runoff characteristics and hydraulic analyses.

Approach Roadway and Embankment

Inspection of the approach roadway and embankment includes an evaluation of the functional adequacy (see Figure 14.1.29).

Inspect the approach roadway and embankment for the following functional requirements:

- Signing
- Alignment
- Clearances
- Adequate shoulder profile
- Safety features

Figure 14.1.29 Approach Roadway at a Culvert Site

Defects in the approach roadway and embankment may be indicators of possible structural or hydraulic problems in the culvert. Inspect the approach roadway and embankment for the following conditions:

- Sag in roadway or guardrail
- Cracks in pavement
- Pavement patches or evidence that roadway has settled
- Erosion or failure of side slopes

Examine approach roadways for sudden dips, cracks, and sags in the pavement. These usually indicate excessive deflection of the culvert or inadequate compaction of the backfill material.

New pavement can temporarily hide approach problems. It is advisable for the inspector to have previous inspection reports that may indicate the age of the present overlay (see Figure 14.1.30).

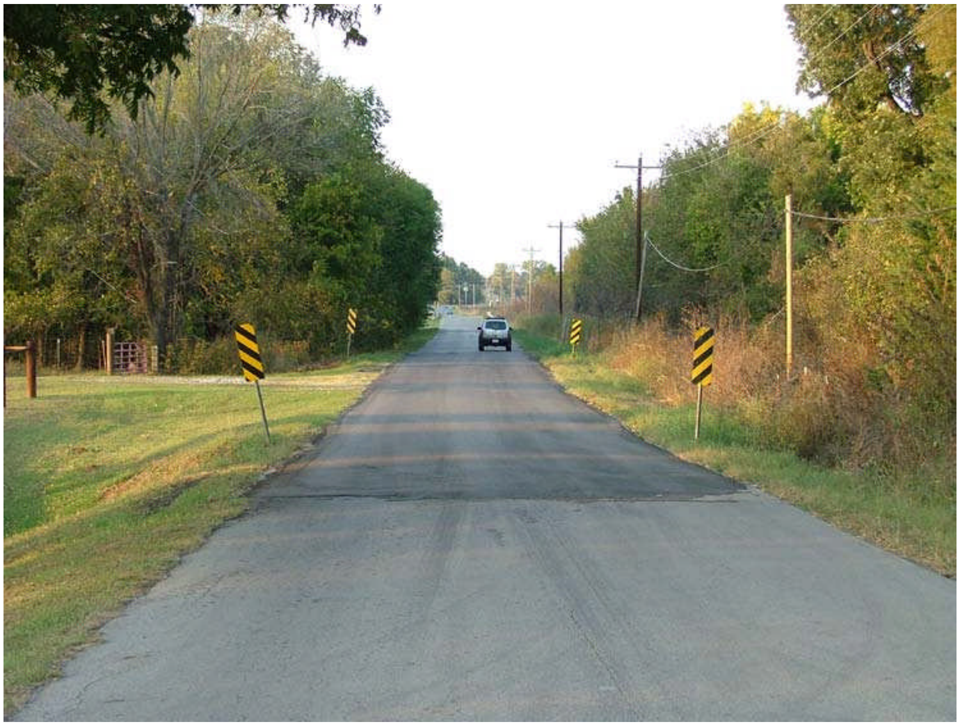


Figure 14.1.30 Repaired Roadway Over a Culvert

It is important to note that not all defects in the approach roadways have an adverse affect on the culvert. Deterioration of the pavement may be due to excessive traffic and no other reason.

Embankment

Inspect the embankment around the culvert entrance and exit for slide failures in the fill around the box (see Figure 14.1.31). Check for debris at the inlet and outlet and within the culvert. Also note if vegetation is obstructing the ends of the culvert.

Figure 14.1.31 Slide Failure

End Treatments

The SI&A Inspection Sheet does not specifically address end treatments in terms of inventory data or condition. The condition rating of end treatments is part of SI&A Item 62, Culvert Condition, and can have an impact on SI&A Item 67, Structural Evaluation.

Inspections of end treatments primarily involve visual inspection, although hand tools such as a plumb bobs, hammers, and probing rods are used to check for misalignment, sound for defects, and check for scour and undermining. In general, inspect headwalls for movement or settlement, cracks, deterioration, and traffic hazards (see Figure 14.1.32). Check culvert ends for undermining, scour, and evidence of piping.

Figure 14.1.32 Headwall and Wingwall End Treatment on Box Culvert

The most common types of box culvert end treatments are:

- Skewed Ends
- Headwalls

Both end treatment types use wingwalls to retain the embankment around the opening.

Inspect wingwalls to ensure they are in proper vertical alignment (see Figures 14.1.32 and 14.1.33). Wingwalls may be tilted due to settlement, slides or scour. See Topic 12.1 for a detailed description of defects and inspection procedures of wingwalls.

Figure 14.1.33 Potential for Tilted Wingwalls

Skewed Ends - Skewing the end of a culvert has nearly the same effect on structural capacity as does mitering (see Figure 14.1.34). Stresses increase because a full box shape is not present at the end.

Figure 14.1.34 Skewed End

Headwalls – Inspect headwalls and wingwalls for undermining and settlement. Cracking, tipping or separation of culvert barrel from the headwall and wingwalls is usually evidence of undermining (see Figure 14.1.35).

Figure 14.1.35 Culvert Headwall and Wingwall End Treatment

Appurtenance Structures Typical appurtenance structures are:

- Aprons
- Energy Dissipators

Aprons – Check aprons for any undermining or settlement. Also inspect the joints between the apron and headwalls to see if they are watertight (see Figure 14.1.36). Piping may occur is water is allowed contact with the culvert outer surfaces.

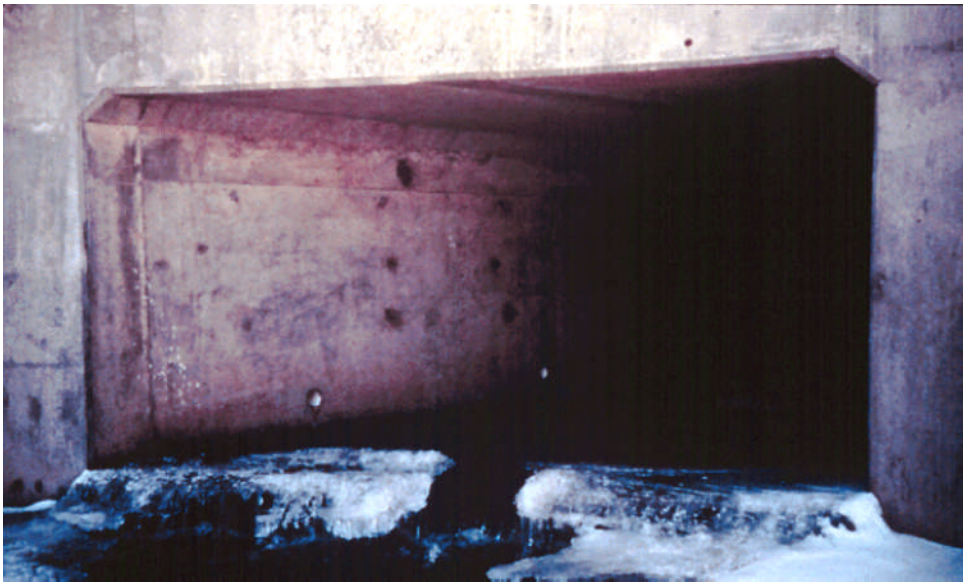


Figure 14.1.36 Apron

Energy Dissipaters – Energy dissipaters may include stilling basins, riprap or other devices. Inspect energy dissipaters for material defects, settlement, undermining, and overall effectiveness (see Figure 14.1.37).

Figure 14.1.37 Energy Dissipater

Culvert Barrel

Inspect the full length of the culvert from the inside. Visually examine all components of the culvert barrel including walls, floor, top slab, and joints. It is important to time the inspection so that water levels are low. Culverts with small diameters can be inspected by looking through the culvert from both ends or by using a small movable camera. The condition of the culvert barrel is rated under SI&A Item 62, which covers all structural components of a culvert.

Inspect the culvert barrels for defects such as misalignment, joint defects, cracking, spalling, section loss, and other material defects. For a detailed description of culvert inspection, refer to Topic 14.2 for rigid culverts or Topic 14.3 for flexible culverts.

14.1.10 Durability

Although the structural condition is a very important element in the performance of culverts, durability problems are probably the most frequent cause of replacement. Culverts are more likely to "wear away" than fail structurally. Durability is affected by two mechanisms: corrosion and abrasion. See Topics 14.2 and 14.3 for detailed explanations on how abrasion and corrosion affects the durability of rigid and flexible culverts.

14.1.11 Soil and Water Conditions that Affect Culverts

Certain soil and water conditions have been found to have a strong relationship to accelerated culvert deterioration. These conditions are referred to as "aggressive" or "hostile." The most significant conditions of this type are:

- pH Extremes
- Electrical Resistivity
- Soil Characteristics

pH Extremes

pH is a measure of the relative acidity or alkalinity of water. A pH of 7.0 is neutral; values of less than 7.0 are acid, and values of more than 7.0 are alkaline. For culvert purposes, soils or water having a pH of 5.5 or less are strongly acid and those of 8.5 or more are strongly alkaline.

Acid water stems from two sources, mineral and organic. Mineral acidity comes from sulfurous wells and springs, and drainage from coal mines. These sources contain dissolved sulfur and iron sulfide which may form sulfurous and sulfuric acids. Mineral acidity as strong as pH 2.3 has been encountered. Organic acidity usually found in swampy land and barnyards rarely produce a pH of less than 4.0. Alkalinity in water is caused by strong alkali-forming minerals and from limed and fertilized fields. Acid water (low pH) is more common to wet climates and alkaline water (high pH) is more common to dry climates. As the pH of water in contact with culvert materials, either internally or externally, deviates from neutral, 7.0, it generally becomes more hostile.

Electrical Resistivity

This measurement depends largely on the nature and amount of dissolved salts in the soil. The greater the resistance the less the flow of electrical current associated with corrosion. High moisture content and temperature lower the resistivity and increase the potential for corrosion. Soil resistivity generally decreases as the depth increases. The use of granular backfill around the entire pipe will increase electrical resistivity and will reduce the potential for galvanic corrosion.

Several states rely on soil and water resistivity measurements as an important index of corrosion potential. Some states and the FHWA have published guidelines that use a combination of the pH and electrical resistivity of soil and water to indicate the corrosion potential at proposed culvert sites. The collection of pH and electrical resistivity data during culvert inspections can provide valuable information for developing local guidelines.

Soil Characteristics

The chemical and physical characteristics of the soil, which will come into contact with a culvert, can be analyzed to determine the potential for corrosion. The presence of base-farming and acid-forming chemicals is important. Chlorides and other dissolved salts increase electrical conductivity and promote the flow of corrosion currents. Sulfate soils and water can be erosive to metals and harmful to concrete. The permeability of soil to water and to oxygen is another variable in the corrosion process.

14.1.12 Culvert Protective Systems

There are several protective measures that can be taken to increase the durability of culverts. The more commonly used measures are:

Extra Thickness

For some aggressive environments, it may be economical to provide extra thickness of concrete or metal.

Bituminous Coating

This is the most common protective measure used on corrugated steel pipe. This procedure can increase the resistance of metal pipe to acidic conditions if the coating is properly applied and remains in place. Careful handling during transportation, storage, and placement is required to avoid damage to the coating. Bituminous coatings can also be damaged by abrasion. Make field repairs when bare metal has been exposed. Fiber binding is sometimes used to improve the adherence of bituminous material to the metallic-coated pipe.

Bituminous Paved Inverts

Paving the inverts of corrugated metal culverts to provide a smooth flow and to protect the metal has sometimes been an effective protection from particularly abrasive and corrosive environments. Bituminous paving is usually at least 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.

Other Coatings

There are several other coating materials that are being used to some degree throughout the country. Polymeric, epoxy, fiberglass, clay, and reinforced concrete field paving, have all been used as protection against corrosion. Galvanizing is the most common of the metallic coatings used for steel. It involves the application of a thin layer of zinc on the metal culvert. Other metallic coatings used to protect steel culverts are aluminum and aluminum-zinc.

Table of Contents

Chapter 14

Characteristics, Inspection and Evaluation of Culverts

Topic 14.2 Rigid Culverts

14.2.1 Introduction

Culverts are classified as rigid culverts when the load-carrying capacity of the culvert is primarily provided by the structural strength of the culvert, with little strength developed from the surrounding soil. By this definition, rigid culverts do not bend or deflect appreciably when loaded.

Unlike bridges, culverts have no distinction between substructure and superstructure. Culverts also have no "deck", since earth backfill separates the culvert structure from the riding surface (see Figure 14.2.1).

Figure 14.2.1 Rigid Culvert

14.2.2 Design Characteristics

Concrete Culverts

Concrete culverts are the most common type of rigid culverts used today. Types of concrete culverts include:

- Concrete box culverts (either cast-in-place or precast)
- Concrete pipe culverts
- Concrete arch culverts
- Concrete frame culverts

See Figures 14.2.25a through 14.2.25c at the end of this topic for standard sizes of concrete pipes and Figure 14.2.26 at the end of this topic for standard concrete pipe shapes.

Concrete Box Culverts

One of the most common rigid culverts used today is the concrete box culvert (see Figure 14.2.2). A box culvert has an integral bottom slab that supports the side walls and provides a lined channel for the water to flow. The dimensions of the box culvert are determined by hydraulic, structural and geotechnical design criteria, as well as site constraints, which include channel dimensions and the amount of available cover. Box culverts are used in a variety of circumstances for both small and large channel openings and are easily adaptable to a wide range of site conditions, including sites that require low profile structures. In situations where the required size of the opening is very large, a multi-cell box culvert can be used (see Figure 14.2.3). It is important to note that although a box culvert may have multiple barrels, it is still a single structure. The internal walls are provided to reduce the unsupported length of the top slab.

Figure 14.2.2 Concrete Box Culvert

Figure 14.2.3 Multi-Cell Concrete Box Culvert

There are two basic types of concrete box culverts: cast-in-place and precast. Precast concrete box culverts are generally the preferred type of concrete box culvert. For situations with complex site geometries or other special applications, cast-in-place concrete box culverts may be the preferred choice.

Cast-in-Place

Reinforced cast-in-place (CIP) concrete box culverts are typically constructed with multiple cells (barrels) to accommodate longer spans. The major advantage of cast-in-place construction is that the culvert can be designed to meet the specific geometric requirements of the site. Cast-in-place box culverts are also generally preferred for special applications, such as side- or slope-tapered inlets, aquatic organism passage, or customized fit with other infrastructure including additional culverts, stormdrains and drop inlets.

Precast

Precast concrete box culverts are designed for various depths of cover and various live loads and are manufactured in a wide range of sizes. One of the major advantages of precast concrete box culverts is the increased speed of construction. Standard box sections are available with spans as large as 12 feet (see Figure 14.2.4). Some box sections may have spans of up to 20 feet if a special design is used.

ASTM C 1433 Precast Reinforced Concrete Box Sections for Culverts, Storm Drains and Sewers is an industry recognized reference. These specifications cover single-cell precast reinforced concrete box sections intended to be used for the construction of culverts for the conveyance of storm water, industrial wastes, and sewage.

Figure 14.2.4 Precast Concrete Box Culvert

Concrete Pipe Culverts

Precast concrete pipe culverts are manufactured in three standard shapes:

- Circular
- Horizontal elliptical
- Vertical elliptical

Circular pipe culverts are very common (see Figure 14.2.5). In situations where the required size of the opening is very large, two or more concrete pipe culverts may be used (see Figure 14.2.6).

Figure 14.2.5 Concrete Pipe Culvert

Figure 14.2.6 Twin Concrete Pipe Culvert

The size of the opening is primarily determined by the following factors: a) magnitude of the peak design flow; b) allowable headwater (pooled water surface) at the inlet for the peak design flow; c) permissible barrel and outlet flow velocities; and d) aquatic organism passage design considerations. The circular shape is the most common shape manufactured for pipe culverts. It is hydraulically and structurally efficient under most conditions. Elliptical shapes are used in situations where horizontal or vertical clearance is limited. The oblong shape allows the pipe to fit where a circular pipe may not, but still allows for the necessary size opening. Elliptical shaped pipe culverts may also be used when a wider section is desirable for low flow levels. No matter the shape, a pipe culvert tends to reduce the flow area of the design discharge, and possibly lesser flows, thereby increasing the flow velocity. An increased flow velocity has greater potential to scour the streambed at the outlet of the pipe.

Concrete culvert pipe is manufactured in up to five standard strength classifications. Higher classification numbers indicate higher strength. All of these standard shapes are manufactured in a wide range of sizes. Circular and elliptical pipes are available with standard sizes as large as 12 feet in diameter, with larger sizes available for special designs. Several factors such as span length, vertical and horizontal clearance, peak stream flow and terrain determine which shape of pipe culvert is used.

Concrete Arch Culverts

An arch culvert is a curved-shape culvert that works primarily in compression and does not have a bottom, or floor (see Figure 14.2.7). This type of culvert, as well as embedded culverts (i.e., culverts having buried inverts), are commonly and effectively used at stream crossings required to provide aquatic organism passage.

A variation of the arch culvert is the tied arch culvert. It is basically the same as the arch culvert, but it has an integral floor serving as a tie between the ends of the arch. Concrete arch culverts are either cast-in-place or precast.

Figure 14.2.7 Concrete Arch Culvert

Concrete Frame Culverts

Concrete frame culverts are either cast-in-place or precast reinforced concrete, which is generally shaped similar to a box culvert. It differs from a box culvert, however, since there is no floor in a frame culvert (see Figure 14.2.8). Rigid culverts with a natural bottom (by way of embedment or having an open bottom) are commonly used to provide for aquatic organism passage.

Figure 14.2.8 Concrete Frame Culvert

Masonry Culverts

Stone Masonry Arch Culverts

Stone and brick are durable, low maintenance materials. Currently stone and brick are seldom used for constructing new culvert barrels. Stone masonry culverts, when constructed, were usually in the shape of an arch (see Figure 14.2.9).

Figure 14.2.9 Stone Masonry Arch Culvert

Timber Culverts

Timber Box Culverts

There are a limited amount of timber culverts throughout the nation. Timber culverts are generally box culverts and are constructed from individual timbers similar to railroad ties (see Figure 14.2.10). These culverts are normally utilized in areas of seasonal flows, such as heavy flow in the spring and little to no flow during the summer months.

Figure 14.2.10 Timber Box Culvert

Loads on Culverts

There are several basic loads applied in the design of a culvert and include:

- Dead loads (culvert self –weight)
- Vertical earth pressure (weight of earth such as fill and road surface)
- Horizontal (lateral) earth pressure
- Live loads (vehicular traffic, pedestrian traffic)

Box Culverts

Box culverts face similar types of loads on each slab and wall of the culvert (see Figure 14.2.11).

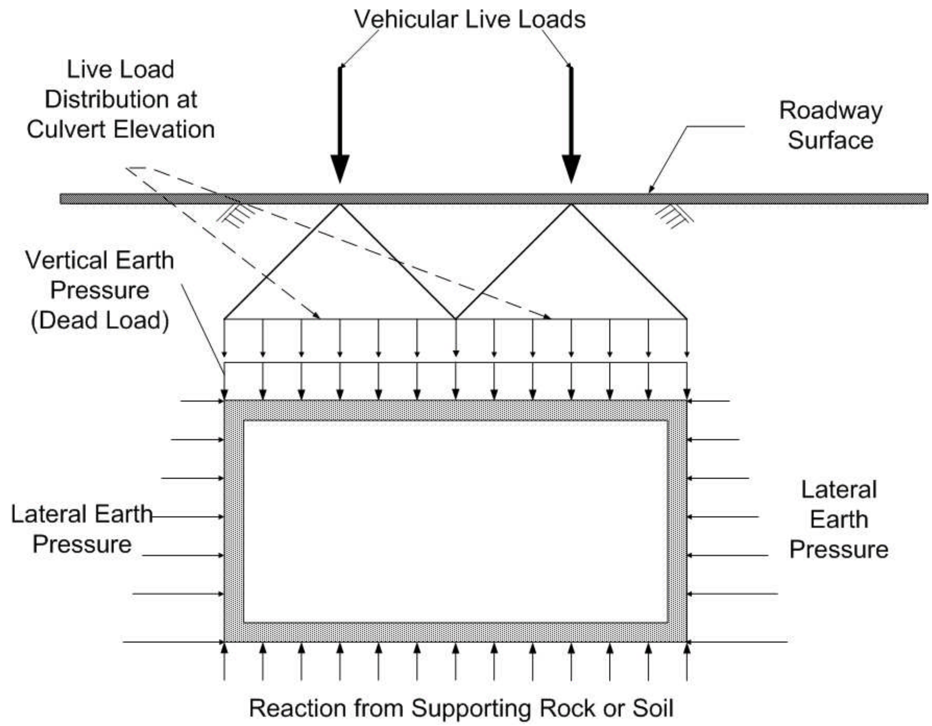


Figure 14.2.11 Loads on a Concrete and Timber Box Culvert

Pipe Culverts

Pipe culverts are subject to the same types of forces that are placed upon the box culverts which are dead loads, vertical earth pressure, horizontal earth pressure, and live loads

Arch and Frame Culverts

Arch and frame culverts have the same types of loads as box culverts.

For a detailed description of loads on pipe, arch and frame culverts, see Topic 14.1.3.

Primary and Secondary Members

Primary members for culverts may vary based upon the type of culvert. Primary members for the various types of culverts are:

- Box culverts – top slab, bottom slab and the walls (webs)
- Frame culverts – top slab, wall (webs), foundation and footing
- Arch culverts – culvert barrel, foundation and footing
- Pipe culverts – culvert barrel

There are no secondary members for the culvert barrels. Wingwalls and headwalls are discussed in Topic 14.2.4 inspection locations.

Steel Reinforcement for Concrete Culverts

Steel reinforcement for culverts is in the form of either primary or secondary reinforcement. Depending upon the potential for corrosion, chemical attack or other steel reinforcement deficiencies, states may use epoxy-coated reinforcing bars. Some states have also incorporated stainless steel reinforcement into concrete culverts.

Primary Reinforcement

The primary reinforcing steel for box culverts resists tension and shear forces. Tension reinforcement is placed transversely in the box culvert slabs and vertically in the walls. Shear reinforcement may be placed diagonally in each of the box culvert corners (see Figure 14.2.12). Single cell precast concrete box culverts may use steel welded wire for tension and shear reinforcement.

Primary reinforcement for arch (see Figure 14.2.14) and pipe culverts (see Figure 14.2.15) also resists tension and shear. Arch and pipe culvert primary reinforcement is placed transversely in the walls of the culverts.

Secondary Reinforcement

Longitudinal temperature and shrinkage reinforcement is placed in the slabs and the walls of box culverts (see Figure 14.2.12).

Ducts may be provided in the precast box sections for optional longitudinal post-tensioning of the boxes with high strength steel strands or bars (see Figure 14.2.13).

Secondary reinforcement for arch (see Figure 14.2.14) and pipe culverts (see Figure 14.2.15) follow the shape of the culvert itself from support to support.

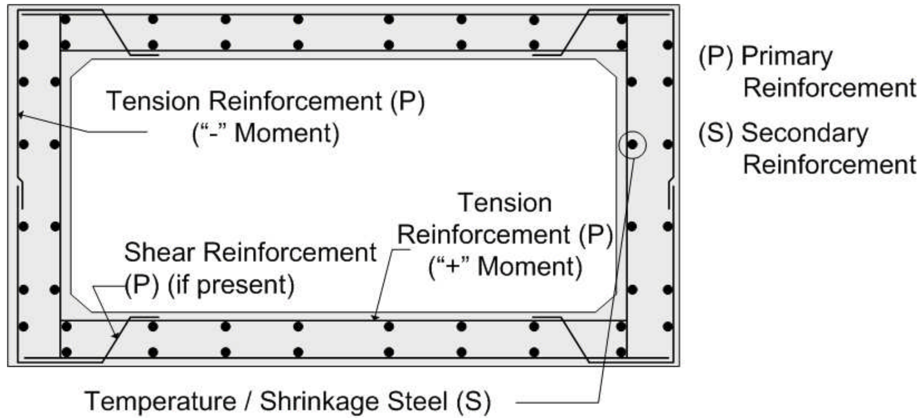


Figure 14.2.12 Steel Reinforcement in a Concrete Box Culvert

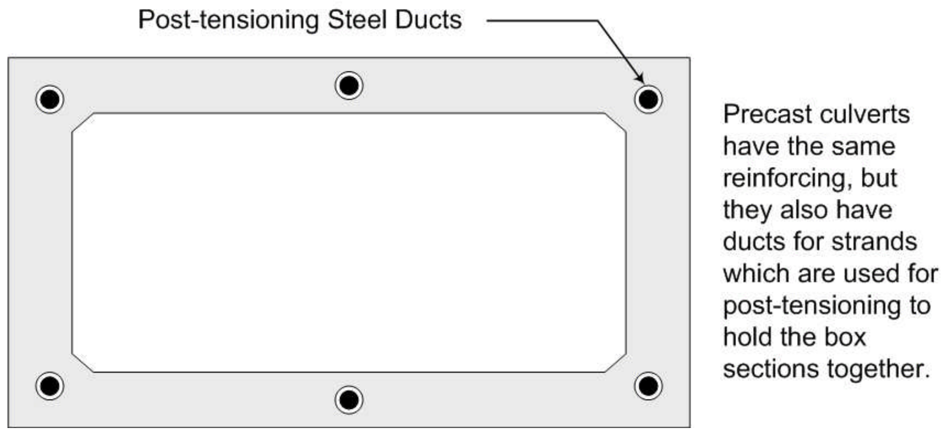


Figure 14.2.13 Precast Box Section with Post-tensioning Steel Ducts

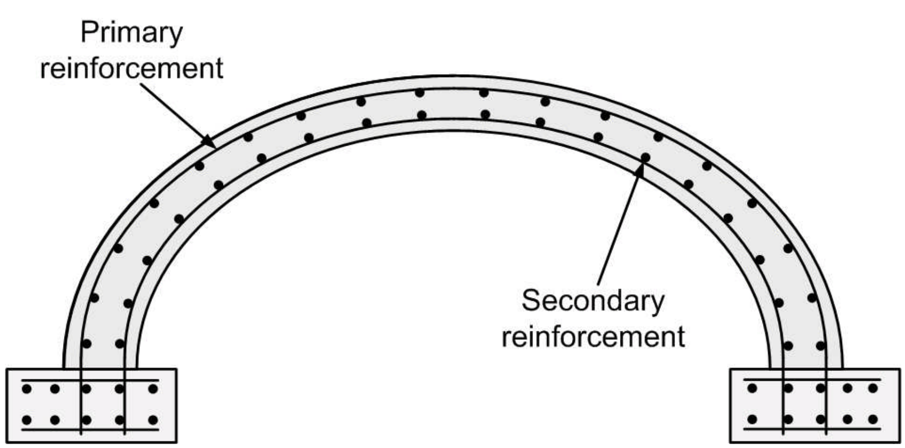


Figure 14.2.14 Steel Reinforcement in a Concrete Arch Culvert

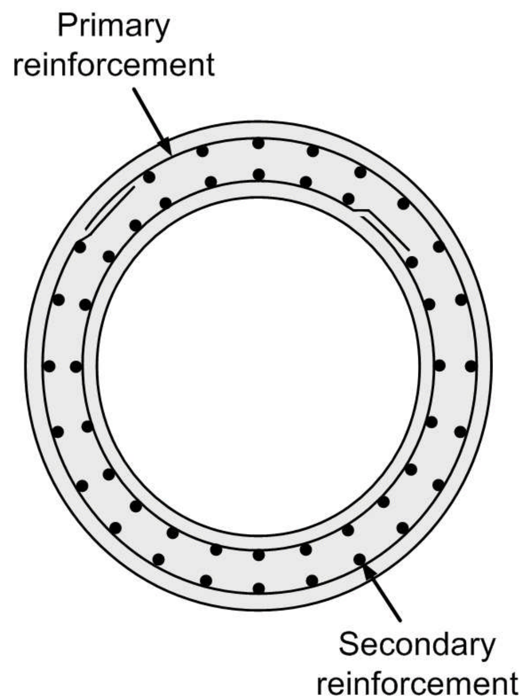


Figure 14.2.15 Steel Reinforcement in a Concrete Pipe Culvert

14.2.3 Overview of Common Deficiencies

Common deficiencies that occur in concrete rigid culverts include:

- Cracking (structural, flexure, shear, crack size, nonstructural, crack orientation)
- Scaling
- Delamination
- Spalling
- Chloride contamination
- Freeze-thaw
- Efflorescence
- Alkali-Silica Reactivity (ASR)
- Ettringite formation
- Honeycombs
- Pop-outs
- Wear
- Collision damage
- Abrasion
- Overload damage
- Internal steel corrosion

- Loss of prestress
- Carbonation

Refer to Topic 6.2.6 for a detailed explanation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

Common deficiencies that occur in masonry rigid culverts include:

- Weathering
- Spalling
- Splitting
- Fire damage
- Embankment scour at culvert inlet and outlet
- Roadway settlement

Refer to Topic 6.5.4 for a detailed explanation of the properties of masonry, types and causes of masonry deterioration, and the examination of masonry.

Common deficiencies that occur in timber rigid culverts include:

- Inherent defects (checks, splits, shakes, knots)
- Fungi
- Insects
- Marine borers
- Chemical attack
- Delaminations
- Loose connections
- Surface depressions
- Fire
- Impact or collisions
- Abrasion and mechanical wear
- Overstress
- Weathering or warping
- Protective coating failure
- Embankment scour at culvert inlet and outlet
- Roadway settlement

Refer to Topic 6.1.5 for a detailed explanation of the properties of timber, types and causes of timber deterioration, and the examination of timber.

14.2.4 Inspection Methods and Locations

Previous inspection reports and as-built plans, when available, are reviewed prior to, and during, the field inspection. Review of previous reports familiarizes the inspector with the structure and makes detection of changed conditions easier. Reviewing the previous inspection reports also indicate critical areas that need special attention and the possible need for special equipment.

A logical sequence for inspecting culverts helps ensure that a thorough and complete inspection is conducted. In addition to the culvert components, the inspector looks for high-water marks, changes in the drainage area, settlement of the roadway, and other indications of potential problems. In this regard, the inspection of culverts is similar to the inspection of bridges.

Methods

Inspection methods for various rigid culvert materials include timber Topic 6.1.7, concrete Topic 6.2.8, and masonry Topic 6.5.6.

Visual

Concrete

The inspection of concrete culverts for cracks, spalls, and other deficiencies is primarily a visual activity.

Masonry

The inspection of masonry culverts for cracks, loose or missing mortar, vegetation, water seepage, crushing, missing stones, bulging, and misalignment is primarily a visual activity.

Timber

The inspection of timber culverts for checks, splits, shakes, fungus decay, deflection, and loose fasteners is primarily a visual activity.

Physical

Concrete

Hammer sounding of the exposed concrete is performed to determine areas of delamination. A delaminated area has a distinctive hollow “clacking” sound when tapped with a hammer. A hammer hitting sound concrete results in a solid “pinging” type sound.

Masonry

Physical inspection of a masonry culvert is similar to that of concrete.

Timber

Hammer sounding of the exposed timber is performed to determine areas of internal decay. If the area has internal decay, there is a hollow sound when the hammer is tapped.

Advanced Inspection Methods

Concrete/Masonry

Several advanced methods are available for concrete and masonry inspection. Nondestructive methods, described in Topic 15.2.2, include:

- Acoustic Wave Sonic/Ultrasonic Velocity Measurements
- Electrical Methods
- Delamination Detection Machinery
- Ground-Penetrating Radar
- Electromagnetic Methods
- Pulse Velocity
- Flat Jack Testing
- Impact-Echo Testing
- Infrared Thermography
- Laser Ultrasonic Testing
- Magnetic Field Disturbance
- Neutron Probe for Detection of Chlorides
- Nuclear Methods
- Pachometer
- Rebound and Penetration Methods
- Ultrasonic Testing
- Smart Concrete

Other methods, described in Topic 15.2.3, include:

- Carbonation
- Concrete Permeability
- Concrete Strength
- Endoscopes and Videoscopes
- Moisture Content
- Petrographic Examination
- Reinforcing Steel Strength
- Chloride Test
- ASR Evaluation

Timber

Several advanced methods are available for timber inspection. Nondestructive methods, described in Topic 15.1.2, include:

- Sonic testing
- Spectral analysis
- Ultrasonic testing
- Vibration

Other methods, described in Topic 15.1.3, include:

- Boring or drilling
- Moisture content
- Probing
- Field Ohmmeter

Locations

Areas Subjected to Movement and Misalignment

Vertical Movement

Vertical movement can occur in the form of uniform settlement or differential settlement. Uniform settlement has little effect on the culvert. However, differential settlement can produce severe distress which varies in magnitude based upon the span length. This may cause cracking of the culvert. See Topic 6.2.6 for a detailed presentation of concrete deficiencies including cracking. Common causes of vertical movement are soil bearing failure, consolidation of soil, scour, undermining, and subsidence from mining or solution cavities. Locations to inspect for vertical movement include the following:

- Railing for evidence of settlement
- Existing and new cracks in the roadway pavement or concrete
- Check for scour and undermining around the culvert footing or foundation

Lateral Movement

Lateral movement occurs when the horizontal earth pressure acting on the walls exceeds the friction forces that hold the structure in place. Common causes of lateral movement are slope failure, seepage, changes in soil characteristics (i.e. frost and ice), and time consolidation of the original soil. Locations to inspect for lateral movement include the following:

- General alignment
- Settled approach pavement
- Clogged drain or weep holes

Rotational Movement

Rotational movement, or tipping, of the culvert is generally the result of unsymmetrical settlements or lateral movements due to horizontal earth pressure. Common causes are undermining, scour, saturation of backfill, and improper design. Locations to inspect for rotational movement include the following:

- Vertical alignment of the walls
- Clogged drains or weep holes
- Cracks

Vertical and horizontal misalignment is checked by visual observation. Look for culvert sagging, cracking or separation of joints in precast culverts. Sags can best be detected during low flows by looking for areas where the water is deeper or where sediment has been deposited. Sags may also trap water which may further aggravate settlement problems by saturating the soil.

When excessive accumulations of sediment are present, it may be necessary to have the sediment removed before checking for sags. An alternate method is to take profile elevations of the top slab. Check horizontal alignment or bulging for straightness or smooth curvature for those culverts that were constructed with a curved alignment. It can be checked by sighting along the walls and by examining joints for differential movement (see Figure 14.2.16).

Alignment problems may be caused by improper installation, undermining or uneven settlement of the fill. It is important to determine which of these problems may be causing the settlement. If it is determined that undermining is the cause, notify maintenance forces since the damage will continue until the problem is corrected. Also, try to determine whether the undermining is due to piping (loss of fill from underneath the culvert), water exfiltration or infiltration of backfill material. Look for holes in the downstream side embankment. If the misalignment is due to improper installation or uneven settlement, repeat inspections may be necessary to determine if the settlement is progressing or if it has stabilized.

Figure 14.2.16 Sighting Along Culvert Sidewall to Check Horizontal Alignment

Bearing Areas

Bearing zones for rigid culverts will be located where the footing is supported by the earth. For concrete and masonry culverts, look for cracking and spalling. In timber culverts, look for crushing.

Shear Zones

Horizontal and vertical forces can cause high shear zones in culvert walls or slabs. For concrete and masonry culverts, look for diagonal cracking. In timber culverts, look for splitting.

Flexural Zones

High flexural moments are caused by horizontal and vertical forces which occur at the slabs and culvert walls. These moments cause compression and tension depending on the load type and location of the neutral axis. Look for deficiencies caused by overstress due to compression or tension caused by flexural moments. Check compression areas for splitting, crushing or buckling. Check tension areas for cracking or distortion.

Areas Exposed to Drainage

Examine areas that are exposed to drainage for decay on timber culverts. For concrete culverts, examine for spalling, delamination and exposed rebar (see Figure 14.2.17). Also inspect concrete culvert headwalls and wingwalls, since these areas are often exposed to surface drainage carrying road salts, which chemically attack and destroy the walls. In masonry culverts, look for spalling, delamination, and seepage which can result in stone and mortar deterioration with the eventual loosening and/or the loss of stones (see Figure 14.2.18).

Figure 14.2.17 Spalls and Delaminations on Top Slab of Concrete Box Culvert

Figure 14.2.18 Missing Stones in Masonry Culvert

Areas Exposed to Traffic

Check for collision damage from vehicles passing adjacent to the culvert.

Damage to concrete culverts may include spalls and exposed reinforcement and possibly steel reinforcement section loss. Damage to timber culverts includes split or broken members.

Scour and Undermining

Scour is the removal of material from a streambed as a result of the erosive action of running water. Scour can cause undermining or the removal of supporting foundation material from beneath the culvert. Refer to Topic 13.2 for a more detailed description of scour and undermining.

Inspection for scour includes probing around the culvert inlet and outlet for signs of undermining. Sometimes silt loosely fills in a scour hole and offers no protection or bearing capacity for the culvert inlet and outlet. Also check timber culverts frames (no floors) for these conditions.

Joints

Expansion joints are carefully inspected to verify that the filler material or joint sealant is in place and that the joint is not filled with incompressible material that would prohibit expansion (see Figure 14.2.19). When inspecting a joint in a rigid culvert, be sure to check for the following deficiencies:

- Exfiltration - This occurs when leaking joints allow water flowing through the culvert to leak into the supporting material. Minor leaking may not be a significant problem, but if the leaking joint contributes to or the loss of supporting material (also known as piping), a serious misalignment of the culvert or failure may occur. Leaking joints may be detected during low flows visually and by checking around the ends of the culvert for piping.
- Infiltration - This occurs when water is flowing or seeping into the culvert through open joints, which may allow supporting soil into the culvert. Infiltration occurs when the water is higher than the culvert inlet, with the water seeping into the culvert. This can cause settlement and misalignment if the water carries soil particles from the backfill. Infiltration may be difficult to detect visually in its early stages, but it may be indicated by open joints, staining at the joints on the sides and top of the culvert, deposits of soil in the invert, or depressions over the culvert.
- Cracks - Spalls or cracks along joint edges are usually an indication that the expansion joint is full of incompressible materials or that one or more expansion joints are not working. Cracks may also indicate improper handling during installation, improper gasket placement, and movement or settlement of the culvert sections. If no other problems other than cracks are evident, such as differential movement between culvert sections, and the cracks are not open or spalling, they could be considered a minor problem. Severe cracking at the joints will be similar in significance to separated joints.
- Separated joints - Joint inspection also identifies any joints that are opened widely or are not open to uniform width. Joint separations are significant because they accelerate the damage caused by exfiltration and infiltration, resulting in the erosion of the backfill material. They are noted when severe misalignment is observed. Longitudinal movement of the soil in the general direction of the culvert's centerline could cause the sections to pull apart. The slippage of the embankment may also cause a joint separation to occur.

Figure 14.2.19 Precast Concrete Box Culvert Joint

Cracks

Longitudinal Cracks

Concrete is strong in compression but weak in tension. Reinforcing steel is provided to accommodate the tensile stresses. Hairline longitudinal cracks in the crown or invert indicate that the steel has accepted part of the load. Cracks less than 0.01 inches in width are minor and only need to be noted in the inspection report. Document cracks greater than 0.01 inches in width but less than 0.1 inches, in the inspection report and noted as possible candidates for maintenance. Longitudinal cracking in excess of 0.1 inches in width may indicate overloading or poor bedding. If the pipe is placed on hard material and backfill is not adequately compacted around the pipe or under the haunches of the pipe, loads will be concentrated along the bottom of the pipe and may result in flexure or shear cracking (see Figure 14.2.20).

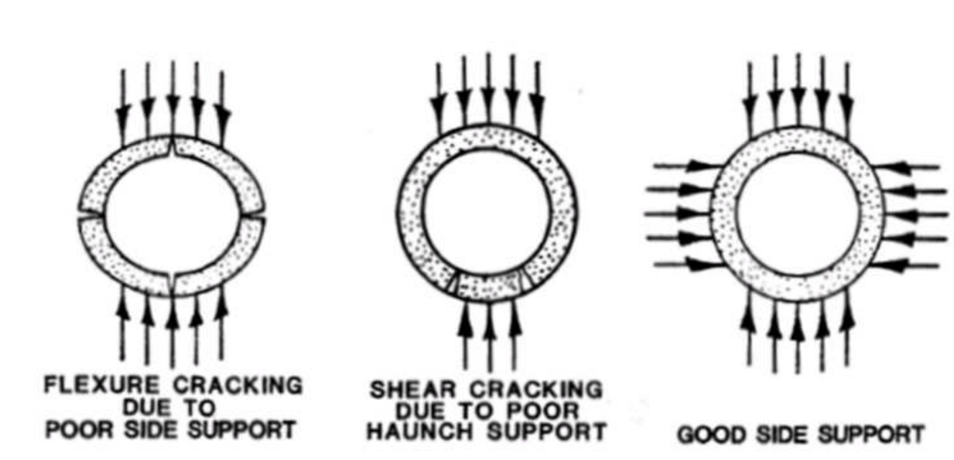


Figure 14.2.20 Longitudinal Cracks in Pipe Culvert

Also note other signs of distress such as differential movement, efflorescence, spalling, or rust stains. When cracks are wider than 0.1 inches, take measurements of the fill height and the diameter of the pipe both horizontally and vertically to permit analysis of the original design. Crack measurements and photographs are useful for monitoring conditions during subsequent inspections.

Transverse Cracks

Transverse cracks may also be caused by poor bedding (see Figure 14.2.21). Cracks can occur across the bottom of the pipe (broken belly) when the pipe is only supported at the ends of each section. This is generally the result of poor installation practices such as not providing indentions (bell holes) in hard foundation material for the ends of bell and spigot-type pipe or not providing a sufficient depth of suitable bedding material. Cracks may occur across the top of pipe (broken back) when settlement occurs and rocks or other areas of hard foundation material near the midpoint of a pipe section are not adequately covered with suitable bedding material.

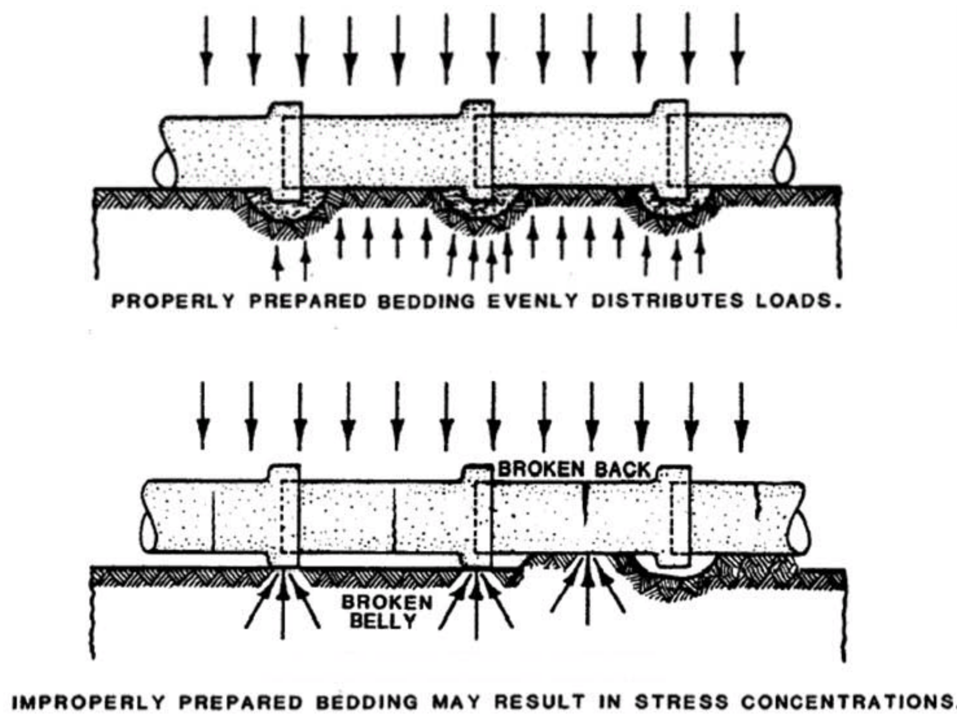


Figure 14.2.21 Transverse Cracks in Pipe Culvert

Spalls

A spall is a depression in the concrete resulting from the separation and removal of a portion of the surface concrete, revealing a fracture roughly parallel to the surface of the concrete. In precast concrete culverts, spalls often occur along the edges of either longitudinal or transverse cracks when the crack is due to overloading or poor support rather than simple tension cracking. Spalling may also be caused by the corrosion of the steel reinforcing when water is able to reach the steel through cracks or shallow cover. As the steel corrodes, the oxidized steel expands, causing the concrete covering the steel to spall. Spalling may be detected by visual examination of the concrete along the edges of cracks. Perform tapping with a hammer along cracks to check for areas that have fractured but are not visibly separated. These areas will produce a hollow sound when tapped. These areas may be referred to as delaminations.

Slabbing

Slabbing, also known as shear-slabbing or slab shear, refers to a radial failure of the concrete which occurs from straightening of the reinforcement cage due to excessive deflection. This is characterized by large slabs of concrete "peeling" away from the sides of the pipe and a straightening of the reinforcing steel (see Figure 14.2.22). Slabbing may be a severe problem that can occur under high fills.

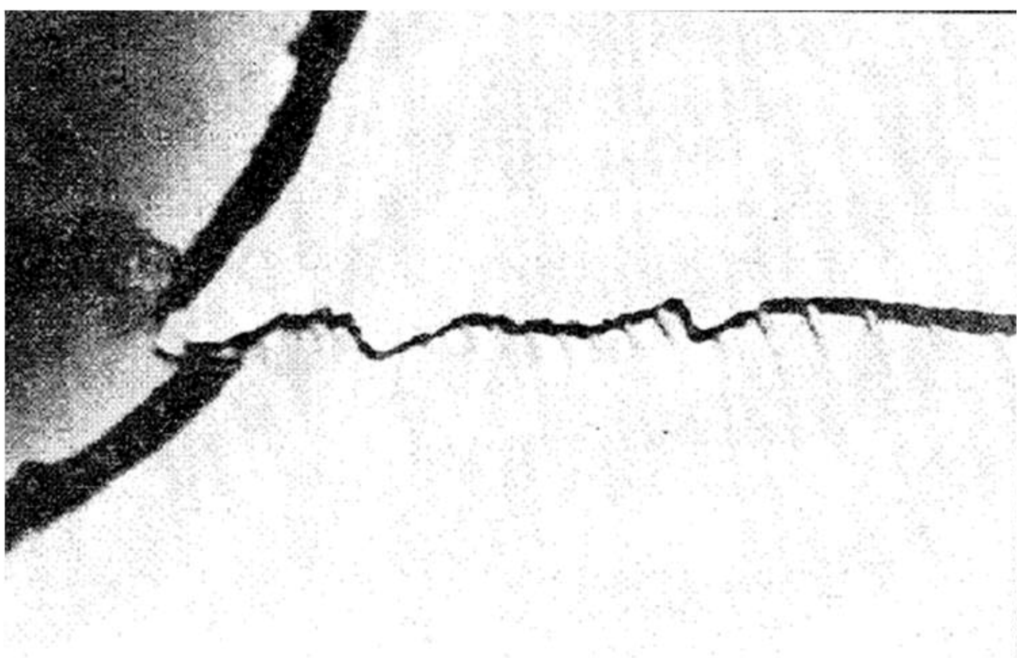


Figure 14.2.22 Shear Slabbing (Source: *FHWA Culvert Inspection Manual*)

Durability

Durability is a measure of a culvert's ability to withstand chemical attack and abrasion. Rigid culvers are subject to chemical attack in strongly acidic environments such as drainage from mines and may also be damaged by abrasion. Note any mild deterioration or abrasion that is less than 1/4 inch deep in the inspection report. Document severe surface deterioration greater than 1/4 inch deep as a potential candidate for maintenance. When the invert is completely deteriorated, it may be considered a critical finding. Note in the report when linings are used to protect against chemical attack or abrasion. Also document the condition of the lining, if present.

End Section Drop-off

This type of distress is usually due to outlet erosion as discussed earlier in the sections on end treatments and waterways. It is caused by the erosion of the material supporting the pipe sections on the outlet end of the culvert barrel.

Wingwalls and Headwalls

Wingwalls and headwalls are provided to support the embankment around the openings of the culvert (see Figure 14.2.23). Inspect wingwalls for differential settlement and proper vertical alignment. See Topic 14.1 for general culvert characteristics including wingwalls and Topic 12.1 for a detailed description of deficiencies and inspection methods of wingwalls.

Figure 14.2.23 Cast-in-Place Concrete Headwall and Wingwall

14.2.5 Evaluation

State and Federal rating guideline systems have been developed to aid in the inspection of rigid culverts. The two major rating guideline systems currently in use are the FHWA's *Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges* used for the National Bridge Inventory (NBI) component condition rating method and the *AASHTO Guide Manual for Bridge Element Inspection* for element level condition state assessment.

NBI Component Condition Rating Guidelines

Using NBI component condition rating guidelines, a one-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the culvert (Item 62). This item evaluates the alignment, settlement, joints, structural condition, scour, and other items associated with culverts. Component condition rating codes range from 9 to 0, where 9 is the best rating possible. See Topic 4.2 (Item 62) for additional details about NBI component condition rating guidelines. Item 62 component condition rating guidelines are included in Figure 14.2.24. It is also important to note that Items 58-Deck, 59-Superstructure, and 60-Substructure are coded “N” for culvert structures.

For rigid culverts, the NBI component condition rating guidelines yield a one-digit code on the Federal (SI&A) sheet that indicates the overall condition of the culvert. The culvert item not only evaluates the structural condition of the culvert, but also encompasses the alignment, settlement in the approach roadway and embankment, joints, scour, headwalls and wingwalls. Integral wingwalls are included in the evaluation up to the first construction or expansion joint. The one-digit code that best describes the culvert’s overall condition is chosen, and the component condition rating codes range from 9 to 0, where 9 is the highest possible component condition rating.

Consider previous inspection data along with current inspection findings to determine the correct component condition rating.

Element Level Condition State Assessment

In an element level condition state assessment of a rigid culvert, possible AASHTO National Bridge Elements (NBEs) and Bridge Management Elements (BMEs) are:

NBE No.	**Description**
Substructure	
241	Reinforced Concrete Culvert
242	Timber Culvert
244	Masonry Culvert
243	Other Culvert

BME No.	**Description**
Wearing Surfaces and Protection Systems	
521	Concrete Protective Coating

The unit quantity for culverts is feet and represents the culvert length along the barrel multiplied by the number of barrels (for multiple barrel culverts). The inspector visually evaluates each 1-foot slice of the culvert barrel(s) and assigns the appropriate condition state description. The total length is distributed among the four available condition states depending on the extent and severity of the deficiency. The unit quantity for protective coatings is square feet, with the total area distributed among the four condition states depending on the extent and severity of the deficiency. The sum of all condition states equals the total quantity of the National Bridge Element or Bridge Management Element. Condition State 1 is the best possible rating. See the *AASHTO Guide Manual for Bridge Element Inspection* for condition state descriptions.

The following Defect Flags are applicable in the evaluation of rigid culverts:

Defect Flag No.	**Description**
358	Concrete Cracking
359	Concrete Efflorescence
360	Settlement
361	Scour
368	Barrel Distortion

See the AASHTO *Guide Manual for Bridge Element Inspection* for the application of Defect Flags.

The culvert item evaluates the alignment, settlement, joints, structural condition, scour, and other items associated with culverts. The rating code is intended to be an overall condition evaluation of the culvert. Integral wingwalls to the first construction or expansion joint shall be included in the evaluation.

Code	Description
N	Not applicable. Use if structure is not a culvert.
9	No deficiencies.
8	No noticeable or noteworthy deficiencies which affect the condition of the culvert. Insignificant scrape marks caused by drift.
7	Shrinkage cracks, light scaling, and insignificant spalling which does not expose reinforcing steel. Insignificant damage caused by drift with no misalignment and not requiring corrective action. Some minor scouring has occurred near curtain walls, wingwalls, or pipes. Metal culverts have a smooth symmetrical curvature with superficial corrosion and no pitting.
6	Deterioration or initial disintegration, minor chloride contamination, cracking with some leaching, or spalls on concrete or masonry walls and slabs. Local minor scouring at curtain walls, wingwalls, or pipes. Metal culverts have a smooth curvature, non-symmetrical shape, significant corrosion, or moderate pitting.
5	Moderate to major deterioration or disintegration, extensive cracking and leaching, or spalls on concrete or masonry walls and slabs. Minor settlement or misalignment. Noticeable scouring or erosion at curtain walls, wingwalls, or pipes. Metal culverts have significant distortion and deflection in one section, significant corrosion or deep pitting.
4	Large spalls, heavy scaling, wide cracks, considerable efflorescence, or opened construction joint permitting loss of backfill. Considerable settlement or misalignment. Considerable scouring or erosion at curtain walls, wingwalls, or pipes. Metal culverts have significant distortion and deflection throughout, extensive corrosion or deep pitting.
3	Any condition described in Code 4 but which is excessive in scope. Severe movement or differential settlement of the segments, or loss of fill. Holes may exist in walls or slabs. Integral wingwalls nearly severed from culvert. Severe scour or erosion at curtain walls, wingwalls, or pipes. Metal culverts have extreme distortion and deflection in one section, extensive corrosion, or deep pitting with scattered perforations.
2	Integral wingwalls collapsed, severe settlement of roadway due to loss of fill. Section of culvert may have failed and can no longer support embankment. Complete undermining at curtain walls and pipes. Corrective action required to maintain traffic. Metal culverts have extreme distortion and deflection throughout with extensive perforations due to corrosion.
1	Bridge closed. Corrective action may put bridge back in light service.
0	Bridge closed. Replacement necessary.

Figure 14.2.24 NBI Component Condition Rating Guidelines for Culverts

Dimensions and Approximate Weights of Concrete Pipe

*ASTM C 76 – Reinforced Concrete Culvert, Storm Drain and Sewer Pipe, Tongue and Groove Joints						
WALL A			WALL B		WALL C	
Internal Diameter inches	**Minimum Wall Thickness, inches**	**Approximate Weight, pounds per foot**	**Minimum Wall Thickness, inches**	**Approximate Weight, pounds per foot**	**Minimum Wall Thickness, inches**	**Approximate Weight, pounds per foot**
96	8	2710	9	3090	9 ¾	3355
102	8 ½	3078	9 ½	3480	10 ¼	3760
108	9	3446	10	3865	10 ¾	4160

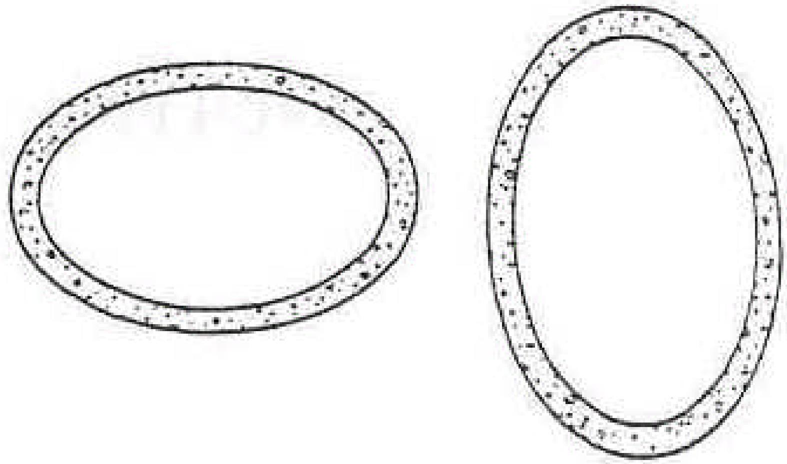
Large Sizes of Pipe Tongue and Groove Joint			
Internal Diameter Inches	**Internal Diameter Feet**	**Wall Thickness Inches**	**Approximate Weight, pounds per foot**
114	9 ½	9 ½	3840
120	10	10	4263
126	10 ½	10 ½	4690
132	11	11	5148
138	11 ½	11 ½	5627
144	12	12	6126
150	12 ½	12 ½	6647
156	13	13	7190
162	13 ½	13 ½	7754
168	14	14	8339
174	14 ½	14 ½	8942
180	15	15	9572

* For description of ASTM C 76 see page 14.2.30

Figure 14.2.25a Standard Sizes for Concrete Pipe (Source: American Concrete Pipe Association)

Typical Cross Section of Arch Pipe

Horizontal and Vertical Ellipse Pipe



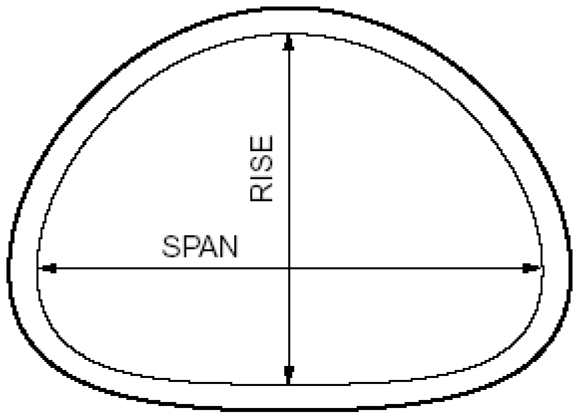
Dimensions and Approximate Weights of Elliptical Concrete Pipe

*ASTM C 507 – Reinforced Concrete Elliptical Culvert, Storm Drain and Sewer Pipe					
Equivalent Round Size, inches	**Minor Axis, inches**	**Major Axis, inches**	**Minimum Wall Thickness, inches**	**Water-Way Area, square feet**	**Approximate Weight, pounds per foot**
96	77	121	9 ½	52.4	3420
102	82	128	9 ¾	59.2	3725
108	87	136	10	66.4	4050
114	92	143	10 ½	74.0	4470
120	97	151	11	82.0	4930
132	106	166	12	99.2	5900
144	116	180	13	118.6	7000

* For description of ASTM C 507 see page 14.2.30

Figure 14.2.25b Standard Sizes for Concrete Pipe (Source: American Concrete Pipe Association)

Typical Cross Section of Arch Pipe



Dimensions and Approximate Weights of Concrete Arch Pipe

*ASTM C 506 – Reinforced Concrete Arch Culvert, Storm Drain and Sewer Pipe					
Equivalent Round Size, inches	**Minimum Rise, inches**	**Minimum Span, inches**	**Minimum Wall Thickness, inches**	**Water-Way Area, square feet**	**Approximate Weight, pounds per foot**
96	77 1/4	122	9	51.7	3110
108	87 1/8	138	10	66.0	3850
120	96 7/8	154	11	81.8	5040
132	106 1/2	168 3/4	10	99.1	5220

* For description of ASTM C 506 see page 14.2.30

Figure 14.2.25c Standard Sizes for Concrete Pipe (Source: American Concrete Pipe Association)

American Society for Testing and Materials (ASTM) Descriptions for Select Rigid Pipe Culverts

ASTM C 76 Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe: Covers reinforced concrete pipe intended to be used for the conveyance of sewage, industrial wastes, and storm waters, and for the construction of culverts. Class I – 60 inches through 144 inches in diameter; Class II, III, IV and V – 12 inches through 144 inches in diameter. Larger sizes and higher classes are available as special designs.

ASTM C 506 Reinforced Concrete Arch Culvert, Storm Drain, and Sewer Pipe: Covers pipe to be used for the conveyance of sewage, industrial waste, and storm water and for the construction of culverts in sizes from 15 inch through 132 inch equivalent circular diameter. Larger sizes are available as special designs.

ASTM C 507 Reinforced Concrete Elliptical Culvert, Storm Drain, and Sewer Pipe: Covers reinforced elliptically shaped concrete pipe to be used for the conveyance of sewage, industrial waste and storm water, and for the construction of culverts. Five standard classes of horizontal elliptical, 18 inches through 144 inches in equivalent circular diameter and five standard classes of vertical elliptical, 36 inches through 144 inches in equivalent circular diameter are included. Larger sizes are available as special designs.

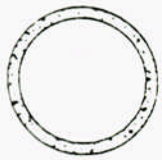
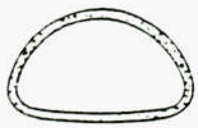
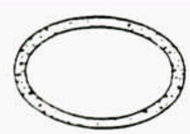
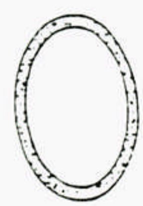
SHAPE	RANGE OF SIZES	COMMON USES
CIRCULAR 	12 to 180 inches reinforced 4 to 36 inches non-reinforced	Culverts, storm drains, and sewers.
PIPE ARCH 	15 to 132 inches equivalent diameter	Culverts, storm drains, and sewers. Used where head is limited.
HORIZONTAL ELLIPSE [redacted] 	Span x Rise [redacted] 18 to 144 inches equivalent diameter	[redacted] Culverts, storm drains, and sewers. Used where head is limited.
VERTICAL ELLIPSE 	Span x Rise 36 to 144 inches equivalent diameter	Culverts, storm drains, and sewers. Used where lateral clearance is limited.

Figure 14.2.26 Standard Concrete Pipe Shapes
(Source: *FHWA Culvert Inspection Manual*, Supplement to the *BIRM*, July 1986)

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Characteristics, Inspection and Evaluation of Culverts

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Topic 14.3 Flexible Culverts

14.3.1 Introduction

Like all culverts, flexible culverts are designed for full flow. Unlike bridges, culverts have no distinction between substructure and superstructure and because earth backfill separates the culvert structure from the riding surface, culverts have no "deck." Most flexible culverts have a circular or elliptical configuration (see Figure 14.3.1). Some flexible box and arch culverts are in use today (see Figure 14.3.2). From their design nature, flexible culverts have little structural bending strength without proper backfill. The material from which they are made, such as corrugated steel or aluminum can be flexed or bent and can be distorted significantly without cracking. Consequently, flexible culverts depend on the backfill support to resist bending. In flexible culvert designs, proper interaction between the soil and structure is critical.

Figure 14.3.1 Pipe Arch Flexible Culvert

Figure 14.3.2 Flexible Box Culvert

14.3.2 Design Characteristics

Structural Behavior

A flexible culvert is a composite structure made up of the culvert barrel and the surrounding soil. The barrel and the soil are both vital elements to the structural performance of the culvert.

Flexible pipe has relatively little bending stiffness or bending strength on its own. Flexible culvert materials include steel, aluminum, and plastic. As loads are applied to the culvert, it attempts to deflect. In the case of a round pipe, the vertical diameter decreases and the horizontal diameter increases (see Figure 14.3.3). When good embankment material is well-compacted around the culvert, the increase in horizontal diameter of the culvert is resisted by the lateral soil pressure. With round pipe the result is a relatively uniform radial pressure around the pipe which creates a compressive thrust in the pipe walls. As illustrated in Figure 14.3.4, the compressive thrust is approximately equal to vertical pressure times one-half the span length.

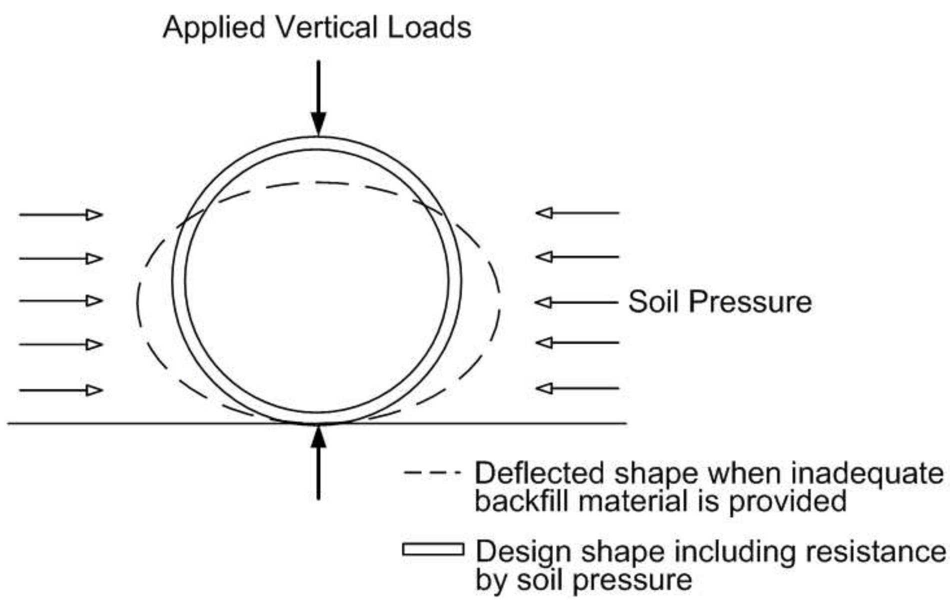


Figure 14.3.3 Flexible Culvert: Load vs. Shape

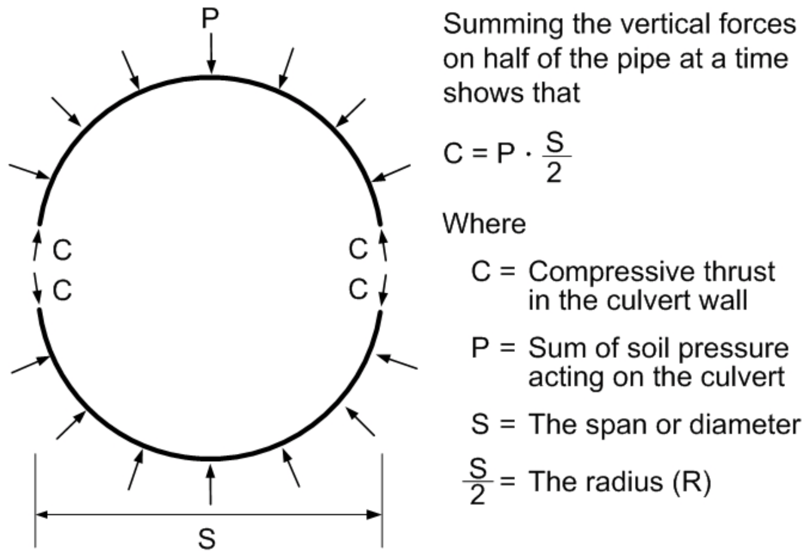


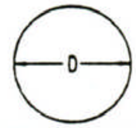
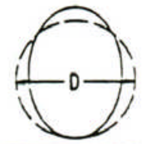
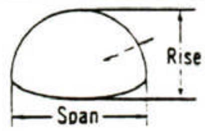
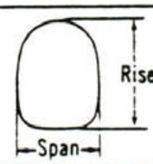
Figure 14.3.4 Formula for Ring Compression

An arc of a flexible round pipe, or other shape will be stable as long as adequate soil pressures are achieved, and as long as the soil pressure is resisted by the compressive force C on each end of the arc. Good quality backfill material and proper installation are critical in obtaining a stable soil envelope around a flexible culvert.

In long span culverts the radius (R) is usually large. To prevent excessive deflection due to permanent dead and/or transient live loads, longitudinal or circumferential stiffeners are sometimes added. The circumferential stiffeners are usually metal ribs bolted to the outside of the culvert. Longitudinal stiffeners may be metal or reinforced concrete. Concrete thrust beams provide some circumferential stiffening as well as longitudinal stiffening. The thrust beams are added to the structure prior to backfill. They also provide a solid vertical surface for soil pressures to act on and a surface which is easier to backfill against. The use of concrete stress relieving slabs is another method used to achieve longer spans or reduce minimum cover. A stress-relieving slab is cast over the top of the backfill above the structure to distribute transient live loads to the adjacent soil.

14.3.3 Types and Shapes of Flexible Culverts

Flexible culverts are constructed from corrugated steel or aluminum pipe or field assembled structural plate products. Structural plate steel products are available as structural plate pipes, box culverts, or long span structures. See Figure 14.3.5 for standard shapes for corrugated flexible culverts.

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 18 in. x 11 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).
		Span x Rise	

[redacted]

Figure 14.3.5 (Exhibit 11 Culvert Inspection Manual Report No. FHWA-IP-86-2) Standard Corrugated Steel Culvert Shapes (Source: Handbook of Steel Drainage and Highway Construction Products, American Iron and Steel Institute)

Corrugated Pipe

Factory-made pipe is produced in two basic shapes: round and pipe arch. Both shapes are produced in several wall thicknesses, several corrugation sizes, and with annular (circumferential) or helical (spiral) corrugations. Pipes with helical corrugations have continuously welded seams or lock seams. Both round and arch steel pipe shapes are available in a wide range of standard sizes.

Structural Plate

Structural plate steel pipes are field assembled from standard corrugated galvanized steel plates. Standard plates have corrugations with a 6-inch pitch and a depth of 2 inches. Plates are manufactured in a variety of thicknesses and are pre-curved for the size and shape of structure to be erected.

Structural steel plate pipes are available in four basic shapes:

- Round
- Pipe arch
- Arch
- Underpass

Structural plate aluminum pipes are field assembled with a 9 inch pitch and a depth of 2.5 inches.

Structural plate aluminum pipes are produced in five basic shapes:

- Round
- Pipe arch
- Arch
- Pedestrian/animal underpass
- Vehicle underpass

Long Span Culverts

Long span steel culverts are assembled using conventional 6 by 2 inch corrugated galvanized steel plates and longitudinal and circumferential stiffening members. There are five standard shapes for long span steel structures:

- Horizontal elliptical
- Pipe arch
- Low profile arch
- High profile arch
- Pear shape

Each long span installation represents, to a certain extent, a custom design. The inspector reviews the design or as-built plans when checking dimensions of existing long span structures.

Long span aluminum structures are assembled using conventional 9 by 2 1/2 inch corrugated aluminum plates and aluminum rib stiffeners. Long span aluminum structures are essentially the same size and available in the same five basic shapes as steel long spans.

See the end of this Topic for the different standard sizes for each flexible culvert shape (pg 164-193 Culvert Inspection Manual Report No. FHWA-IP-86-2)

Box Culverts

Corrugated steel box sections use standard corrugated galvanized steel plates with special reinforcing elements applied to the areas of maximum moments. Steel box culverts are available with spans that range from 10 feet to 21 feet.

The aluminum box culvert utilizes standard aluminum structural plates with aluminum rib reinforcing added in the areas of maximum bending stresses. Ribs are bolted to the exterior of the aluminum shell during installation. Aluminum box culverts are suitable for shallow depths of fill.

Plastic Culverts

Plastic culverts are most commonly made using high density polyethylene (HDPE). These round sections utilize one or more "walls" and are available up to 60 inches in diameter. Single-walled culverts are often corrugated on the inner and outer surfaces (see Figure 14.3.6), while dual-walled culverts have a smooth inner surface and either a smooth or corrugated outer surface (see Figure 14.3.7). Heavy-duty plastic culverts are also available in sizes up to 36 inches.

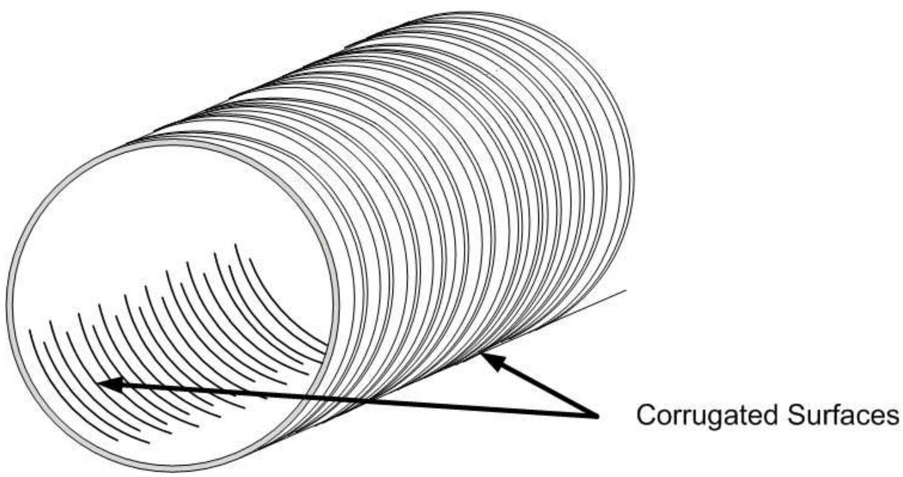


Figure 14.3.6 Schematic of a Single Walled Culvert

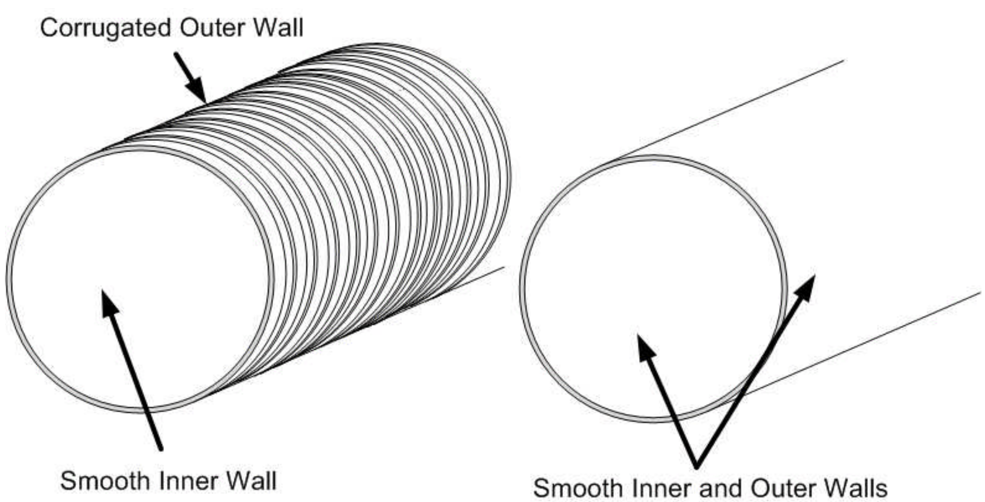


Figure 14.3.7 Schematics of Dual Walled Culverts

Plastic culverts offer several advantages over traditional corrugated metal pipe (CMP) sections:

- Strength-to-weight ratio - the favorable strength-to-weight ratio allows plastic culverts to provide maximum strength and shock resistance from a lighter section, making HDPE sections competitive against CMP sections installed with higher clear cover distances.
- Lightweight - the weight savings compared to CMP or concrete pipe allows HDPE culverts to be installed using minimum manpower and light-duty equipment. Lightweight pipe also provides a safer work environment when compared to heavy weight pipes.
- Hydraulically efficient - compared to CMP, the smoothness of HDPE culverts (for applicable dual-wall culverts) provides increased hydraulic efficiency. This permits a smaller HDPE section to be used for an equally performing larger CMP section.
- Corrosion resistance - unlike CMP culverts, plastic culverts will not "rust". They also have shown good performance against corrosive chemicals, brackish water, and soil elements. Abrasion resistance is also greater for plastic culverts than for CMP culverts. However, plastic culverts are susceptible to low crack growth and oxygen degradation.
- Flexibility - due to the inherent nature of HDPE and other plastic resins, plastic culverts offer increased flexibility over CMP. Although less common in the roadway industry, this allows for easier placement of a curved pipeline.

Applications utilizing plastic culverts include:

- New culvert structures with adequate clear cover above the culvert.
- Rehabilitation of older culverts using a "slip lining" installation method.
- Temporary culvert installations or highway drainage systems.

14.3.4 Overview of Common Deficiencies

Common deficiencies that can occur to flexible culvert materials include the following:

- Pitting
- Surface Rust
- Section Loss
- Overload Damage
- Heat Damage
- Buckling
- Embankment erosion at culvert entrance and exit
- Roadway settlement
- Irregular dimensions
- Loose or missing seams and fasteners

Refer to Topic 6.3 for a more detailed presentation of the properties of steel, types and causes of steel deterioration, and the examination of steel.

14.3.5 Inspection Methods and Locations

Refer to Topic 14.1 for a more detailed presentation of methods and locations of culvert distress.

A logical sequence for inspecting culverts helps ensure that a thorough and complete inspection will be conducted. In addition to the culvert components, look for highwater marks, changes in the drainage area, settlement of the roadway, and other indications of potential problems. In this regard, the inspection of culverts is similar to the inspection of bridges.

For typical installations, it is usually convenient to begin the field inspection with general observations of the overall condition of the structure and inspection of the approach roadway. Select one end of the culvert and inspect the embankment, waterway, headwalls, wingwalls, and culvert barrel. Progress toward the other end of the culvert. The following sequence is applicable to all culvert inspections:

- Review available information
- Observe overall condition
- Inspect approach roadway and embankment
- Inspect waterway (see in Topic 13.2)
- Inspect end treatments
- Inspect culvert barrel

Methods

Visual

Most defects in flexible culverts are first detected by visual inspection. In order for this to occur, a hands-on inspection, or inspection where the inspector is close enough to touch the area being inspected, is required. The types of defects to look for when inspecting the culvert barrel will depend upon the type of culvert being inspected. In general, inspect corrugated metal culvert barrels for cross-sectional shape and barrel defects such as joint defects (exhiltration or infiltration through joints or joint misalignment), seam defects (exhiltration or infiltration through seams or seam misalignment), plate buckling, lateral shifting, missing or loose bolts, corrosion, excessive abrasion, material deficiencies, and localized construction damage. A critical area for the inspection of long span metal culverts is at the 2 o'clock and 10 o'clock locations. An inward bulge at these locations may indicate potential failure of the structure.

It is becoming more common that flexible culverts are being repaired or rehabilitated with structural plate sections or with structural invert paving by using reinforced concrete. Inspect the concrete for deficiencies such as surface cracks, spalls, wear, and other deficiencies is primarily a visual activity. Structural plates can be visually inspected for deficiencies to those discussed previously for steel.

Physical

A geologist's pick hammer can be used to scrape off heavy deposits of rust and scale and to check the longitudinal seams by tapping the nuts. The hammer can then be used to locate areas of corrosion by striking the culvert walls. The walls will deform or the hammer will break through the culvert wall if significant section loss exists.

For aluminum structural plate, the bolts are checked with a torque wrench.

Sometimes surveying the culvert is necessary to determine if there is any shape distortion, and if there is distortion how much exists.

It is important to check the repairs for deficiencies as well. For concrete repairs, be sure to check for delaminations by using a hammer to “sound” the concrete. A delaminated area will have a distinctive hollow "clacking" sound when tapped with a hammer or revealed with a chain drag. A hammer hitting sound concrete will result in a solid "pinging" type sound.

For the structural plates, inspect for section loss. This is achieved by using a wire brush, grinder, or a hammer to remove loose or flaked steel and then measure the remaining section and compare to a similar section with no loss.

It may be necessary to get a permit to work in culverts due to the confined spaces which have the potential for hazardous conditions for the inspector.

Advanced Inspection Methods

In metal culverts, visual inspections can only point out surface defects. Therefore, advanced inspection methods may be used to achieve a more rigorous and thorough inspection of the flexible culvert, including:

Several advanced methods are available for steel inspection. Nondestructive methods, described in Topic 15.3.2, include:

- Computer programs
- Corrosion sensors
- Dye penetrant
- Magnetic particle

Other inspection methods or tests for material properties, described in Topic 15.3.3, include:

- Brinell hardness test
- Charpy impact test
- Chemical analysis
- Tensile strength test

Locations

End Treatments

End treatments are inspected like any other structural component. Their effectiveness can directly affect the performance of the culvert.

The most common types of end treatments for flexible culverts are:

- Projections
- Mitered
- Pipe end section

Projections

Indicate the location and extent of any scour or undermining around the culvert ends. The depth of any scouring is measured with a probing rod. In low flow conditions scour holes have a tendency to fill up with debris or sediment. If no probing rod is used, the scour could be mistakenly reported as less than has taken place.

Inspect end treatments for evidence of water leaking around the end treatment and into the embankment. Water flowing along the outside of a culvert can remove supporting material. This is referred to as piping and it can lead to the culvert end being unsupported. If not repaired in time, piping can cause cantilevered end portions of the culvert to bend down and restrict the stream flow.

Mitered Ends

Inspection items for mitered ends are the same as for projecting ends. Take additional care to measure any deformation of the end. Mitering the end of corrugated pipe culvert reduces its structural capacity.

Pipe End Sections

Pipe end sections are typically used on relatively smaller culverts. For inspection purposes, treat the pipe end section similar to a projection.

Excerpts from a reproduction of the out-of-print Culvert Inspection Manual Report No.-IP-86-2 are located on page 14.3.12 of this topic.

14.3.6 Evaluation

State and Federal rating guideline systems have been developed to aid in the inspection of flexible culverts. The two major rating guideline systems currently in use are the FHWA's *Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges* used for the National Bridge Inventory (NBI) component condition rating method and the AASHTO *Guide Manual for Bridge Element Inspection* for element level condition state assessment.

NBI Component Condition Rating Guidelines

Using NBI component condition rating guidelines, a one-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the culvert (Item 62). This item evaluates the alignment, settlement, joints, structural condition, scour, and other items associated with culverts. Component condition rating codes range from 9 to 0 where 9 is the best rating possible. See Topic 4.2 (Item 62) for additional details about NBI component condition rating guidelines. The component condition rating code is intended to be an overall evaluation of the culvert. Integral wingwalls to the first construction or expansion joint shall be included in the evaluation. It is also important to note that Items 58-Deck, 59-

Superstructure, and 60-Substructure shall be coded "N" for all culverts.

Consider previous inspection data along with current inspection findings to determine the correct component condition rating.

Element Level Condition State Assessment

In an element level condition state assessment of a flexible culvert, possible AASHTO National Bridge Elements (NBEs) and Bridge Management Elements (BMEs) are:

NBE No.	Description
Substructure	
240	Steel Culvert
243	Other Culvert

BME No.	Description
Wearing Surfaces and Protection Systems	
515	Steel Protective Coating

The unit quantity for culverts is feet and represents the culvert length along the barrel multiplied by the number of barrels (for multiple barrel culverts). The inspector visually evaluates each 1-foot slice of the culvert barrel(s) and assigns the appropriate condition state description. The total length is distributed among the four available condition states depending on the extent and severity of the deficiency. The unit quantity for protective coatings is square feet, with the total area distributed among the four condition states depending on the extent and severity of the deficiency. The sum of all condition states equals the total quantity of the National Bridge Element or Bridge Management Element. Condition state 1 is the best possible rating. See the *AASHTO Guide Manual for Bridge Element Inspection* for condition state descriptions.

The following Defect Flags are applicable in the evaluation of flexible culverts:

Defect Flag No.	Description
356	Steel Cracking/Fatigue
357	Pack Rust
360	Settlement
361	Scour
363	Steel Section Loss
368	Culvert Barrel Distortion

See the AASHTO *Guide Manual for Bridge Element Inspection* for the application of Defect Flags.

The following excerpts are from a reproduction of the Culvert Inspection Manual Report No.-IP-86-2 – Chapter 5, Section 4 which can be found at the following website: http://www.fhwa.dot.gov/

Section 4 - CORRUGATED METAL CULVERTS

5-4.0 General

Corrugated aluminum and corrugated steel culverts are classified as flexible structures because they respond to and depend upon the soil backfill to provide structural stability and support to the culvert. The flexible corrugated metal acts essentially as a liner. The liner acts mainly in compression and can carry large ring compression thrust, but very little bending or moment force. (Rib reinforced box culverts are exceptions.) Inspection of the culvert determines whether the soil envelope provides adequate structural stability for the culvert and verifies that the "liner" is capable of carrying the compressive forces and protecting the soil backfill from water flowing through the culvert. Verification of the stability of the soil envelope is accomplished by checking culvert shape. Verification of the integrity of the "liner" is accomplished by checking for pipe and plate culvert barrel defects.

This section contains discussions on inspecting corrugated metal structures for shape and barrel defects. Because shape inspection requirements do vary somewhat for different shapes, separate sections with detailed guidelines are provided for corrugated metal pipe culvert shapes and long-span culvert shapes. Section 5 of this chapter addresses corrugated metal pipe culverts, and section 6 covers long-span corrugated metal culverts.

5-4.1 Shape Inspections

The single most important feature to observe and measure when inspecting corrugated metal culverts is the cross-sectional shape of the culvert barrel. The corrugated metal culvert barrel depends on the backfill or embankment to maintain its proper shape and stability. When the backfill does not provide the required support, the culvert will deflect, settle, or distort. Shape changes in the culvert therefore provide a direct indication of the adequacy and stability of the supporting soil envelope. By periodic observation and measurement of the culvert's shape, it is possible to verify the adequacy of the backfill. The design or theoretical cross-section of the culvert should be the standard against which field measurements and visual observations are compared. If the design cross section is unknown, a comparison can be made between the unloaded culvert ends and the loaded sections beneath the roadway or deep fills. This can often provide an indication of structure deflection or settlement. Symmetrical shape and uniform curvature around the perimeter are generally the critical factors. If the curvature around the structure becomes too flat, and/or the soil continues to yield under load, the culvert wall may not be able to carry the ring thrust without either buckling inward or deflecting excessively to the point of reverse curvature. Either of these events leads to partial or total failure.

As explained earlier in this Topic, an arc of a circular pipe or other shape structure will be stable and perform as long as the soil pressure on the outside of the pipe is resisted by the compression force in the pipe at each end of the arc.

Corrugated metal pipes can change shape safely within reasonable limits as long as there is adequate exterior soil pressure to balance the ring compression. Therefore, size and shape measurements taken at any one time do not provide conclusive data on backfill instability even when there is significant deviation from the design shape. Current backfill stability cannot be reliably determined unless changes in shape are measured over time. It is therefore necessary to identify current or recent shape changes to reliably check backfill stability. If there is instability of the backfill, the pipe will continue to change shape.

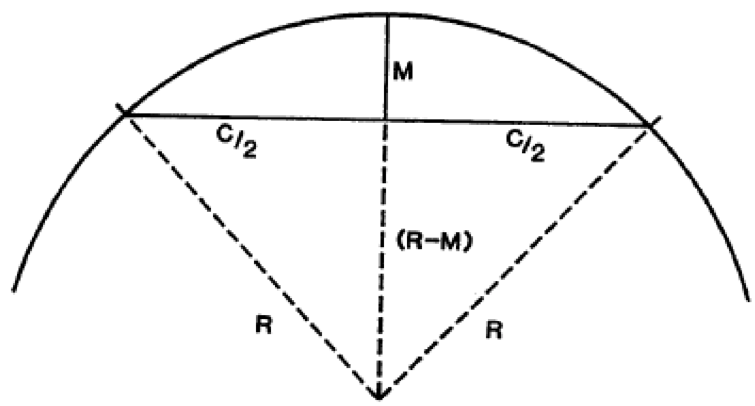
In general, the inspection process for checking shape will include visual observations for symmetrical shape and uniform curvature as well as measurements of important dimensions. The specific measurements to be obtained depend upon factors such as the size, shape, and condition of the structure. If shape changes are observed, more measurements may be necessary. For small structures in good condition, one or two simple measurements may be sufficient, for example, measuring the horizontal diameter on round pipe. For larger structures such as long span culverts, key measurements may be difficult to obtain. Horizontal diameters may be both high and large. The inspection process for long span culverts generally requires that elevations be established for key points on the structure. Although some direct measurements may also be required for long-span structures, elevations are needed to check for settlement and for calculating vertical distances such as the middle ordinate of the top arc. For structures with shallow cover, observations of the culvert with a few live loads passing over are recommended. Discernible movement in the structure may indicate possible instability and a need for more in-depth investigation.

The number of measurement locations depends upon the size and condition of the structure. Long-span culverts should normally be measured at the end and at 25 foot intervals. Measurements may be required at more frequent intervals if significant shape changes are observed. The smaller pipe culverts can usually be measured at longer intervals than long-span culverts.

Locations in sectional pipe can be referenced by using pipe joints as stations to establish the stationing of specific cross-sections. Stations should start with number 1 at the outlet and increase going upstream to the inlet. The location of points on a circular cross section can be referenced like hours on a clock. The clock should be oriented looking upstream. On structural plate corrugated metal culverts, points can be referenced to bolted circumferential and longitudinal seams.

It is extremely important to tie down exact locations of measurement points. Unless the same point is checked on each inspection, changes cannot be accurately monitored. The inspection report must, therefore, include precise descriptions of reference point locations. It is safest to use the joints, seams, and plates as the reference grid for measurement points. Exact point locations can then be easily described in the report as well as physically marked on the structures. This guards against loss of paint or scribe marks and makes points easy to find or reestablish. All dimensions in structures should be measured to the inside crest of corrugation. When possible, measurement points on structural plate should be located at the center of a longitudinal seam. However, some measurement points are not on a seam.

When distortion or curve flattening is apparent, the extent of the flattened area, in terms of arc length, length of culvert affected, and the location of the flattened area should be described in the inspection report. The length of the chord across the flattened area and the middle ordinate of the chord should be measured and recorded. The chord and middle ordinate measurements can be used to calculate the curvature of the flattened area using the formula shown in Exhibit 66.



C = MEASURED CHORD
M = MEASURED MIDDLE ORDINATE

SOLVE FOR R_A = ACTUAL RADIUS

$$R_A = \frac{4M^2 + C^2}{8M}$$

IF R_A IS > R_D (DESIGN RADIUS) THEN
ACTUAL CURVE IS FLATTER THAN DESIGN

Figure 14.3.8 (Exhibit 66) Checking Curvature by Curve and Middle Ordinate

5-4.2 Inspecting Barrel Defects

The structural integrity of corrugated metal culverts and long-span structures is dependent upon their ability to perform in ring compression and their interaction with the surrounding soil envelope. Defects in the culvert barrel itself, which can influence the culvert's structural and hydraulic performance, are discussed in the following paragraphs. Rating guidelines are provided in the sections dealing with specific shapes.

a. Misalignment - The inspector should check the vertical and horizontal alignment of the culvert. The vertical alignment should be checked visually for sags and deflection at joints. Poor vertical alignment may indicate problems with the subgrade beneath the pipe bedding. Sags trap debris and sediment and may impede flow. Since most highway culverts do not have watertight joints, sags which pocket water could saturate the soil beneath and around the culvert, reducing the soil's stability. The horizontal alignment should be checked by sighting along the sides for straightness. Vertical alignment can be checked by sighting along bolt lines. Minor horizontal and vertical misalignment is generally not a significant problem in corrugated metal structures unless it causes shape or joint problems. Occasionally culverts are intentionally installed with a change in gradient.

b. Joint Defects - Field joints are generally only found with factory manufactured pipe. There are ordinarily no joints in structural plate culverts, only seams. (In a few cases, preassembled lengths of structural plate pipe have been coupled or banded together like factory pipe.)

   Field joints in factory pipe serve to maintain the water conveyance of the culvert from section to section, to keep the pipe sections in alignment, keep the backfill soil from infiltrating, and to help prevent sections from pulling apart. Joint separation may indicate a lack of slope stability as described in section 5-4.2 e., circumferential seams. Key factors to look for in the inspection of joints are indications of backfill infiltration and water exfiltration. Excessive seepage through an open joint can cause soil infiltration or erosion of the surrounding backfill material reducing lateral support. Open joints may be probed with a small rod or flat rule to check for voids. Indications of joint defects include open joints, deflection, seepage at the joints, and surface sinkholes over the culvert as illustrated in Exhibits 67 and 68. Any evidence of joint defects should be recorded. Culverts in good condition should have no open joints, those in fair condition may have a few open joints but no evidence of soil infiltration, and those in marginal to poor condition will show evidence of soil infiltration.

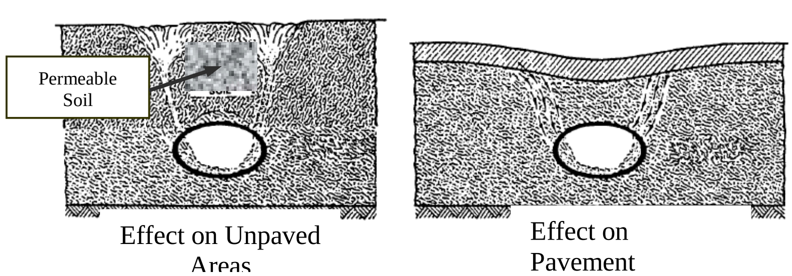


Figure 14.3.9 (Exhibit 67) Surface Indications of Infiltration

Figure 14.3.10 (Exhibit 68) Surface Hole Above Open Joint

c. Seam Defects in Fabricated Pipe - Pipe seams in helical pipe do not carry a significant amount of the ring compression thrust in the pipe. That is the reason that a lock seam is an acceptable seam. Helical seams should be inspected for cracking and separation. An open seam could result in a loss of backfill into the pipe, or exfiltration of water. Either condition could reduce the stability of the surrounding soil.

   In riveted or spot welded pipes, the seams are longitudinal and carry the full ring compression in the pipe. These seams, then, must be sound and capable of handling high compression forces. They should be inspected for the same types of defects as those described in the text for structural plate culverts, Section 12.4.3, Structural Pipe. When inspecting the longitudinal seams of bituminous-coated corrugated metal culverts, cracking in the bituminous coating may indicate seam separation.

d. Longitudinal Seam Defects in Structural Plate Culverts - Longitudinal seams should be visually inspected for open seams, cracking at bolt holes, plate distortion around the bolts, bolt tipping, cocked seams, cusped seams, and for significant metal loss in the fasteners due to corrosion.

   Culverts in good condition should have only minor joint defects. Those in fair condition may have minor cracking at a few bolt holes or minor opening at seams that could lead to infiltration or exfiltration. Marginal to poor culvert barrel conditions are indicated by significant cracking at bolt holes, or deflection of the structure due to infiltration of backfill through an open seam. Cracks 3 inches long on each side of the bolts indicate very poor to critical conditions.

(1) Loose Fasteners - Seams should be checked for loose or missing fasteners as shown in Exhibit 69. For steel structures the longitudinal seams are bolted together with high-strength bolts in two rows; one row in the crests and one row in the valleys of the corrugations. These are bearing type connections and are not dependent on a minimum clamping force of bolt tension to develop interface friction between the plates. Fasteners in steel structural plate may be checked for tightness by tapping lightly with a hammer and checking for movement.

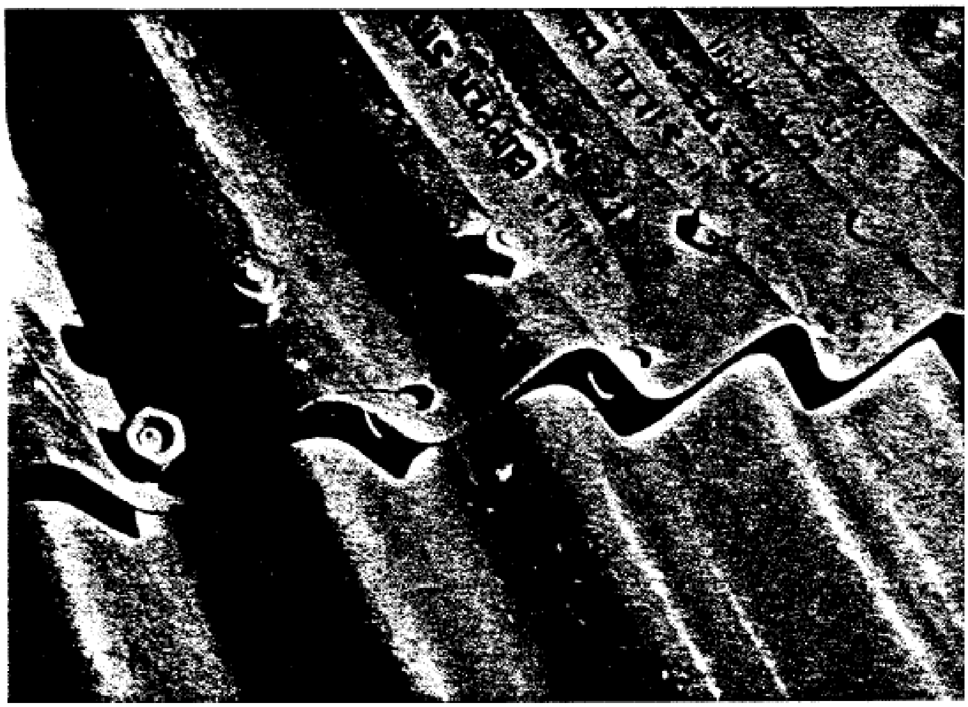


Figure 14.3.11 (Exhibit 69) Close-Up of Loose and Missing Bolts at a Cusped Seam; Loose Fasteners are Usually Detected by Tapping the Nuts with a Hammer

For aluminum structural plate, the longitudinal seams are bolted together with normal strength bolts in two rows with bolts in the crests and valleys of both rows. These seams function as bearing connections, utilizing bearing of the bolts on the edges of holes and friction between the plates. The seams in aluminum structural plate should be checked with a torque wrench (125 ft-lbs minimum to 150 ft-lbs maximum). If a torque wrench is not available fasteners can be checked for tightness with a hammer as described for steel plates.

(2) Cocked and Cusped Seams - The longitudinal seams of structural plate are the principal difference from factory pipe. The shape and curvature of the structure is affected by the lapped, bolted longitudinal seam. Improper erection or fabrication can result in cocked seams or cusped effects in the structure at the seam, as illustrated in Exhibit 70. Slight cases of these conditions are fairly common and frequently not significant. However, severe cases can result in failure of the seam or structure. When a cusped seam is significant the structure's shape appearance and key dimensions will differ significantly from the design shape and dimensions.

The cusp effect should cause the structure to receive very low ratings on the shape inspection if it is a serious problem. A cocked seam can result in loss of backfill and may reduce the ultimate ring compression strength of the seam.

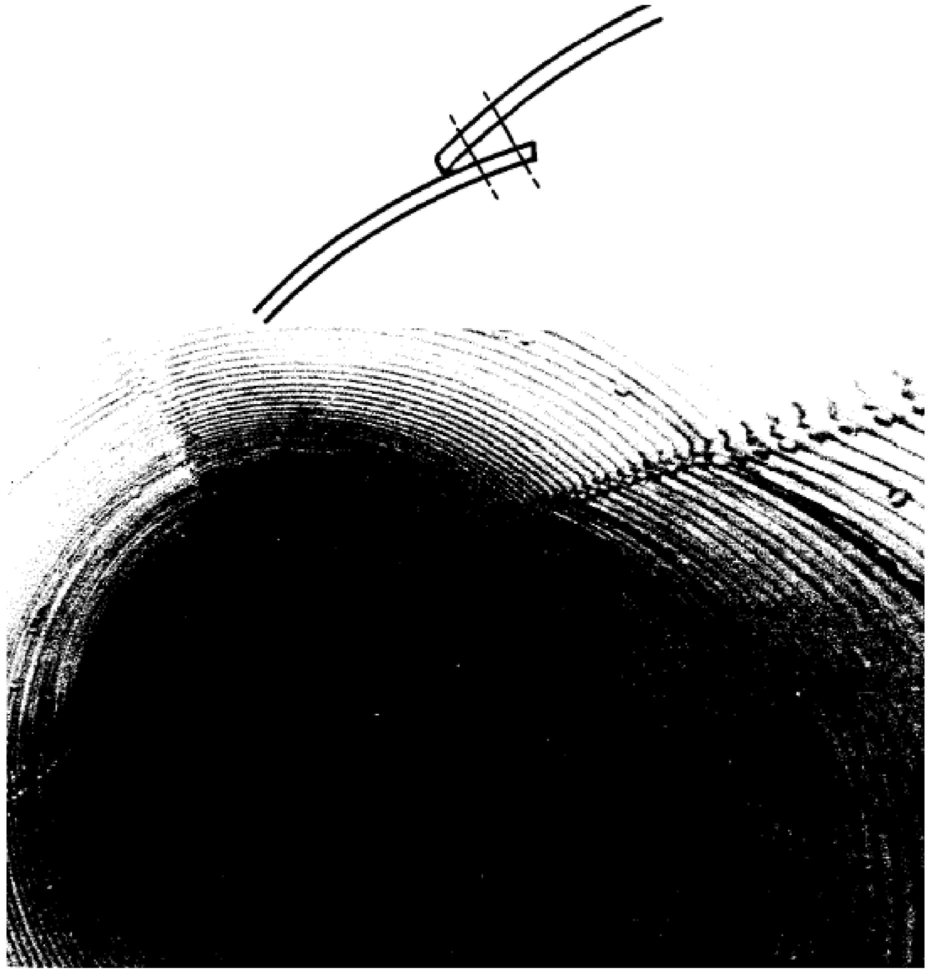


Figure 14.3.12 (Exhibit 70) Cocked Seam with Cusp Effect

(3) Seam Cracking - Cracking along the bolt holes of longitudinal seams can be serious if allowed to progress. As cracking progresses, the plate may be completely severed and the ring compression capability of the seam lost. This could result in deformation or possible failure of the structure. Longitudinal cracks are most serious when accompanied by significant deflection, distortion, and other conditions indicative of backfill or soil problems. Longitudinal cracks are caused by excessive bending strain, usually the result of deflection, Exhibit 71. Cracking may occasionally be caused by improper erection practices such as using bolting force to "lay down" a badly cocked seam.

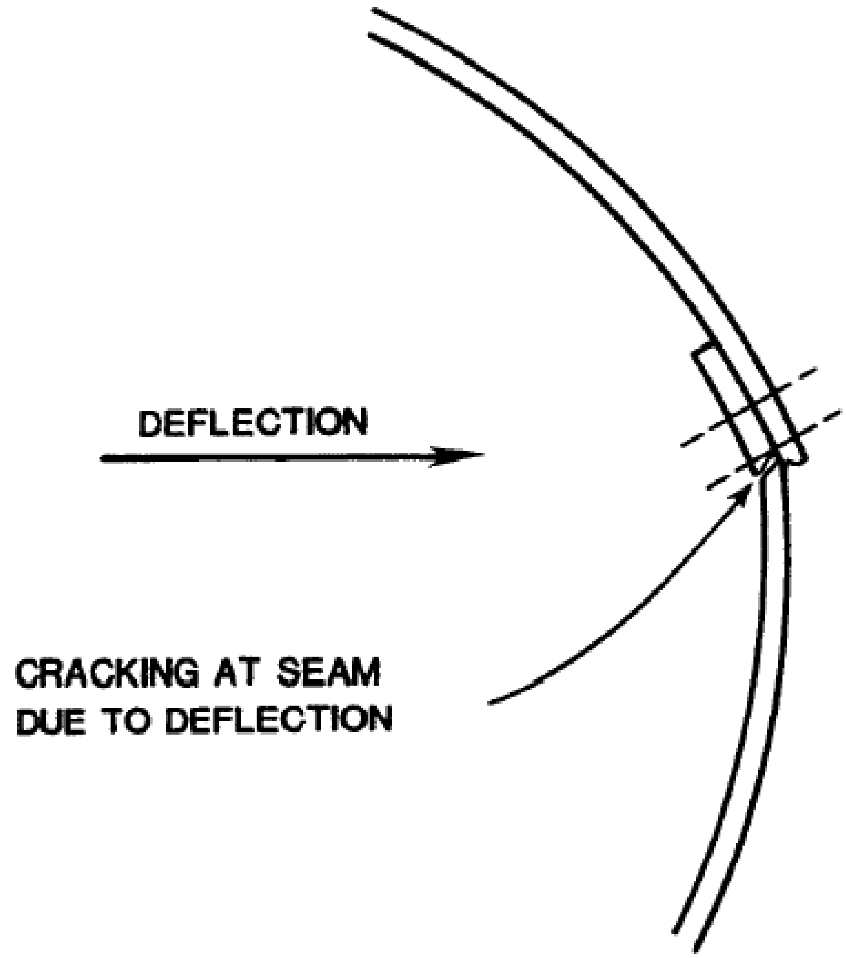


Figure 14.3.13 (Exhibit 71) Cracking Due to Deflection

(4) Bolt Tipping - The bolted seams in structural plate culverts only develop their ultimate strength under compression. Bolt tipping occurs when the plates slip. As the plates begin to slip, the bolts tip, and the bolt holes are plastically elongated by the bolt shank. High compressive stress is required to cause bolt tipping. Structures have rarely been designed with loads high enough to produce a ring compression that will cause bolt tip. However, seams should be examined for bolt tip particularly in structures under higher fills. Excessive compression on a seam could result in plate deformations around the tipped bolts and failure is reached when the bolts are eventually pulled through the plates.

e. Circumferential Seams - The circumferential seams, like joints in factory pipe, do not carry ring compression. They do make the conduit one continuous structure. Distress in these seams is rare and will ordinarily be a result of a severe differential deflection or distortion problem or some other manifestation of soil failure. For example, a steep sloping structure through an embankment may be pulled apart longitudinally if the embankment moves down as shown in Exhibit 72. Plates should be installed with the upstream plate overlapping the downstream plate to provide a "shingle" effect in the direction of flow.

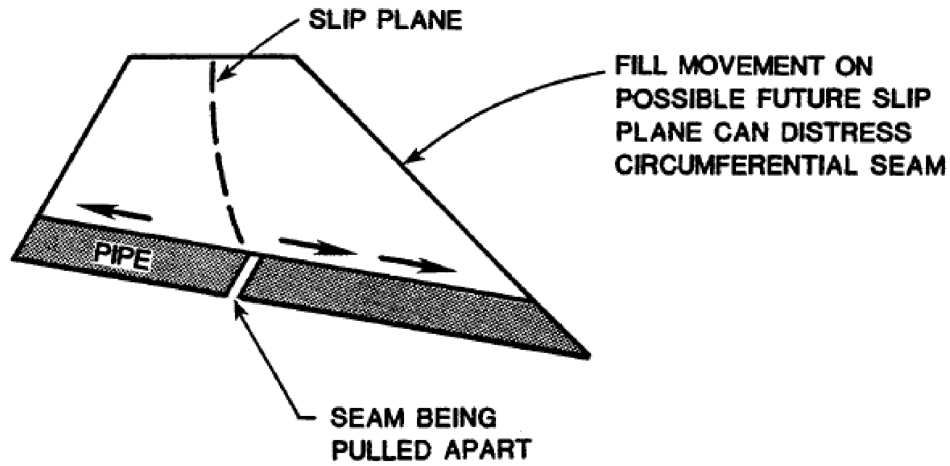


Figure 14.3.14 (Exhibit 72) Circumferential Seam Failure Due to Embankment Slippage

The circumferential seam at one or more locations would be distressed by the movement of the fill. Such distress is important to note during inspections since it would indicate a basic problem of stability in the fill. Circumferential seam distress can also be a result of foundation failure, but in such cases should be clearly evident by the vertical alignment.

f. Dents and Localized Damage - All corrugated metal culverts should be inspected for localized damage. Pipe wall damage such as dents, bulges, creases, cracks, and tears can be serious if the defects are extensive and can impair either the integrity of the barrel in ring compression or permit infiltration of backfill. Small, localized examples are not ordinarily critical. When the deformation type damages are critical, they will usually result in a poorly shaped cross section. The inspector should document the type, extent, and location of all significant wall damage defects. When examining dents in corrugated steel culverts, the opposite side of the plate should be checked, if possible, for cracking or disbonding of the protective coating.

g. Durability (Wall Deterioration) - Durability refers to the ability of a material to resist corrosion and abrasion. Corrosion is the deterioration of metal due to electrochemical or chemical reactions. Abrasion is the wearing away of culvert materials by the erosive action of bedload carried in the stream.

Abrasion is generally most serious in steep or mountainous areas where high flow rates carry sand and rocks that wear away the culvert invert. Abrasion can also accelerate corrosion by wearing away protective coatings.

Metal culverts are subject to corrosion in certain aggressive environments. For example, steel rapidly corrodes in salt water and in environments with highly acidic (low pH) conditions in the soil and water. Aluminum is fairly resistant to salt water but will corrode rapidly in highly alkaline (high pH) environments, particularly if metals such as iron or copper and their salts are present. The electrical resistivity of soil and water also provide an indication of the likelihood of corrosion. Many agencies have established guidelines in terms of pH and resistivity that are based on local performance. The FHWA has also published guidelines for aluminum and steel culverts including various protective coatings.

Corrosion and abrasion of corrugated metal culverts can be a serious problem with adverse effects on structural performance. Damage due to corrosion and abrasion is the most common cause for culvert replacement. The inspection should include visual observations of metal corrosion and abrasion. As steel corrodes it expands considerably. Relatively shallow corrosion can produce thick deposits of scale. A geologist's pick-hammer can be used to scrape off heavy deposits of rust and scale permitting better observation of the metal. A hammer can also be used to locate unsound areas of exterior corrosion by striking the culvert wall with the pick end of the hammer. When severe corrosion is present, the pick will deform the wall or break through it. Protective coatings should be examined for abrasion damage, tearing, cracking, and removal. The inspector should document the extent and location of surface deterioration problems.

When heavy corrosion is found by observation or sounding, special inspection methods such as pH testing, electrical resistivity measurement, and obtaining cores from the pipe wall are recommended. A routine program for testing pH and electrical resistivity should be considered since it is relatively easy to perform and provides valuable information.

Durability problems are the most common cause for the replacement of pipe culverts. The condition of the metal in corrugated metal culverts and any coatings, if used, should be considered when assigning a rating to the culvert barrel. Suggested rating guidelines for metal culverts with metallic coatings are shown in Exhibit 73. Modification of these guidelines may be required when inspecting culverts with non-metallic coatings. Aluminum culvert barrels may be rated as being in good condition if there is superficial corrosion. Steel culverts rated as in good condition may have superficial rust with no pitting. Perforation of the invert as shown in Exhibit 74 would indicate poor condition. Complete deterioration of the invert in all or part of the culvert barrel would indicate a critical condition as shown in Exhibit 75. Culverts with deteriorated inverts may function as an arch structurally, but are highly susceptible to failure due to erosion of the bedding.

Rating Value	General Description	Corrugated Steel	Corrugated Aluminum
9	New	Near original condition	Near original condition
8	Good	Superficial rust, no pitting	Superficial corrosion slight pitting
7	Generally Good	Moderate rust, slight pitting	Moderate corrosion no attack of core alloy
6	Fair	Fairly heavy rust, moderate pitting, slight thinning	Significant corrosion minor attack of core alloy
[redacted]			
deep pitting,	moderate attack of core		rust,

Figure 14.3.15 (Exhibit 73) Suggested Rating Criteria for Condition of Corrugated Metal

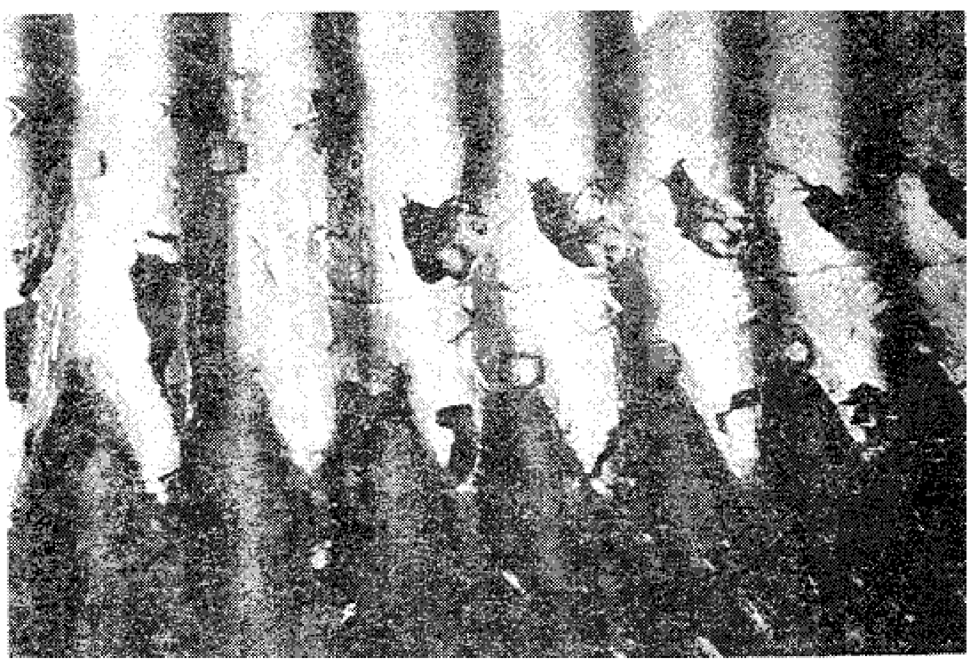


Figure 14.3.16 (Exhibit 74) Perforation of the Invert Due to Corrosion

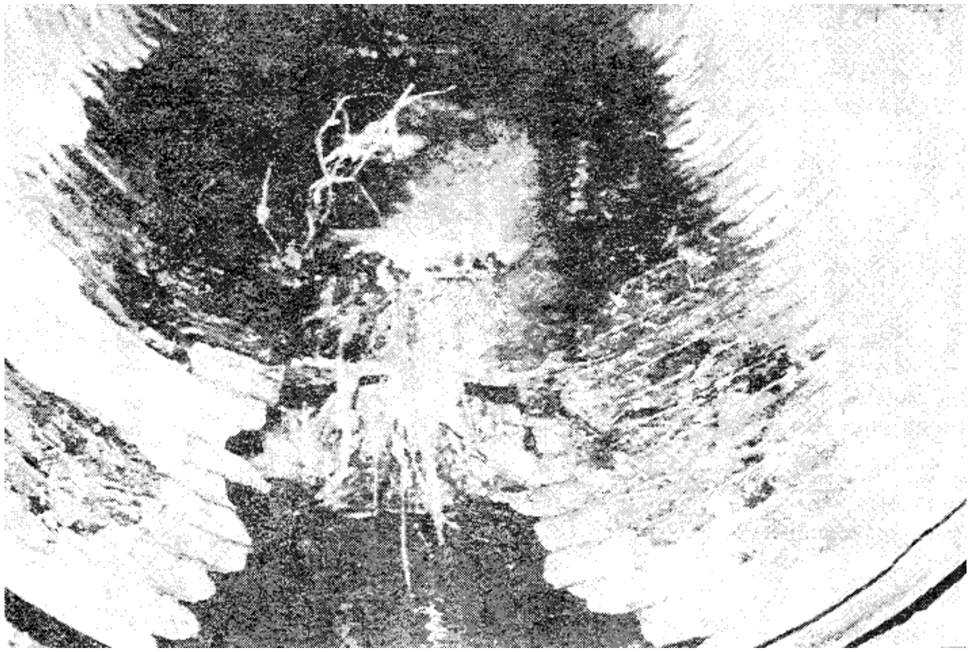


Figure 14.3.17 (Exhibit 75) Invert Deterioration

h. Concrete Footing Defects - Structural plate arches, long-span arches, and box culverts use concrete footings. Metal footings are occasionally used for the arch and box culvert shapes. The metal "superstructure" is dependent upon the footing to transmit the vertical load into the foundation. The structural plate arch is usually bolted in a base channel which is secured in the footing.

The most probable structural defect in the footing is differential settlement. One section of a footing settling more than the rest of the footing can cause wrinkling or other distortion in the arch. Flexible corrugated metal culverts can tolerate some differential settlement but will be damaged by excessive differential settlement. Uniform settlement will not ordinarily affect a metal arch but can affect the clearances in a grade separation structure if the footings settle and the road does not. The significance of differential footing settlement increases as the amount of the difference in settlement increases, the length it is spread over decreases, and the height of the arch decreases. This concept is illustrated in Exhibit 76.

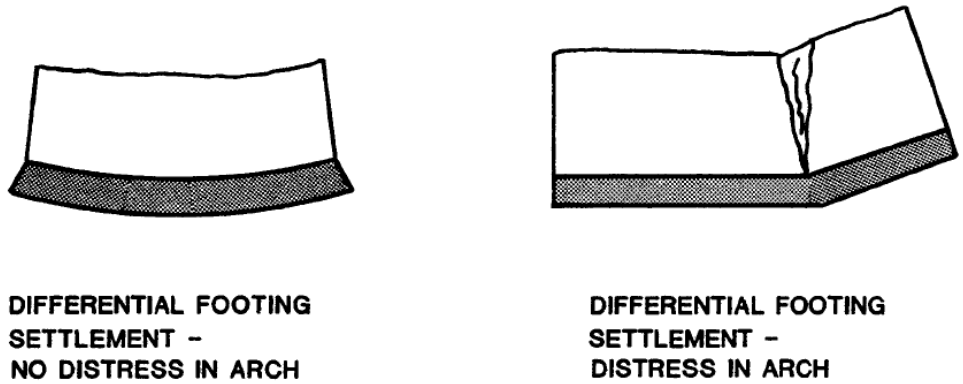


Figure 14.3.18 (Exhibit 76) Differential Footing Settlement

The inspection of footings in structural plate and long-span arches should include a check for differential settlement along the length of a footing. This might show up in severe cracking, spalling, or crushing across the footing at the critical spot. If severe enough, it might be evidenced by compression or stretching of the corrugations in the culvert barrel. Deterioration may occur in concrete and masonry footings which is not related to settlement but is caused by the concrete or mortar. In arches with no invert slab, the inspector should check for erosion and undermining of the footings and look for any indication of rotation of the footing as illustrated in Exhibits 77 and 78.

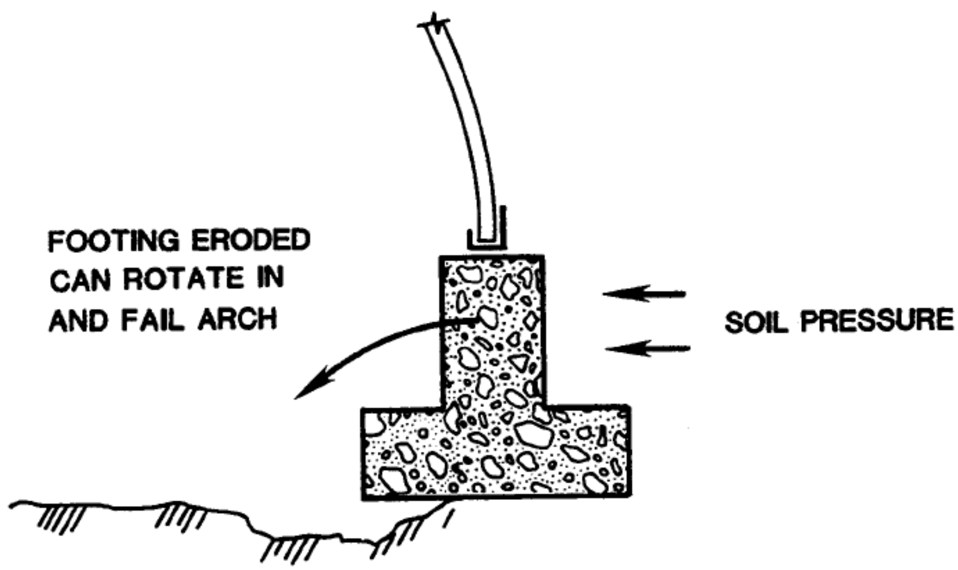


Figure 14.3.19 (Exhibit 77) Footing Rotation due to Undermining

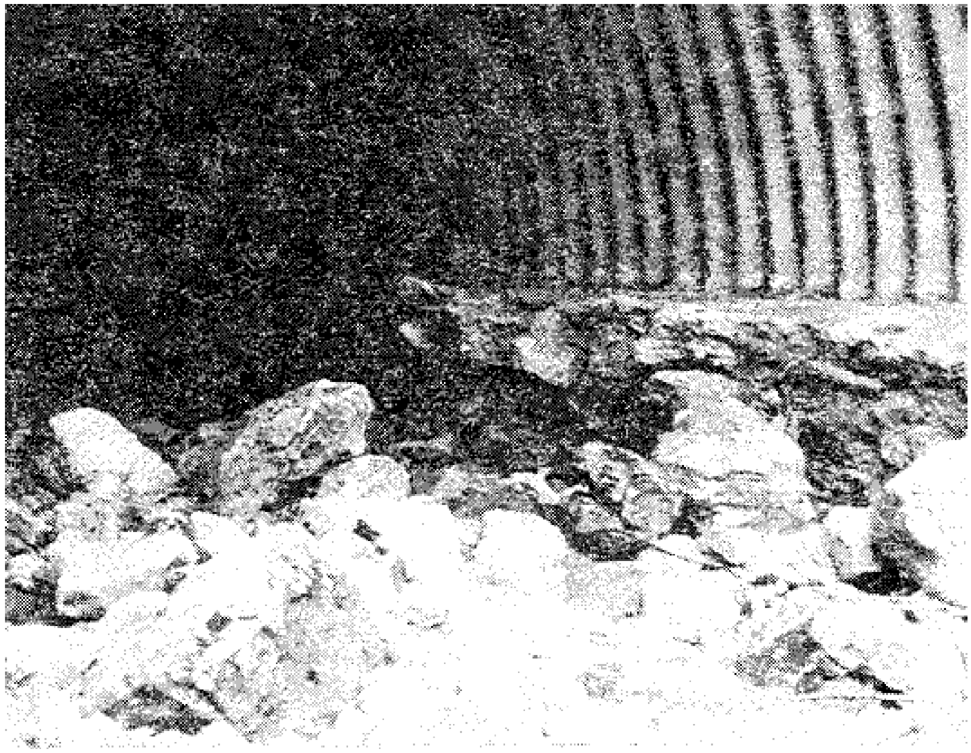


Figure 14.3.20(Exhibit 78) Erosion of Invert Undermining footing of Arch

Culverts rated in good condition may have minor footing damage. Poor to critical condition would be indicated by severe footing undermining, damage, or rotation, or by differential settlement causing distortion and circumferential kinking in the corrugated metal as shown in Exhibit 79.

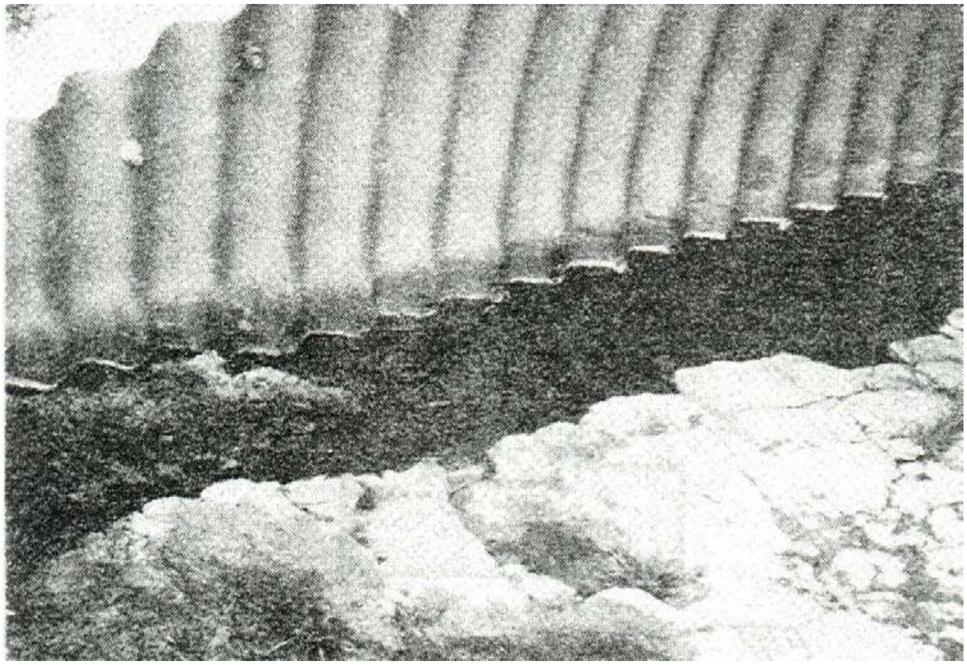


Figure 14.3.21 (Exhibit 79) Erosion Damage to Concrete Invert

i. Defects in Concrete Inverts - Concrete inverts in arches are usually floating slabs used to carry water or traffic. Invert slabs provide protection against erosion and undercutting, and are also used to improve hydraulic efficiency. Concrete inverts are sometimes used in circular, as well as other culvert shapes, to protect the metal from severe abrasive or severe corrosive action. Concrete invert slabs in arches should be checked for undermining and damage such as spalls, open cracks, and missing portions. The significance of damage will depend upon its effect on the footings and corrugated metal.

The following excerpts are from a reproduction of the out-of-print Culvert Inspection Manual (Supplement to Manual 70), July 1986 – Chapter 5, Section 5.

Section 5 - SHAPE INSPECTION OF CORRUGATED METAL CULVERT BARRELS

5-5.0 General

This section deals with shape inspections of common culvert shapes including round and vertical elongated, pipe arches, arches, and box culvert shapes. Specific guidelines for recommended measurements to be taken for each location are provided for each typical culvert shape. Additional measurements are also recommended when field measurements differ from the design dimensions or when significant shape changes are observed. Rating guidelines are also provided for each shape. The guidelines include condition descriptions with shape and barrel defects defined for each rating.

5-5.1 Using the Rating Guidelines

When using the rating guidelines, the inspector should keep the following factors in mind:

a. The inspector should select the lowest rating which best describes either the shape condition or the barrel condition. Structure shape is the most critical factor in flexible culverts, and this should be kept in mind when selecting the rating.

b. The shape criteria described for each numerical rating should be considered as a group rather than as separate criteria for each measurement check listed. Good curvature and the rate of change are critical. Significant changes in shape since the last inspection should be carefully evaluated even if the structure is still in fairly good condition.

c. The guidelines merely offer a starting point for the inspector. The inspector must still use judgment in assigning the appropriate numerical rating. The numerical rating should be related to the actions required. The inspector may wish to refer to Section 4.2 of this manual.

5-5.2 Round and Vertical Elongated Pipe

Round and vertically elongated pipes are expected to deflect vertically during construction resulting in a slightly increased horizontal span. Round pipes are sometimes vertically elongated five percent to compensate for settlement during construction. It is frequently difficult to determine in the field if a pipe was round or elongated when installed. Large round pipes may appear to be elongated if they were subjected to minor flattening of the sides during backfill.

Vehicular underpasses sometimes use 10 percent vertically elongated very large pipe which is susceptible to side flattening during installation. In shallow cover situations, adequate curvature in the sides is the important factor. The soil pressures on the sides may be greater than the weight of the shallow fill over the pipe. The result is a tendency to push the sides inward rather than outward as in deeper buried or round pipes. Side flattening, such as that shown in Exhibit 80, can be caused by unstable backfill. A deteriorated invert may have contributed to the problem by reducing the pipe's ability to transmit compressive forces.

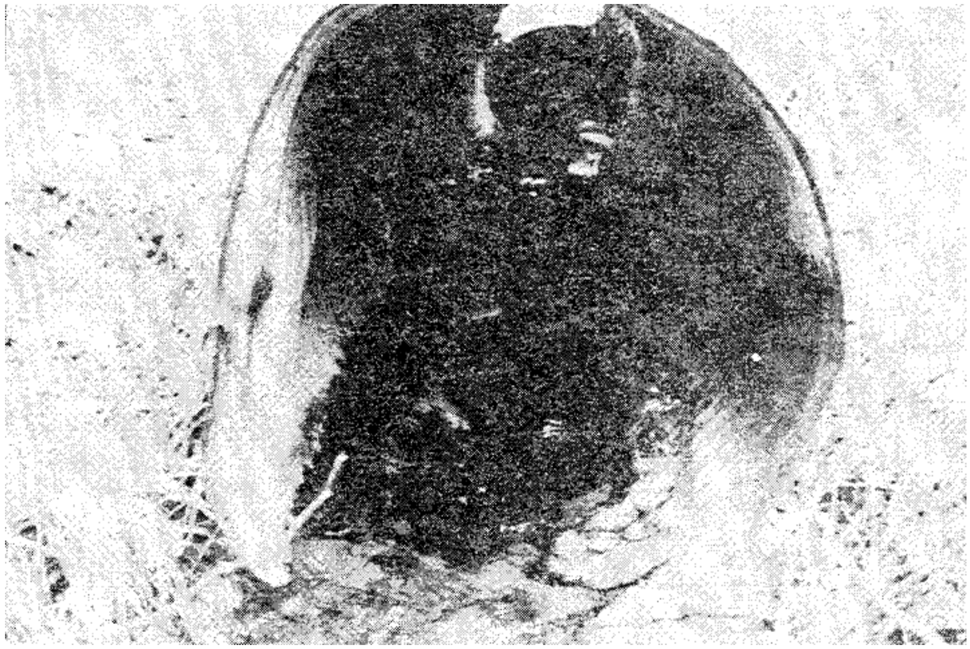


Figure 14.3.22 (Exhibit 80) Excessive Side Deflection

Flattening of the top arc is an indication of possible distress. Flattening of the invert is not as serious. Pipes not installed on shaped bedding will often exhibit minor flattening of the invert arc. However, severe flattening of the bottom arc would indicate possible distress.

The inspector should note the visual appearance of the culvert's shape and measure the horizontal span as shown in Exhibit 81. Almost all round or vertical elongated pipe can be directly measured and will not require elevations. Exceptions are large vertical elongated grade separation structures. On such structures, elevations should be obtained similar to those recommended for the long-span pear shape.

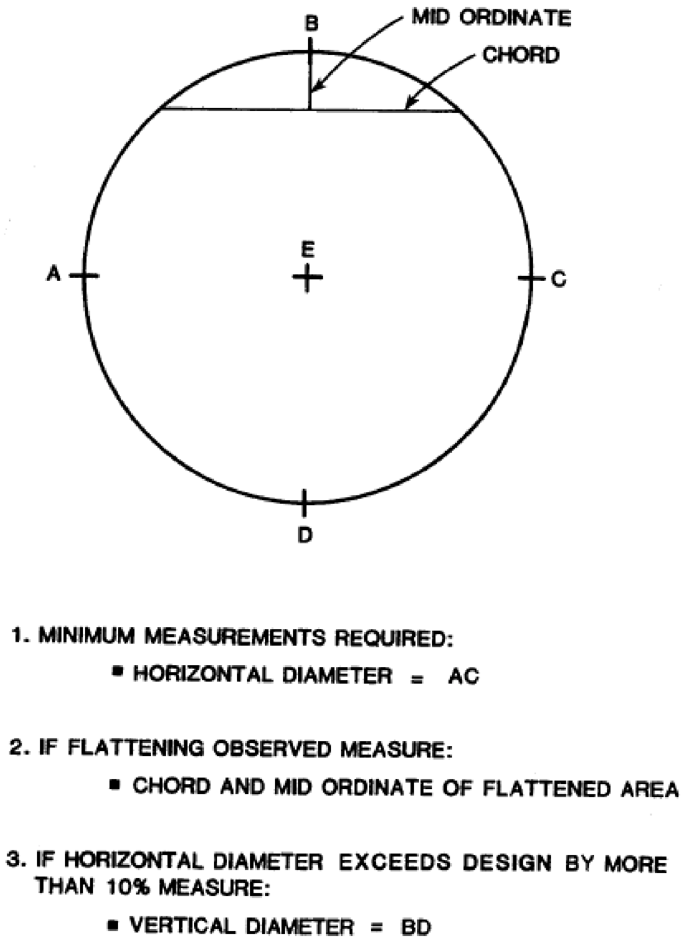


Figure 14.3.23 (Exhibit 81) Shape Inspection Circular and Vertical Elongated Pipe

If the visual appearance or measured horizontal diameter differs significantly from the design specifications, additional measurement, such as vertical diameter, should be taken. Flattened areas should be checked by measuring a chord and the mid ordinate of the chord. The chord length and ordinate measurement should be noted in the report with a description of the location and extent of the flattened area.

Round and vertically elongated pipe with good to fair shape will have a generally good shape appearance. Good shape appearance means that the culvert's shape appears to match the design shape, with smooth, symmetrical curvature and no visible deformations. The horizontal span should be within 10 percent of the design span. Pipe with marginal shape will be indicated by characteristics such as a fair or marginal general shape appearance, distortion in the upper half of the pipe, severe flattening in the lower half of the pipe, or horizontal spans 10 to 15 percent greater than design.

Pipe with poor to critical shape will have a poor shape appearance that does not match the design shape, does not have smooth or symmetrical curvature, and may have obvious deformations. Severe distortion in the upper half of the pipe, a horizontal diameter more than 15 percent to 20 percent greater than the design diameter, or flattening of the crown to an arc with a radius of 20 to 30 feet or more would indicate poor to critical condition. It should be noted that pipes with deflection of less than 15 to 20 percent may be rated as critical based on poor shape appearance. Guidelines for rating round corrugated metal culvert are presented in Exhibit 82.

of core alloy

but bottom half has

f design
is prevalent in one
backfill infiltration

ttack of core alloy
ng

ortion at isolated
of invert
percent greater than

holes along one seam
caused by backfill

ate attack of core

		• flat… - Ho… de… • Seams • Metal - Al… sc… - St… pe…
	2	• Shape pipe, - Ho… • Seams • Metal - Al… - St…
	1	• Shape • Seams • Road:
	0	• Pipe: • Road:

description of Rating Scale.

select the lowest rating which ma[redacted]tches actual conditions.

VERTICAL ELONGATED CORRUGATE[redacted]

	RATING	
	4	• Shap… pipe - H… d… • Seam… near open • Meta… - A… a… - S…
pitting		
e smooth but minor		
f design w bolt holes, minor ill infiltration	3	• Shape

[redacted]

D METAL PIPE BARRELS

CONDITION

e: marginal significant distortion throughout length of
, lower third may be kinked
orizontal Diameter: 10 percent to 15 percent greater than
esign
s or Joints: Moderate cracking at bolt holes on one seam
top of pipe, deflection caused by loss of backfill through
joints
:
luminum: extensive corrosion, significant attack of core
lloy
eel: extensive heavy rust, deep pitting

e: poor with extreme deflection at isolated locations,
ening of crown, crown radius 20 to 30 feet
rizontal Diameter: in excess if 15 percent greater than
sign
: 3 in. long cracks at bolt holes on one seam
:
uminum: extensive corrosion, attack of core alloy,
attered perforations
eel: extensive heavy rust, deep pitting, scattered
rforations

: critical, extreme distortion and deflection throughout
flattening of crown, crown radius over 30 feet
rizontal Diameter: More than 20 percent greater than design
: plate cracked from bolt to bolt on one seam
:
uminum: extensive perforations due to corrosion
eel: extensive perforations due to rust

: partially collapsed with crown in reverse curve
: failed
closed to traffic

totally failed
closed to traffic

Figure 14.3.24 (Exhibit 82) Condition Rating Guidelines

5-5.3 Pipe Arch

The pipe arch is a completely closed structure but is essentially an arch. The load is transmitted to the foundation principally at the corners. The corners are much like footings of an arch. There is relatively little force or pressure on the large radius bottom plate. The principal type of distress in a pipe arch is a result of inadequate soil support at the corners where the pressure is relatively high. The corner may push down or out into the sail while the bottom stays in place. The effect will appear as if the bottom pushed up. This problem is illustrated in Exhibits 83 and 84.

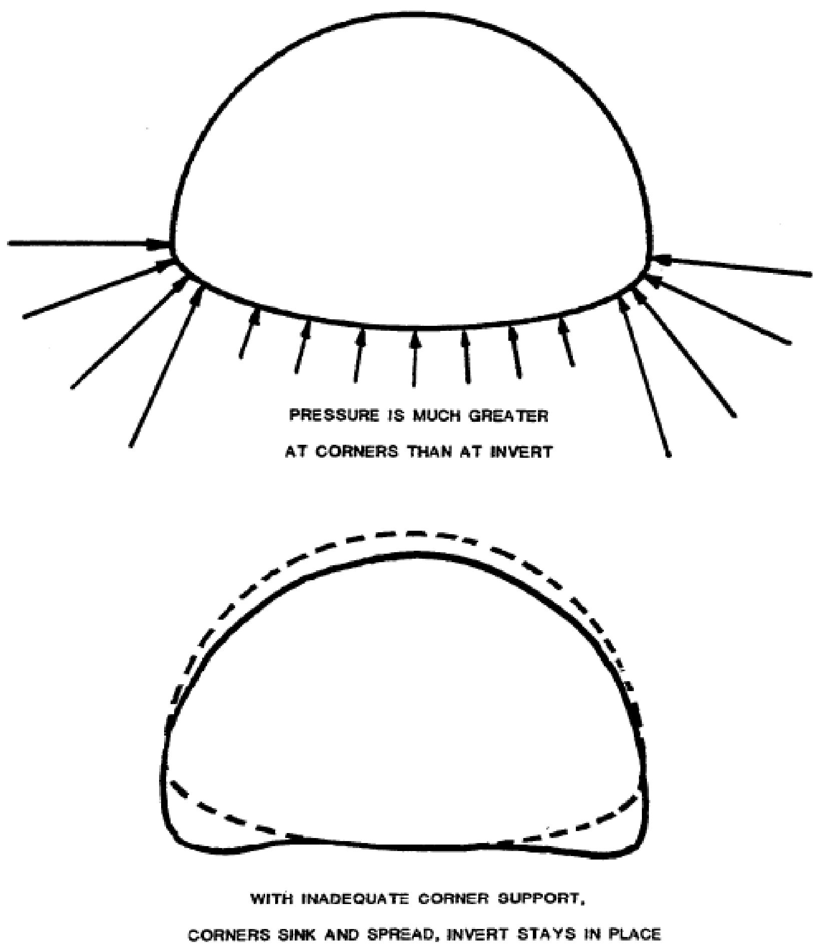


Figure 14.3.25 (Exhibit 83) Bottom Distortion in Pipe Arches

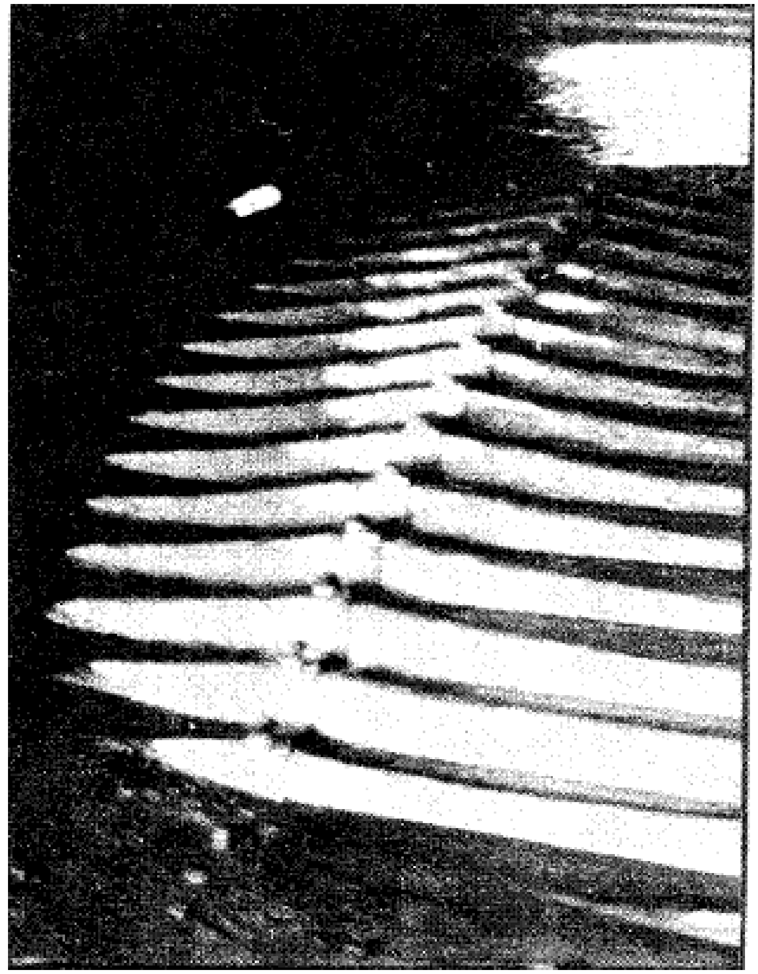


Figure 14.3.26 (Exhibit 84) Bottom and Corners of this Pipe Arch have Settled

The bottom arc should be inspected for signs of flattening and the bottom corners for signs of spreading. The extent and location of bottom flattening and corner spreading should be noted in the inspection report.

Complete reversal of the bottom arc can occur without failure if corner movement into the foundation has stabilized. The top arc of the structure is supporting the load above and its curvature is an important factor. However, if the "footing" corner should fail, the top arc would also fail. The spreading of the corners is therefore very important as it affects the curvature of the top arc.

The inspector should record the visual appearance of the shape and measure both the span and the rise. If the span exceeds the design span by more than 3 percent, the span of the top arc, the mid ordinate of the top arc, and the mid ordinate of the bottom arc should also be measured. Recommended measurements are shown in Exhibit 85.

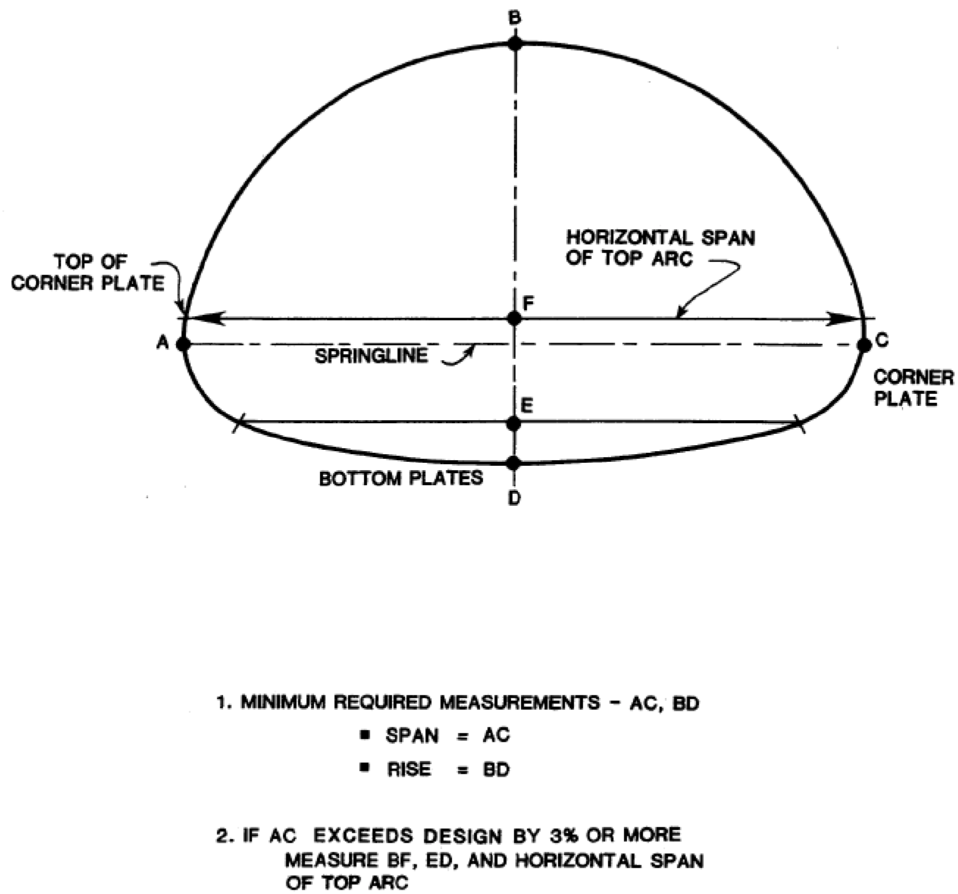


Figure 14.3.27 (Exhibit 85) Shape Inspection Structural Plate Pipe Arch

Pipe arches in fair to good condition will have a symmetrical appearance, smooth curvature in the top of the pipe, and a span less than five percent greater than theoretical. The bottom may be flattened but should still have curvature. Pipe arches in marginal condition will have fair to marginal shape appearance, with distortion in the top half of the pipe, slight reverse curvature in the bottom of the pipe, and a horizontal span five to seven percent greater than theoretical. Pipe in poor to critical condition will have characteristics such as a poor shape appearance, severe deflection or distortion in the top half of the pipe, severe reverse curvature in the bottom of the pipe, flattening of one side, flattening of the crown to an arc with a radius of 20 to 30 feet, or a horizontal span more than seven percent greater than theoretical. Guidelines for rating pipe arches are shown in Exhibit 86.

n
seam
oint

1
• Shape
• Seams
• Road:

core

0
• Shape
• Road:

ion of Rating Scale.
ne lowest rating which ma

PIPE-ARCH BARRELS

RATING

4
• Shape
botto
- Ho
• Joint
backf
• Metal
- Al
al
- St

t

ttom

3
• Shape
botto
- Ho
• Seams
• Metal
- Al
sc
- St
pe

n
inor

oint

2
• Shape
- Ho
• Seams
• Metal
- Al
- St

oy

one
n

[redacted]

CONDITION

: marginal, significant distortion all along top of arch,
n has reverse curve
rizontal Span: more than 7 percent greater than design
s and Seams: moderate cracking all along one seam;
ill infiltration causing major deflection
:
uminum: extensive corrosion, significant attack of core
loy
eel: extensive heavy rust, deep pitting

: poor, extreme deflection in top arch in one section;
n has reverse curvature throughout
rizontal Span: more than 7 percent greater than design
: seam cracked 3 in. on each side of bolt holes
:
uminum: extensive corrosion, attack of core alloy,
attered perforations
eel: extensive heavy rust, deep pitting, scattered
rforations

: critical, extreme deflection along top of pipe
rizontal Span: more than 7 percent greater than design
: seam cracked from bolt to bolt down one seam
:
uminum: extensive perforations due to corrosion
eel: extensive perforations due to rust

: structure partially collapsed
: seam failed
closed to traffic

: structure collapsed
closed to traffic

tches actual conditions.

Figure 14.3.28 (Exhibit 86) Condition Rating Guidelines

5-5.4 Arches.

Arches are fixed on concrete footings, usually below or at the springline. The springline is a line connecting the outermost points on the sides of a culvert. This difference between pipes and arches means that an arch tends to deflect differently during backfill. Backfill forces tend to flatten the arch sides and peak its top because the springline cannot move inward like the wall of a round pipe as shown in Exhibit 87. As a result, important shape factors to look for in an arch are flattened sides, peaked crown, and flattened top arc.

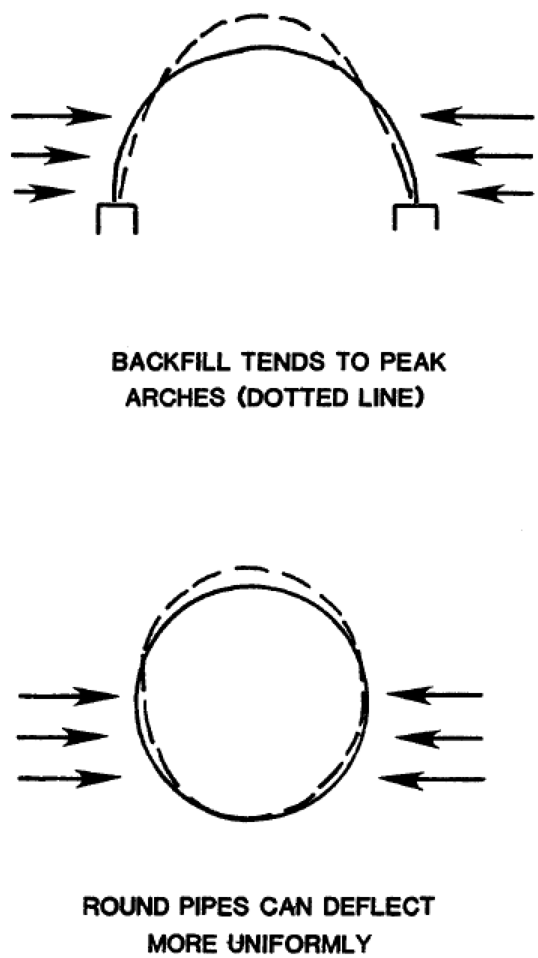
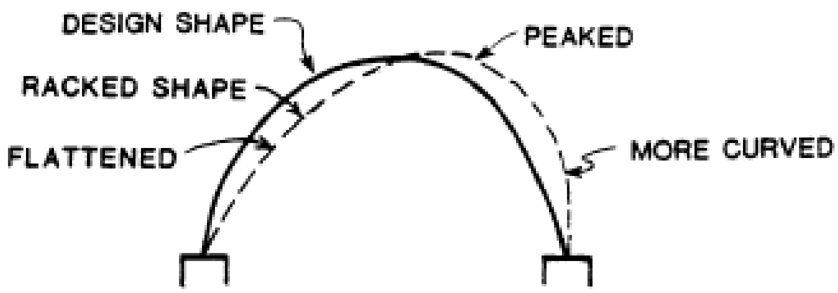


Figure 14.3.29 (Exhibit 87) Arch Deflection During Installation

Another important shape factor in arches is symmetrical shape. If the arch was erected with the base channels not square to the centerline, it causes a racking of the cross section. A racked cross-section is one that is not symmetrical about the centerline of the culvert. One side tends to flatten while the other side tends to curve more while the crown moves laterally and possibly upward. If these distortions are not corrected before backfilling the arch, they usually get worse during backfill. Exhibit 88 illustrates racked or peaked arches.



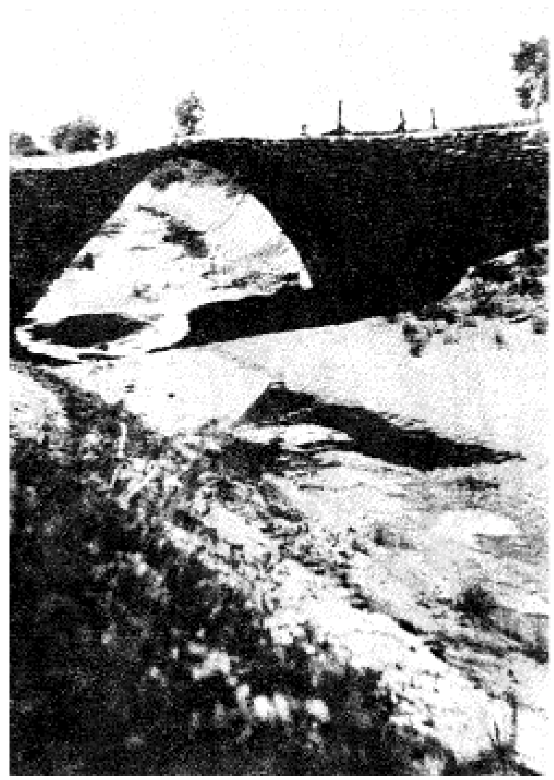
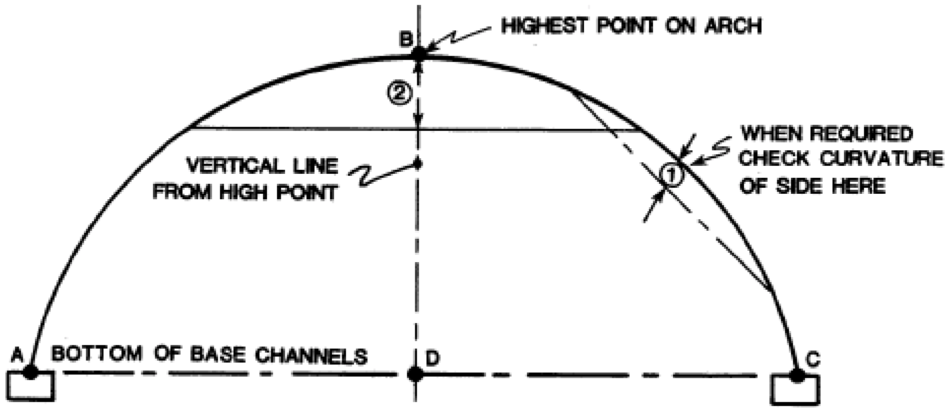


Figure 14.3.30 (Exhibit 88) Racked and Peaked Arch

Visual observation of the shape should involve looking for flattening of the sides, peaking or flattening of the crown, or racking to one side. The measurements to be recorded are illustrated in Exhibit 89. Minimum measurements include the vertical distance from the crown to the bottom of the base channels and the horizontal distances from each of the base channels to a vertical line from the highest point on the crown. These horizontal distances should be equal. When they differ by more than 10 inches or 5 percent of the span, whichever is less, racking has occurred and the curvature on the flatter side of the arch should be checked by recording chord and midordinate measurements. Racking can occur when the rise checks with the design rise. When the rise is more than 5 percent less than the design rise, the curvature of the top arc should be checked.



1. MINIMUM REQUIRED MEASUREMENTS
   - SPAN = AD + DC
   - RISE = BD

2. MINIMUM REQUIRED ELEVATIONS – B

3. IF BD GREATER THAN DESIGN BY 5% OR MORE
   CHECK SIDE CURVATURE

4. IF AD AND DC NOT EQUAL CHECK SIDE CURVATURE ①

5. IF BD LESS THAN DESIGN BY 5% OR MORE
   CHECK TOP CURVATURE ②

Figure 14.3.31 (Exhibit 89) Shape Inspection Structural Plate Arch

Arches in fair to good condition will have the following characteristics: a good shape appearance with smooth and symmetrical curvature, and a rise within three to four percent of theoretical. Marginal condition would be indicated when the arch is significantly non-symmetrical, when arch height is five to seven percent less or greater than theoretical, or when side or top plate flattening has occurred such that the plate radius is 50 to 100 percent greater than theoretical. Arches in poor to critical condition will have a poor shape appearance including significant distortion and deflection, extremely non-symmetrical shape, severe flattening (radius more than 100 percent greater than theoretical) of sides or top plates, or a rise more than eight percent greater or less than the theoretical rise. Guidelines for rating structural plate arches are shown in Exhibit 90.

ɔr description of Rating Scale.

t, select the lowest rating which m [redacted] atches actual conditions.

ꞁAL PLATE ARCH BARREL

N	RATING	[redacted] CONDITION
' ntraction ıt pitting ːurvature, symmetrical; section	4	• Shap thro than • Rise • Seam caus • Meta - A a - S • Foot has [redacted] e: marginal, significant distortion and deflection ughout; sides flattened with radius 100 percent greater design : within 7 to 8 percent of design s: major cracking of seam near crown; infiltration of soil ing major deflection l: luminum: extensive corrosion, significant attack of core lloy teel: extensive heavy rust, deep pitting ings: rotated due to erosion and undercutting; settlement caused damage to metal arch
es; minor seam opening, ːk of core alloy erential settlement and non-symmetrical; slight	3	• Shap side • Rise • Seam • Meta - A s - S p • Foot [redacted] e: poor, extreme distortion and deflection in one section; s virtually flattened; extremely non-symmetrical : within 8 to 10 percent of design s: cracked 3° to either side of bolts l: luminum: extensive corrosion, attack of core alloy, cattered perforations teel: extensive heavy rust, deep pitting, scattered erforations ing: rotated, severely undercut; major cracking and spalling
ong one or more seams; r attack of core alloy tting erential settlement of ɔrtion and deflection in ; non-symmetrical	2	• Shap flat • Rise • Seam back • Meta - A - S • Foot and [redacted] e: critical, extreme deflection, throughout; sides tened; extremely non-symmetrical : greater than 10 percent of design s: cracked from bolt to bolt; significant amounts of fill infiltration l: luminum: extensive perforations due to corrosion teel: extensive perforations due to rust ing: severe differential settlement has caused distortion kinking of metal arch
ar footing; infiltration ɔderate attack of core	1	• Shap crow • Seam • Road [redacted] e: severe due to partial collapse; local reverse curve of n and sides s: failed, backfill pushing in : closed to traffic
ting f footing and extreme in footing	0	• Stru • Road [redacted] cture: completely collapsed : closed to traffic

Figure 14.3.32 (Exhibit 90) Condition Rating Guidelines

5-5.5 Corrugated Metal Box Culverts.

The box culvert is not like the other flexible buried metal structures. It behaves as a combination of ring compression action and conventional structure action. The sides are straight, not curved and the plates are heavily reinforced and have moment or bending strength that is quite significant in relation to the loads carried.

The key shape factor in a box culvert is the top arc. The design geometry is clearly very "flat" to begin with and therefore cannot be allowed to deflect much. The span at the top is also important and cannot be allowed to increase much.

The side plates often deflect slightly inward or outward. Generally an inward deflection would be the more critical as an outward movement would be restrained by soil.

Shape factors to be checked visually include flattening of top arc, outward movement of sides, or inward deflection of the sides. The inspector should note the visual appearance of the shape and should measure and record the rise and the horizontal span at the top of the straight legs as shown in Exhibit 91. If the rise is more or less than 1 ½ percent of the design rise, the curvature of the large top radius should be checked.

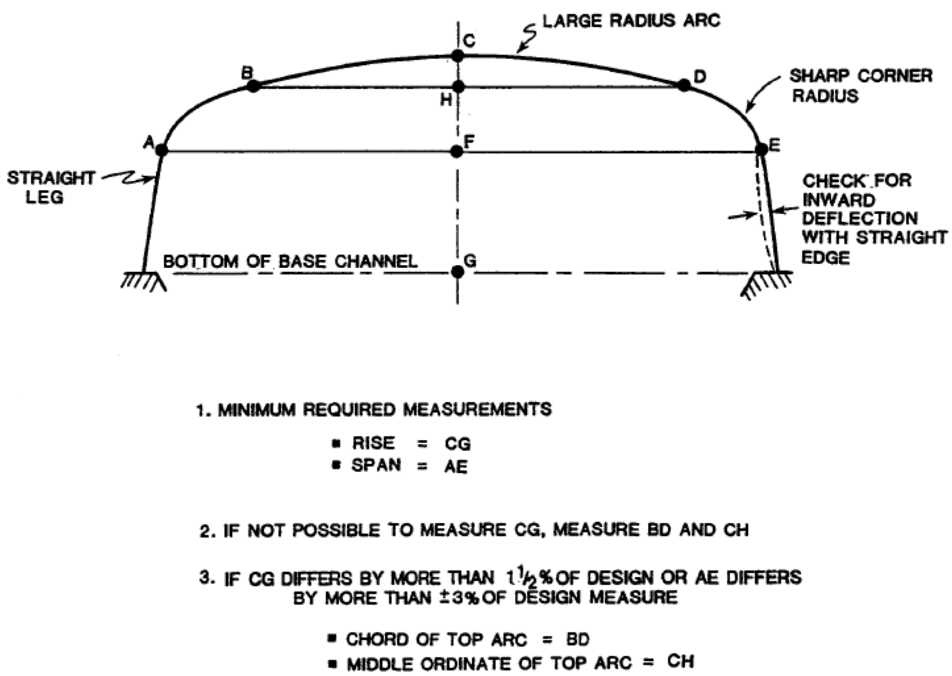


Figure 14.3.33 (Exhibit 91) Shape Inspection Structural Plate Box Culverts

The radius points are not necessarily located at the longitudinal seams. Many box culverts use double radius plates and the points where the radius changes must be estimated by the inspector or can be determined from the manufacturer's literature. These points can still be referenced to the bolt pattern to describe exactly where they are. Since these are all low structures, the spots should also be marked and painted for convenient repeat inspection.

Box culverts in fair to good condition will appear to be symmetrical with smooth curves, slight or no deflection of the straight legs, a horizontal span length within five percent of the design span and the middle ordinate of the tops are within ten percent of the design. Culverts in marginal condition may appear to be non-symmetrical, have noticeable deflection in the straight legs, have spans that differ from design by five percent, or have a middle ordinate of the top arc that differ from design by 20 to 30 percent. Poor to critical conditions exist when the culvert shape appears poor, the culvert has severe deflections of the straight legs, a horizontal span that differs from design by more than five percent, or a middle ordinate of the top arc that differs from the theoretical by more than 40 to 50 percent. Guidelines for rating structural plate box culverts are shown in Exhibit 92.

throughout; mid-ord
of design
- Top Arc Mid-Ordin
- Horizontal Span:
- Sides: straight
bowed outward fo
curvature irregul
• Seams: significant
of soil causing majo
• Metal:
- Aluminum: extens
alloy
- Steel: extensive
• Footings: rotated d
caused damage to met

3
• Shape: poor extreme
and ordinate of half
- Top Arc Mid-Ordin
- Horizontal Span:
Sides: straight
than 1/2 span le
bulges in metal
• Seams: cracked 3" o
of backfill causing
• Metal:
- Aluminum: exten
scattered perfora
- Steel: extensiv
perforations
• Footing: rotated,
spalling of footing,

2
• Shape: critical, ex
mid-ordinate of hal
design
- Top Arc Mid-Ordin
- Horizontal Span:
- Sides: straight l
1/2 to 1 span le
bulges or kinking
• Seams: cracked fro
backfill infiltratio
• Metal:
- Aluminum: extensi
- Steel: extensive
• Footing: severe dif
and kinking of metal

1
• Shape: severe due t
or reverse curved
• Seams; failed, backf
• Road closed to traff

0
• Structure: complete
• Road: closed to traf

of Rating Scale.

owest rating which

ERT BARREL

RATING

4 • Shape: marginal.

[redacted]

CONDITION

significant distortion and deflection
inate of half top arc less than 50 percent

ate: within 20 to 30 percent of design
more than + or - 5 percent of design
leg bowed inward significantly or extremely
r distance between 1/4 and 1/2 span length,
ar
seam cracking all along seam; infiltration
r deflection

ive corrosion, significant attack of core

heavy rust, deep pitting
e erosion and undercutting; settlement has
al arch

distortion and deflection in one section
top arc 50 to 70 percent less than design
ate: 30 to 40 percent less than design
more than + or - 6 percent of design
eg extremely bowed inward for distance less
ngth or leg bowed outward severely causing

more to either side of bolt; infiltration
severe deflection locally

ive corrosion, attack of core alloy,
tions
heavy rust, deep pitting, scattered

severely undercut, major cracking and
significant damage to structure

reme distortion and deflection throughout;
f top arc more than 70 percent less than

ate: more than 40 percent less than design
more then + or - 8 percent of design
eg extremely bowed inward for a distance of
ngth, or leg bowed outward severely causing
in metal
bolt to bolt; significant amounts of
n throughout

ve perforations due to corrosion
perforations due to rust
ferential settlement has caused distortion
arch

partial collapse; top arc curvature flat

ill pushing in
ic

collapsed
fic

matches actual conditions.

Figure 14.3.34 (Exhibit 92) Condition Rating Guidelines

The following excerpts are from a reproduction of the out-of-print Culvert Inspection Manual (Supplement to Manual 70), July 1986 – Chapter 5, Section 6.

Section 6. CORRUGATED METAL LONG-SPAN CULVERTS

5-6.0 General.

This section describes methods for conducting shape inspections of long-span structures. The long-span structures addressed include four typical shapes: low profile arch, horizontal ellipse, high profile arch, and pear. These shapes are illustrated in Exhibit 93. The evaluation of shape characteristics of long-spans will vary somewhat depending upon the typical shape being inspected. However, the top or crown sections of all long-span structures have very similar geometry. The crown sections on all long-span structures can be inspected using the same criteria. This section therefore includes separate discussions on the crown section and on each of the typical long-span shapes. Guidelines are also provided for rating the condition of each shape in terms of shape characteristics and barrel defects. The methods for using the rating guidelines are the same as those described in section 5-5.1.

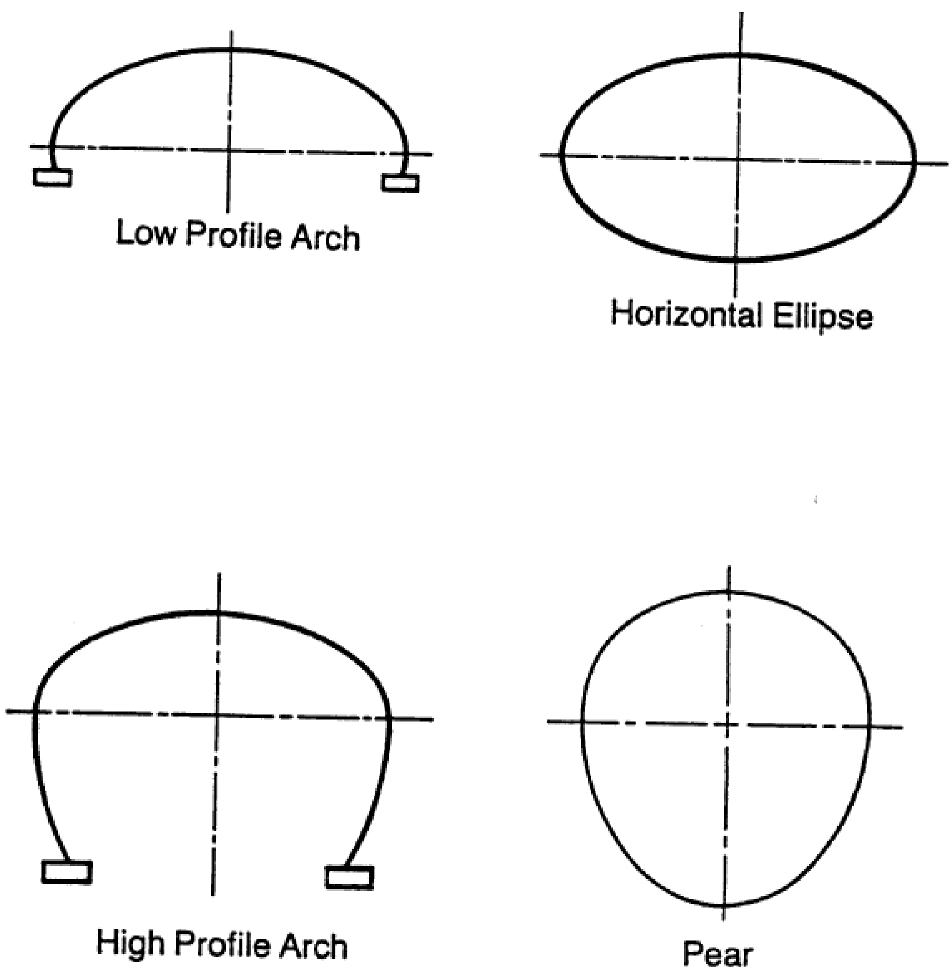


Figure 14.3.35 (Exhibit 93) Typical Long-Span Shapes

Shape inspections of long-span structures will generally consist of 1) visual observations of shape characteristics such as smooth or distorted curvature and symmetrical or non-symmetrical shape, 2) measurements of key dimensions, and 3) elevations of key points. Additional measurements may be necessary if measurements or observed shape differ significantly from design.

The visual observations are extremely important to evaluate the shape of the total cross section. Simple measurements such as rise and span do not describe curvature, yet adequate curvature is essential, as shown in Exhibit 94. However, measurements and elevations are also needed to document the current shape so that the rate change, if any, can be monitored.

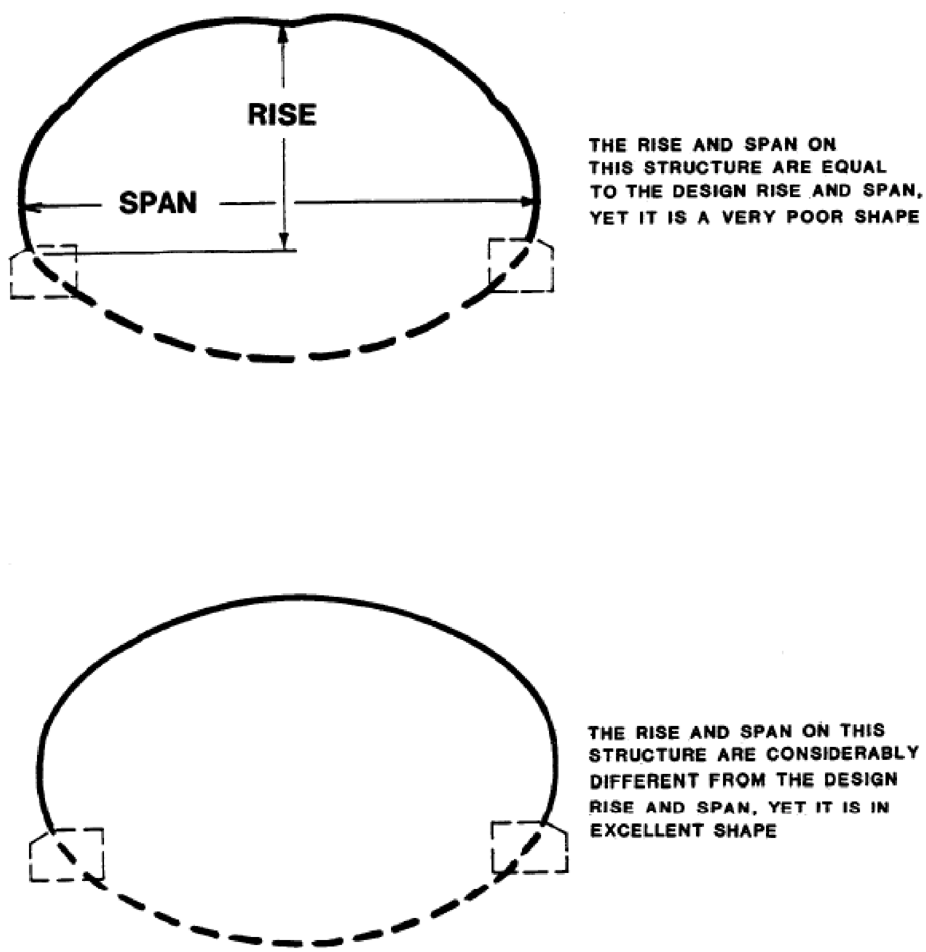


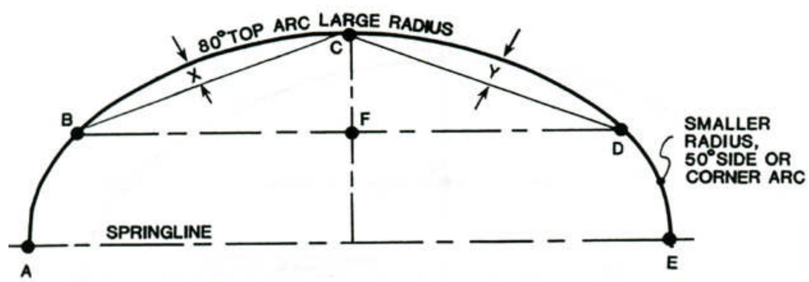
Figure 14.3.36 (Exhibit 94) Erosion Damage to Concrete Invert

Many long-spans will be too large to allow simple direct measuring. Vertical heights may be as large as 20 to 30 feet and horizontal spans may be large and as high as 12 to 15 feet above inverts. Culverts may have flowing water obscuring the invert and any reference points there. It is, therefore, in general desirable to have instrument survey points, which can be quickly checked for elevation. When direct measuring is practical a 25 foot telescoping extension rod can be used for measuring. Such rods can also serve as level rods for taking elevations.

5-6.1 Long-Span Crown Section - Shape Inspection.

As previously mentioned, the section above the springline is essentially the same for most long-span shapes. With the exception of pear shapes, the standard top geometry uses a large radius top arc of approximately 80 degrees with a radius of 15 to 25 feet. The adjacent corner or side plates are from one-half to one-fifth the top arc radius. The most important part of a long-span shape is the standard top arch geometry. Adequate curvature of the large radius top arc is critical. Inspection of the crown section should consist of a visual inspection of the general shape for smooth curvature (no distortion, flattening, peaks, or cusps) and symmetrical shape (no racking).

An inspection should also include key measurements such as the middle ordinate of the top arc. Recommended measurements and elevations are shown in exhibit 95.



[redacted]

1. MINIMUM REQUIRED ELEVATIONS - B, C, D

MINIMUM REQUIRED MEASUREMENTS -

- TOP SPAN = AE

$$\text{CALCULATE CF} = \text{ELEV C} - \frac{\text{ELEV B} + \text{ELEV D}}{2}$$

Figure 14.3.37 (Exhibit 95) Shape Inspection Crown Section of Long Span Structures

The initial inspection should establish elevations for the radius points and the top of the crown. From these elevations the middle ordinate for the top arc can be calculated. If the actual middle ordinate is 10 percent more or less than the theoretical design mid-ordinate the horizontal span for the top arc should also be measured. For standard 80 degree arcs the theoretical middle ordinate is equal to 0.234 times the theoretical radius of the top arc. This span is not easy to measure on many long-span structures and need not be measured if the top arc mid-ordinate is within 10 percent of theoretical. Even if it is convenient and practical to direct measure the vertical heights of the points on the top arc from the bottom of the structure, it is wise to also establish their elevations from a reliable benchmark. Bottom reference points can be wiped out by erosion, covered with debris, or covered by water. When direct vertical measuring is practical, the shape may be checked on subsequent inspections with direct measurement. However, it is still important to establish elevations in case bottom reference points are lost or inaccessible.

Crown sections in good condition will have a shape appearance that is good, with smooth and symmetrical curvature. The actual middle ordinate should be within 10 percent of the theoretical, and the horizontal span (if measured) should be within five percent of theoretical. Crown sections in fair condition will have a fair to good shape appearance, smooth curvature but possibly slightly non-symmetrical. Middle ordinates of the top arc may be within 11 to 15 percent of theoretical and the horizontal span may differ by more than 5 percent of theoretical.

Crown sections in marginal condition will have measurements similar to those described for fair shape. However, the shape appearance will be only fair to marginal with noticeable distortion, deflection, or non-symmetrical curvature. When the curvature is noticeably distorted or non-symmetrical, the sides should be checked for flattening by measuring the middle ordinates of the halves of the top arc. Crown sections with marginal shape may have middle ordinates for top half arcs that are 30 to 50 percent less than theoretical.

Crown sections in poor to critical condition will have a poor to critical shape appearance with severe distortion or deflection. The middle ordinate of the top arc may be as much as 20 percent less than theoretical, while middle ordinates of the top arc halves may be 50 to 70 percent less than theoretical.

5-6.2 Low Profile Long-Span Arch - Shape Inspection.

The low profile arch is essentially the same as the crown section except that the sides are carried about 10 degrees below the springline to the footing. These structures are low and can be measured more easily than other long-span shapes. Recommended measurements and elevations are shown in exhibit 96. Rating guidelines are listed in exhibit 97.

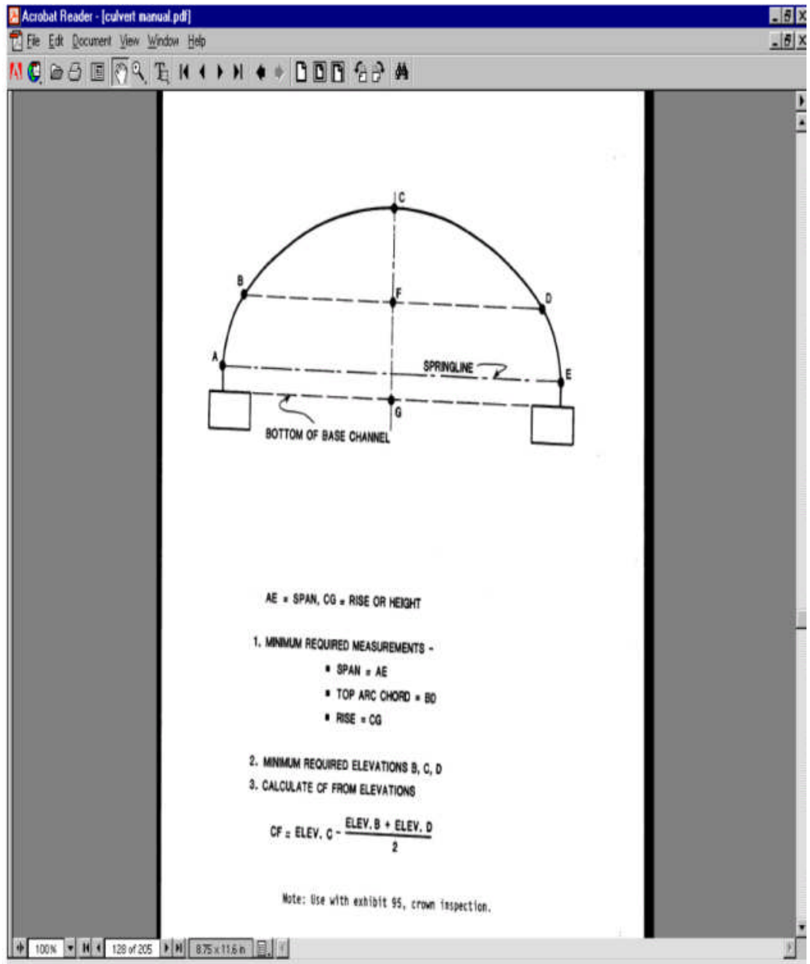


Figure 14.3.38 (Exhibit 96) Shape Inspection Low Profile Long Span Arch

perforation
- Footing: rota
spalling of fo

2
- Shape: critica
mid-ordinate o
design
  - Top Arc Mid-
  - Horizontal S
- Seams: cracked
backfill infilt
- Metal:
  - Aluminum: ex
  - Steel: exten
- Footing: sever
and kinking of

1
- Shape: severe
or reverse curv
- Seams: failed,
- Road closed to

0
- Structure: comp
- Road: closed to

n of Rating Scale.
lowest rating whic

AN CULVERT BARREL

RATING	
4	• Shape: margi throughout; mi of design - Top Arc Mid- - Horizontal S • Seams: signifi of soil causin • Metal: - Aluminum: alloy, - Steel: exter • Footings: rota caused damage
3	• Shape: poor e and ordinate o - Top Arc Mid- - Horizontal S • Seams: cracked of backfill ca • Metal: - Aluminum: scattered p - Steel: ext

[redacted]

CONDITION

al, significant distortion and deflection
d-ordinate of half top arc less than 50 percent

Ordinate: within 15 to 20 percent of design
Span: more than + or - 5 percent of design
cant seam cracking all along seam; infiltration
major deflection

xtensive corrosion, significant attack of core

sive heavy rust, deep pitting
ted due erosion and undercutting; settlement has
o metal arch

treme distortion and deflection in one section
half top arc 50 to 70 percent less than design
Ordinate: 20 to 30 percent less than design
Span: more than + or - 6 percent of design
3" or more to either side of bolt; infiltration
sing severe deflection locally

extensive corrosion, attack of core alloy,
rforations
ensive heavy rust, deep pitting, scattered

ted, severely undercut, major cracking and
ting, significant damage to structure

, extreme distortion and deflection throughout;
half top arc more than 70 percent less than

Ordinate: more than 30 percent less than design
Span: more then + or - 8 percent of design
from bolt to bolt; significant amounts of
ration throughout

tensive perforations due to corrosion
sive perforations due to rust
differential settlement has caused distortion
metal arch

due to partial collapse; top arc curvature flat
ed
backfill pushing in
traffic

letely collapsed
traffic

h matches actual conditions.

Figure 14.3.39 (Exhibit 97) Condition Rating Guidelines

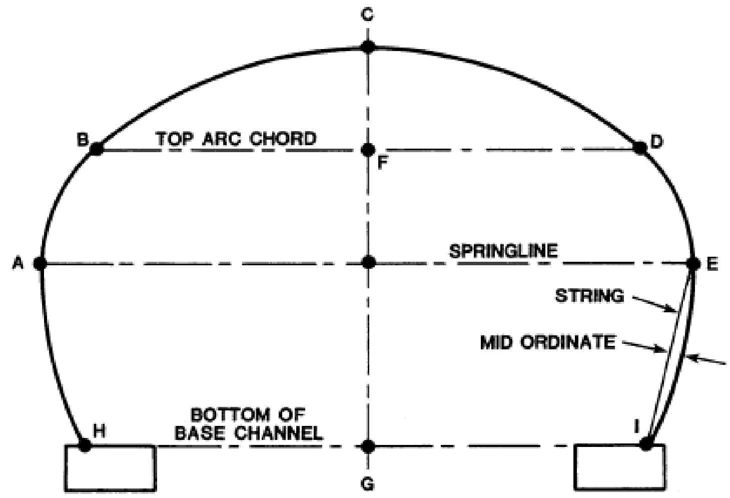
Because arches are fixed on concrete footings, backfill pressures will try to flatten the sides and peak the top. Another important shape factor is symmetry. If the base channels are not square to the centerline of the structure racking may occur during erection. In racked structures, the crown moves laterally and the curvature in one side becomes flatter while the curvature in the other side increases. Backfill pressures may cause this condition to worsen.

5-6.3 High Profile Long-Span Arch – Shape Inspection.

High profile arches have a standard crown section geometry but have high large radius side walls below the springline. Curvature in these side plates is important. In shallow fills or minimum covers, the lateral soil pressures may approach or exceed the loads over the culvert. Excessive lateral forces could cause the sidewall to flatten or buckle inward.

Inspectors should visually inspect high profile arches for flattening of the side plates. Additionally, high profile arches have the same tendencies as regular arches for peaking and racking, so inspectors must also look for peaked top arcs and non-symmetrical or racked arches.

Recommended measurements and elevations are shown in Exhibit 98. The shape of the crown section is the most important shape factor. It can be measured and evaluated using the same criteria as that described for the standard crown section. If flattening is observed in the high sidewall the curvature of the sides should be checked by measuring the middle ordinate of the side walls. If the sidewall middle ordinate is no more than 50 to 70 percent less than the theoretical middle ordinate and no other shape problems are found the arch's shape may be considered fair. When the middle ordinate approaches 75 to 80 percent less than theoretical, the shape should be considered marginal. If the middle ordinate is more than 80 to 90 percent less than theoretical the shape should be considered poor to critical. Rating guidelines are provided in Exhibit 99.



AE = SPAN, CG = RISE

1. MINIMUM REQUIRED MEASUREMENTS
   - SPAN = AE

2. MINIMUM REQUIRED ELEVATIONS – B, C, D, H, I

3. CALCULATE CF FROM ELEVATIONS

Note: Use with exhibit 95, crown inspection.

Figure 14.3.40 (Exhibit 98) Shape Inspection High Profile Long-Span Arch

ULVERT BARREL [redacted]

RATING	C [redacted] CONDITION
4	• Shape: marginal, sig [redacted] nificant distortion and deflection throughout; mid-ordinate [redacted] of half top arc less than 50 percent of design - Top Arc Mid-Ordinate: [redacted] within 15 to 20 percent of design - Horizontal Span: more [redacted] than + or - 5 percent of design - Side Plates: side [redacted] flattened, mid-ordinate less than 20 percent of design • Seams: significant seam [redacted] cracking all along seam; infiltration of soil causing major de [redacted] flection • Metal: - Aluminum: extensive [redacted] corrosion, significant attack of core alloy - Steel: extensive heav [redacted] y rust, deep pitting • Footings: rotated due e [redacted] rosion and undercutting; settlement has caused damage to metal a [redacted] rch
3	• Shape: poor extreme di [redacted] stortion and deflection in one section and ordinate of half top [redacted] arc 50 to 70 percent less than design - Top Arc Mid-Ordinate: [redacted] 20 to 30 percent less than design - Horizontal Span: more [redacted] than + or - 6 percent of design - Side Plates: side [redacted] flattened, mid-ordinate less than 12 percent of design • Seams: cracked 3" or mo [redacted] re to either side of bolt; infiltration of backfill causing seve [redacted] re deflection locally • Metal: - Aluminum: extensive [redacted] corrosion, attack of core alloy, scattered perforation [redacted] s - Steel: extensive h [redacted] eavy rust, deep pitting, scattered perforations • Footing: rotated, sev [redacted] erely undercut, major cracking and spalling of footing, sig [redacted] nificant damage to structure
2	• Shape: critical, extreme [redacted] distortion and deflection throughout; mid-ordinate of half to [redacted] op arc more than 70 percent less than design - Top Arc Mid-Ordinate: [redacted] more than 30 percent less than design - Horizontal Span: more [redacted] then + or - 8 percent of design - Side Plates: side fla [redacted] ttened, mid-ordinate less than10percent of design • Seams: cracked from b [redacted] olt to bolt; significant amounts of backfill infiltration th [redacted] roughout • Metal: - Aluminum: extensive p [redacted] erforations due to corrosion - Steel: extensive perf [redacted] orations due to rust • Footing: severe differe [redacted] ntial settlement has caused distortion and kinking of metal arc [redacted] h
1	• Shape: severe due to pa [redacted] rtial collapse; top arc curvature flat or reverse curved - Side Plates: side fla [redacted] t or reversed curved • Seams: failed, backfill [redacted] pushing in • Road closed to traffic
0	• Structure: completely co [redacted] llapsed • Road: closed to traffic

of Rating Scale. [redacted]

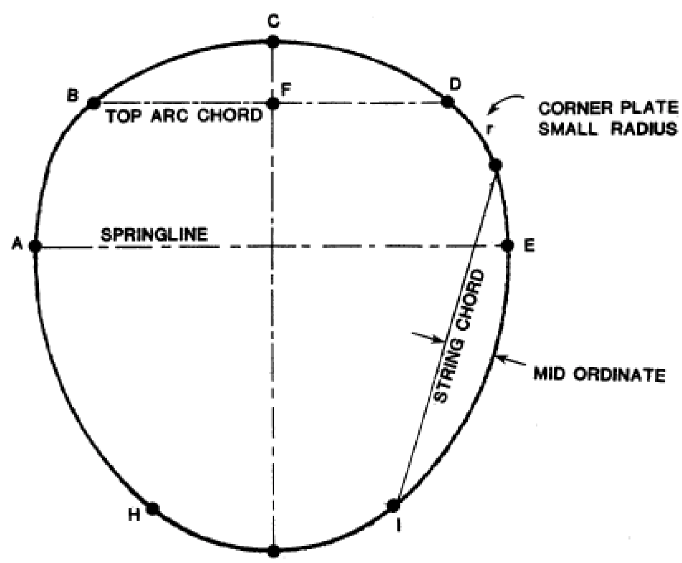
lowest rating which [redacted] matches actual conditions.

Figure 14.3.41 (Exhibit 99) Condition Rating Guidelines

5-6.4 Pear Shape Long-Span – Shape Inspection.

The crown section of the pear shape differs from the standard top arch in that smaller radius corner arcs stop short of the horizontal springline. The large radius sides extend above the plane of the horizontal span. In checking curvature of the sides, the entire arc should be checked. Side flattening, particularly in shallow fills, is the most critical shape factor.

The pear shape behaves similarly to the high profile arch. It is essentially a high profile with a metal bottom instead of concrete footings. Pears may be inspected using the criteria for a high profile arch. The recommended measurements and elevations are shown in Exhibit 100. Rating guidelines are provided in Exhibit 101.



AE = SPAN, CG = RISE

1. MINIMUM REQUIRED MEASUREMENT – AE
   ▪ SPAN = AE

2. MINIMUM REQUIRED ELEVATIONS B, C, D

3. WHEN FLATTENING OBSERVED IN SIDE, CHECK MID ORDINATE (RECORD CHORD LENGTH USED)

Note: Use with exhibit 95, crown inspection.

Figure 14.3.42 (Exhibit 100) Shape Inspection Long Span Pear-Shape

0	• Structure: comp • Road: closed to

on of Rating Scale.

e lowest rating whic

CULVERT BARREL

RATING	
4	• Shape: margin throughout; mi of design - Top Arc Mid- - Horizontal S - Side Plates percent of d • Seams: signifi of soil causing • Metal: - Aluminum: ex - Steel: exten
3	• Shape: poor ex and ordinate of - Top Arc Mid- - Horizontal S - Side Plates percent of d • Seams: cracked of backfill cau • Metal: - Aluminum: scattered pe - Steel: ext perforations
2	• Shape: critica mid-ordinate o design - Top Arc Mid- - Horizontal S - Side Plates: of design • Seams: cracked backfill infilt • Metal: - Aluminum: ex - Steel: exten
1	• Shape: severe or reverse curv - Side Plates: - Seams: faile • Road closed to

[redacted]

CONDITION

al, significant distortion and deflection
-ordinate of half top arc less than 50 percent

Ordinate: within 15 to 20 percent of design
pan: more than + or - 5 percent of design
: side flattened, mid-ordinate less than 20
esign
ant seam cracking all along seam; infiltration
major deflection

tensive corrosion, significant attack of alloy
sive heavy rust, deep pitting

treme distortion and deflection in one section
half top arc 50 to 70 percent less than design
Ordinate: 20 to 30 percent less than design
pan: more than + or - 6 percent of design
: side flattened, mid-ordinate less than 12
esign
3" or more to either side of bolt; infiltration
sing severe deflection locally

xtensive corrosion, attack of core alloy,
rforations
nsive heavy rust, deep pitting, scattered

, extreme distortion and deflection throughout;
half top arc more than 70 percent less than

Ordinate: more than 30 percent less than design
pan: more then + or - 8 percent of design
side flattened, mid-ordinate less than10percent

from bolt to bolt; significant amounts of
ration throughout

tensive perforations due to corrosion
sive perforations due to rust

ue to partial collapse; top arc curvature flat
ed
side flat or reversed curved
d, backfill pushing in
traffic

letely collapsed
traffic

n matches actual conditions.

Figure 14.3.43 (Exhibit 101) Condition Rating Guidelines

5-6.5 Horizontal Ellipse – Shape Inspections.

For horizontal ellipses the most important shape factor is adequate curvature in the crown section. The crown section uses the standard long-span crown geometry. The sides and bottom behave similar to the corners and bottom of pipe arches. The invert has relatively minor pressure when compared with the sides, which may have several times the bearing pressure of the invert. As a result the corners and sides have the tendency to push down into the soil while the bottom does not move. The effect is as if the bottom pushed up. Inspectors should look for indications of bottom flattening and differential settlement between the side and bottom sections, as illustrated in Exhibit 102.

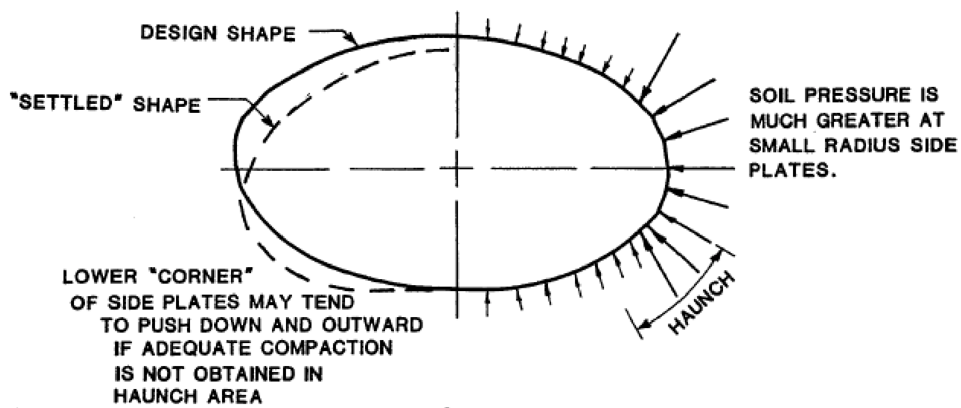


Figure 14.3.44 (Exhibit 102) Potential for Differential Settlement in Horizontal Ellipse

The recommended measurements and evaluations for a shape inspection of horizontal ellipse are shown in Exhibit 103. The measurements are essentially the same as those recommended for a standard crown section. Shape evaluation of an ellipse is also essentially the same as the evaluation of a standard crown section except that the curvature of the bottom should also be evaluated. Marginal shape would be indicated when the bottom is flat in the center and corners are beginning to deflect downward or outward. Critical shape conditions would be indicated by reverse curvature in the bottom arc. Guidelines for rating horizontal ellipse shape culverts are provided in Exhibit 104.

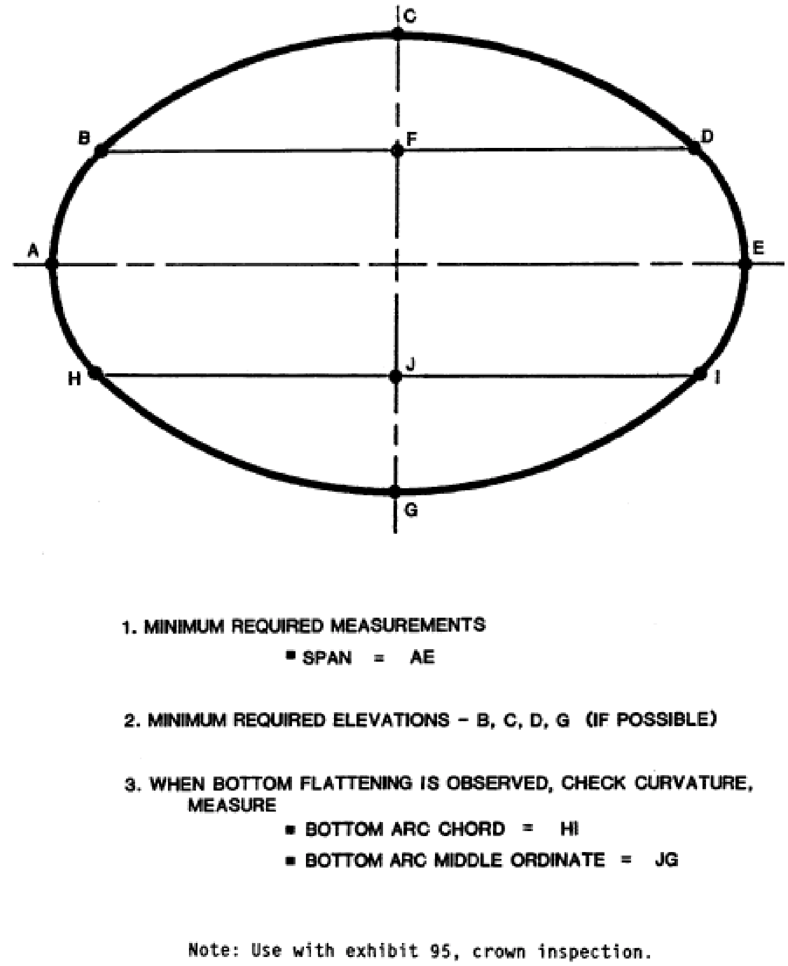


Figure 14.3.45 (Exhibit 103) Shape Inspection Long-Span Horizontal Ellipse

or reverse c
• Seams: faile
• Road closed

0
• Structure: c
• Road: closed

ion of Rating Scale.

ne lowest rating whic

NG SPAN CULVERT BARREL

RATING

4
• Shape: mar
throughout;
of design
- Top Arc M
- Horizonta
- Bottom Ar
and defle
• Seams: signi
of soil caus
• Metal:
- Aluminum:
- Steel: ex
• Footings: ro
caused damag

3
• Shape: poor
and ordinate
- Top Arc M
- Horizonta
- Bottom Ar
• Seams: crack
of backfill
• Metal:
- Aluminum:
scattered
- Steel:
perforati
• Footing: r
spalling of

2
• Shape: criti
mid-ordinate
design
- Top Arc M
- Horizonta
- Bottom Ar
at sides
• Seams: crac
backfill inf
• Metal:
- Aluminum:
- Steel: ex
• Footing: sev
and kinking

1
• Shape: sever

[redacted]

CONDITION

inal, significant distortion and deflection
mid-ordinate of half top arc less than 50 percent

d-Ordinate: within 15 to 20 percent of design
Span: more than + or - 5 percent of design
c: bottom virtually flat over center half of arc
cted down at corners
ficant seam cracking all along seam; infiltration
ing major deflection

extensive corrosion, significant attack of alloy
ensive heavy rust, deep pitting
tated due erosion and undercutting; settlement has
to metal arch

extreme distortion and deflection in one section
of half top arc 50 to 70 percent less than design
d-Ordinate: 20 to 30 percent less than design
Span: more than + or - 6 percent of design
c: bottom reverse curved in center
ed 3" or more to either side of bolt; infiltration
causing severe deflection locally

extensive corrosion, attack of core alloy,
perforations
xtensive heavy rust, deep pitting, scattered
ons
tated, severely undercut, major cracking and
footing, significant damage to structure

cal, extreme distortion and deflection throughout;
of half top arc more than 70 percent less than

d-Ordinate: more than 30 percent less than design
Span: more then + or - 8 percent of design
c: bottom reversed curved in center and bulged out

ed from bolt to bolt; significant amounts of
ltration throughout

extensive perforations due to corrosion
ensive perforations due to rust
ere differential settlement has caused distortion
of metal arch

e due to partial collapse; top arc curvature flat
urved
d, backfill pushing in
to traffic

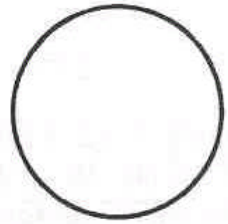
ompletely collapsed
to traffic

h matches actual conditions.

Figure 14.3.46 (Exhibit 104) Condition Rating Guidelines

STANDARD SIZES

FOR CORRUGATED STEEL CULVERTS



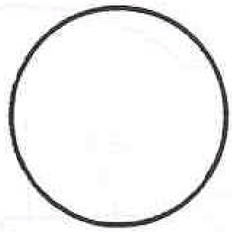
Handling Weight of Corrugated Steel Pipe (2⅔ × ½ in.)
Estimated Average Weights—Not for Specification Use*

Inside Diameter, in.	Specified Thickness, in.	Approximate Pounds per Lineal Ft**			
		Galvanized	Full-Coated	Full-Coated and Invert Paved	Full-Coated and Full Paved
12	0.052	8	10	13	
	0.064	10	12	15	
	0.079	12	14	17	
15	0.052	10	12	15	
	0.064	12	15	18	
	0.079	15	18	21	
18	0.052	12	14	17	
	0.064	15	19	22	
	0.079	18	22	25	
21	0.052	14	16	19	
	0.064	17	21	26	
	0.079	21	25	30	
24	0.052	15	17	20	
	0.064	19	24	30	45
	0.079	24	29	35	50
30	0.052	20	22	25	
	0.064	24	30	36	55
	0.079	30	36	42	60
36	0.052	24	26	29	
	0.064	29	36	44	65
	0.079	36	43	51	75
42	0.052	28	30	33	
	0.054	34	42	51	
	0.079	42	50	59	85
48	0.052	31	33	36	
	0.064	38	48	57	
	0.079	48	58	67	95
54	0.064	44	55	66	95
	0.079	54	65	76	105
60	0.079	60	71	85	
	0.109	81	92	106	140
66	0.109	89	101	117	160
	0.138	113	125	141	180
72	0.109	98	112	129	170
	0.138	123	137	154	210
78	0.109	105	121	138	200
	0.138	133	149	166	230
84	0.109	113	133	155	225
	0.138	144	161	179	240
90	0.109	121	145	167	
	0.138	154	172	192	
	0.168	186	204	224	
96	0.138	164	191	217	
	0.168	198	217	239	

Figure 14.3.47 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute)

STANDARD SIZES FOR CORRUGATED STEEL CULVERTS

ROUND

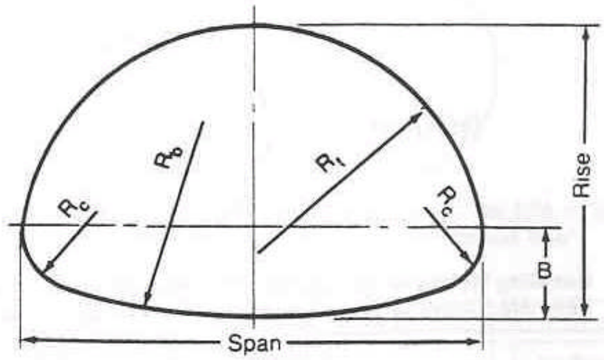


Handling Weight of Corrugated Steel Pipe (3 × 1 in. or 5 × 1 in.)***
Estimated Average Weights—Not for Specification Use

Inside Diameter, in.	Specified Thickness, in.	Approximate Pounds per Lineal Ft**			
		Galvanized	Full-Coated	Full-Coated and Invert Paved	Full-Coated and Full Paved
54	0.064	50	66	84	138
	0.079	61	77	95	149
60	0.064	55	73	93	153
	0.079	67	86	105	165
66	0.064	60	80	102	168
	0.079	74	94	116	181
72	0.064	66	88	111	183
	0.079	81	102	126	197
78	0.064	71	95	121	198
	0.079	87	111	137	214
84	0.064	77	102	130	213
	0.079	94	119	147	230
90	0.064	82	109	140	228
	0.079	100	127	158	246
96	0.064	87	116	149	242
	0.079	107	136	169	262
102	0.064	93	124	158	258
	0.079	114	145	179	279
108	0.064	98	131	166	273
	0.079	120	153	188	295
114	0.064	104	139	176	289
	0.079	127	162	199	312
120	0.064	109	146	183	296
	0.079	134	171	210	329
	0.109	183	220	259	378
126	0.079	141	179	220	346
	0.109	195	233	274	400
132	0.079	148	188	231	363
	0.109	204	244	287	419
138	0.079	154	196	241	379
	0.109	213	255	300	438
144	0.109	223	267	314	458
	0.138	282	326	373	517

Figure 14.3.47 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



Sizes and Layout Details—CSP Pipe Arches
2⅔ × ½ in. Corrugation

Equiv. Diameter, in.	Span, in.	Rise, in.	Waterway Area, ft²	Layout Dimensions			
				B in.	R_c in.	R_t in.	R_b in.
15	17	13	1.1	4⅛	3½	8⅝	25⅝
18	21	15	1.6	4⅞	4⅛	10¾	33⅛
21	24	18	2.2	5⅝	4⅞	11⅞	34⅝
24	28	20	2.9	6½	5½	14	42¼
30	35	24	4.5	8⅛	6⅞	17⅞	55⅛
36	42	29	6.5	9¾	8¼	21½	66⅛
42	49	33	8.9	11⅜	9⅝	25⅛	77¼
48	57	38	11.6	13	11	28⅝	88¼
54	64	43	14.7	14⅝	12⅜	32¼	99¼
60	71	47	18.1	16¼	13¾	35¾	110¼
66	77	52	21.9	17⅞	15⅛	39⅜	121¼
72	83	57	26.0	19½	16½	43	132¼

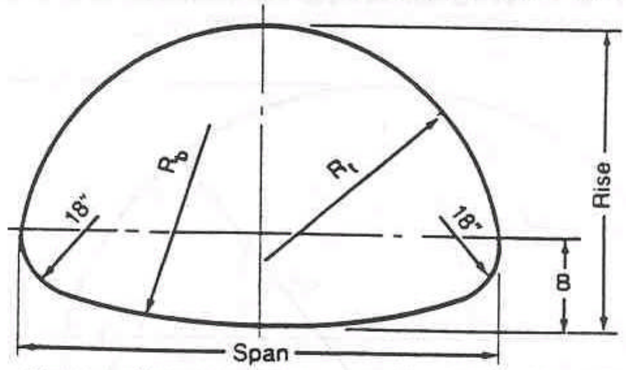
Dimensions shown not for specification purposes, subject to manufacturing tolerances.

Sizes and Layout Details—CSP Pipe-Arches
3 × 1 in. Corrugation

Equiv. Diameter, in.	Size, in.	Span, in.	Rise, in.	Waterway Area, ft²	Layout Dimensions			
					B in.	R_c in.	R_t in.	R_b in.
54	60 × 46	58½	48½	15.6	20½	18¾	29⅜	51⅛
60	66 × 51	65	54	19.3	22¾	20¾	32⅝	56¼
66	73 × 55	72½	58¼	23.2	25⅛	22⅞	36¾	63¾
72	81 × 59	79	62½	27.4	23¾	20⅞	39½	82⅝
78	87 × 63	86½	67¼	32.1	25¾	22⅝	43⅜	92¼
84	95 × 67	93½	71¾	37.0	27¾	24⅜	47	100¼
90	103 × 71	101½	76	42.4	29¾	26⅛	51¼	111⅝
96	112 × 75	108½	80½	48.0	31⅝	27¾	54⅞	120¼
102	117 × 79	116½	84¾	54.2	33⅝	29½	59⅜	131¾
108	128 × 83	123½	89¼	60.5	35⅝	31¼	63¼	139¾
114	137 × 87	131	93¾	67.4	37⅝	33	67⅜	149½
120	142 × 91	138½	98	74.5	39½	34¾	71⅝	162⅜

Figure 14.3.47 Standard Sizes for Corrugated Steel (Source: American Iron and Steel Institute), continued

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS

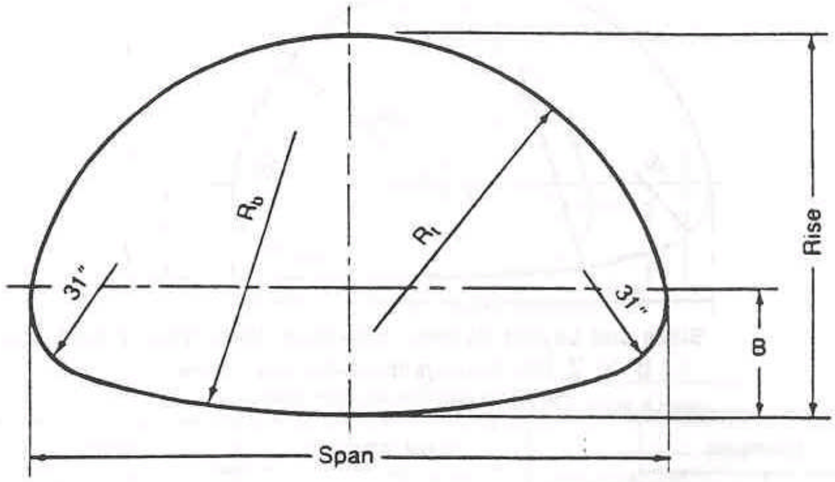


Sizes and Layout Details—Structural Plate Steel Pipe-Arches
6 × 2 in. Corrugations—Bolted Seams
18-inch Corner Radius Rc

Dimensions		Waterway Area, ft²	Layout Dimensions			Periphery		
Span, ft-in.	Rise, ft-in.		B in.	R_t ft	R_b ft	No. of Plates	Total N	Total Pi
6-1	4-7	22	21.0	3.07	6.36	5	22	66
6-4	4-9	24	20.5	3.18	8.22	5	23	69
6-9	4-11	26	22.0	3.42	6.96	5	24	72
7-0	5-1	28	21.4	3.53	8.68	5	25	75
7-3	5-3	31	20.8	3.63	11.35	6	26	78
7-8	5-5	33	22.4	3.88	9.15	6	27	81
7-11	5-7	35	21.7	3.98	11.49	6	28	84
8-2	5-9	38	20.9	4.08	15.24	6	29	87
8-7	5-11	40	22.7	4.33	11.75	7	30	90
8-10	6-1	43	21.8	4.42	14.89	7	31	93
9-4	6-3	46	23.8	4.68	12.05	7	32	96
9-6	6-5	49	22.9	4.78	14.79	7	33	99
9-9	6-7	52	21.9	4.86	18.98	7	34	102
10-3	6-9	55	23.9	5.13	14.86	7	35	105
10-8	6-11	58	26.1	5.41	12.77	7	36	108
10-11	7-1	61	25.1	5.49	15.03	7	37	111
11-5	7-3	64	27.4	5.78	13.16	7	38	114
11-7	7-5	67	26.3	5.85	15.27	8	39	117
11-10	7-7	71	25.2	5.93	18.03	8	40	120
12-4	7-9	74	27.5	6.23	15.54	8	41	123
12-6	7-11	78	26.4	6.29	18.07	8	42	126
12-8	8-1	81	25.2	6.37	21.45	8	43	129
12-10	8-4	85	24.0	6.44	26.23	8	44	132
13-5	8-5	89	26.3	6.73	21.23	9	45	135
13-11	8-7	93	28.9	7.03	18.39	9	46	138
14-1	8-9	97	27.6	7.09	21.18	9	47	141
14-3	8-11	101	26.3	7.16	24.80	9	48	144
14-10	9-1	105	28.9	7.47	21.19	9	49	147
15-4	9-3	109	31.6	7.78	18.90	9	50	150
15-6	9-5	113	30.2	7.83	21.31	10	51	153
15-8	9-7	118	28.8	7.89	24.29	10	52	156
15-10	9-10	122	27.4	7.96	28.18	10	53	159
16-5	9-11	126	30.1	8.27	24.24	10	54	162
16-7	10-1	131	28.7	8.33	27.73	10	55	165

Figure 14.3.47 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



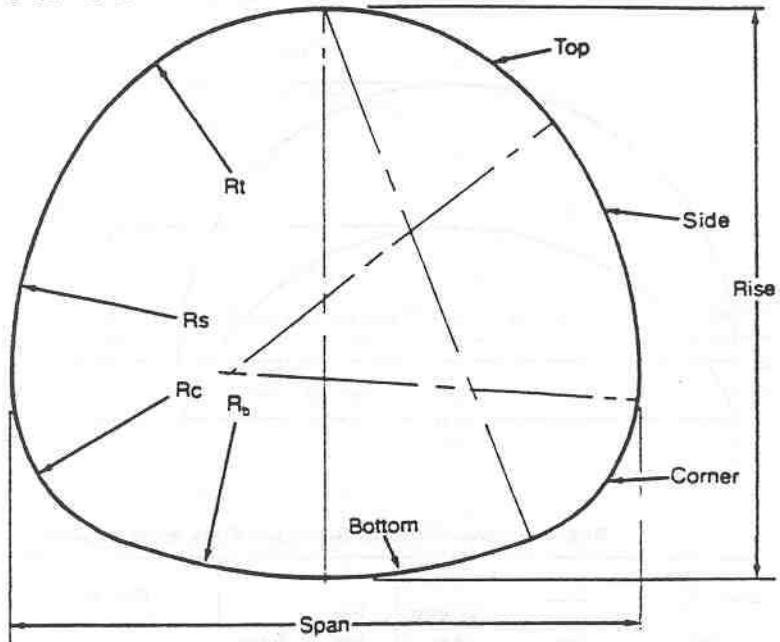
Sizes and Layout Details—Structural Plate Steel Pipe-Arches[11]
6 × 2 in. Corrugations—Bolted Seams
31-In Corner Radius, R_c

Dimensions		Waterway Area, ft²	Layout Dimensions			Periphery		
							Total	
Span, ft-in.	Rise, ft-in.		B in.	R_t ft	R_b ft	No. of Plates	*N*	Pi
13-3	9-4	97	38.5	6.68	16.05	8	46	138
13-6	9-6	102	37.7	6.78	18.33	8	47	141
14-0	9-8	105	39.6	7.03	16.49	8	48	144
14-2	9-10	109	38.8	7.13	18.55	8	49	147
14-5	10-0	114	37.9	7.22	21.38	8	50	150
14-11	10-2	118	39.8	7.48	18.98	9	51	153
15-4	10-4	123	41.8	7.76	17.38	9	52	156
15-7	10-6	127	40.9	7.84	19.34	10	53	159
15-10	10-8	132	40.0	7.93	21.72	10	54	162
16-3	10-10	137	42.1	8.21	19.67	10	55	165
16-6	11-0	142	41.1	8.29	21.93	10	56	168
17-0	11-2	146	43.3	8.58	20.08	10	57	171
17-2	11-4	151	42.3	8.65	22.23	10	58	174
17-5	11-6	157	41.3	8.73	24.83	10	59	177
17-11	11-8	161	43.5	9.02	22.55	10	60	180
18-1	11-10	167	42.4	9.09	24.98	10	61	183
18-7	12-0	172	44.7	9.38	22.88	10	62	186
18-9	12-2	177	43.6	9.46	25.19	10	63	189
19-3	12-4	182	45.9	9.75	23.22	10	64	192
19-6	12-6	188	44.8	9.83	25.43	11	65	195
19-8	12-8	194	43.7	9.90	28.04	11	66	198
19-11	12-10	200	42.5	9.98	31.19	11	67	201
20-5	13-0	205	44.9	10.27	28.18	11	68	204
20-7	13-2	211	43.7	10.33	31.13	12	69	207

Dimensions are to inside crests and are subject to manufacturing tolerances.
N = 3 Pi = 9.6 in

Figure 14.3.47 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES FOR CORRUGATED STEEL CULVERTS



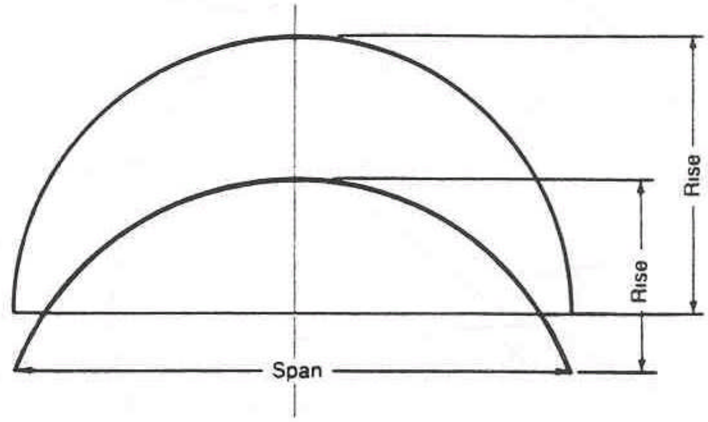
Structural Plate Steel Underpasses
Sizes and Layout Details

Span × Rise, ft and in.		Periphery			Layout Dimensions in In.			
		N	Pi	No. of Plates per Ring	R_t	R_s	R_c	R_b
5-8	5-9	24	72	6	27	53	18	Flat
5-8	6-6	26	78	6	29	75	18	Flat
5-9	7-4	28	84	6	28	95	18	Flat
5-10	7-8	29	87	7	30	112	18	Flat
5-10	8-2	30	90	6	28	116	18	Flat
12-2	11-0	47	141	8	68	93	38	136
12-11	11-2	49	147	9	74	92	38	148
13-2	11-10	51	153	11	73	102	38	161
13-10	12-2	53	159	11	77	106	38	168
14-1	12-10	55	165	11	77	115	38	183
14-6	13-5	57	171	11	78	131	38	174
14-10	14-0	59	177	11	79	136	38	193
15-6	14-4	61	183	12	83	139	38	201
15-8	15-0	63	189	12	82	151	38	212
16-4	15-5	65	195	12	86	156	38	217
16-5	16-0	67	201	12	88	159	38	271
16-9	16-3	68	204	12	89	168	38	246
17-3	17-0	70	210	12	90	174	47	214
18-4	16-11	72	216	12	99	157	47	248
19-1	17-2	74	222	13	105	156	47	262
19-6	17-7	76	228	13	107	158	47	295
20-4	17-9	78	234	13	114	155	47	316

All dimensions, to nearest whole number, are measured from inside crests.
Tolerances should be allowed for specification purposes. 6 × 2 in. Corrugations.

Figure 14.3.47 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



Representative Sizes of Structural Plate Steel Arches

Dimensions(1)		Waterway Area, ft²	Rise over Span(2)	Radius, in.	Nominal Arc Length	
Span, ft	Rise, ft-in.				N(3)	Pi, in.
6.0	1-9½	7½	0.30	41	9	27
	2-3½	10	0.38	37½	10	30
	3-2	15	0.53	36	12	36
7.0	2-4	12	0.34	45	11	33
	2-10	15	0.40	43	12	36
	3-8	20	0.52	42	14	42
8.0	2-11	17	0.37	51	13	39
	3-4	20	0.42	48½	14	42
	4-2	26	0.52	48	16	48
9.0	2-11	18½	0.32	59	14	42
	3-10½	26½	0.43	55	16	48
	4-8½	33	0.52	54	18	54
10.0	3-5½	25	0.35	64	16	48
	4-5	34	0.44	60½	18	54
	5-3	41	0.52	60	20	60
11.0	3-6	27½	0.32	73	17	51
	4-5½	37	0.41	67½	19	57
	5-9	50	0.52	66	22	66
12.0	4-0½	35	0.34	77½	19	57
	5-0	45	0.42	73	21	63
	6-3	59	0.52	72	24	72
13.0	4-1	38	0.32	86½	20	60
	5-1	49	0.39	80½	22	66
	6-9	70	0.52	78	26	78
14.0	4-7½	47	0.33	91	22	66
	5-7	58	0.40	86	24	72
	7-3	80	0.52	84	28	84

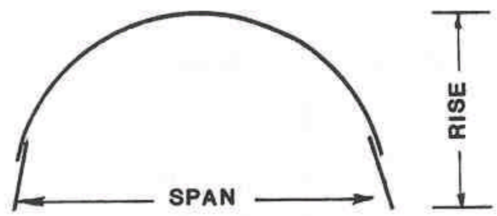
(Table continued on following page)

(1)Dimensions are to inside crests and are subject to manufacturing tolerances.
(2)R/S ratio varies from 0.30 to 0.52. Intermediate spans and rises are available.
(3)N = 3 Pi = 9.6 in. 6 × 2 in. Corrugations—Bolted Seams.

Figure 14.3.47 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS

ARCH



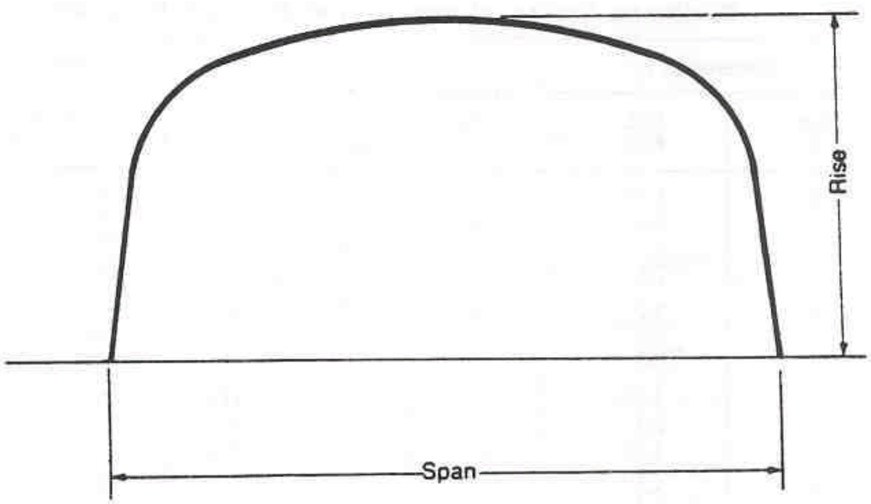
Continued. Representative Sizes of Structural Plate Steel Arches

Dimensions(¹)		Waterway Area, ft²	Rise over Span(²)	Radius, in.	Nominal Arc Length	
Span, ft	Rise, ft-in.				N(³)	Pi, in.
15.0	4-7½	50	0.31	101	23	69
	5-8	62	0.38	93	25	75
	6-7	75	0.44	91	27	81
	7-9	92	0.52	90	30	90
16.0	5-2	60	0.32	105	25	75
	7-1	86	0.45	97	29	87
	8-3	105	0.52	96	32	96
17.0	5-2½	63	0.31	115	26	78
	7-2	92	0.42	103	30	90
	8-10	119	0.52	102	34	102
18.0	5-9	75	0.32	119	28	84
	7-8	104	0.43	109	32	96
	8-11	126	0.50	108	35	105
19.0	6-4	87	0.33	123	30	90
	8-2	118	0.43	115	34	102
	9-5½	140	0.50	114	37	111
20.0	6-4	91	0.32	133	31	93
	8-3½	124	0.42	122	35	105
	10-0	157	0.50	120	39	117
21.0	6-11	104	0.33	137	33	99
	8-10	140	0.42	128	37	111
	10-6	172	0.50	126	41	123
22.0	6-11	109	0.31	146	34	102
	8-11	146	0.40	135	38	114
	11-0	190	0.50	132	43	129
23.0	8-0	134	0.35	147	37	111
	9-10	171	0.43	140	41	123
	11-6	208	0.50	138	45	135
24.0	8-6	150	0.35	152	39	117
	10-4	188	0.43	146	43	129
	12-0	226	0.50	144	47	141
25.0	8-6½	155	0.34	160	40	120
	10-10½	207	0.43	152	45	135
	12-6	247	0.50	150	49	147

(¹)Dimensions are to inside crests and are subject to manufacturing tolerances.
(²)R/S ratio varies from 0.30 to 0.52. Intermediate spans and rises are available.
(³W = 3 Pi = 9.6 in. 6 × 2 in. Corrugations—Bolted Seams.

Figure 14.3.47 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



Layout Details
Corrugated Steel Box Culverts

Rise, ft-in.	Span, ft-in.	Area ft²	Rise, ft-in.	Span, ft-in.	Area ft²
2-7	9-8	20.8	3-9	12-10	41.0
2-8	10-5	23.2	3-10	13-6	44.5
2-9	11-1	25.7	3-10	17-4	55.0
2-10	11-10	28.3	3-11	14-2	48.2
2-11	12-6	31.1	3-11	18-0	59.1
3-1	13-3	34.0	4-1	14-10	52.0
3-2	13-11	37.1	4-1	18-8	63.4
3-3	14-7	40.4	4-2	10-7	36.4
3-4	10-1	28.4	4-2	15-6	55.9
3-5	10-10	31.4	4-3	11-2	39.9
3-5	15-3	43.8	4-3	19-4	67.9
3-6	11-6	34.5	4-4	11-10	43.5
3-6	16-0	47.3	4-4	16-2	60.1
3-8	12-2	37.7	4-5	12-6	47.3
3-8	16-8	51.1	4-6	13-2	51.2

Figure 14.3.47 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

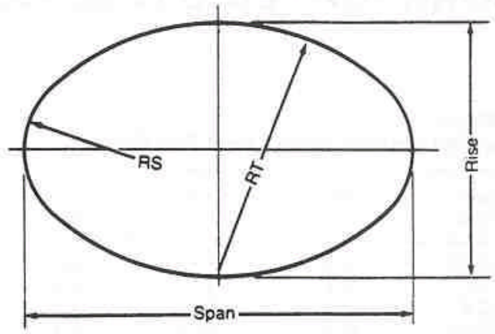
STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS

Continued.
Layout Details Corrugated Steel Box Culverts

Rise, ft-in.	Span, ft-in.	Area ft²	Rise, ft-in.	Span, ft-in.	Area ft²
4-6	16-10	64.4	6-9	13-7	77.9
4-7	17-6	68.9	6-9	16-9	99.3
4-7	20-8	77.6	6-10	14-2	83.3
4-8	13-10	55.3	6-10	17-4	105.1
4-9	14-6	59.5	7-0	14-9	88.9
4-9	18-1	73.5	7-0	17-11	111.1
4-10	15-1	63.8	7-0	20-8	127.2
4-11	11-0	44.7	7-1	15-4	94.6
4-11	18-9	78.4	7-2	18-6	117.3
5-0	11-7	48.7	7-3	12-3	71.5
5-0	15-9	68.3	7-3	15-10	100.5
5-1	12-3	52.9	7-4	12-10	77.1
5-1	16-4	73.0	7-4	16-5	106.5
5-1	19-5	83.4	7-4	19-1	123.6
5-2	12-10	57.2	7-5	13-5	82.8
5-3	17-0	77.8	7-6	13-11	88.6
5-4	13-6	61.7	7-6	17-0	112.7
5-5	14-1	66.2	7-8	14-6	94.5
5-5	17-7	82.8	7-8	17-6	119.0
5-5	20-8	94.1	7-9	15-0	100.6
5-6	14-9	71.0	7-9	18-1	125.5
5-7	18-3	88.0	7-11	15-7	106.8
5-8	11-5	53.3	7-11	18-7	132.1
5-8	15-4	75.8	8-0	12-8	81.1
5-8	18-10	93.4	8-0	16-1	113.1
5-9	12-0	57.9	8-1	19-2	138.9
5-9	16-0	80.9	8-2	16-8	119.6
5-10	12-7	62.6	8-2	13-9	93.3
5-10	19-6	98.9	8-3	19-8	145.9
5-11	16-7	86.1	8-4	17-2	126.2
6-0	13-3	67.4	8-5	14-10	106.0
6-1	13-10	72.4	8-5	17-8	133.0
6-1	17-2	91.4	8-7	18-3	139.9
6-2	14-5	77.5	8-7	20-9	160.3
6-2	17-9	96.9	8-8	15-10	119.2
6-2	20-8	110.6	8-9	18-9	147.0
6-4	15-0	82.7	8-11	16-10	132.9
6-4	18-4	102.6	8-11	19-3	154.2
6-5	11-10	62.2	9-1	19-9	161.6
6-5	15-7	88.1	9-3	17-10	147.1
6-6	18-11	108.5	9-5	20-9	176.9
6-7	12-5	67.3	9-6	18-10	162.0
6-7	16-2	93.6	9-10	19-10	177.4
6-8	13-0	72.5	10-2	20-9	193.5
6-8	19-6	114.5			

Figure 14.3.47 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS

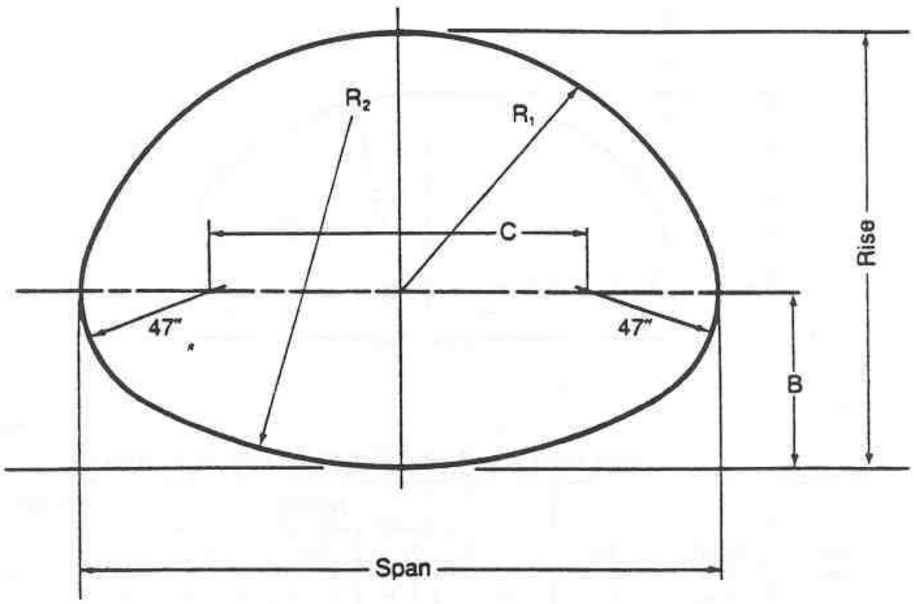


Long Span Horizontal Ellipse Sizes and Layout Details

Span, ft-in.	Rise, ft-in.	Area, ft²	Periphery						Inside Radius	
			Top or Bottom		Side		Total		Top Rad. in.	Side Rad. in.
			N	Pi	N	Pi	N	Pi		
19- 4	12- 9	191	22	66	10	30	64	192	12- 6	4- 6
20- 1	13- 0	202	23	69	10	30	66	198	13- 1	4- 6
20- 2	11-11	183	24	72	8	24	64	192	13- 8	3- 7
20-10	12- 2	194	25	75	8	24	66	198	14- 3	3- 7
21- 0	15- 2	248	23	69	13	39	72	216	13- 1	5-11
21-11	13- 1	221	26	78	9	27	70	210	14-10	4- 1
22- 6	15- 8	274	25	75	13	39	76	228	14- 3	5-11
23- 0	14- 1	249	27	81	10	30	74	222	15- 5	4- 6
23- 3	15-11	288	26	78	13	39	78	234	14-10	5-11
24- 4	16-11	320	27	81	14	42	82	246	15- 5	6- 4
24- 6	14- 8	274	29	87	10	30	78	234	16- 6	4- 6
25- 2	14-11	287	30	90	10	30	80	240	17- 1	4- 6
25- 5	16- 9	330	29	87	13	39	84	252	16- 6	5-11
26- 1	18- 2	369	29	87	15	45	88	264	16- 6	6-10
26- 3	15-10	320	31	93	11	33	84	252	17- 8	4-11
27- 0	16- 2	334	32	96	11	33	86	258	18- 3	4-11
27- 2	19- 1	405	30	90	16	48	92	276	17- 1	7- 3
27-11	19- 5	421	31	92	16	48	94	282	17- 8	7- 3
28- 1	17- 1	369	33	99	12	36	90	270	18-10	5- 5
28-10	17- 5	384	34	102	12	36	92	276	19- 5	5- 5
29- 5	19-11	455	33	99	16	48	98	294	18-10	7- 3
30- 1	20- 2	472	34	102	16	48	100	300	19- 5	7- 3
30- 3	17-11	415	36	108	12	36	96	288	20- 7	5- 5
31- 2	21- 2	512	35	105	17	51	104	312	20- 0	7- 9
31- 4	18-11	454	37	111	13	39	100	300	21- 1	5-11
32- 1	19- 2	471	38	114	13	39	102	306	21- 8	5-11
32- 3	22- 2	555	36	108	18	54	108	324	20- 7	8- 2
33- 0	22- 5	574	37	111	18	54	110	330	21- 1	8- 2
33- 2	20- 1	512	39	117	14	42	106	318	22- 3	6- 4
34- 1	23- 4	619	38	114	19	57	114	342	21- 8	8- 8
34- 7	20- 8	548	41	123	14	42	110	330	23- 5	6- 4
34-11	21- 4	574	41	123	15	45	112	336	23- 5	6-10
35- 1	24- 4	665	39	117	20	60	118	354	22- 3	9- 1
35- 9	25- 9	718	39	117	22	66	122	366	22- 3	10- 0
36- 0	22- 4	619	42	126	16	48	116	348	24- 0	7- 3
36-11	25- 7	735	41	123	21	63	124	372	23- 5	9- 7
37- 2	22- 2	631	44	132	15	45	118	354	25- 2	6-10
38- 0	26- 7	785	44	132	22	66	128	384	24- 0	10- 0
38- 8	27-11	843	42	126	24	72	132	396	24- 0	10-11
40- 0	29- 7	927	43	129	26	78	138	414	27-11	11-10

Figure 14.3.47 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



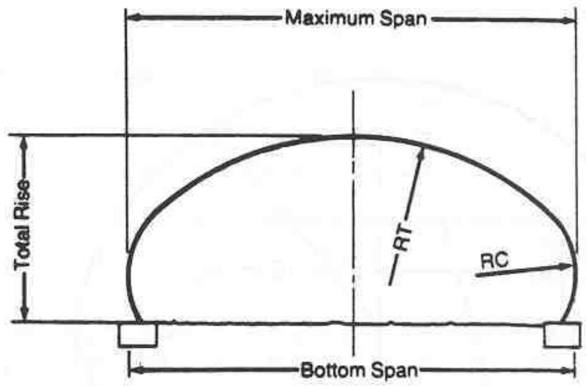
Long Span Pipe Arch Sizes and Layout Details

Span, ft-in.	Rise, ft-in.	Area, ft²	Total No. Plates	Periphery						B, in.	C, in.	Inside Radius	
				Top		Bottom		Total				R_1, in.	R_2, in.
				N	Pi	N	Pi	N	Pi				
20- 0	13-11	218	10	34	102	20	60	68	204	62.8	146.2	122.5	223.6
20- 6	14- 3	231	10	36	108	20	60	70	210	61.4	152.3	124.7	255.7
21- 5	14- 6	243	11	36	108	22	66	72	216	65.3	162.8	131.4	236.7
21-11	14-11	256	11	38	114	22	66	74	222	63.7	168.9	133.5	268.1
22- 5	15- 3	270	11	40	120	22	66	76	228	62.1	174.6	135.5	307.1
23- 4	15- 7	284	11	40	120	24	72	78	234	66.2	185.5	142.4	280.2
24- 2	15-11	297	12	40	120	26	78	80	240	70.7	196.2	149.7	262.1
24- 8	16- 2	312	12	42	126	26	78	82	246	68.8	202.2	151.4	292.2
25- 2	16- 7	326	12	44	132	26	78	84	252	66.9	207.9	153.2	328.6
25- 7	16-11	342	12	46	138	26	78	86	258	64.8	213.3	155.0	373.3
26- 7	17- 3	357	12	46	138	28	84	88	264	69.4	224.7	162.1	339.4
27- 6	17- 6	372	12	46	138	30	90	90	270	74.2	235.8	169.6	315.8
28- 0	17-10	388	12	48	144	30	90	92	276	72.1	241.5	171.1	350.2
28- 5	18- 3	405	13	50	150	30	90	94	282	69.9	246.8	172.7	392.3
29- 4	18- 6	421	13	50	150	32	96	96	288	74.8	258.2	180.2	361.1
30- 4	18-10	438	14	52	156	34	102	100	300	80.0	269.4	188.2	339.1

*Includes 14N for two N7 corner plates

Figure 14.3.47 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES FOR CORRUGATED STEEL CULVERTS



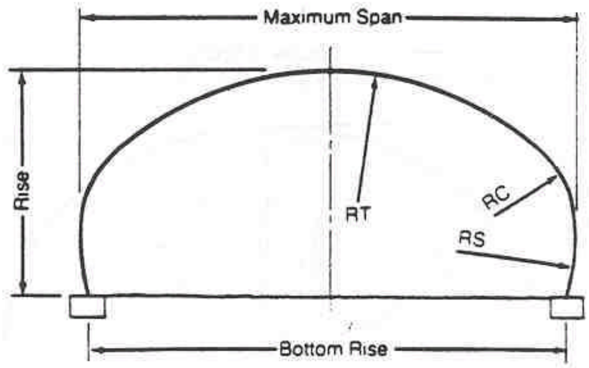
Long Span Low Profile Arch Sizes and Layout Details

Max. Span, ft-in.	Bottom Span, ft-in.	Total Rise, ft-in.	Area, ft²	Periphery						Inside Radius	
				Top		Side		Total		Top rad. in.	Side rad. in.
				N	Pi	N	Pi	N	Pi		
20- 1	19-10	7- 6	121	23	69	6	18	35	105	13- 1	4- 6
19- 5	19- 1	6-10	105	23	69	5	15	33	99	13- 1	3- 7
21- 6	21- 4	7- 9	134	25	75	6	18	37	111	14- 3	4- 6
22- 3	22- 1	7-11	140	26	78	6	18	38	114	14-10	4- 6
23- 0	22- 9	8- 0	147	27	81	6	18	39	117	15- 5	4- 6
23- 9	23- 6	8- 2	154	28	84	6	18	40	120	16- 0	4- 6
24- 6	24- 3	8- 4	161	29	87	6	18	41	123	16- 6	4- 6
25- 2	25- 0	8- 5	169	30	90	6	18	42	126	17- 1	4- 6
25-11	25- 9	8- 7	176	31	93	6	18	43	129	17- 8	4- 6
27- 3	27- 1	10- 0	217	31	93	8	24	47	141	17- 8	6- 4
28- 1	27-11	9- 7	212	33	99	7	21	47	141	18-10	5- 5
28- 9	28- 7	10- 3	234	33	99	8	24	49	147	18-10	6- 4
28-10	28- 8	9- 8	221	34	102	7	21	48	144	19- 5	5- 5
30- 3	30- 1	9-11	238	36	108	7	21	50	150	20- 7	5- 5
30-11	30- 9	10- 8	261	36	108	8	24	52	156	20- 7	6- 4
31- 7	31- 2	12- 1	309	36	108	10	30	56	168	20- 7	7- 3
31- 0	30-10	10- 1	246	37	111	7	21	51	153	21- 1	5- 5
32- 4	31-11	12- 3	320	37	111	10	30	57	171	21- 1	7- 3
31- 9	31- 7	10- 3	255	38	114	7	21	52	156	21- 8	5- 5
33- 1	32- 7	12- 5	330	38	114	10	30	58	174	21- 8	7- 3
33- 2	33- 0	11- 1	289	39	117	8	24	55	165	22- 3	6- 4
34- 5	34- 1	13- 3	377	39	117	11	33	61	183	22- 3	8- 2
34- 7	34- 6	11- 4	308	41	123	8	24	57	183	23- 5	6- 4
37-11	37- 7	15- 8	477	41	123	14	42	69	207	23- 5	10-11
35- 4	35- 2	11- 5	318	42	126	8	24	58	174	24- 0	6- 4
38- 8	38- 4	15- 9	490	42	126	14	42	70	210	24- 0	10-11

NOTE: Larger sizes available for special designs.

Figure 14.3.47 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



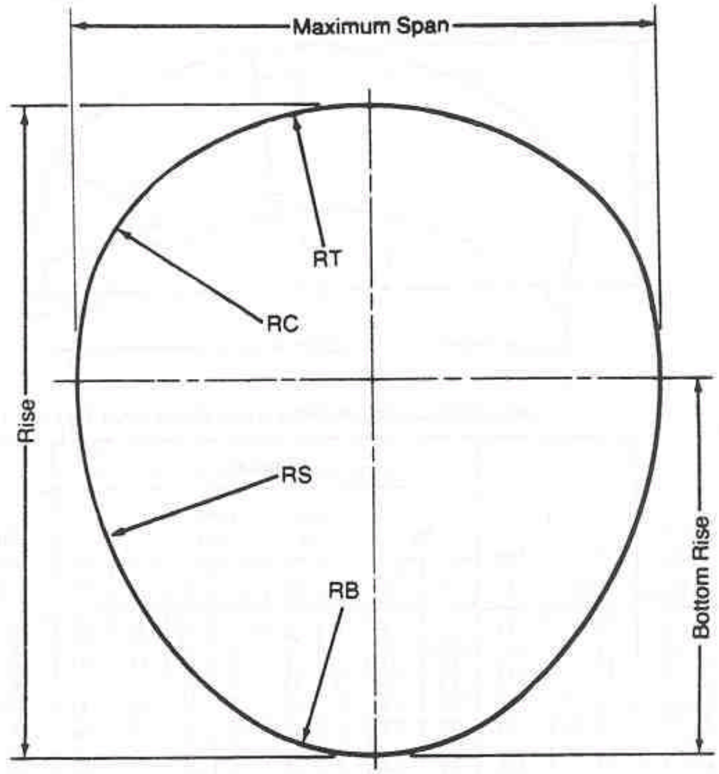
Long Span High Profile Arch Sizes and Layout Details

Max. Span, ft-in.	Bottom Span, ft-in.	Total Rise, ft-in.	Area, ft²	Periphery								Inside Radius		
				Top		Upper Side		Lower Side		Total		Top Radius, ft-in.	Upper Side, ft-in.	Lower Side, ft-in.
				N	Pi	N	Pi	N	Pi	N	Pi			
20- 1	19- 6	9- 1	152	23	69	5	15	3	9	39	117	13- 1	4- 6	13- 1
20- 8	18-10	12- 1	214	23	69	6	18	6	18	47	141	13- 1	5- 5	13- 1
21- 6	19-10	11- 8	215	25	75	5	15	6	18	47	141	14- 3	4- 6	14- 3
22-10	19-10	14- 7	285	25	75	7	21	8	24	55	165	14- 3	6- 4	14- 3
22- 3	20- 7	11-10	225	26	78	5	15	6	18	48	144	14-10	4- 6	14-10
22-11	20- 0	14- 0	276	26	78	6	18	8	24	54	162	14-10	5- 5	14-10
23- 0	21- 5	12- 0	235	27	81	5	15	6	18	49	147	15- 5	4- 6	15- 5
24- 4	21- 6	14-10	310	27	81	7	21	8	24	57	171	15- 5	6- 4	15- 5
23- 9	22- 2	12- 1	245	28	84	5	15	6	18	50	150	16- 0	4- 6	16- 0
24- 6	21-11	13- 9	289	29	87	5	15	8	24	55	165	16- 6	4- 6	16- 6
25- 9	23- 2	15- 2	335	29	87	7	21	8	24	59	177	16- 6	6- 4	16- 6
25- 2	23- 3	13- 2	283	30	90	5	15	7	21	54	162	17- 1	4- 6	17- 1
26- 6	24- 0	15- 3	348	30	90	7	21	8	24	60	180	17- 1	6- 4	17- 1
25-11	24- 1	13- 3	295	31	93	5	15	7	21	55	165	17- 8	4- 6	17- 8
27- 3	24-10	15- 5	360	31	93	7	21	8	24	61	183	17- 8	6- 4	17- 8
27- 5	25- 8	13- 7	317	33	99	5	15	7	21	57	171	18-10	4- 6	18-10
29- 5	27- 1	16- 5	412	33	99	8	28	8	24	65	195	18-10	7- 3	18-10
28- 2	25-11	14- 5	349	34	102	5	15	8	24	60	180	19- 5	4- 6	19- 5
30- 1	26- 9	18- 1	467	34	102	8	24	10	30	70	210	19- 5	7- 3	19- 5
30- 3	28- 2	15- 5	399	36	108	6	18	8	24	64	192	20- 7	5- 5	20- 7
31- 7	28- 4	18- 4	497	36	108	8	24	10	30	72	216	20- 7	7- 3	20- 7
31- 0	29- 0	15- 7	413	37	111	6	18	8	24	65	195	21- 1	5- 5	21- 1
31- 8	28- 6	17- 9	484	37	111	7	21	10	30	71	213	21- 1	6- 4	21- 1
32- 4	27-11	19-11	554	37	111	8	24	12	36	77	231	21- 1	7- 3	21- 1
31- 9	28- 8	17- 3	470	38	114	6	18	10	30	70	210	21- 8	5- 5	21- 8
33- 1	28- 9	20- 1	571	38	114	8	24	12	36	78	234	21- 8	7- 3	21- 8
32- 6	29- 6	17- 4	484	39	117	6	18	10	30	71	213	22- 3	5- 5	22- 3
33-10	29- 7	20- 3	588	39	117	8	24	12	36	79	237	22- 3	7- 3	22- 3
34- 0	31- 2	17- 8	514	41	123	6	18	10	30	73	219	23- 5	5- 5	23- 5
34- 7	30- 7	19-10	591	41	123	7	21	12	36	79	237	23- 5	6- 4	23- 5
35- 3	30- 7	21- 3	645	41	123	8	24	13	39	83	249	23- 5	7- 3	23- 5
37- 3	32- 6	23- 5	747	41	123	11	33	13	39	89	267	23- 5	10- 0	23- 5
34- 8	31-11	17-10	529	42	126	6	18	10	30	74	222	24- 0	5- 5	24- 0
35- 4	31- 5	20- 0	608	42	126	7	21	12	36	80	240	24- 0	6- 4	24- 0
36- 0	31- 5	21- 5	663	42	126	8	24	13	39	84	252	24- 0	7- 3	24- 0
38- 0	33- 5	23- 6	767	42	126	11	33	13	39	90	270	24- 0	10- 0	24- 0

NOTE: Larger sizes available for special designs.

Figure 14.3.47 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES FOR CORRUGATED STEEL CULVERTS



Long Span Pear Shape Sizes and Layout Details

Max. Span, ft-in.	Rise, ft-in.	Rise Bottom, ft-in.	Area	Periphery										Inside Radius			
				Top		Corner		Side		Bottom		Total		Bottom Radius, ft-in.	Side Radius, ft-in.	Corner Radius, ft-in.	Top Radius, ft-in.
				N	Pi	N	Pi	N	Pi	N	Pi	N	Pi				
23- 8	25- 8	14-11	481	25	75	5	15	24	72	15	30	98	294	8-11	16- 7	6- 3	14- 8
24- 0	25-10	15- 1	496	22	66	7	21	22	66	20	60	100	300	9-11	17- 4	7- 0	16- 2
25- 6	25-11	15-10	521	27	81	7	21	20	60	21	63	102	306	10- 7	18- 1	6-11	15-10
24-10	27- 8	16- 9	544	27	81	5	15	25	75	18	54	105	315	9- 3	19- 8	5- 9	15-11
27- 5	27- 0	18- 1	578	30	90	6	18	26	78	16	48	110	330	9- 7	20- 4	4- 7	19-11
26- 8	28- 3	18- 0	593	28	84	5	15	30	90	12	36	110	330	8- 0	20- 1	4- 9	20-11
28- 1	27-10	16-10	624	27	81	8	24	22	66	25	75	112	336	12- 2	19- 0	7- 3	20- 5
28- 7	30- 7	19- 7	689	32	96	7	21	24	72	24	72	118	354	11- 2	24- 0	7- 0	18- 2
30- 0	29- 8	20- 0	699	32	96	8	24	23	69	25	75	119	357	11-11	24- 0	6- 7	21-10
30- 0	31- 2	19-11	736	34	102	7	21	24	72	26	78	122	366	12- 1	24- 0	7- 0	19- 3

Figure 14.3.47 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES FOR ALUMINUM CULVERTS

Helical Pipe Availability, Weights

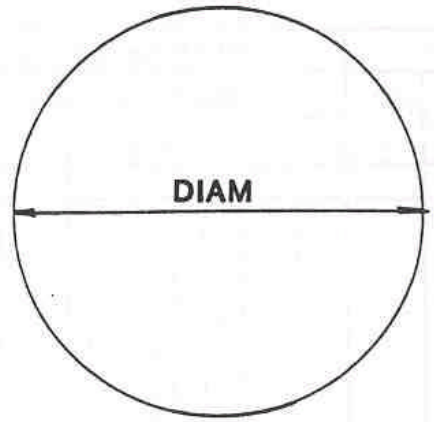
CORR. PATTERN				WEIGHT (Lbs./Lineal Ft.)					
				Equiv. Standard Gauge					
1-1/2 x 1/4	2-2/3 x 1/2	3 x 1	6' x 1	18	16	14	12	10	8
Diameter (In.)									
6				1.4	1.7				
8				1.8	2.2				
10				2.2	2.7				
	12				3.2	4.0	5.5		
	15				3.9	4.9	6.8		
	18				4.7	5.9	8.1		
	21				5.4	6.8	9.4		
	24				6.2	7.8	10.7	13.8	
	27				7.0	8.7	12.1	15.4	
	30				7.8	9.6	13.4	17.1	
		30			8.9	11.2	15.5	19.9	
	36					11.5	16.0	20.5	
		36			10.7	13.4	18.5	23.7	
	42						18.6	23.8	
		42			12.4	15.5	21.5	27.5	
	48						21.2	27.2	32.7
		48			14.1	17.7	24.5	31.4	37.8
			48		12.5	15.6	21.8	28.1	34.1
	54						23.8	30.5	36.7
		54			15.8	19.9	27.5	35.2	42.4
			54		14.0	17.5	24.5	31.5	38.3
	60							33.9	40.8
		60			17.6	22.0	30.5	39.0	47.0
			60		15.5	19.4	27.2	34.9	42.5
	66							37.2	44.8
		66			17.0	21.3	29.8	38.4	46.6
	72								48.8
		72				26.3	36.5	46.7	56.2
			72			23.2	32.5	41.8	50.8
	78								52.9
		78				28.5	39.5	50.5	60.8
			78			25.1	35.2	45.2	55.0
	84								56.9
		84				30.7	42.5	54.3	65.4
			84				37.8	48.7	59.1
		90					45.4	58.2	70.0
			90				40.5	52.1	63.3
		96					48.4	62.0	74.6
			96				43.2	55.5	67.5
		102					51.4	65.8	79.3
			102				45.8	58.9	71.6
		108					54.4	69.7	83.9
			108				48.5	62.4	75.8
		114					57.4	73.5	88.5
			114				51.2	65.8	80.0
		120					60.4	77.3	93.1
			120				53.8	69.2	84.1

NOTES: 1. Sizes 6" thru 10" are available in helical corrugation only.

2. Sizes 12" through 21" in helical configuration have corrugation depth of 7/16" rather than 1/2".

Figure 14.3.48 Standard Sizes for Aluminum Culvert (Source: Aluminum Association)

STANDARD SIZES FOR ALUMINUM CULVERTS



Geometric Data — Structural Plate Pipe

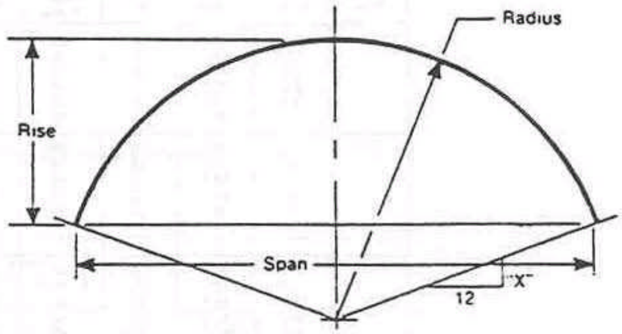
Nom. Diam. In.	Area Sq. Ft.	Total N	Nom. Diam. In.	Area Sq. Ft.	Total N
60	19	20	162	145	54
66	23	22	168	156	56
72	27	24	174	167	58
78	32	26	180	179	60
84	38	28	186	191	62
90	44	30	192	204	64
96	50	32	198	217	66
102	56	34	204	231	68
108	63	36	210	245	70
114	71	38	216	259	72
120	79	40	222	274	74
126	87	42	228	289	76
132	95	44	234	305	78
138	104	46	240	321	80
144	114	48	246	337	82
150	124	50	252	354	84
156	134	52	—	—	—

Figure 14.3.48 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES FOR ALUMINUM CULVERTS

GEOMETRIC DATA – ARCH

"X" Values For Rise/Span Ratio			
R/S Ratio	"X"	R/S Ratio	"X"
.30	6.40	.42	2.10
.31	5.96	.43	1.82
.32	5.54	.44	1.54
.33	5.13	.45	1.27
.34	4.74	.46	1.00
.35	4.37	.47	.74
.36	4.01	.48	.48
.37	3.67	.49	.24
.38	3.33	.50	.00
.39	3.01	.51	.24
.40	2.70	.52	.47
.41	2.40		

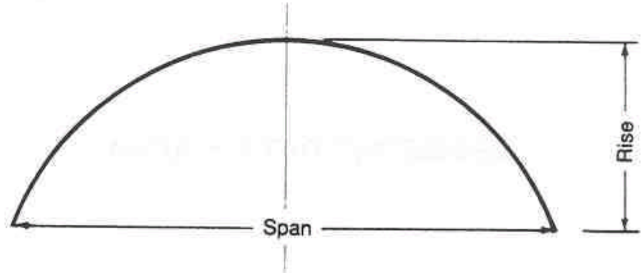


Typical Section

Span Ft.In.	Rise Ft.In.	Area Sq.Ft.	Total N	Rise/Span Ratio	Radius Inches
5-0	2-7	10.4	10	.52	30
	2-3	8.5	9	.44	30¾
	1-9	6.5	8	.36	31¼
6-0	3-2	14.9	12	.52	36
	2-9	12.6	11	.46	36¼
	2-4	10.2	10	.38	37¼
	1-10	7.8	9	.30	40½
7-0	3-8	20.3	14	.52	42
	3-3	17.5	13	.46	42
	2-10	14.8	12	.40	43
	2-4	12.0	11	.34	45¼
8-0	4-2	26.4	16	.52	48
	3-9	23.3	15	.47	48
	3-4	20.2	14	.42	48¼
	2-11	17.0	13	.36	50½
	2-5	13.6	12	.30	54½
9-0	4-8	33.4	18	.50	54
	4-3	29.9	17	.48	54
	3-10	26.3	16	.43	54½
	3-5	22.8	15	.38	56
	2-11	19.1	14	.33	59
10-0	5-2	41.2	20	.52	60
	4-10	37.3	19	.48	60
	4-5	33.3	18	.44	60½
	3-11	29.4	17	.40	61½
	3-6	25.3	16	.35	64
	3-0	21.1	15	.30	68½
11-0	5-8	49.8	22	.52	66
	5-4	45.5	21	.48	66
	4-11	41.2	20	.45	66½
	4-6	36.8	19	.41	67½
	4-0	32.4	18	.36	69¼
	3-6	27.8	17	.32	72¾

Figure 14.3.48 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES FOR ALUMINUM CULVERTS



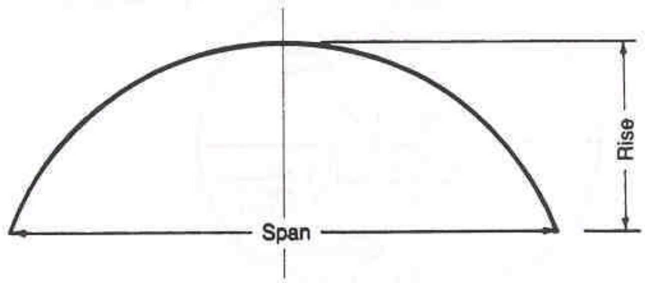
ARCH (CONT'D)

Geometric Data—Arch (Continued)

Span Ft.In.	Rise Ft.In.	Area Sq.Ft.	Total N	Rise/Span Ratio	Radius Inches
12-0	6-3	59.3	24	.52	72
	5-10	54.5	23	.49	72
	5-5	49.8	22	.45	72½
	5-0	45.0	21	.42	73¼
	4-7	40.2	20	.38	75
	4-1	35.3	19	.34	77½
13-0	6-9	69.5	26	.52	78
	6-4	64.4	25	.49	78
	5-11	59.3	24	.46	78¼
	5-6	54.1	23	.42	79
	5-1	48.9	22	.39	80½
	4-7	43.6	21	.35	82¾
	4-1	38.1	20	.31	86½
14-0	7-3	80.6	28	.52	84
	6-10	75.1	27	.49	84
	6-5	69.5	26	.46	84¼
	6-0	64.0	25	.43	85
	5-7	58.4	24	.40	86
	5-2	52.7	23	.37	88
	4-8	46.9	22	.33	91¼
15-0	7-9	92.5	30	.52	90
	7-5	86.5	29	.49	90
	7-0	80.6	28	.46	90¼
	6-7	74.7	27	.44	91
	6-1	68.7	26	.41	92
	5-8	62.6	25	.38	93½
	5-2	56.4	24	.34	96¼
	4-8	50.0	23	.31	100½
16-0	8-3	105.2	32	.52	96
	7-11	98.9	31	.49	96
	7-6	92.5	30	.47	96¼
	7-1	86.2	29	.44	96¾
	6-8	79.8	28	.41	97¾
	6-2	73.3	27	.39	99¼
	5-9	66.8	26	.36	101½
	5-3	60.0	25	.32	105
17-0	8-10	118.7	34	.52	102
	8-5	112.0	33	.49	102
	8-0	105.2	32	.47	102¼
	7-7	98.5	31	.45	102¾
	7-2	91.7	30	.42	103½
	6-9	84.9	29	.39	105
	6-3	77.9	28	.37	107
	5-9	70.9	27	.34	110
	5-3	63.5	26	.31	114¼
18-0	9-4	133.1	36	.52	108
	8-11	125.9	35	.50	108
	8-6	118.8	34	.47	108¼
	8-1	111.6	33	.45	108½
	7-8	104.5	32	.43	109¼
	7-3	97.2	31	.40	110½
	6-9	89.9	30	.38	112½
	6-4	82.5	29	.35	115
	5-9	74.8	28	.32	118¾
19-0	9-10	148.2	38	.52	114
	9-5	140.7	37	.50	114
	9-0	133.2	36	.48	114¼
	8-8	125.8	35	.45	114½
	8-2	118.0	34	.43	115¼
	7-9	110.4	33	.41	116¼
	7-4	102.7	32	.38	118
	6-10	94.9	31	.36	120¼
	6-4	86.9	30	.33	123½
	5-10	78.7	29	.31	128¼
20-0	10-4	164.2	40	.52	120
	10-0	156.3	39	.50	120
	9-7	148.3	38	.48	120
20-0 cont.	9-2	140.4	37	.46	120½
	8-9	132.4	36	.44	121
	8-3	124.4	35	.41	122¼
	7-10	116.3	34	.39	123½
	7-4	108.4	33	.37	125¾
	6-10	99.8	32	.34	128½
	6-4	91.2	31	.32	132½
21-0	10-10	181.0	42	.52	126
	10-6	172.7	41	.50	126
	10-1	164.3	40	.48	126
	9-8	156.0	39	.46	126½
	9-3	147.6	38	.44	127
	8-10	139.2	37	.42	128
	8-4	130.7	36	.40	129¼
	7-11	122.2	35	.38	131¼
	7-5	113.5	34	.35	133¾
	6-11	104.6	33	.33	137¼
	6-4	95.4	32	.30	142
22-0	11-5	198.6	44	.52	132
	11-0	189.9	43	.50	132
	10-7	181.1	42	.48	132
	10-2	172.4	41	.46	132½
	9-9	163.6	40	.44	133
	9-4	154.8	39	.42	133¾
	8-11	146.0	38	.40	135
	8-5	137.0	37	.38	135¾
	7-11	127.9	36	.36	139
	7-5	118.7	35	.34	142¼
	6-11	109.2	34	.31	142¼
23-0	11-11	217.1	46	.52	138
	11-6	207.9	45	.50	138
	11-1	198.8	44	.48	138
	10-8	189.5	43	.47	138¼
	10-3	180.5	42	.45	139
	9-10	171.3	41	.43	139½
	9-5	162.0	40	.41	140¾
	8-11	152.7	39	.39	142¼
	8-6	143.2	38	.37	144½
	8-0	133.6	37	.35	147¼
	7-6	123.8	36	.33	151
	6-11	113.8	35	.30	156
24-0	12-5	236.3	48	.52	144
	12-0	226.8	47	.50	144
	11-7	217.2	46	.48	144
	11-3	207.7	45	.47	144¼
	10-10	198.1	44	.45	144¾
	10-4	188.5	43	.43	145½
	9-11	178.9	42	.41	146½
	9-6	169.2	41	.39	148
	9-0	159.3	40	.38	150
	8-6	149.4	39	.36	152½
	8-0	139.2	38	.33	155¾
	7-6	128.9	37	.31	160¼
25-0	12-11	256.4	50	.52	150
	12-6	246.4	49	.50	150
	12-2	236.5	48	.49	150
	11-9	226.6	47	.47	150¼
	11-4	216.6	46	.45	150¾
	10-11	206.8	45	.44	151½
	10-5	196.6	44	.42	152½
	10-0	186.4	43	.40	153¾
	9-6	176.3	42	.38	155½
	9-1	165.9	41	.36	157¾
	8-7	155.4	40	.34	160¾
	8-1	144.7	39	.32	164¾
	7-6	133.7	38	.30	170
26-0	13-5	277.3	52	.52	156
	13-1	266.9	51	.50	156
	12-8	256.8	50	.49	156

Figure 14.3.48 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES FOR ALUMINUM CULVERTS



ARCH (CONT'D)

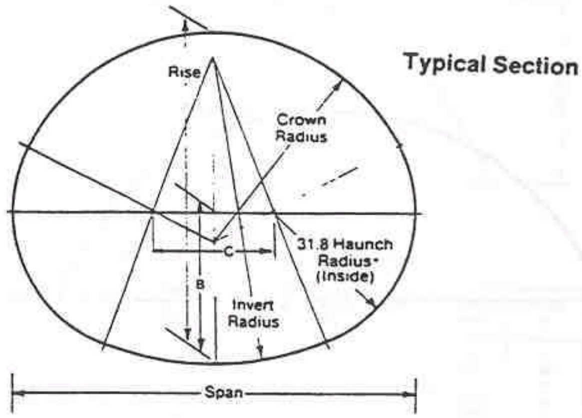
Geometric Data—Arch (Continued)

Span Ft.In.	Rise Ft.In.	Area Sq.Ft.	Total N	Rise/ Span Ratio	Radius Inches
26-0 cont.	12-3	246.2	49	.47	156¼
	11-10	235.9	48	.46	156¾
	11-5	225.5	47	.44	157¼
	11-0	215.1	46	.42	158¼
	10-6	204.6	45	.40	159½
	10-1	194.0	44	.39	161
	9-7	183.3	43	.37	163¼
	9-1	172.4	42	.35	166
	8-7	161.4	41	.33	169½
	8-1	150.1	40	.31	174
27-0	14-0	299.0	54	.52	162
	13-7	288.2	53	.50	162
	13-2	277.5	52	.49	162
	12-9	266.7	51	.47	162¼
	12-4	256.0	50	.46	162¾
	11-11	245.2	49	.44	163¼
	11-6	234.4	48	.43	164
	11-1	223.5	47	.41	165¼
	10-7	212.6	46	.39	166¾
	10-2	201.4	45	.38	168¾
	9-8	190.2	44	.36	171¼
	9-2	178.8	43	.34	174½
	8-7	167.2	42	.32	178½
	8-1	155.3	41	.30	183¾
28-0	14-6	321.5	56	.52	168
	14-1	310.4	55	.50	168
	13-8	299.2	54	.49	168
	13-3	288.1	53	.47	168¼
	12-10	276.9	52	.46	168½
	12-5	265.7	51	.44	169¼
	12-0	254.5	50	.43	170
	11-7	243.2	49	.41	171
	11-1	231.9	48	.40	172½
	10-8	220.4	47	.38	174¼
28-0 cont.	10-2	208.8	46	.36	176½
	9-8	197.1	45	.35	179½
	9-2	185.1	44	.33	183¼
	8-8	172.9	43	.31	188
29-0	15-0	344.8	58	.52	174
	14-7	333.3	57	.50	174
	14-2	321.7	56	.49	174
	13-10	310.2	55	.48	174¼
	13-5	298.6	54	.46	174½
	13-0	287.1	53	.45	175
	12-6	275.4	52	.43	175¾
	12-1	263.8	51	.42	176¾
	11-8	252.0	50	.40	178¼
	11-2	240.2	49	.39	180
	10-9	228.2	48	.37	182
	10-3	216.1	47	.35	184¾
	9-9	203.8	46	.34	188
	9-2	191.3	45	.32	192¼
	8-8	178.5	44	.30	197¾
30-0	15-6	369.0	60	.52	180
	15-1	357.1	59	.50	180
	14-9	345.1	58	.49	180
	14-4	333.2	57	.48	180¼
	13-11	321.2	56	.46	180½
	13-6	309.2	55	.45	181
	13-1	297.2	54	.44	181¾
	12-7	285.1	53	.42	182¾
	12-2	273.0	52	.41	184
	11-9	260.8	51	.39	185½
	11-3	248.5	50	.37	187½
	10-9	236.0	49	.36	190
	10-3	223.3	48	.34	193
	9-9	210.5	47	.32	197
	9-2	197.3	46	.31	201¾

Figure 14.3.48 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES FOR ALUMINUM CULVERTS

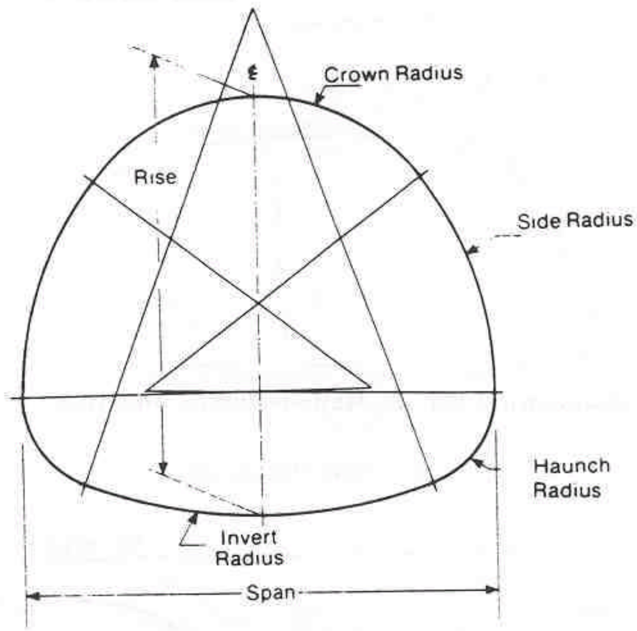
Geometric Data—Pipe Arch



Span Ft.-In.	Rise Ft.-In.	Area Sq. Ft.	Required N Total	Required N Crown	Required N Invert	Required N Haunch	Inside Radius Crown In.	Inside Radius Invert In.	B	C
6-7	5-8	29.6	25	8	3	7	41.5	69.9	32.5	15.3
6-11	5-9	31.9	26	9	3	7	43.7	102.9	32.4	19.6
7-3	5-11	34.3	27	10	3	7	45.6	188.3	32.2	23.8
7-9	6-0	36.8	28	9	5	7	51.6	83.8	33.8	29.0
8-1	6-1	39.3	29	10	5	7	53.3	108.1	33.5	33.3
8-5	6-3	41.9	30	11	5	7	54.9	150.1	33.2	37.4
8-10	6-4	44.5	31	10	7	7	63.3	93.0	35.6	42.8
9-3	5-5	47.1	32	11	7	7	64.4	112.6	35.2	47.1
9-7	6-6	49.9	33	12	7	7	65.4	141.6	34.7	51.3
9-11	6-8	52.7	34	13	7	7	66.4	188.7	34.2	55.3
10-3	6-9	55.5	35	14	7	7	67.4	278.8	33.5	59.2
10-9	6-10	58.4	36	13	9	7	77.5	139.6	36.8	65.2
11-1	7-0	61.4	37	14	9	7	77.8	172.0	36.1	69.3
11-5	7-1	64.4	38	15	9	7	78.2	222.0	35.3	73.3
11-9	7-2	67.5	39	16	9	7	78.7	309.5	34.4	77.1
12-3	7-3	70.5	40	15	11	7	90.8	165.2	38.4	83.4
12-7	7-5	73.7	41	16	11	7	90.5	200.0	37.5	87.4
12-11	7-6	77.0	42	17	11	7	90.4	251.7	36.5	91.3
13-1	8-2	83.0	43	18	13	6	88.8	143.6	42.0	93.6
13-1	8-4	86.8	44	21	11	6	81.7	300.8	35.8	93.7
13-11	8-5	90.3	45	18	15	6	100.4	132.0	46.0	103.3
14-0	8-7	94.2	46	21	13	6	90.3	215.1	39.4	104.5
13-11	9-5	101.5	47	23	14	5	86.2	159.3	42.8	103.9
14-3	9-7	105.7	48	24	14	5	87.2	176.3	42.0	107.0
14-8	9-8	109.9	49	24	15	5	90.9	166.2	44.0	112.3
14-11	9-10	114.2	50	25	15	5	91.8	183.0	43.2	115.5
15-4	10-0	118.6	51	25	16	5	95.5	173.0	45.3	120.8
15-7	10-2	123.1	52	26	16	5	96.4	189.6	44.4	123.9
16-1	10-4	127.6	53	26	17	5	100.2	179.7	46.6	129.2
16-4	10-6	132.3	54	27	17	5	101.0	196.1	45.7	132.3
16-9	10-8	136.9	55	27	18	5	105.0	186.3	47.9	137.7
17-0	10-10	141.8	56	28	18	5	105.7	202.5	46.9	140.8
17-3	11-0	146.7	57	29	18	5	106.5	221.3	45.9	143.8
17-9	11-2	151.6	58	29	19	5	110.4	208.9	48.2	149.3
18-0	11-4	156.7	59	30	19	5	111.1	227.3	47.2	152.3
18-5	11-6	161.7	60	30	20	5	115.2	215.2	49.6	157.8
18-8	11-8	167.0	61	31	20	5	115.8	233.3	48.5	160.7
19-2	11-9	172.2	62	31	21	5	119.9	221.5	50.9	166.2
19-5	11-11	177.6	63	32	21	5	120.5	239.3	49.8	169.2
19-10	12-1	182.9	64	32	22	5	124.7	227.7	52.3	174.8
20-1	12-3	188.5	65	33	22	5	125.2	245.3	51.1	177.7
20-1	12-6	194.4	66	35	21	5	122.5	310.8	46.2	177.5
20-10	12-7	199.7	67	34	23	5	130.0	251.2	52.5	186.2
21-1	12-9	205.5	68	35	23	5	130.5	270.9	51.2	189.1
21-6	12-11	211.2	69	35	24	5	134.8	257.2	53.9	194.8

Figure 14.3.48 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES FOR ALUMINUM CULVERTS



Typical Section

Geometric Data—Vehicular Underpass

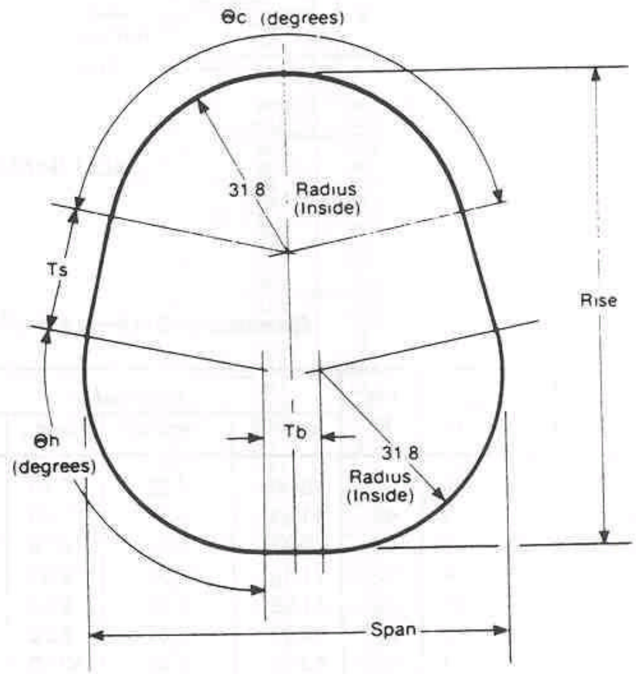
Span Ft	Span In.	Rise Ft	Rise In.	Tot N	Required N Invert	Required N Haunch	Required N Side	Required N Crown	Inside Radius (Inches) Invert	Inside Radius (Inches) Haunch	Inside Radius (Inches) Side	Inside Radius (Inches) Crown
12	1	11	0	47	10.00	4.32	7.69	12.99	135.95	37.95	88.00	67.95
12	10	11	2	49	11.04	4.44	7.50	14.10	148.53	38.53	86.78	74.53
13	0	12	0	51	10.97	4.27	8.79	13.91	160.54	37.54	98.19	72.54
13	8	12	4	53	11.98	4.36	8.67	14.96	167.77	37.77	102.62	76.77
14	0	12	11	55	11.99	4.39	9.62	14.98	182.90	37.90	110.65	76.90
14	6	13	5	57	13.07	4.61	9.26	16.18	174.88	38.88	124.73	78.88
14	8	14	1	59	13.00	4.42	10.58	15.99	192.96	37.96	130.01	78.96
15	5	14	5	61	14.04	4.59	10.33	17.11	201.54	38.54	135.39	83.54
15	6	15	2	63	13.97	4.45	11.61	16.92	211.59	37.59	149.14	81.59
16	2	15	6	65	14.99	4.50	11.52	17.97	216.85	37.85	154.40	85.85
16	6	16	0	67	14.07	4.73	12.10	19.29	272.34	39.34	153.89	89.34
16	8	16	4	68	15.01	4.49	12.49	19.03	246.17	38.17	160.82	89.17
17	3	17	1	70	15.04	5.71	12.20	19.13	214.64	47.64	171.19	90.64
18	5	16	11	72	16.09	5.87	11.95	20.27	249.37	48.37	155.02	100.37
19	0	17	3	74	17.02	5.60	12.36	21.06	262.29	47.29	153.14	105.29
19	7	17	7	76	17.07	5.79	13.06	21.24	296.21	48.21	154.46	108.21
20	5	17	9	78	18.08	5.78	13.05	22.27	317.39	48.39	149.94	115.39

Figure 14.3.48 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES FOR ALUMINUM CULVERTS

Geometric Data—Pedestrian/Animal Underpass

Span Ft.-In.	Rise Ft.-In.	Total N	Tb In.	Ts In.	Θc Degrees	Θh Degrees
6-1	5-9	24	9.2	7.2	100.2	129.9
6-3	6-1	25	11.1	11.0	119.3	120.4
6-3	6-6	26	11.6	15.6	136.5	111.7
6-2	7-0	27	10.2	21.1	152.2	103.9
6-3	7-4	28	11.6	25.2	153.3	103.4
6-1	7-10	29	9.8	30.9	161.7	99.2
6-3	8-2	30	11.3	35.0	161.3	99.3

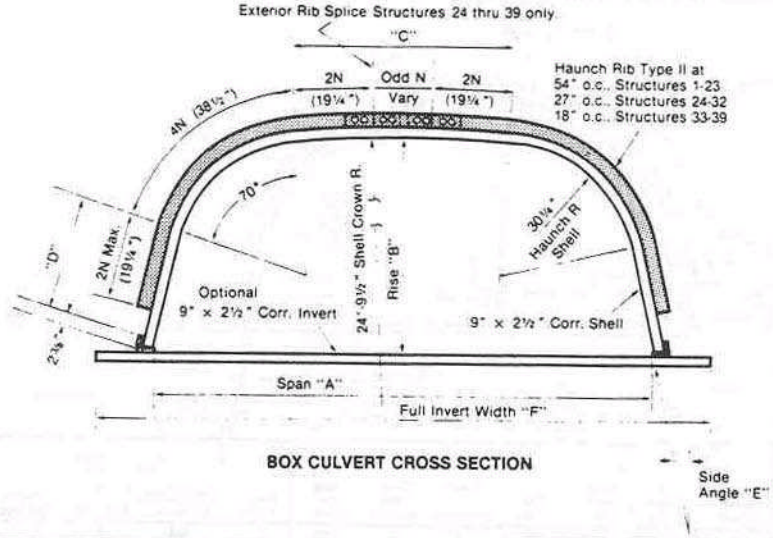


Typical Section

Figure 14.3.48 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES
FOR ALUMINUM CULVERTS

Box Culvert Geometric Data



BOX CULVERT CROSS SECTION

Structure Number	Span "A" (Ft.-In.)	Rise "B" (Ft.-In.)	Area (Sq. Ft.)	SHELL Crown Width "C" (N)	Leg Length "D" (N)	Side Angle "E" Deg. Min.	Total N	Haunch Plate Length (N)	Crown Plate Length (N)	Bolts/Ft.	FULL INVERT Width "F" (N)	Supplemental/Stub Pt. Thick.	Supplemental/Stub Pt. Width (N)	Weight/Ft.	Bolts/Ft.
1	8- 9	2- 6	18.4	5	.5	15-24	14	1 @ 14	—	6.67	13	—	—	23.06	5.78
2	9- 2	3- 3	25.4	5	1.5	15-24	16	2 @ 8	—	11.56	13	—	—	23.06	5.78
3	9- 7	4- 1	32.6	5	2.5	15-24	18	2 @ 9	—	12.00	14	—	—	24.44	6.00
4	10- 0	4-10	40.2	5	3.5	15-24	20	2 @ 10	—	12.44	14	—	—	24.44	6.00
5	10- 6	5- 7	48.1	5	4.5	15-24	22	2 @ 11	—	12.89	15	—	—	25.82	6.22
6	10-11	6- 4	56.4	5	5.5	15-24	24	2 @ 12	—	13.33	17	—	—	28.58	6.57
7	11- 4	7- 2	65.0	5	6.5	15-24	26	2 @ 13	—	13.78	17	—	—	28.58	6.67
8	10- 2	2- 8	23.0	7	.5	13-33	16	2 @ 8	—	12.89	15	—	—	25.82	6.22
9	10- 7	3- 5	31.1	7	1.5	13-33	18	2 @ 9	—	13.33	15	—	—	25.82	6.22
10	10-11	4- 3	39.5	7	2.5	13-33	20	2 @ 10	—	13.78	17	—	—	28.58	6.57
11	11- 4	5- 0	48.2	7	3.5	13-33	22	2 @ 11	—	14.22	17	—	—	28.58	6.57
12	11- 8	5- 9	57.2	7	4.5	13-33	24	2 @ 12	—	14.67	17	—	—	28.58	6.57
13	12- 1	6- 7	66.4	7	5.5	13-33	26	2 @ 13	—	15.11	17	—	—	28.58	6.57
14	12- 5	7- 4	76.0	7	6.5	13-33	28	2 @ 14	—	15.56	17	—	—	28.58	6.57
15	11- 7	2-10	28.1	9	0.5	11-42	18	2 @ 9	—	14.67	17	—	—	28.58	6.57
16	11-11	3- 7	37.4	9	1.5	11-42	20	2 @ 10	—	15.11	17	—	—	28.58	6.57
17	12- 3	4- 5	46.9	9	2.5	11-42	22	2 @ 11	—	15.56	17	—	—	28.58	6.67
18	12- 7	5- 2	56.6	9	3.5	11-42	24	2 @ 12	—	16.00	19	—	—	32.02	7.11
19	12-11	6- 0	66.6	9	4.5	11-42	26	2 @ 13	—	16.44	19	—	—	32.02	7.11
20	13- 3	6- 9	76.9	9	5.5	11-42	28	2 @ 14	—	16.89	19	—	—	32.02	7.11
21	13- 0	3- 0	33.8	11	0.5	9-52	20	2 @ 10	—	16.44	19	—	—	32.02	7.11
22	13- 4	3-10	44.2	11	1.5	9-52	22	2 @ 11	—	16.89	19	—	—	32.02	7.11
23	13- 7	4- 7	54.8	11	2.5	9-52	24	2 @ 12	—	17.33	19	—	—	32.02	7.11
24	13-10	5- 5	65.6	11	3.5	9-52	26	2 @ 13	—	23.11	19	—	—	32.02	7.11
25	14- 1	6- 2	76.6	11	4.5	9-52	28	2 @ 14	—	23.56	20	—	—	33.34	12.14
26	14- 5	3- 3	40.0	13	0.5	8-1	22	2 @ 11	—	22.67	20	—	—	33.34	12.14
27	14- 8	4- 1	51.5	13	1.5	8-1	24	2 @ 8	8	25.56	21	.100	2	40.23	12.57
28	14-10	4-10	63.2	13	2.5	8-1	26	2 @ 9	8	26.44	21	.100	2	40.23	12.57
29	15- 1	5- 8	75.1	13	3.5	8-1	28	2 @ 10	8	26.89	21	.100	2	40.23	12.57
30	15- 4	6- 5	87.2	13	4.5	8-1	30	2 @ 11	8	27.33	21	.100	2	40.23	12.57
31	15- 6	7- 3	99.4	13	5.5	8-1	32	2 @ 12	8	27.78	22	.100	2	41.61	12.49
32	15- 9	8- 0	111.8	13	6.5	8-1	34	2 @ 13	8	28.22	22	.100	2	41.61	12.39
33	15-10	3- 6	46.8	15	0.5	6-10	24	2 @ 8	8	32.22	22	.100	2	41.61	12.39
34	16- 0	4- 3	59.5	15	1.5	6-10	26	2 @ 9	8	33.56	22	.100	2	41.61	12.49
35	16- 2	5- 1	72.3	15	2.5	6-10	28	2 @ 10	8	34.89	23	.100	2	42.99	13.11
36	16- 4	5-11	85.2	15	3.5	6-10	30	2 @ 11	8	35.33	23	.100	3	45.75	13.11
37	16- 6	6- 8	98.3	15	4.5	6-10	32	2 @ 12	8	35.78	23	.100	3	45.75	13.11
38	16- 8	7- 6	111.5	15	5.5	6-10	34	2 @ 13	8	36.22	23	.100	3	45.75	13.11
39	16-10	8- 3	124.8	15	6.5	6-10	36	2 @ 14	8	36.67	24	.100	3	47.13	13.33

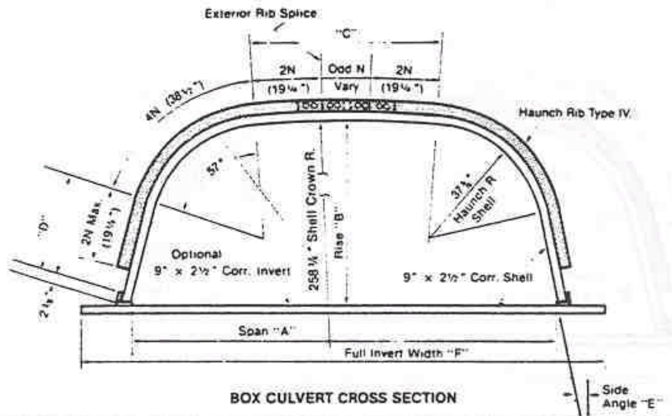
NOTES:

1) "N" equals 9.62".
2) All crowns of shells have Type IV ribs outside at 18" on centers.
3) Weights per foot listed do not include bolt weight.
4) Weight per foot of full invert includes 3½ × 3 × ¼ connecting angle and scalloped closure plate for each side. Inverts for 20N and greater are two-piece.
5) Weight per foot of footing pad includes a 3½ × 3 × ¼-in. connecting angle for each side. Optional wale beam not included.
6) Full invert plates are .100 thick. When reactions to invert require additional thickness supplemental plates of thickness and width listed are furnished to bolt between full invert and side connecting angle.
7) Width of footing pad is for each side.
8) For structures using short footing pads with leg length "D" equal to 3.5 N or more, either wale beam stiffeners should be used to avoid

Figure 14.3.48 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES
FOR ALUMINUM CULVERTS

Box Culvert Geometric Data



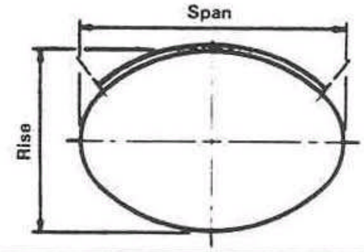
				SHELL							FULL INVERT				
Structure Number	Span "A" (Ft.-In.)	Rise "B" (Ft.-In.)	Area (Sq. Ft.)	Crown Width "C" (N)	Leg Length "D" (N)	Side Angle "E" Deg. Min.	Total N	Haunch Plate Length (N)	Crown Plate Length (N)	Bolts Per Foot	Width "F" (N)	Supplemental Stub Plates Thickness	Supplemental Stub Plates Width (N)	Weight Per Foot	Bolts Per Foot
40	17- 9	3-10	54.4	17	.5	14-54	26	8	10	33.56	25	.100	3	48.51	13.56
41	18- 2	4- 7	68.3	17	1.5	14-54	28	9	10	34.89	25	.100	3	48.51	13.56
42	18- 7	5- 4	82.5	17	2.5	14-54	30	10	10	36.22	26	.100	3	49.88	13.78
43	19- 0	6- 1	97.1	17	3.5	14-54	32	11	10	36.67	27	.100	3	51.26	14.00
44	19- 5	6-11	111.9	17	4.5	14-54	34	12	10	37.11	27	.100	3	51.26	14.00
45	19-10	7- 8	127.1	17	5.5	14-54	36	13	10	37.56	28	.100	3	52.64	14.22
46	20- 3	8- 5	142.6	17	6.5	14-54	38	14	10	38.00	28	.100	3	52.64	14.22
47	19- 1	4- 2	63.3	19	.5	12-47	28	8	12	34.89	27	.100	3	51.26	14.00
48	19- 5	4-11	78.3	19	1.5	12-47	30	9	12	36.22	27	.100	3	51.26	14.00
49	19- 9	5- 8	93.6	19	2.5	12-47	32	10	12	37.56	27	.100	3	51.26	14.00
50	20- 1	6- 6	109.2	19	3.5	12-47	34	11	12	38.00	28	.100	3	52.64	14.22
51	20- 6	7- 3	125.0	19	4.5	12-47	36	12	12	54.44	29	.125	3	56.09	14.44
52	20-10	8- 1	141.2	19	5.5	12-47	38	13	12	54.89	29	.100	3	54.02	14.44
53	21- 2	8-10	157.6	19	6.5	12-47	40	14	12	55.33	30	.150	3	59.54	14.67
54	20- 4	4- 6	73.1	21	.5	10-40	30	8	14	49.56	29	.150	3	58.16	14.44
55	20- 7	5- 3	89.2	21	1.5	10-40	32	9	14	52.22	29	.125	3	56.09	14.44
56	20-11	6- 1	105.5	21	2.5	10-40	34	10	14	54.89	29	.100	3	54.02	14.44
57	21- 3	6-10	122.1	21	3.5	10-40	36	11	14	55.33	30	.150	3	59.54	14.67
58	21- 6	7- 8	139.0	21	4.5	10-40	38	12	14	55.78	30	.125	3	57.47	14.67
59	21-10	8- 5	156.0	21	5.5	10-40	40	13	14	56.22	31	.175	3	62.99	14.89
60	22- 1	9- 3	173.3	21	6.5	10-40	42	14	14	56.67	31	.150	3	60.92	14.89
61	21- 7	4-11	83.8	23	.5	8-32	32	9	14	50.89	30	.125	3	57.47	14.67
62	21-10	5- 8	101.0	23	1.5	8-32	34	10	14	53.56	31	.175	3	62.99	14.89
63	22- 1	6- 6	118.4	23	2.5	8-32	36	11	14	56.22	31	.150	3	60.92	14.89
64	22- 3	7- 3	135.9	23	3.5	8-32	38	12	14	56.67	31	.150	4	65.05	14.89
65	22- 6	8- 1	153.7	23	4.5	8-32	40	13	14	57.11	32	.200	4	71.95	15.11
66	22- 9	8-10	171.6	23	5.5	8-32	42	14	14	57.56	32	.175	4	69.19	15.11
67	23- 0	9- 8	189.8	23	6.5	8-32	44	15	14	58.00	32	.150	4	66.43	15.11
68	22- 9	5- 4	95.5	25	.5	6-25	34	10	14	52.22	32	.175	4	69.19	15.11
69	23- 0	6- 1	113.7	25	1.5	6-25	36	11	14	54.89	32	.150	4	66.43	15.11
70	23- 2	6-11	132.1	25	2.5	6-25	38	12	14	57.56	33	.225	4	76.09	15.33
71	23- 4	7- 8	150.6	25	3.5	6-25	40	13	14	58.00	33	.200	4	73.33	15.33
72	23- 6	8- 6	169.3	25	4.5	6-25	42	14	14	58.44	33	.200	4	73.33	15.33
73	23- 8	9- 3	188.1	25	5.5	6-25	44	15	14	58.89	33	.175	4	70.57	15.33
74	23-10	10- 1	207.0	25	6.5	6-25	46	16	14	59.33	34	.250	4	80.22	15.56
75	24- 0	5- 9	108.2	27	.5	4-18	36	10	16	53.56	34	.225	4	77.46	15.56
76	24- 1	6- 6	127.5	27	1.5	4-18	38	11	16	56.22	34	.225	4	77.46	15.56
77	24- 3	7- 4	146.8	27	2.5	4-18	40	12	16	58.89	34	.200	4	74.71	15.56
78	24- 4	8- 2	166.2	27	3.5	4-18	42	13	16	59.33	34	.200	4	74.71	15.56
79	24- 5	8-11	185.7	27	4.5	4-18	44	14	16	59.78	34	.200	4	74.71	15.56
80	24- 7	9- 9	205.3	27	5.5	4-18	46	15	16	60.22	35	.300	4	87.12	15.78
81	24- 8	10- 6	225.0	27	6.5	4-18	48	16	16	60.67	35	.250	4	81.60	15.78
82	25- 2	6- 2	122.0	29	.5	2-11	38	11	16	54.89	35	.200	4	76.09	15.78
83	25- 2	7- 0	142.2	29	1.5	2-11	40	12	16	57.56	35	.200	4	76.09	15.78
84	25- 3	7- 9	162.4	29	2.5	2-11	42	13	16	60.22	36	.300	4	88.50	16.00
85	25- 4	8- 7	182.6	29	3.5	2-11	44	14	16	60.67	36	.300	4	88.50	16.00
86	25- 4	9- 5	202.9	29	4.5	2-11	46	15	16	61.11	36	.300	4	88.50	16.00
87	25- 5	10- 2	223.3	29	5.5	2-11	48	16	16	61.56	36	.300	4	88.50	16.00

NOTES:

1) "N" = 9.62"
2) All shells have Type IV ribs outside only. Both haunch and crown ribs are 18" on centers for structures 40 through 50 and 9" on centers for structures 51 through 87.
3) Weights per foot listed do not include bolt weight.
4) Weight per foot of full invert includes 3½ x 3 x ¼ connecting angle and scalloped closure plate for each side. Inverts for 20 N width and greater are two piece.
5) Full invert plates are 100" thick. When reactions to invert require additional thickness, supplemental plates of thickness and width listed are furnished to bolt between full invert and side connecting angles. When thickness listed is greater than a .250" supplemental plates will be two pieces equalling the composite thickness required.
6) Weight per foot of footing pads includes 3½ x 3 x ¼ connecting angle for each side. Optional wale beam weight is not included.
7) Width of footing pads is for each side. When thickness listed is greater than .250" the footing pads will be two pieces equalling the composite thickness required.

Figure 14.3.48 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES
FOR ALUMINUM CULVERTS



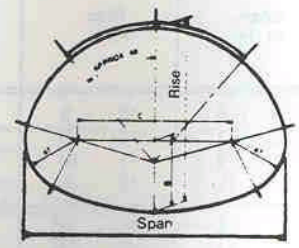
Span Ft.-in		Rise Ft-in.		Area ft²	Required N			Inside Radius	
					Crown or Invert	Haunch	Total	Crown & Invert in.	Haunch in.
19	4	12	9	191	22	10	64	150.3	53.9
20	1	13	0	202	23	10	66	157.2	53.9
20	2	11	10	183	24	8	64	164.1	42.8
20	10	12	2	193	25	8	66	171.0	42.8
21	0	15	1	248	23	13	72	157.2	70.4
21	11	13	1	220	26	9	70	177.9	48.4
22	6	15	8	274	25	13	76	171.0	70.4
23	0	14	1	249	27	10	74	184.8	53.9
23	3	15	11	288	26	13	78	177.9	70.4
24	4	16	11	320	27	14	82	184.8	75.9
24	6	14	7	274	29	10	78	198.6	53.9
25	3	14	11	287	30	10	80	205.4	53.9
25	6	16	9	330	29	13	84	198.6	70.4
26	1	18	2	369	29	15	88	198.6	81.4
26	3	15	10	320	31	11	84	212.3	59.4
27	0	16	2	334	32	11	86	219.2	59.4
27	2	19	1	405	30	16	92	205.4	86.9
27	11	19	5	421	31	16	94	212.3	86.9
28	1	17	1	369	33	12	90	226.1	64.9
28	10	17	4	384	34	12	92	233.0	64.9
29	5	19	11	455	33	16	98	226.1	86.9
30	2	20	2	472	34	16	100	233.0	86.9
30	4	17	11	415	36	12	96	246.8	64.9
31	2	21	2	513	35	17	104	239.9	92.5
31	4	18	11	454	37	13	100	253.7	70.4
32	1	19	2	471	38	13	102	260.6	70.4
32	3	22	2	555	36	18	108	246.8	98.0
33	0	22	5	574	37	18	110	253.7	98.0
33	2	20	1	513	39	14	106	267.5	75.9
34	1	23	4	619	38	19	114	260.6	103.5
34	8	20	8	548	41	14	110	281.2	75.9
35	0	21	4	574	41	15	112	281.2	81.4
35	2	24	4	666	39	20	118	267.5	109.0
35	10	25	9	719	39	22	122	267.5	120.0
36	1	22	4	620	42	16	116	288.1	86.9
36	11	25	7	736	41	21	124	281.2	114.5
37	2	22	2	632	44	15	118	301.9	81.4
38	0	26	7	786	42	22	128	288.1	120.0
38	8	28	0	844	42	24	132	288.1	131.0
40	1	29	8	928	43	26	138	295.0	142.1

SOURCE: ALUMINUM ASSOCIATION

Figure 14.3.48 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES FOR ALUMINUM CULVERTS

Geometric Data—Pipe Arch

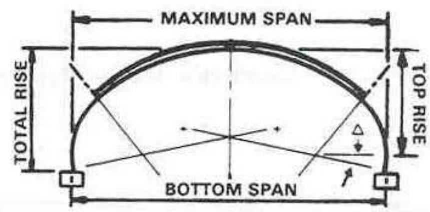


Span Ft-in	Rise Ft-in.	Area ft²	Required N				Inside Radius		B	C
			Total	Crown	Invert	Haunch	Crown in.	Invert in.		
20 1	13 11	216	68	34	20	7	122.7	224.2	62.9	146.7
20 7	14 3	229	70	36	20	7	124.9	256.4	61.4	152.8
21 5	14 7	241	72	36	22	7	131.7	237.3	65.4	163.4
21 11	14 11	254	74	38	22	7	133.7	268.8	63.8	169.4
22 8	15 3	267	76	39	23	7	138.2	274.9	65.0	177.8
23 4	15 7	281	78	40	24	7	142.7	281.0	66.3	186.1
24 3	15 10	295	80	40	26	7	150.0	262.8	70.8	196.8
24 9	16 3	309	82	42	26	7	151.7	293.0	68.9	202.9
25 5	16 7	324	84	43	27	7	156.2	299.0	70.2	211.3
26 4	16 10	339	86	43	29	7	163.9	281.3	75.0	222.1
27 0	17 2	354	88	44	30	7	168.6	287.4	76.4	230.5
27 9	17 6	369	90	45	31	7	173.3	293.5	77.9	238.9
28 5	17 10	385	92	46	32	7	178.0	299.6	79.3	247.3
29 4	18 2	401	94	46	34	7	186.6	286.7	84.6	257.9
29 10	18 6	418	96	48	34	7	187.5	311.6	82.3	264.2
30 4	18 10	435	98	50	34	7	188.6	340.1	80.0	270.2

14.3.48 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES
FOR ALUMINUM CULVERTS

Geometric Data—Low Profile Arch



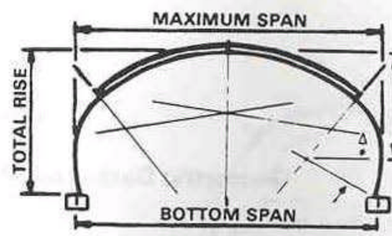
Max. Span Ft-in.		Total Rise Ft-in		Area ft²	Bottom Span Ft-in.		Top Rise Ft-in.		Required N			Inside Radius		Δ	
									Crown	Side	Total	Crown In.	Side In.	Deg.	Min.
20	1	7	6	120	19	10	6	6	23	6	35	157.2	54.0	12	19
19	5	6	9	105	19	2	5	10	23	5	33	157.2	43.0	15	22
21	6	7	9	133	21	4	6	9	25	6	37	171.0	54.0	12	19
22	3	7	11	140	22	1	6	11	26	6	38	177.9	54.0	12	19
23	0	8	0	147	22	10	7	1	27	6	39	184.8	54.0	12	19
23	9	8	2	154	23	6	7	2	28	6	40	191.7	54.0	12	19
24	6	8	3	161	24	3	7	4	29	6	41	196.6	54.0	12	19
25	3	8	5	168	25	0	7	5	30	6	42	205.4	54.0	12	19
26	0	8	7	175	25	9	7	7	31	6	43	212.3	54.0	12	19
27	3	10	0	217	27	1	9	0	31	8	47	212.3	76.0	8	51
28	1	9	6	212	27	11	8	7	33	7	47	226.1	65.0	10	17
28	9	10	3	234	28	7	9	3	33	8	49	226.1	76.0	8	52
28	10	9	8	220	28	8	8	8	34	7	48	233.0	65.0	10	17
30	4	9	11	237	30	2	9	0	36	7	50	246.8	65.0	10	17
31	0	10	8	261	30	10	9	8	36	8	52	246.8	76.0	8	52
31	7	12	1	309	31	2	10	4	36	10	56	246.8	87.0	14	0
31	1	10	1	246	30	10	9	1	37	7	51	253.7	65.0	10	17
32	4	12	3	319	31	11	10	6	37	10	57	253.7	87.0	14	0
31	9	10	2	255	31	7	9	3	38	7	52	260.6	65.0	10	17
33	1	12	5	330	32	8	10	8	38	10	58	260.6	87.0	14	0
33	2	11	0	289	33	0	10	1	39	8	55	267.5	76.0	8	52
34	6	13	3	367	34	1	11	6	39	11	61	267.5	98.0	12	26
34	8	11	4	308	34	6	10	4	41	8	57	281.2	76.0	8	52
37	11	15	7	478	37	8	13	10	41	14	69	281.2	131.0	9	23
35	5	11	5	318	35	3	10	6	42	8	58	288.1	76.0	8	52
38	8	15	9	491	38	4	14	0	42	14	70	288.1	131.0	9	23

See "Notes" Table 5-20A or 5-20B for rib spacing when required.

Figure 14.3.48 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES
FOR ALUMINUM CULVERTS

Geometric Data—High Profile Arch



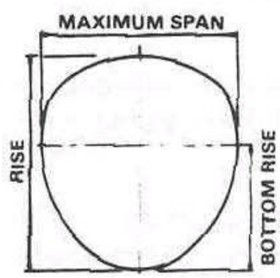
Max Span Ft.-in.		Total Rise Ft.-in.		Area ft²	Bottom Span Ft-in.		Top Rise Ft-in.		Required N Crown	Required N Haunch	Required N Side	Required N Total	Inside Radius Crown in.	Inside Radius Haunch in.	Inside Radius Side in.	Δ Deg.	Δ Min.
20	1	9	1	152	19	6	6	6	23	5	3	39	157.2	54.0	157.2	11	40
20	9	12	1	214	18	10	7	3	23	6	6	47	157.2	65.0	157.2	22	8
21	6	11	8	215	19	10	6	9	25	5	6	47	171.0	54.0	171.0	20	20
22	10	14	6	284	19	10	8	6	25	7	8	55	171.0	76.0	171.0	26	48
22	3	11	9	224	20	7	6	11	26	5	6	48	177.9	54.0	177.9	19	33
22	11	14	0	275	20	1	7	7	26	6	8	54	177.9	65.0	177.9	25	44
23	0	11	11	234	21	5	7	1	27	5	6	49	184.8	54.0	184.8	18	49
24	4	14	10	309	21	7	8	5	27	7	8	57	184.8	76.0	184.8	24	50
23	9	12	1	244	22	2	7	2	28	5	6	50	191.7	54.0	191.7	16	8
24	6	13	8	288	21	11	7	4	29	5	8	55	198.6	54.0	198.6	23	2
25	10	15	1	334	23	3	8	9	29	7	8	59	198.6	76.0	198.6	23	6
25	3	13	1	263	23	3	7	5	30	5	7	54	205.4	54.0	205.4	19	35
26	6	15	3	347	24	0	8	10	30	7	8	60	205.4	76.0	205.4	22	19
26	0	13	3	294	24	1	7	7	31	5	7	55	212.3	54.0	212.3	18	57
27	3	15	5	360	24	10	9	0	31	7	8	61	212.3	76.0	212.3	21	36
27	5	13	6	317	25	8	7	10	33	5	7	57	226.1	54.0	226.1	17	48
29	5	16	5	412	27	1	10	0	33	8	8	65	226.1	87.0	226.1	20	18
28	2	14	5	348	25	11	8	0	34	5	8	60	233.0	54.0	233.0	19	37
30	2	18	0	466	26	8	10	2	34	8	10	70	233.0	88.0	233.0	23	51
30	4	15	5	399	28	2	9	0	36	6	8	64	246.8	65.0	246.8	18	34
31	7	18	4	497	28	5	10	4	36	8	10	72	246.8	87.0	246.8	23	3
31	1	15	7	412	29	0	9	1	37	6	8	65	253.7	65.0	253.7	18	3
31	8	17	9	483	28	7	9	10	37	7	10	71	253.7	76.0	253.7	22	25
32	4	19	11	554	27	11	10	6	37	8	12	77	253.7	87.0	253.7	26	45
31	9	17	2	469	28	9	9	3	38	6	10	70	260.6	65.0	260.6	21	47
33	1	20	1	571	28	9	10	8	38	8	12	78	260.6	87.0	260.6	26	3
32	6	17	4	484	29	6	9	4	39	6	10	71	267.5	65.0	267.5	21	14
33	10	20	3	588	29	7	10	9	39	8	12	79	267.5	87.0	267.5	25	23
34	0	17	8	514	31	2	9	8	41	6	10	73	281.2	65.0	281.2	20	11
34	8	19	10	591	30	7	10	4	41	7	12	79	281.2	76.0	281.2	24	7
35	4	21	3	645	30	7	11	0	41	8	13	83	281.2	87.0	281.2	26	6
37	3	23	4	747	32	7	13	2	41	11	13	89	281.2	120.0	281.2	26	8
34	9	17	9	529	31	11	9	9	42	6	10	74	288.1	65.0	288.1	19	42
35	5	20	0	608	31	5✓	10	6	42	7	12	80	288.1	76.0	288.1	23	33
36	1	21	5	663	31	5	11	2	42	8	13	84	288.1	87.0	288.1	25	28
38	0	23	6	767	33	5	13	3	42	11	13	90	288.1	120.0	288.1	25	31

See "Notes" Table 5-20A or 5-20B for rib spacing when required.

Figure 14.3.48 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES
FOR ALUMINUM CULVERTS

Geometric Data—Pear Shape



Max. Span Ft.-in.	Rise Ft.-in.	Rise Bottom Ft-in.	Area ft²	Required N					Inside Radius			
				Top	Corner	Side	Bottom	Total	Bottom in.	Side in.	Corner in.	Top in.
23 7	25 6	14 10	477	25	5	24	15	98	108.31	198.07	74.07	175.07
24 0	25 10	15 1	497	22	7	22	20	100	119.07	208.07	84.07	194.07
25 4	25 11	15 10	518	27	7	20	20	102	124.23	218.24	84.24	191.24
24 10	27 7	16 9	545	27	5	25	18	105	110.90	236.21	69.21	191.21
28 10	27 3	19 8	590	32	7	27	8	110	79.61	257.96	68.96	252.96
26 8	28 3	18 0	594	28	5	30	12	110	95.45	241.24	57.24	251.24
28 0	27 10	16 9	624	27	8	22	25	112	146.38	227.72	86.72	244.72
28 7	30 7	19 7	690	32	7	24	24	118	133.13	288.45	84.45	218.45
30 0	29 7	20 0	699	32	8	23	25	119	142.41	288.26	79.26	262.26
30 0	31 2	19 11	739	34	7	24	26	122	144.43	·288.58	84.58	231.58

Figure 14.3.48 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued