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.

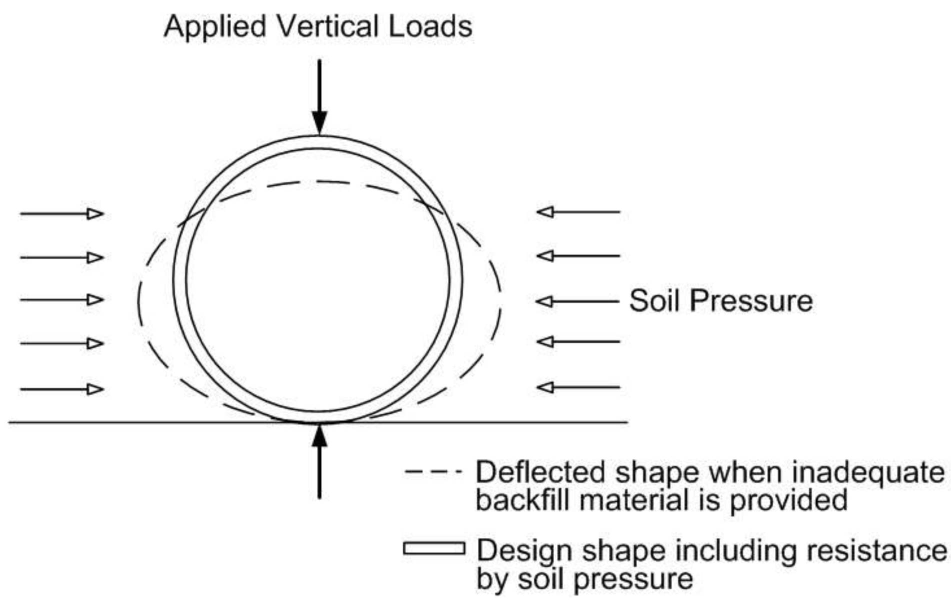


Figure 14.3.3 Flexible Culvert: Load vs. Shape

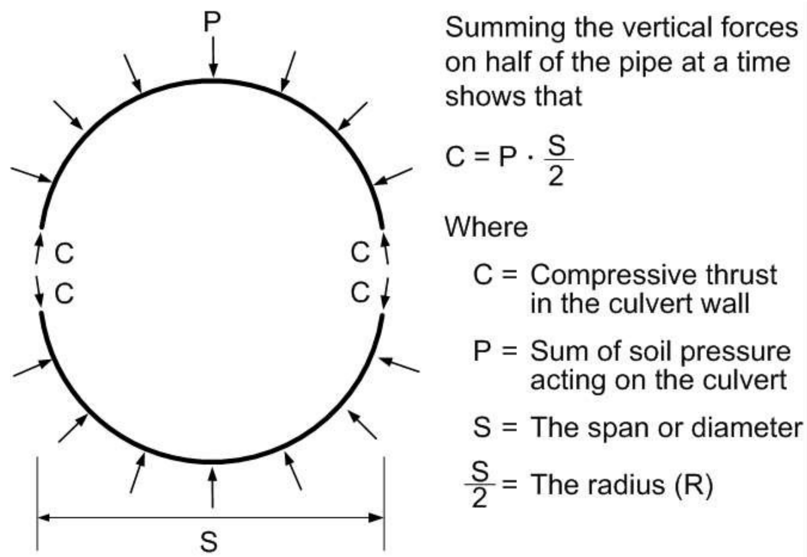


Figure 14.3.4 Formula for Ring Compression

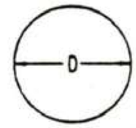
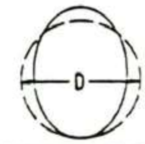
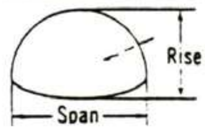
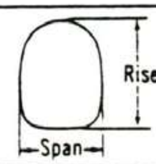
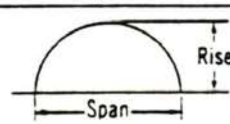
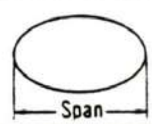
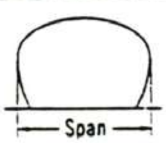
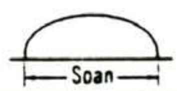
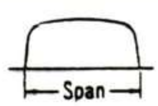
An arc of a flexible round pipe, or other shape will be stable as long as adequate soil pressures are achieved, and as long as the soil pressure is resisted by the compressive force C on each end of the arc. Good quality backfill material and proper installation are critical in obtaining a stable soil 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).
Arch		Span x Rise 6 ft x 1 ft 9½ in. to 25 ft x 12 ft 6 in.	For low clearance large waterway opening, and aesthetics (structural plate).
Horizontal Ellipse		Span 20–40 ft	Culverts, grade separations, storm sewers, tunnels.
Pear		Span 25–30 ft	Grade separations, culverts, storm sewers, tunnels.
High Profile Arch		Span 20–45 ft	Culverts, grade separations, storm sewers, tunnels, Ammo ammunition magazines, earth covered storage.
Low Profile Arch		Span 20–50 ft	Low-Wide waterway enclosures, culverts, storm sewers.
Box Culverts		Span 10–21 ft	Low-wide waterway enclosures, culverts, storm sewers.
Specials		Various	For lining old structures or other special purposes. Special fabrication.

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

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.

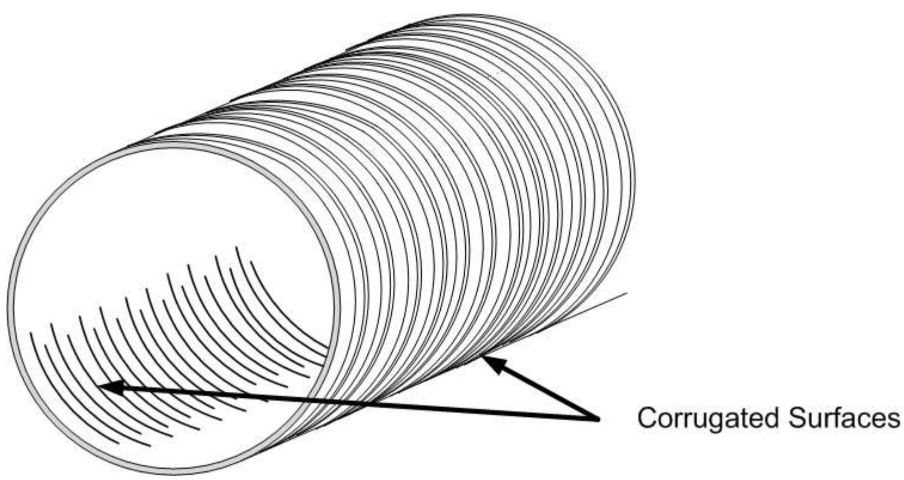


Figure 14.3.6 Schematic of a Single Walled Culvert

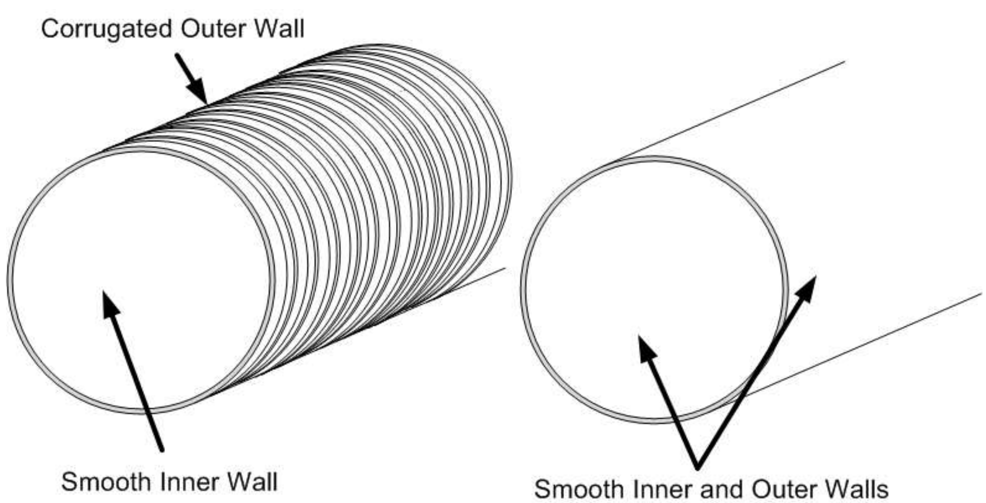


Figure 14.3.7 Schematics of Dual Walled Culverts

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.

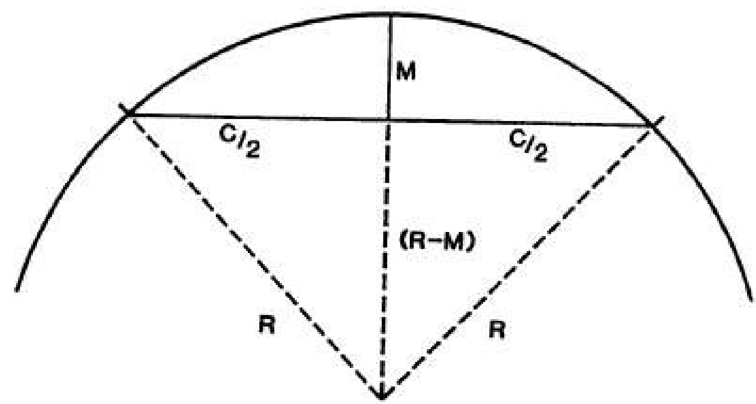
In general, the inspection process for checking shape will include visual observations for symmetrical shape and uniform curvature as well as measurements of important dimensions. The specific measurements to be obtained depend upon factors such as the size, shape, and condition of the structure. If 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.

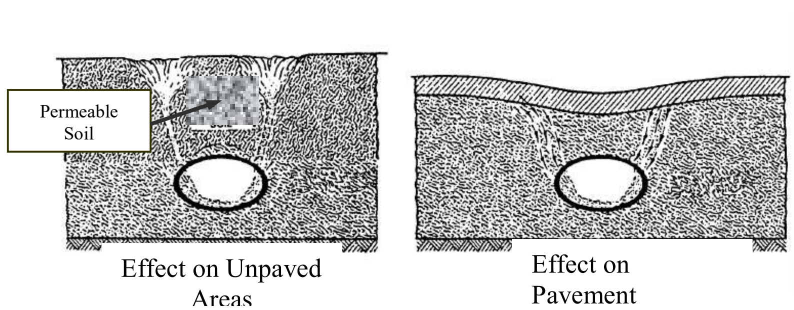


Figure 14.3.9 (Exhibit 67) Surface Indications of Infiltration

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.

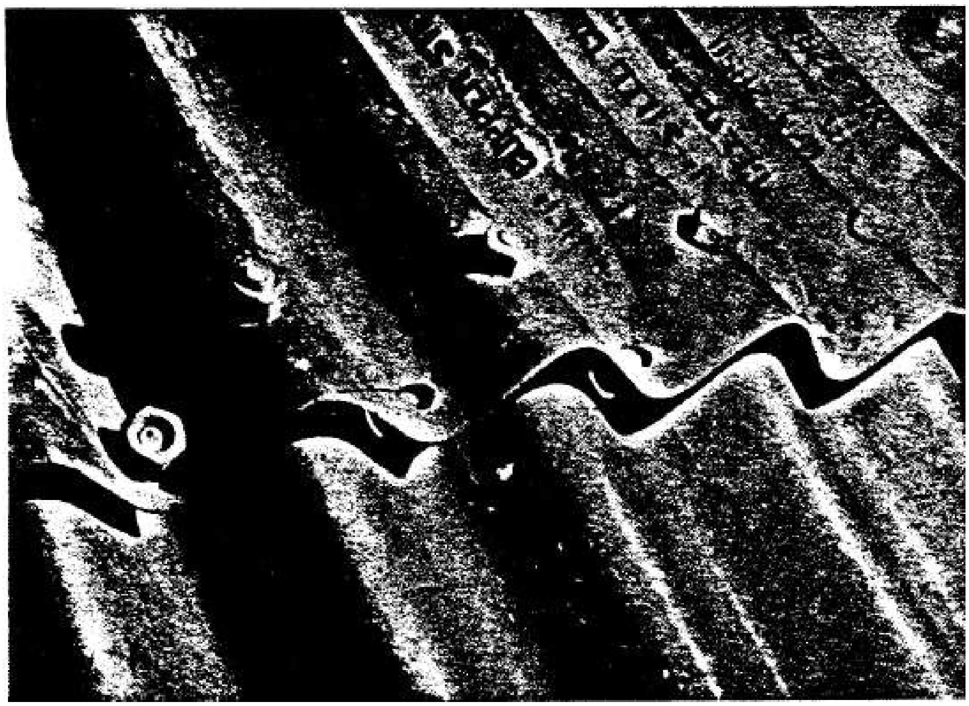


Figure 14.3.11 (Exhibit 69) Close-Up of Loose and Missing Bolts at a Cusped Seam; Loose Fasteners are Usually Detected by Tapping the Nuts with a Hammer

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.

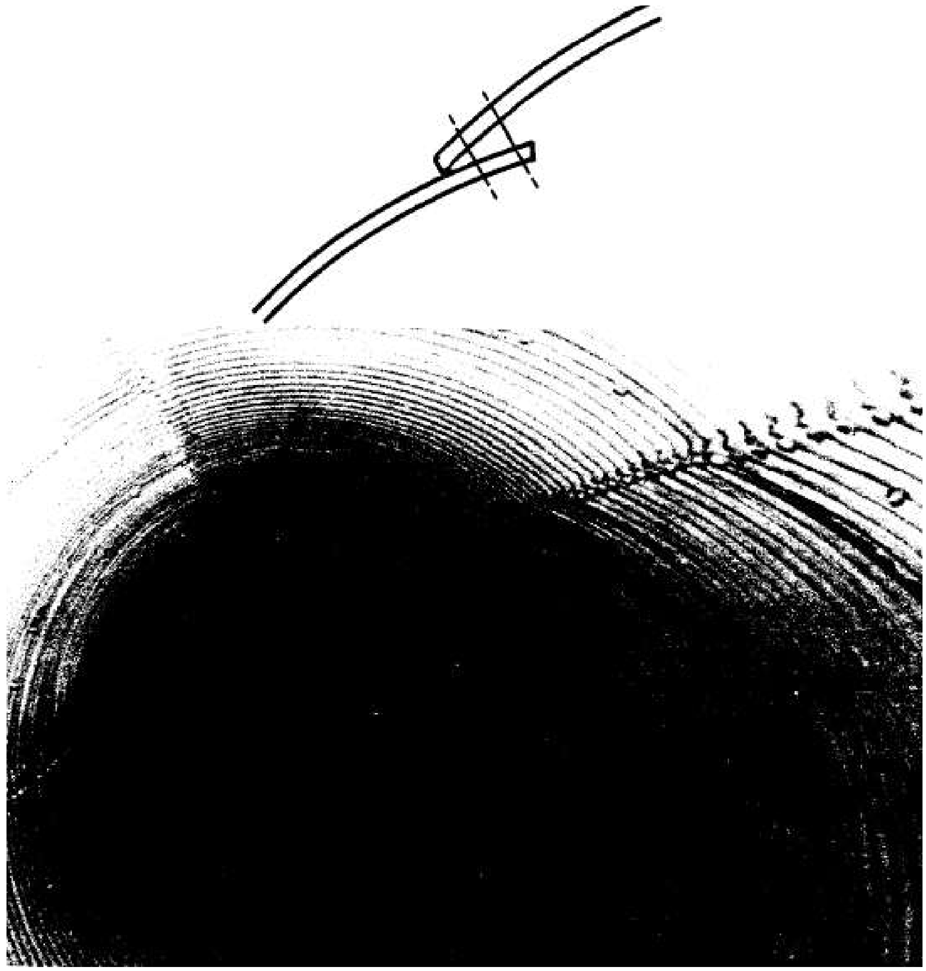


Figure 14.3.12 (Exhibit 70) Cocked Seam with Cusp Effect

(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.

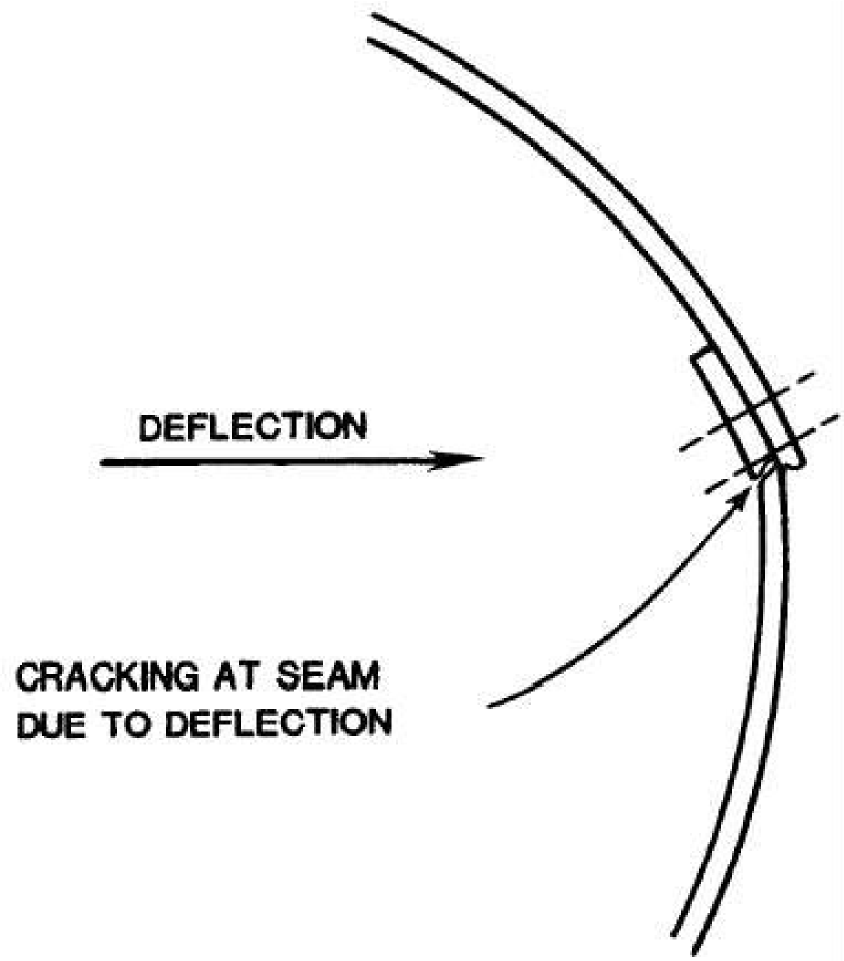


Figure 14.3.13 (Exhibit 71) Cracking Due to Deflection

(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.

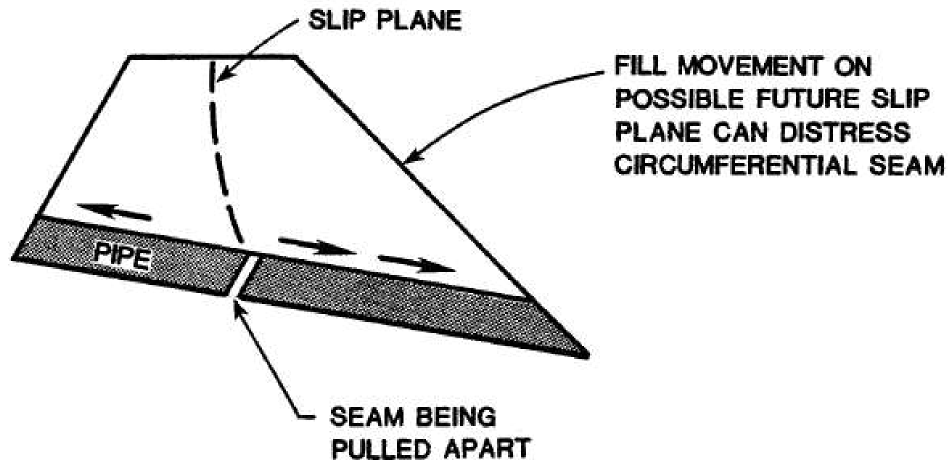


Figure 14.3.14 (Exhibit 72) Circumferential Seam Failure Due to Embankment Slippage

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
5	Generally Fair	Extensive heavy rust, deep pitting, moderate thinning	Significant corrosion moderate attack of core alloy
4	Marginal	Pronounced thinning (some deflection or penetration when struck with pick hammer)	Extensive corrosion significant attack of core alloy
3	Poor	Extensive heavy rust, deep pitting scattered perforations	Extensive corrosion attack of core alloy scattered perforations
2	Critical	Extensive perforations due to rust	Extensive perforations due to corrosion
1	Critical	Invert completely deteriorated	Invert completely deteriorated
0	Critical	Partial or complete collapse	Partial or complete collapse

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

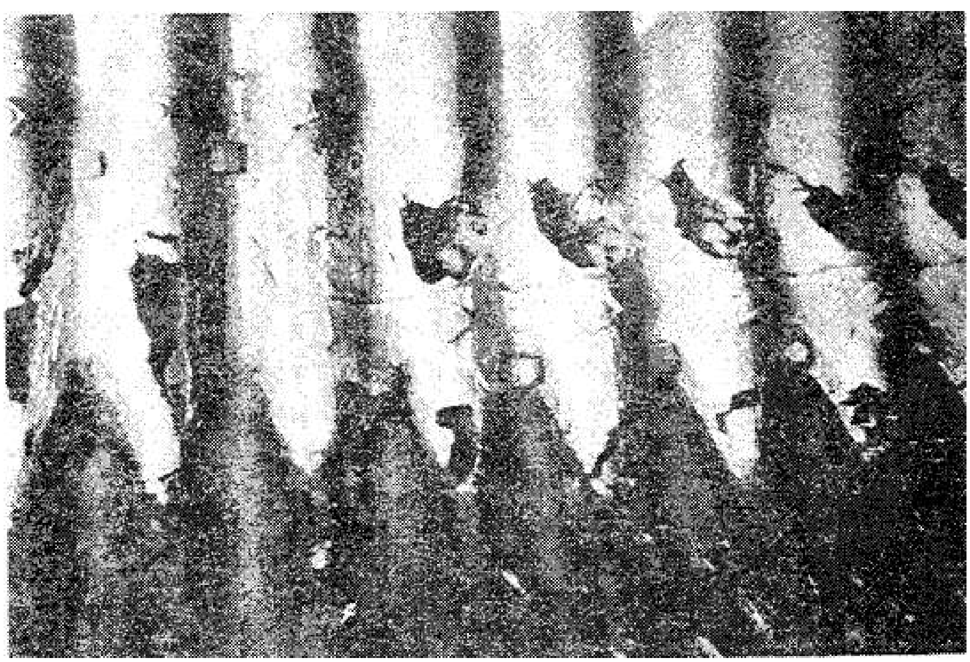


Figure 14.3.16 (Exhibit 74) Perforation of the Invert Due to Corrosion

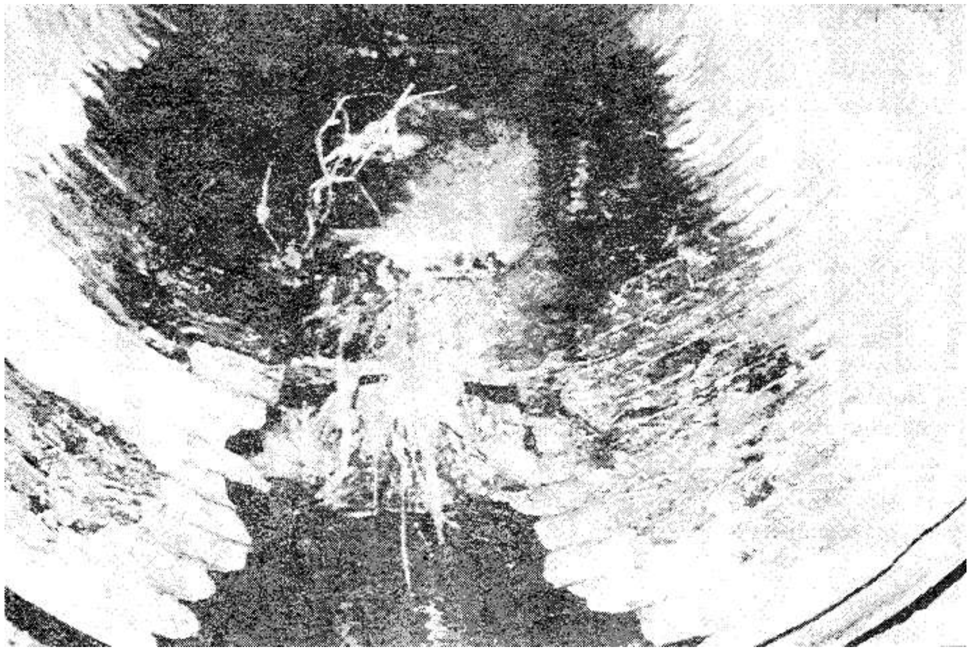


Figure 14.3.17 (Exhibit 75) Invert Deterioration

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.

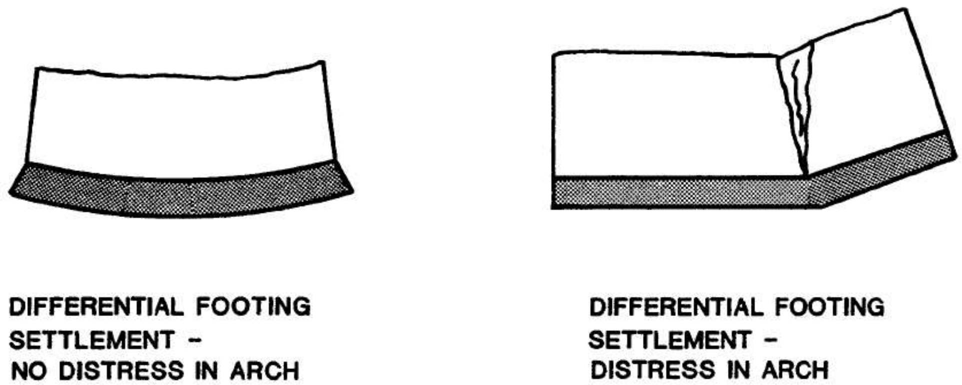


Figure 14.3.18 (Exhibit 76) Differential Footing Settlement

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.

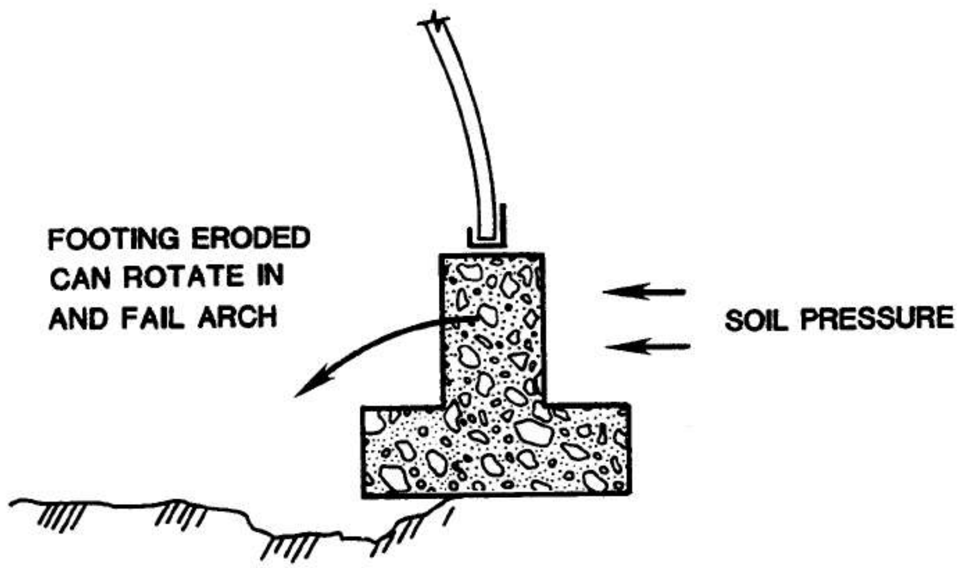


Figure 14.3.19 (Exhibit 77) Footing Rotation due to Undermining

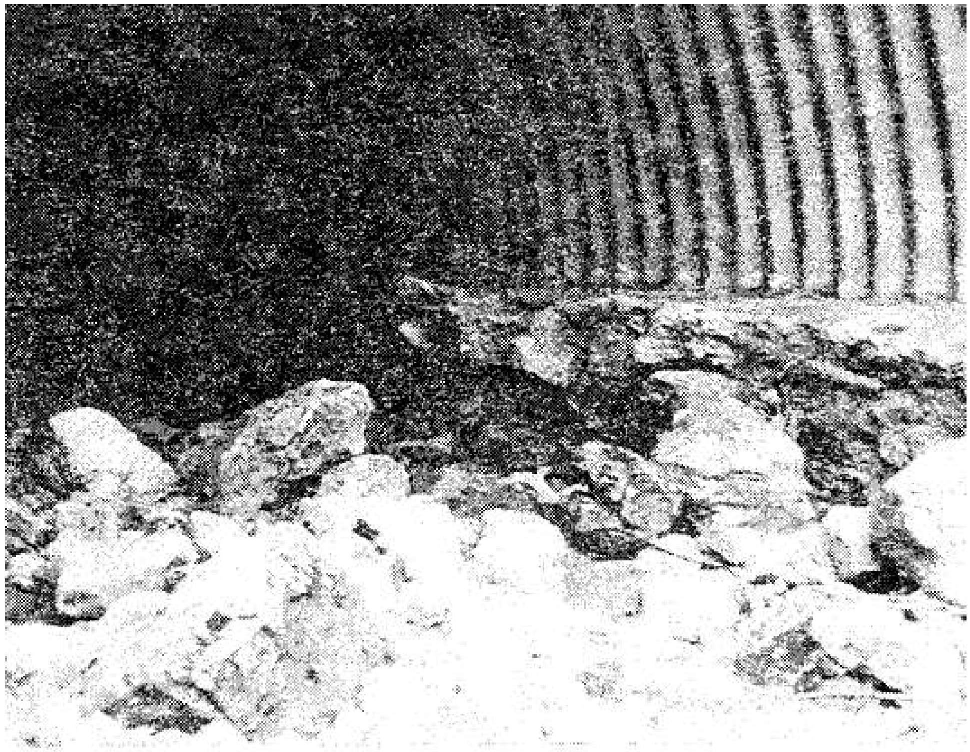


Figure 14.3.20(Exhibit 78) Erosion of Invert Undermining footing of Arch

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.

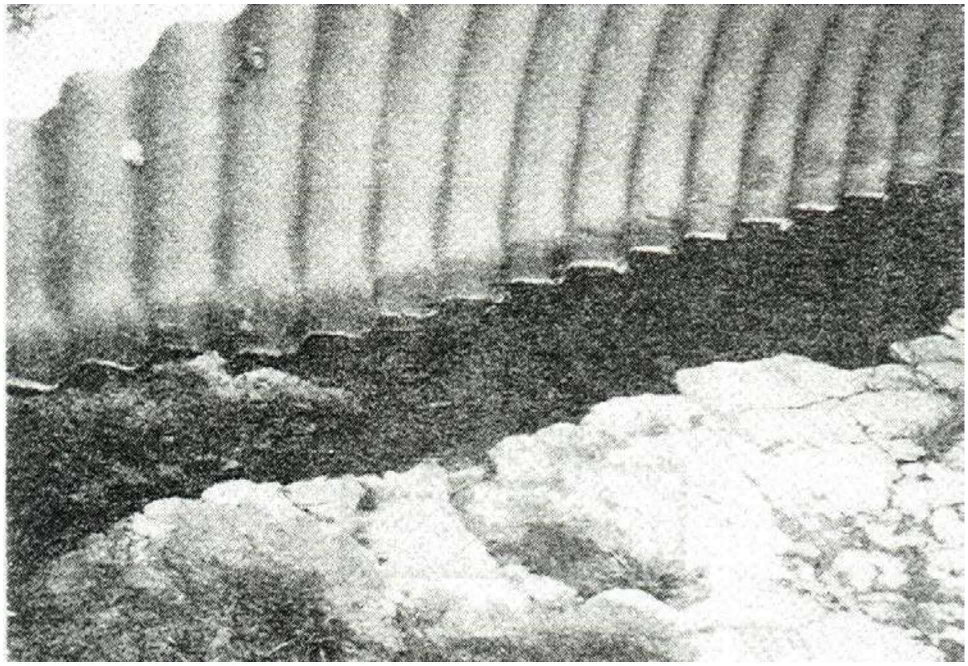


Figure 14.3.21 (Exhibit 79) Erosion Damage to Concrete Invert

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.

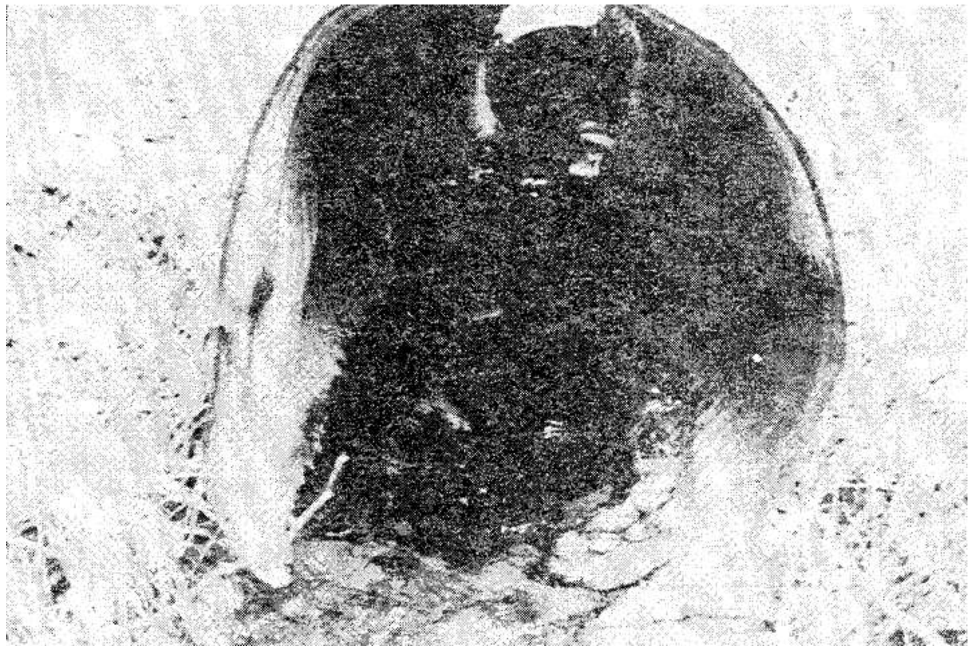
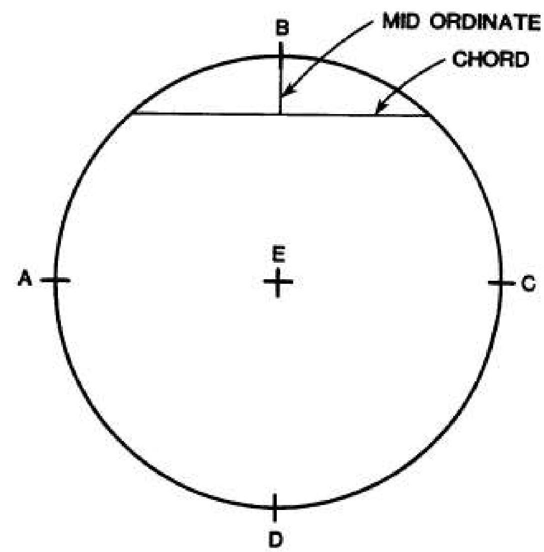


Figure 14.3.22 (Exhibit 80) Excessive Side Deflection

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.



1. MINIMUM MEASUREMENTS REQUIRED:
   - HORIZONTAL DIAMETER = AC
2. IF FLATTENING OBSERVED MEASURE:
   - CHORD AND MID ORDINATE OF FLATTENED AREA
3. IF HORIZONTAL DIAMETER EXCEEDS DESIGN BY MORE THAN 10% MEASURE:
   - VERTICAL DIAMETER = BD

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.

RATING GUIDELINES FOR ROUND OR VERTICAL ELONGATED CORRUGATED METAL PIPE BARRELS

RATING	CONDITION
9	• New condition
8	• <u>Shape</u>: good, smooth curvature in barrel - <u>Horizontal</u>: within 10 percent of design • <u>Seams and Joints</u>: tight, no openings • <u>Metal</u>: - <u>Aluminum</u>: superficial corrosion, slight pitting - <u>Steel</u>: superficial rust, no pitting
7	• <u>Shape</u>: generally good, top half of pipe smooth but minor flattening of bottom - <u>Horizontal Diameter</u>: within 10 percent of design • <u>Seams or Joints</u>: minor cracking at a few bolt holes, minor joint or seam openings, potential for backfill infiltration • <u>Metal</u>: - <u>Aluminum</u>: moderate corrosion, no attack of core alloy - <u>Steel</u>: moderate rust, slight pitting
6	• <u>Shape</u>: fair, top half has smooth curvature but bottom half has flattened significantly - <u>Horizontal Diameter</u>: within 10 percent of design • <u>Seams or Joints</u>: minor cracking at bolts is prevalent in one seam in lower half of pipe. Evidence of backfill infiltration through seams or joints • <u>Metal</u>: - <u>Aluminum</u>: significant corrosion, minor attack of core alloy - <u>Steel</u>: fairly heavy rust, moderate pitting
5	• <u>Shape</u>: generally fair, significant distortion at isolated locations in top half and extreme flattening of invert - <u>Horizontal Diameter</u>: 10 percent to 15 percent greater than design • <u>Seams or Joints</u>: moderate cracking at bolt holes along one seam near bottom of pipe, deflection of pipe caused by backfill infiltration through seams or joints • <u>Metal</u>: - <u>Aluminum</u>: significant corrosion, moderate attack of core alloy - <u>Steel</u>: scattered heavy rust, deep pitting
4	• <u>Shape</u>: marginal significant distortion throughout length of pipe, lower third may be kinked - <u>Horizontal Diameter</u>: 10 percent to 15 percent greater than design • <u>Seams or Joints</u>: Moderate cracking at bolt holes on one seam near top of pipe, deflection caused by loss of backfill through open joints • <u>Metal</u>: - <u>Aluminum</u>: extensive corrosion, significant attack of core alloy - <u>Steel</u>: extensive heavy rust, deep pitting
3	• <u>Shape</u>: poor with extreme deflection at isolated locations, flattening of crown, crown radius 20 to 30 feet - <u>Horizontal Diameter</u>: in excess if 15 percent greater than design • <u>Seams</u>: 3 in. long cracks at bolt holes on one seam • <u>Metal</u>: - <u>Aluminum</u>: extensive corrosion, attack of core alloy, scattered perforations - <u>Steel</u>: extensive heavy rust, deep pitting, scattered perforations
2	• <u>Shape</u>: critical, extreme distortion and deflection throughout pipe, flattening of crown, crown radius over 30 feet - <u>Horizontal Diameter</u>: More than 20 percent greater than design • <u>Seams</u>: plate cracked from bolt to bolt on one seam • <u>Metal</u>: - <u>Aluminum</u>: extensive perforations due to corrosion - <u>Steel</u>: extensive perforations due to rust
1	• <u>Shape</u>: partially collapsed with crown in reverse curve • <u>Seams</u>: failed • <u>Road</u>: closed to traffic
0	• <u>Pipe</u>: totally failed • <u>Road</u>: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.
2. As a starting point, select the lowest rating which matches actual conditions.

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.

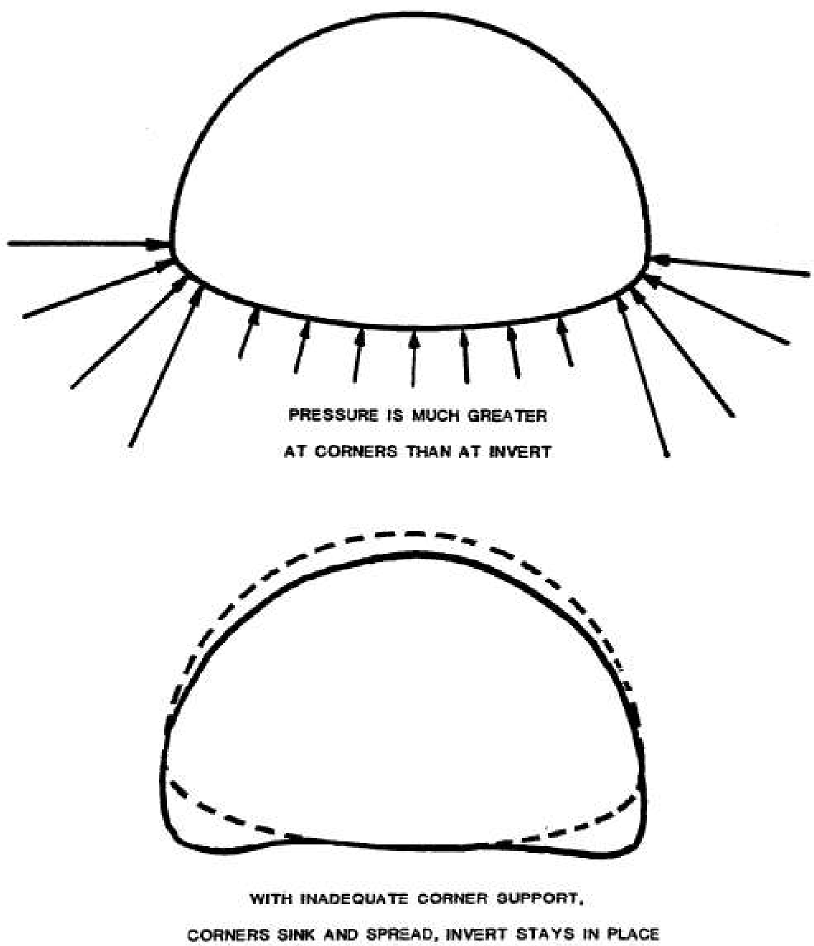


Figure 14.3.25 (Exhibit 83) Bottom Distortion in Pipe Arches

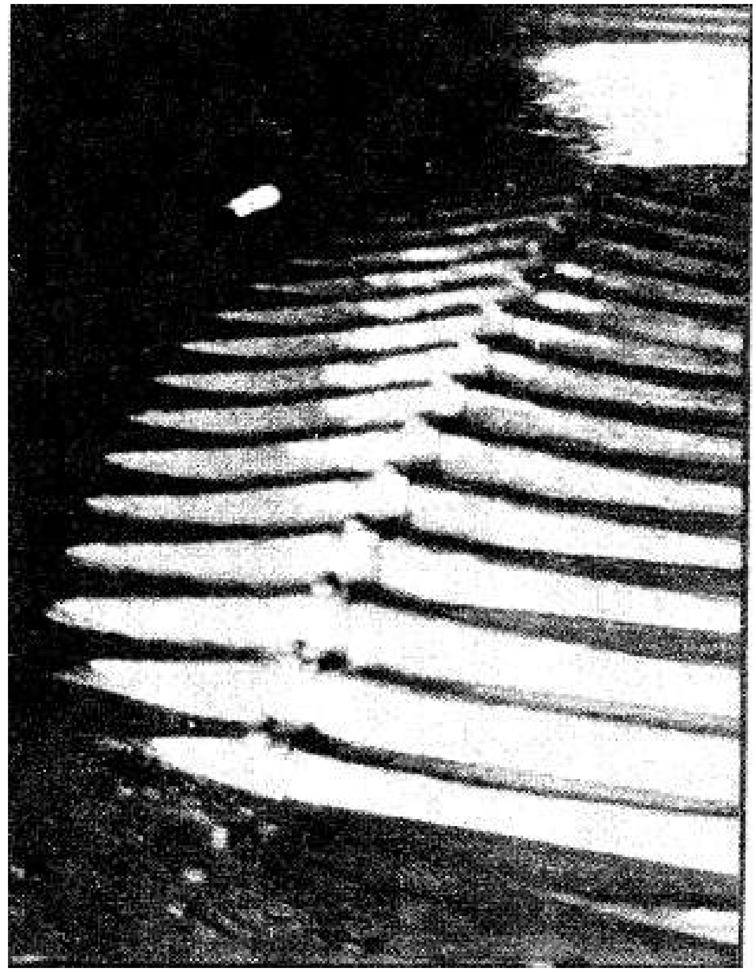


Figure 14.3.26 (Exhibit 84) Bottom and Corners of this Pipe Arch have Settled

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.

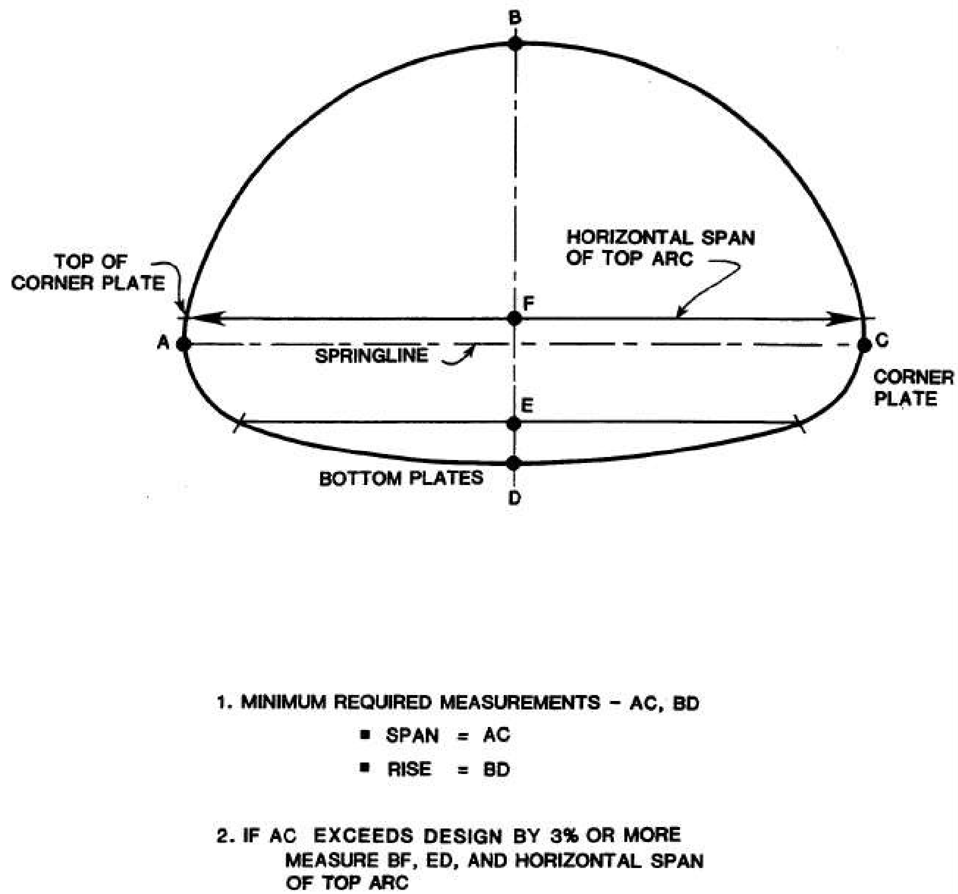


Figure 14.3.27 (Exhibit 85) Shape Inspection Structural Plate Pipe Arch

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.

RATING GUIDELINES FOR CORRUGATED METAL PIPE-ARCH BARRELS

RATING	CONDITION
9	• New condition

8	• Shape: good with smooth curvature
	  - Horizontal Span: less than 3 percent greater than design
	• Joints or Seams: good condition
	• Metal: minor construction defects, protective coatings intact
	  - Aluminum: superficial corrosion, slight pitting
	  - Steel: superficial rust, no pitting

7	• Shape: generally good, smooth curvature in top half, bottom flattened but still curved
	  - Horizontal Span: within 3 to 5 percent greater than design
	• Joints or Seams: minor cracking at a few bolt holes; minor joint or seam openings, infiltration of backfill possible
	• Metal: protective coating ineffective
	  - Aluminum: moderate corrosion, no attack of core alloy
	  - Steel: moderate rust, slight pitting

6	• Shape: fair, smooth curvature in top half, bottom flat
	  - Horizontal Span: 5 percent greater than design
	• Joints or Seams: minor cracking all along one seam; minor joint openings with evidence of infiltration
	• Metal:
	  - Aluminum: significant corrosion, minor attack of core alloy
	  - Steel: fairly heavy rust, moderate pitting

5	• Shape: generally fair, significant distortion in top in one location; bottom has slight reverse curvature in one location
	  - Horizontal Span: within 5 to 7 percent greater than design
	• Joints and Seams: moderate cracking at bolt holes along a seam in one section, backfill being lost through seam or joint causing slight deflection
	• Metal:
	  - Aluminum: significant corrosion, moderate attack of core alloy
	  - Steel: scattered heavy rust, deep pitting

4	• Shape: marginal, significant distortion all along top of arch, bottom has reverse curve
	  - Horizontal Span: more than 7 percent greater than design
	• Joints and Seams: moderate cracking all along one seam; backfill infiltration causing major deflection
	• Metal:
	  - Aluminum: extensive corrosion, significant attack of core alloy
	  - Steel: extensive heavy rust, deep pitting

3	• Shape: poor, extreme deflection in top arch in one section; bottom has reverse curvature throughout
	  - Horizontal Span: more than 7 percent greater than design
	• Seams: seam cracked 3 in. on each side of bolt holes
	• Metal:
	  - Aluminum: extensive corrosion, attack of core alloy, scattered perforations
	  - Steel: extensive heavy rust, deep pitting, scattered perforations

2	• Shape: critical, extreme deflection along top of pipe
	  - Horizontal Span: more than 7 percent greater than design
	• Seams: seam cracked from bolt to bolt down one seam
	• Metal:
	  - Aluminum: extensive perforations due to corrosion
	  - Steel: extensive perforations due to rust

1	• Shape: structure partially collapsed • Seams: seam failed • Road: closed to traffic
0	• Shape: structure collapsed • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.
2. As a starting point, select the lowest rating which matches 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.

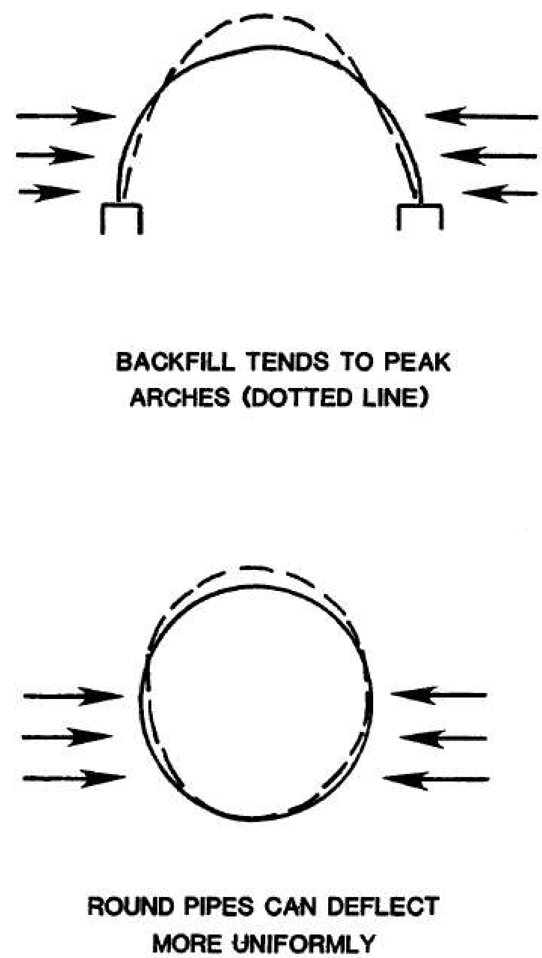


Figure 14.3.29 (Exhibit 87) Arch Deflection During Installation

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.

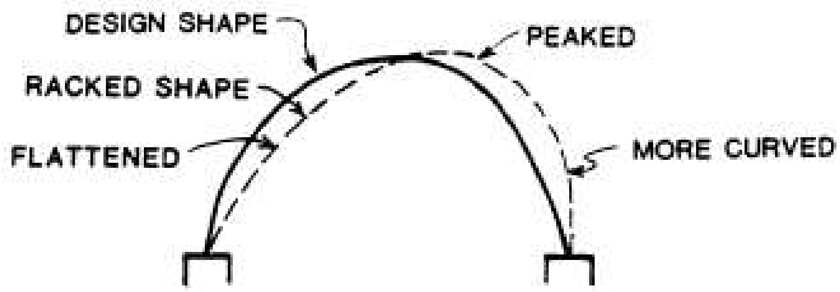


Figure 14.3.30 (Exhibit 88) Racked and Peaked Arch

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.

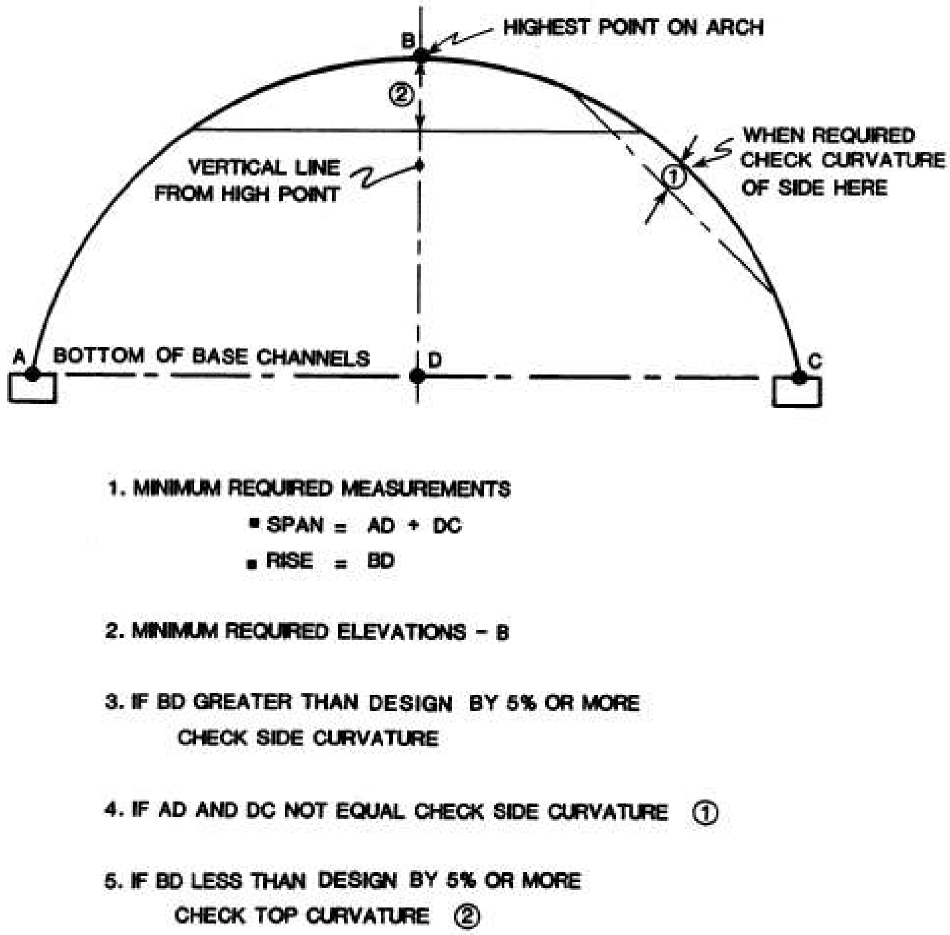


Figure 14.3.31 (Exhibit 89) Shape Inspection Structural Plate Arch

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.

RATING GUIDELINES FOR STRUCTURAL PLATE ARCH BARREL

RATING	CONDITION
9	• New condition
8	• Shape: good, smooth symmetrical curvature • Rise: within ± 3 percent of design • Seams: properly made and tight • Metal: minor defects and damage due to contraction - Aluminum: superficial corrosion, slight pitting - Steel: superficial rust, no pitting • Footings: good with no erosion
7	• Shape: generally good with smooth curvature, symmetrical; slight flattening of top or sides in one section • Rise: within 3 to 4 percent of design • Seams: minor cracking at a few bolt holes; minor seam opening, possibility of soil infiltration • Metal: - Aluminum: moderate corrosion, no attack of core alloy - Steel: moderate rust, slight pitting • Footings: moderate erosion causing differential settlement and minor cracking in footing
6	• Shape: fair, smooth curvature but non-symmetrical; slight flattening of top and sides throughout • Rise: within 4 to 5 percent of design • Seams: minor cracking of bolt holes along one or more seams; evidence of backfill infiltration • Metal: - Aluminum: significant corrosion, minor attack of core alloy - Steel: fairly heavy rust, moderate pitting • Footings: moderate cracking and differential settlement of footing due to extensive erosion
5	• Shape: generally fair, significant distortion and deflection in one section; sides beginning to flattend; non-symetrical • Rise: within 5 to 7 percent of design • Seams: moderate cracking of one seam near footing; infiltration of soil causing slight deflection • Metal: - Aluminum: significant corrosion, moderate attack of core alloy - Steel: scattered heavy rust, deep pitting • Footings: significant undercutting of footing and extreme differential settlement; major cracking in footing
4	• Shape: marginal, significant distortion and deflection throughout; sides flattened with radius 100 percent greater than design • Rise: within 7 to 8 percent of design • Seams: major cracking of seam near crown; infiltration of soil causing major deflection • Metal: - Aluminum: extensive corrosion, significant attack of core alloy - Steel: extensive heavy rust, deep pitting • Footings: rotated due to erosion and undercutting; settlement has caused damage to metal arch
3	• Shape: poor, extreme distortion and deflection in one section; sides virtually flattened; extremely non-symetrical • Rise: within 8 to 10 percent of design • Seams: cracked 3" to either side of bolts • Metal: - Aluminum: extensive corrosion, attack of core alloy, scattered perforations - Steel: extensive heavy rust, deep pitting, scattered perforations • Footing: rotated, severely undercut; major cracking and spalling
2	• Shape: critical, extreme deflection, throughout; sides flattened; extremely non-symetrical • Rise: greater than 10 percent of design • Seams: cracked from bolt to bolt; significant amounts of backfill infiltration • Metal: - Aluminum: extensive perforations due to corrosion - Steel: extensive perforations due to rust • Footing: severe differential settlement has caused distortion and kinking of metal arch
1	• Shape: severe due to partial collapse; local reverse curve of crown and sides • Seams: failed, backfill pushing in • Road: closed to traffic
0	• Structure: completely collapsed • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.
2. As a starting point, select the lowest rating which matches actual conditions.

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.

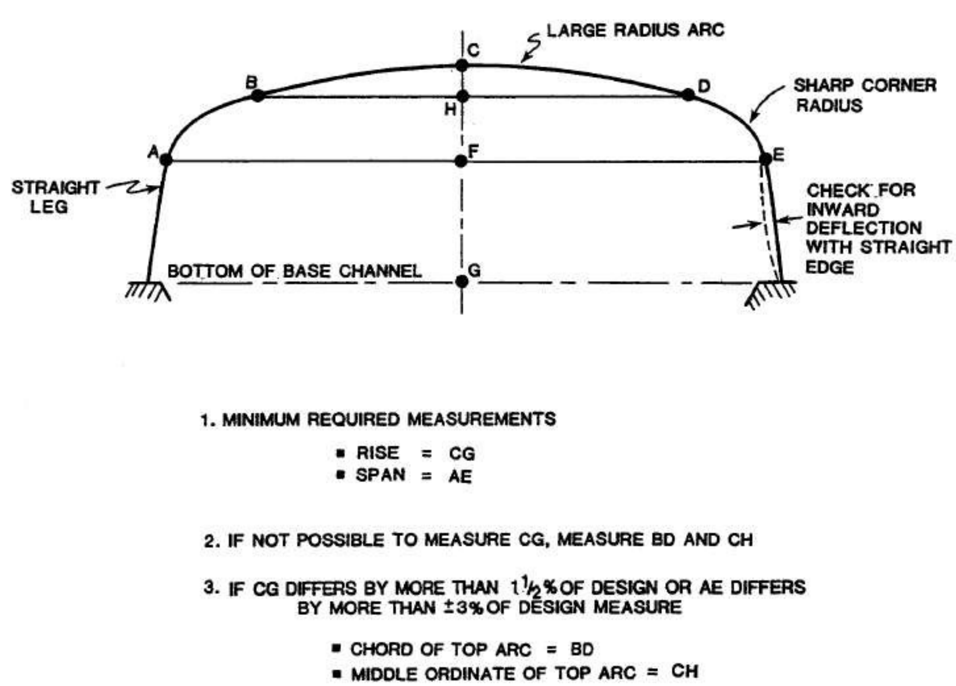


Figure 14.3.33 (Exhibit 91) Shape Inspection Structural Plate Box Culverts

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.

RATING GUIDELINES FOR CORRUGATED METAL BOX CULVERT BARREL

RATING	CONDITION
9	• New condition
8	• Shape: good appearance, smooth symmetrical curvature - Top Arc Mid-Ordinate: within 11 percent of design - Horizontal Span: within 5 percent of design • Sides: straight leg very slightly deflected inward or outward and curvature smooth • Seams: properly made and tight • Metal: minor defects and damage due to construction - Aluminum: superficial corrosion, slight pitting - Steel: superficial rust, no pitting • Footings: good with no erosion
7	• Shape: generally good; curvature is smooth and symmetrical - Top Arc Mid-Ordinate: within 11 percent to 15 percent of design - Horizontal Span: within 5 percent of design • Sides: straight leg slightly deflected inward or moderately deflected outward, curvature smooth • Seams: minor cracking at a few bolt holes; minor seam openings, possibility of backfill infiltration exists • Metal: - Aluminum: moderate corrosion, no attack of core alloy - Steel: moderate rust, slight pitting • Footings: minor differential settlement due to erosion; minor hairline cracking in footing
6	• Shape: smooth curvature, shape is non-symetrical - Top Arc Mid-Ordinate: within 15 percent of design - Horizontal Span: more than + or - 5 percent of design • Sides: straight leg moderately deflected inward or extremely deflected outward, curvature smooth • Seams: minor cracking at bolt holes along one seam; evidence of backfill infiltration • Metal: - Aluminum: significant corrosion, minor attack of core alloy - Steel: fairly heavy rust, moderate pitting • Footing: differential settlement due to extensive erosion; moderate cracking of footing
5	• Shape: generally fair; significant distortion and deflection in one section;half top arcs beginning to flatten; mid-ordinate of half top arc 30 percent less than design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design - Sides: straight leg bowed inward significantly or extremely bowed outward for distance of less than 1/4 span length • Seams: major cracking in one location; infiltration of soil causing slight deflection • Metal: - Aluminum: significant corrosion, moderate attack of core alloy - Steel: scattered heavy rust, deep pitting • Footings: significant undercutting of footing and extreme differential settlement; major cracking of footing
4	• Shape: marginal, significant distortion and deflection throughout; mid-ordinate of half top arc less than 50 percent of design - Top Arc Mid-Ordinate: within 20 to 30 percent of design - Horizontal Span: more than + or - 5 percent of design - Sides: straight leg bowed inward significantly or extremely bowed outward for distance between 1/4 and 1/2 span length, curvature irregular • Seams: significant seam cracking all along seam; infiltration of soil causing major deflection • Metal: - Aluminum: extensive corrosion, significant attack of core alloy - Steel: extensive heavy rust, deep pitting • Footings: rotated due erosion and undercutting; settlement has caused damage to metal arch
3	• Shape: poor extreme distortion and deflection in one section and ordinate of half top arc 50 to 70 percent less than design - Top Arc Mid-Ordinate: 30 to 40 percent less than design - Horizontal Span: more than + or - 6 percent of design Sides: straight leg extremely bowed inward for distance less than 1/2 span length or leg bowed outward severely causing bulges in metal • Seams: cracked 3" or more to either side of bolt; infiltration of backfill causing severe deflection locally • Metal: - Aluminum: extensive corrosion, attack of core alloy, scattered perforations - Steel: extensive heavy rust, deep pitting, scattered perforations • Footing: rotated, severely undercut, major cracking and spalling of footing, significant damage to structure
2	• Shape: critical, extreme distortion and deflection throughout; mid-ordinate of half top arc more than 70 percent less than design - Top Arc Mid-Ordinate: more than 40 percent less than design - Horizontal Span: more then + or - 8 percent of design - Sides: straight leg extremely bowed inward for a distance of 1/2 to 1 span length, or leg bowed outward severely causing bulges or kinking in metal • Seams: cracked from bolt to bolt; significant amounts of backfill infiltration throughout • Metal: - Aluminum: extensive perforations due to corrosion - Steel: extensive perforations due to rust • Footing: severe differential settlement has caused distortion and kinking of metal arch
1	• Shape: severe due to partial collapse; top arc curvature flat or reverse curved • Seams: failed, backfill pushing in • Road closed to traffic
0	• Structure: completely collapsed • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.
2. As a starting point, select the lowest rating which 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.

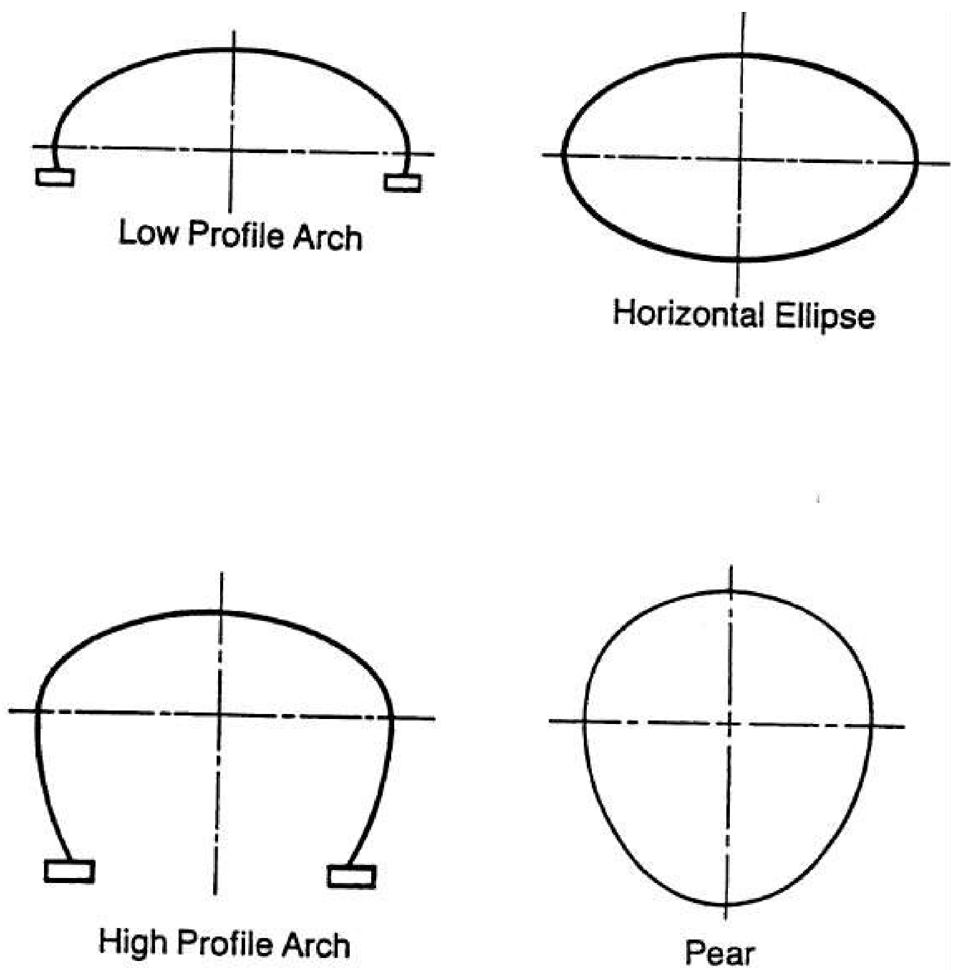


Figure 14.3.35 (Exhibit 93) Typical Long-Span Shapes

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.

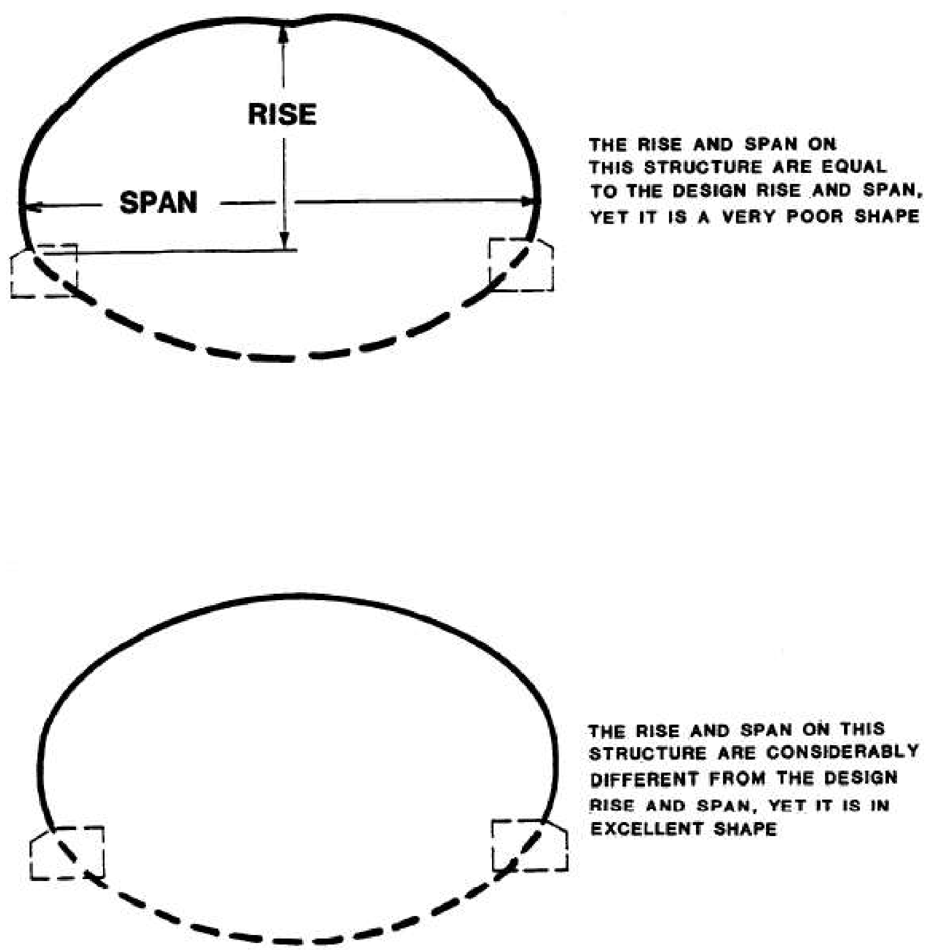


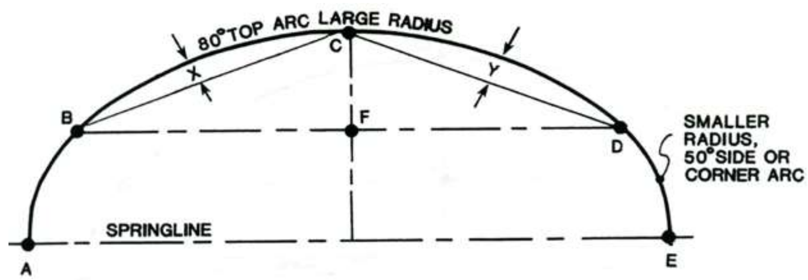
Figure 14.3.36 (Exhibit 94) Erosion Damage to Concrete Invert

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.



1. MINIMUM REQUIRED ELEVATIONS – B, C, D

   MINIMUM REQUIRED MEASUREMENTS –
   - TOP SPAN = AE

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

2. IF CF IS GREATER THAN OR LESS THAN DESIGN BY 10% MEASURE:
   - TOP ARC CHORD = BD

3. IF BD DIFFERS BY MORE THAN 3% FROM DESIGN MEASURE FOR EACH HALF OF TOP ARC
   - HALF TOP ARC MID ORDINATES = X & Y

Note: These measurements and elevations should be obtained on all long span inspections (see exhibits 96, 98, 100 and 103).

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.

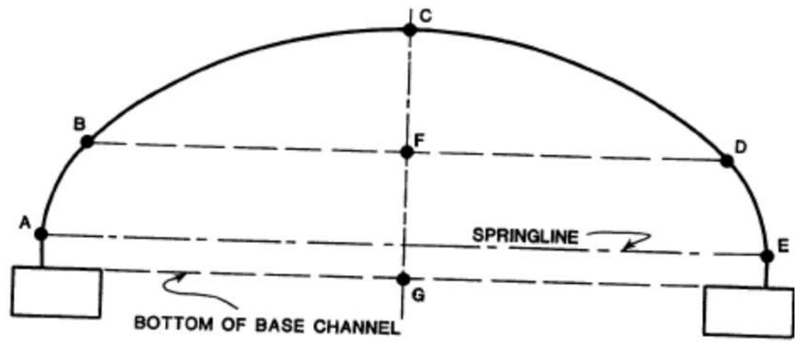
Crown sections in good condition will have a shape appearance that is good, with smooth and symmetrical curvature. The actual middle ordinate should be within 10 percent of the theoretical, and the horizontal span (if measured) should be within five percent of theoretical. Crown sections in fair condition 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.



AE = SPAN, CG = RISE OR HEIGHT

1. MINIMUM REQUIRED MEASUREMENTS -
   - SPAN = AE
   - TOP ARC CHORD = BD
   - RISE = CG
2. MINIMUM REQUIRED ELEVATIONS B, C, D
3. CALCULATE CF FROM ELEVATIONS

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

Note: Use with exhibit 95, crown inspection.

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

RATING GUIDELINES FOR LOW PROFILE ARCH LONG-SPAN CULVERT BARREL

RATING	CONDITION	RATING	CONDITION
9	• New condition	4	• Shape: marginal, significant distortion and deflection throughout; mid-ordinate of half top arc less than 50 percent of design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design • Seams: significant seam cracking all along seam; infiltration of soil causing major deflection • Metal: - Aluminum: extensive corrosion, significant attack of core alloy, - Steel: extensive heavy rust, deep pitting • Footings: rotated due erosion and undercutting; settlement has caused damage to metal arch
8	• Shape: good appearance, smooth symmetrical curvature - Top Arc Mid-Ordinate: within 11 percent of design - Horizontal Span: within 5 percent of design • Seams: properly made and tight • Metal: minor defects and damage due to construction - Aluminum: superficial corrosin, slight pitting - Steel: superficial rust, no pitting • Footings: good with no erosion	3	• Shape: poor extreme distortion and deflection in one section and ordinate of half top arc 50 to 70 percent less than design - Top Arc Mid-Ordinate: 20 to 30 percent less than design - Horizontal Span: more than + or - 6 percent of design • Seams: cracked 3" or more to either side of bolt; infiltration of backfill causing severe deflection locally • Metal: - Aluminum: extensive corrosion, attack of core alloy, scattered perforations - Steel: extensive heavy rust, deep pitting, scattered perforations • Footing: rotated, severely undercut, major cracking and spalling of footing, significant damage to structure
7	• Shape: generally good; curvature is smooth and symmetrical - Top Arc Mid-Ordinate: within 11 percent to 15 percent of design - Horizontal Span: within 5 percent of design • Seams: minor cracking at a few bolt holes; minor seam openings, possibility of backfill infiltration exists • Metal: - Aluminum: moderate corrosion, no attack of core alloy - Steel: moderate rust, slight pitting • Footings: minor differential settlement due to erosion; minor hairline cracking in footing	2	• Shape: critical, extreme distortion and deflection throughout; mid-ordinate of half top arc more than 70 percent less than design - Top Arc Mid-Ordinate: more than 30 percent less than design - Horizontal Span: more then + or - 8 percent of design • Seams: cracked from bolt to bolt; significant amounts of backfill infiltration throughout • Metal: - Aluminum: extensive perforations due to corrosion - Steel: extensive perforations due to rust • Footing: severe differential settlement has caused distortion and kinking of metal arch
6	• Shape: smooth curvature, shape is non-symetrical - Top Arc Mid-Ordinate: within 15 percent of design - Horizontal Span: more than + or - 5 percent of design • Seams: minor cracking at bolt holes along one seam; evidence of backfill infiltration • Metal: - Aluminum: significant corrosion, minor attack of core allow - Steel: fairly heavy rust, moderate pitting • Footing: differential settlement due to extensive erosion; moderate cracking of footing	1	• Shape: severe due to partial collapse; top arc curvature flat or reverse curved • Seams: failed, backfill pushing in • Road closed to traffic
5	• Shape: generally fair; significant distortion and deflection in one section;half top arcs beginning to flatten; mid-ordinate of half top arc 30 percent less than design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design • Seams: major cracking in one location; infiltration of soil causing slight deflection • Metal: - Aluminum: significant corrosion, moderate attack of core alloy - Steel: scattered heavy rust, deep pitting • Footings: significant undercutting of footing and extreme differential settlement; major cracking of footing	0	• Structure: completely collapsed • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.
2. As a starting point, select the lowest rating which matches actual conditions.

Figure 14.3.39 (Exhibit 97) Condition Rating Guidelines

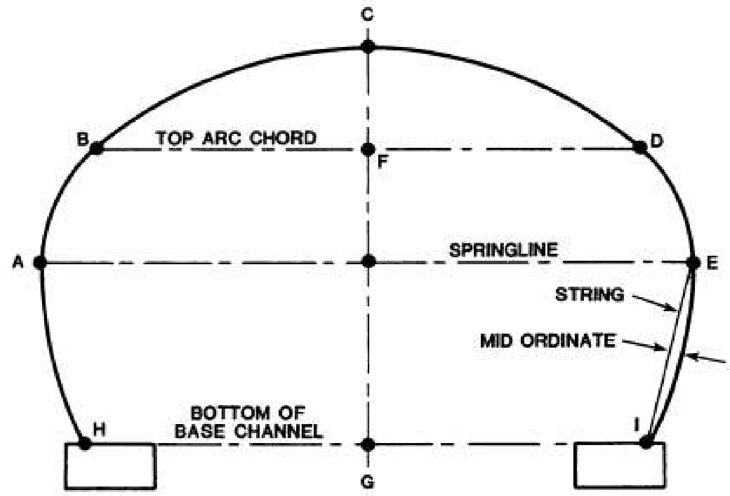
Because arches are fixed on concrete footings, backfill pressures will try to flatten the sides and peak the top. Another important shape factor is symmetry. If the base channels are not square to the centerline of the structure racking may occur during erection. In racked structures, the crown moves 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

RATING GUIDELINES FOR HIGH PROFILE ARCH LONG-SPAN CULVERT BARREL

RATING	CONDITION
9	• New condition
8	• Shape: good appearance, smooth symmetrical curvature - Top Arc Mid-Ordinate: within 11 percent of design - Horizontal Span: within 5 percent of design - Side Plates: smooth curvature • Seams: properly made and tight • Metal: minor defects and damage due to construction - Aluminum: superficial corrosion, slight pitting - Steel: superficial rust, no pitting • Footings: good with no erosion
7	• Shape: generally good; curvature is smooth and symmetrical - Top Arc Mid-Ordinate: within 11 percent to 15 percent of design - Horizontal Span: within 5 percent of design - Side Plates: side flattened, mid-ordinate less than 50 percent of design • Seams: minor cracking at a few bolt holes; minor seam openings, possibility of backfill infiltration exists • Metal: - Aluminum: moderate corrosion, no attack of core alloy - Steel: moderate rust, slight pitting • Footings: minor differential settlement due to erosion; minor hairline cracking in footing
6	• Shape: smooth curvature, shape is non-symetrical - Top Arc Mid-Ordinate: within 15 percent of design - Horizontal Span: more than + or - 5 percent of design - Side Plates: side flattened, mid-ordinate less than 35 percent of design • Seams: minor cracking at bolt holes along one seam; evidence of backfill infiltration • Metal: - Aluminum: significant corrosion, minor attack of core alloy - Steel: fairly heavy rust, moderate pitting • Footing: differential settlement due to extensive erosion; moderate cracking of footing
5	• Shape: generally fair; significant distortion and deflection in one section;half top arcs beginning to flatten; mid-ordinate of half top arc 30 percent less than design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design - Side Plates: side flattened, mid-ordinate less than 25 percent of design • Seams: major cracking in one location; infiltration of soil causing slight deflection • Metal: - Aluminum: significant corrosion, moderate attack of core alloy - Steel: scattered heavy rust, deep pitting • Footings: significant undercutting of footing and extreme differential settlement; major cracking of footing
4	• Shape: marginal, significant distortion and deflection throughout; mid-ordinate of half top arc less than 50 percent of design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design - Side Plates: side flattened, mid-ordinate less than 20 percent of design • Seams: significant seam cracking all along seam; infiltration of soil causing major deflection • Metal: - Aluminum: extensive corrosion, significant attack of core alloy - Steel: extensive heavy rust, deep pitting • Footings: rotated due erosion and undercutting; settlement has caused damage to metal arch
3	• Shape: poor extreme distortion and deflection in one section and ordinate of half top arc 50 to 70 percent less than design - Top Arc Mid-Ordinate: 20 to 30 percent less than design - Horizontal Span: more than + or - 6 percent of design - Side Plates: side flattened, mid-ordinate less than 12 percent of design • Seams: cracked 3" or more to either side of bolt; infiltration of backfill causing severe deflection locally • Metal: - Aluminum: extensive corrosion, attack of core alloy, scattered perforations - Steel: extensive heavy rust, deep pitting, scattered perforations • Footing: rotated, severely undercut, major cracking and spalling of footing, significant damage to structure
2	• Shape: critical, extreme distortion and deflection throughout; mid-ordinate of half top arc more than 70 percent less than design - Top Arc Mid-Ordinate: more than 30 percent less than design - Horizontal Span: more then + or - 8 percent of design - Side Plates: side flattened, mid-ordinate less than10percent of design • Seams: cracked from bolt to bolt; significant amounts of backfill infiltration throughout • Metal: - Aluminum: extensive perforations due to corrosion - Steel: extensive perforations due to rust • Footing: severe differential settlement has caused distortion and kinking of metal arch
1	• Shape: severe due to partial collapse; top arc curvature flat or reverse curved - Side Plates: side flat or reversed curved • Seams: failed, backfill pushing in • Road closed to traffic
0	• Structure: completely collapsed • Road: closed to traffic

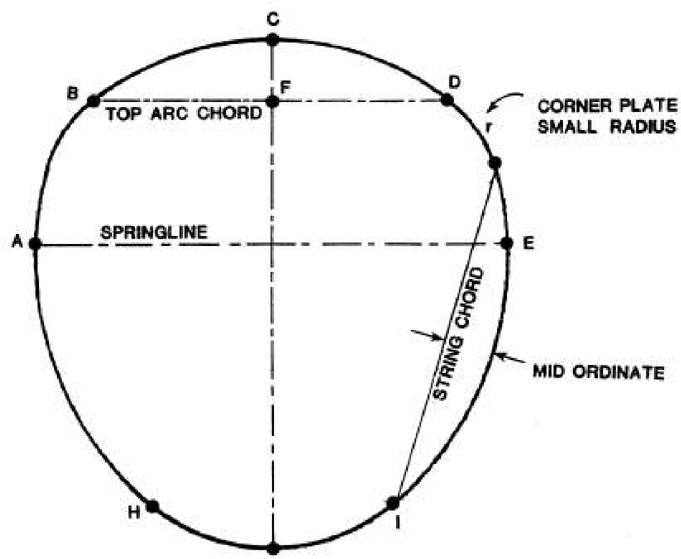
NOTES: 1. See Coding Guide for description of Rating Scale.
2. As a starting point, select the lowest rating which matches actual conditions.

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

RATING GUIDELINES FOR PEAR SHAPED LONG-SPAN CULVERT BARREL

RATING	CONDITION
9	• New condition
8	• Shape: good appearance, smooth symmetrical curvature - Top Arc Mid-Ordinate: within 11 percent of design - Horizontal Span: within 5 percent of design - Side Plates: smooth curvature • Seams: properly made and tight • Metal: minor defects and damage due to construction; superficial corrosion with no pitting - Aluminum: superficial corrosion, slight pitting - Steel: superficial rust, no pitting
7	• Shape: generally good; curvature is smooth and symmetrical - Top Arc Mid-Ordinate: within 11 percent to 15 percent of design - Horizontal Span: within 5 percent of design - Side Plates: side flattened, mid-ordinate less than 50 percent of design • Seams: minor cracking at a few bolt holes; minor seam openings, possibility of backfill infiltration exists • Metal: - Aluminum: moderate corrosion, no attack of core alloy - Steel: moderate rust, slight pitting
6	• Shape: smooth curvature, shape is non-symetrical - Top Arc Mid-Ordinate: within 15 percent of design - Horizontal Span: more than + or - 5 percent of design - Side Plates: side flattened, mid-ordinate less than 35 percent of design • Seams: minor cracking at bolt holes along one seam; evidence of backfill infiltration • Metal: - Aluminum: significant corrosion, minor attack of core alloy - Steel: fairly heavy rust, moderate pitting
5	• Shape: generally fair; significant distortion and deflection in one section;half top arcs beginning to flatten; mid-ordinate of half top arc 30 percent less than design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design - Side Plates: side flattened, mid-ordinate less than 25 percent of design • Seams: major cracking in one location; infiltration of soil causing slight deflection • Metal: corroded locally - Aluminum: significant corrosion, moderate attack of core alloy - Steel: scattered heavy rust, deep pitting
4	• Shape: marginal, significant distortion and deflection throughout; mid-ordinate of half top arc less than 50 percent of design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design - Side Plates: side flattened, mid-ordinate less than 20 percent of design • Seams: significant seam cracking all along seam; infiltration of soil causing major deflection • Metal: - Aluminum: extensive corrosion, significant attack of alloy - Steel: extensive heavy rust, deep pitting
3	• Shape: poor extreme distortion and deflection in one section and ordinate of half top arc 50 to 70 percent less than design - Top Arc Mid-Ordinate: 20 to 30 percent less than design - Horizontal Span: more than + or - 6 percent of design - Side Plates: side flattened, mid-ordinate less than 12 percent of design • Seams: cracked 3" or more to either side of bolt; infiltration of backfill causing severe deflection locally • Metal: - Aluminum: extensive corrosion, attack of core alloy, scattered perforations - Steel: extensive heavy rust, deep pitting, scattered perforations
2	• Shape: critical, extreme distortion and deflection throughout; mid-ordinate of half top arc more than 70 percent less than design - Top Arc Mid-Ordinate: more than 30 percent less than design - Horizontal Span: more then + or - 8 percent of design - Side Plates: side flattened, mid-ordinate less than10percent of design • Seams: cracked from bolt to bolt; significant amounts of backfill infiltration throughout • Metal: - Aluminum: extensive perforations due to corrosion - Steel: extensive perforations due to rust
1	• Shape: severe due to partial collapse; top arc curvature flat or reverse curved - Side Plates: side flat or reversed curved - Seams: failed, backfill pushing in • Road closed to traffic
0	• Structure: completely collapsed • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.
2. As a starting point, select the lowest rating which 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.

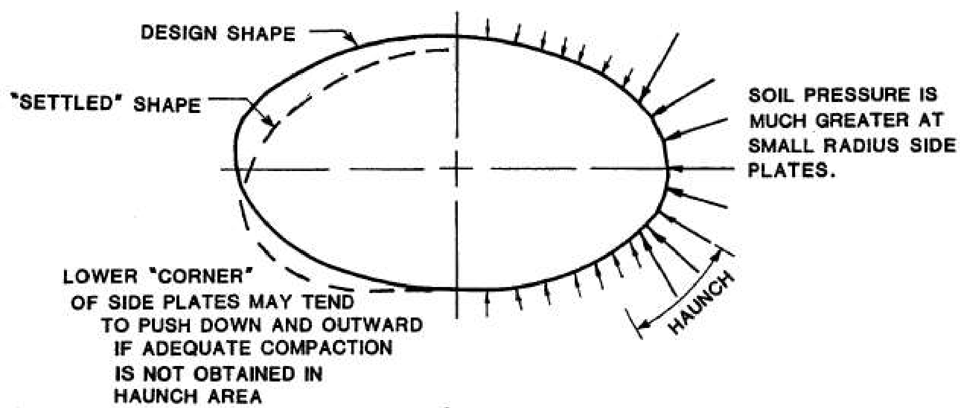
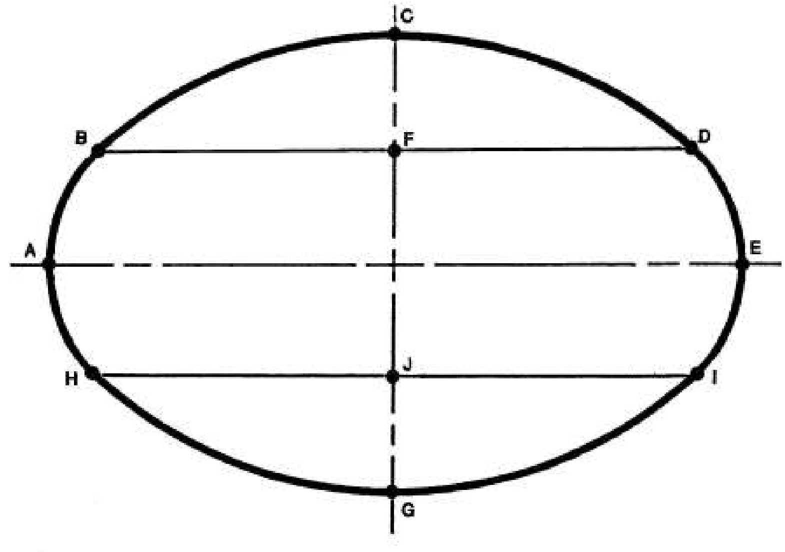


Figure 14.3.44 (Exhibit 102) Potential for Differential Settlement in Horizontal Ellipse

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.



1. MINIMUM REQUIRED MEASUREMENTS
   - SPAN = AE

2. MINIMUM REQUIRED ELEVATIONS – B, C, D, G (IF POSSIBLE)

3. WHEN BOTTOM FLATTENING IS OBSERVED, CHECK CURVATURE, MEASURE
   - BOTTOM ARC CHORD = HI
   - BOTTOM ARC MIDDLE ORDINATE = JG

Note: Use with exhibit 95, crown inspection.

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

RATING GUIDELINES FOR HORIZONTAL ELLIPSE LONG SPAN CULVERT BARREL

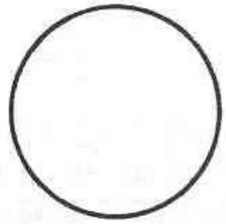
RATING	CONDITION
9	• New condition
8	• Shape: good appearance, smooth symmetrical curvature - Top Arc Mid-Ordinate: within 11 percent of design - Horizontal Span: within 5 percent of design - Bottom Arc: smooth curvature, mid-ordinate within 50 percent of design • Seams: properly made and tight • Metal: minor defects and damage due to construction - Aluminum: superficial corrosion, slight pitting - Steel: superficial rust, no pitting • Footings: good with no erosion
7	• Shape: generally good; curvature is smooth and symmetrical - Top Arc Mid-Ordinate: within 11 percent to 15 percent of design - Horizontal Span: within 5 percent of design - Bottom Arc: bottom flattened, mid-ordinate less than 50 percent of design • Seams: minor cracking at a few bolt holes; minor seam openings, possibility of backfill infiltration exists • Metal: - Aluminum: moderate corrosion, no attack of core alloy - Steel: moderate rust, slight pitting • Footings: minor differential settlement due to erosion; minor hairline cracking in footing
6	• Shape: smooth curvature, shape is non-symetrical - Top Arc Mid-Ordinate: within 15 percent of design - Horizontal Span: more than + or - 5 percent of design - Bottom Arc: bottom flattened and irregular, mid-ordinate less than 50 percent of design • Seams: minor cracking at bolt holes along one seam; evidence of backfill infiltration • Metal: - Aluminum: significant corrosion, minor attack of core alloy - Steel: fairly heavy rust, moderate pitting • Footing: differential settlement due to extensive erosion; moderate cracking of footing
5	• Shape: generally fair; significant distortion and deflection in one section;half top arcs beginning to flatten; mid-ordinate of half top arc 30 percent less than design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design - Bottom Arc: bottom virtually flat over center half of arc • Seams: major cracking in one location; infiltration of soil causing slight deflection • Metal: - Aluminum: significant corrosion, moderate attack of core alloy - Steel: scattered heavy rust, deep pitting • Footings: significant undercutting of footing and extreme differential settlement; major cracking of footing
4	• Shape: marginal, significant distortion and deflection throughout; mid-ordinate of half top arc less than 50 percent of design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design - Bottom Arc: bottom virtually flat over center half of arc and deflected down at corners • Seams: significant seam cracking all along seam; infiltration of soil causing major deflection • Metal: - Aluminum: extensive corrosion, significant attack of alloy - Steel: extensive heavy rust, deep pitting • Footings: rotated due erosion and undercutting; settlement has caused damage to metal arch
3	• Shape: poor extreme distortion and deflection in one section and ordinate of half top arc 50 to 70 percent less than design - Top Arc Mid-Ordinate: 20 to 30 percent less than design - Horizontal Span: more than + or - 6 percent of design - Bottom Arc: bottom reverse curved in center • Seams: cracked 3" or more to either side of bolt; infiltration of backfill causing severe deflection locally • Metal: - Aluminum: extensive corrosion, attack of core alloy, scattered perforations - Steel: extensive heavy rust, deep pitting, scattered perforations • Footing: rotated, severely undercut, major cracking and spalling of footing, significant damage to structure
2	• Shape: critical, extreme distortion and deflection throughout; mid-ordinate of half top arc more than 70 percent less than design - Top Arc Mid-Ordinate: more than 30 percent less than design - Horizontal Span: more then + or - 8 percent of design - Bottom Arc: bottom reversed curved in center and bulged out at sides • Seams: cracked from bolt to bolt; significant amounts of backfill infiltration throughout • Metal: - Aluminum: extensive perforations due to corrosion - Steel: extensive perforations due to rust • Footing: severe differential settlement has caused distortion and kinking of metal arch
1	• Shape: severe due to partial collapse; top arc curvature flat or reverse curved • Seams: failed, backfill pushing in • Road closed to traffic
0	• Structure: completely collapsed • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.
2. As a starting point, select the lowest rating which matches actual conditions.

Figure 14.3.46 (Exhibit 104) Condition Rating Guidelines

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS

ROUND



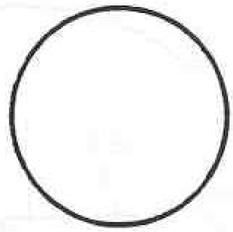
Handling Weight of Corrugated Steel Pipe (2⅔ × ½ in.)
Estimated Average Weights—Not for Specification Use*

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

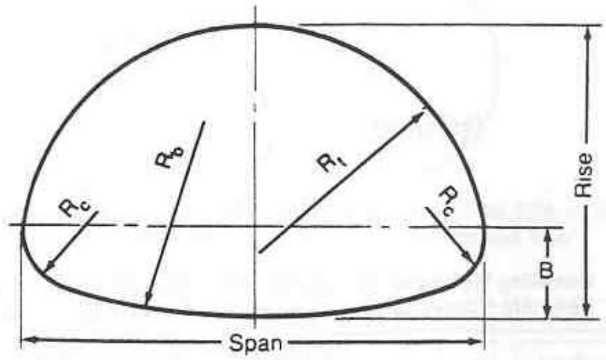


Handling Weight of Corrugated Steel Pipe (3 × 1 in. or 5 × 1 in.)***
Estimated Average Weights—Not for Specification Use

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.	Layout Dimensions R_c in.	Layout Dimensions R_t in.	Layout Dimensions 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

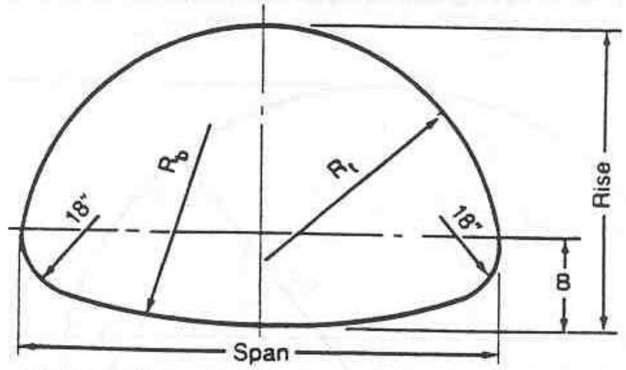
Dimensions shown not for specification purposes, subject to manufacturing tolerances.

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.	Layout Dimensions R_c in.	Layout Dimensions R_t in.	Layout Dimensions 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

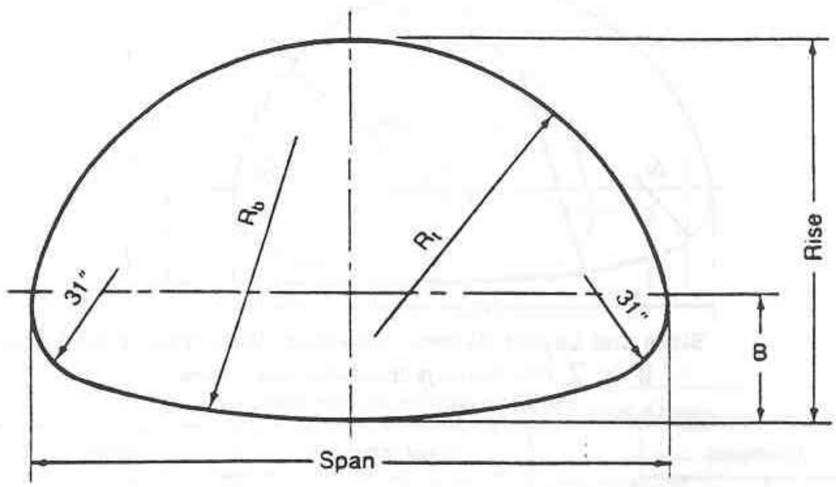


Sizes and Layout Details—Structural Plate Steel Pipe-Arches
6 × 2 in. Corrugations—Bolted Seams
18-inch Corner Radius *Rc*

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



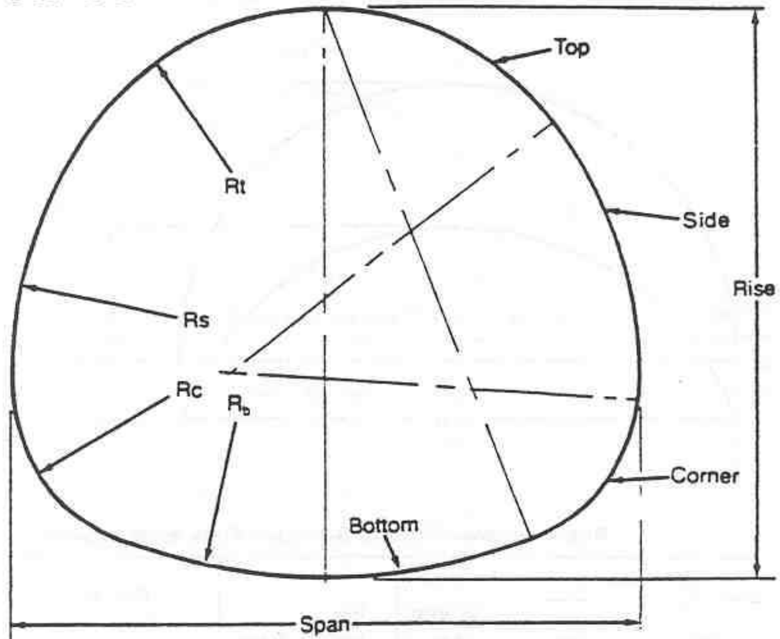
Sizes and Layout Details—Structural Plate Steel Pipe-Arches[11]
6 × 2 in. Corrugations—Bolted Seams
31-in Corner Radius, R_c

Dimensions		Waterway Area, ft²	Layout Dimensions			Periphery		
Span, ft-in.	Rise, ft-in.		B in.	R_t ft	R_b ft	No. of Plates	Total N	Total 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



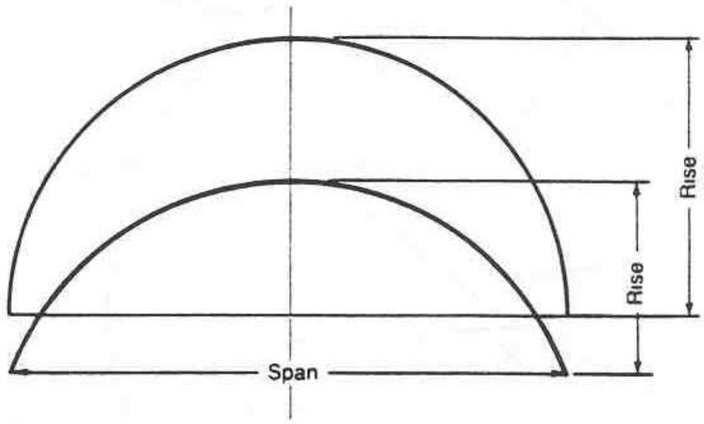
Structural Plate Steel Underpasses
Sizes and Layout Details

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] Span, ft	Rise, ft-in.	Waterway Area, ft^2	Rise over Span[2]	Radius, in.	Nominal Arc Length 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

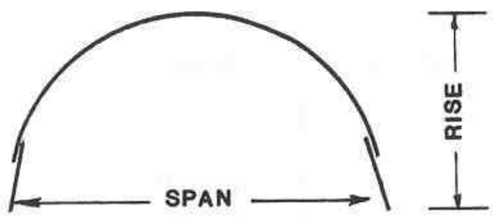
(Table continued on following page)

[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



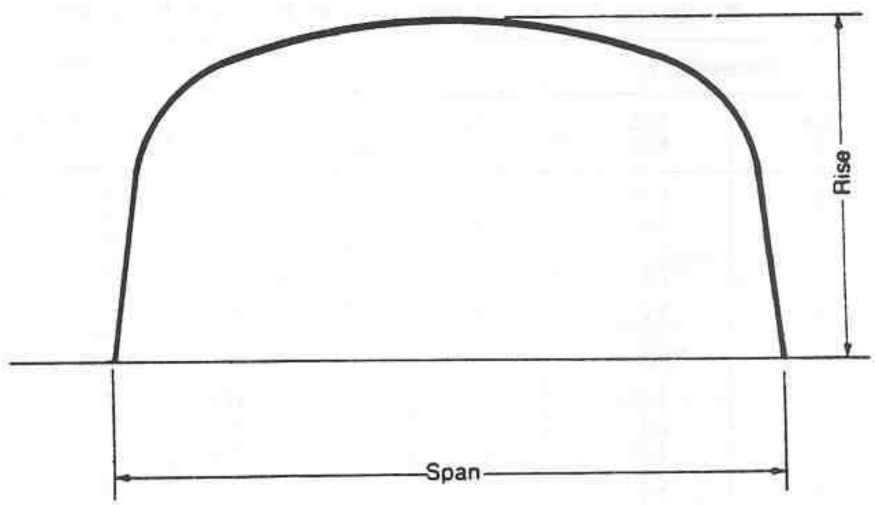
Continued. Representative Sizes of Structural Plate Steel Arches

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.
(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



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

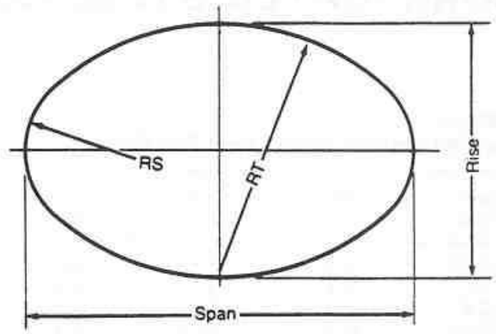
STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS

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

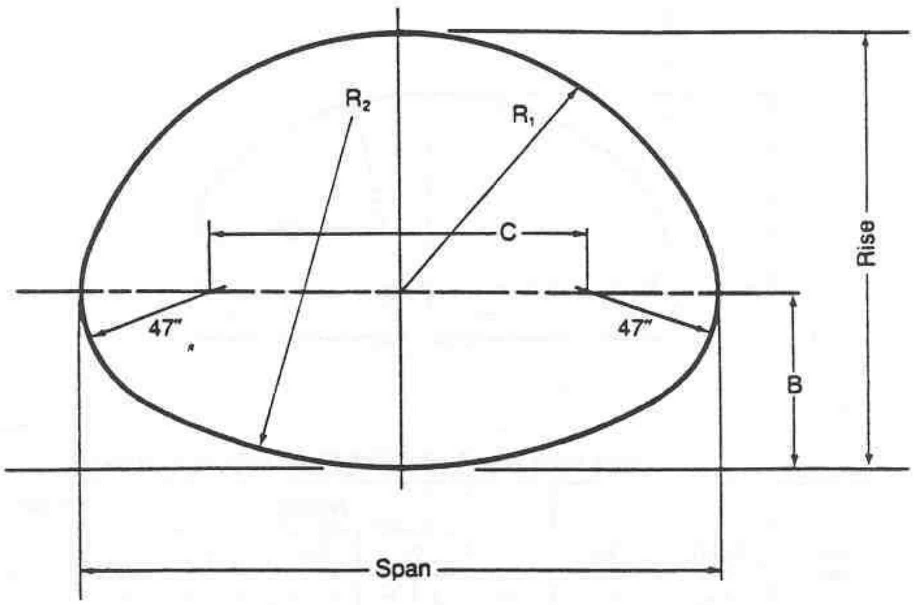


Long Span Horizontal Ellipse Sizes and Layout Details

Span, ft-in.	Rise, ft-in.	Area, ft²	Periphery: Top or Bottom N	Periphery: Top or Bottom Pi	Periphery: Side N	Periphery: Side Pi	Periphery: Total N	Periphery: Total Pi	Inside Radius: Top Rad. in.	Inside Radius: Side Rad. in.
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



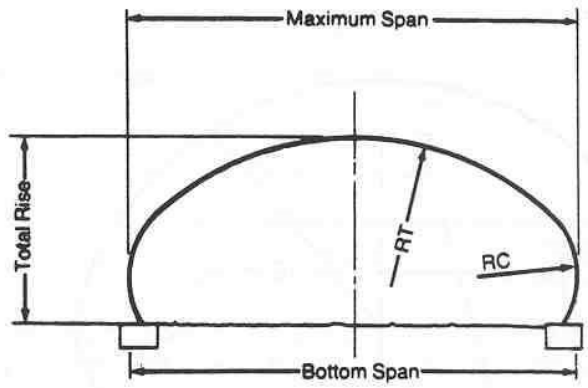
Long Span Pipe Arch Sizes and Layout Details

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



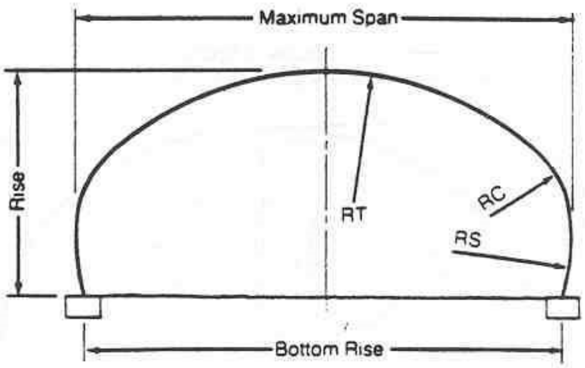
Long Span Low Profile Arch Sizes and Layout Details

Max. Span, ft-in.	Bottom Span, ft-in.	Total Rise, ft-in.	Area, ft²	Periphery: Top N	Top Pi	Side N	Side Pi	Total N	Total Pi	Inside Radius: Top rad. in.	Side rad. in.
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



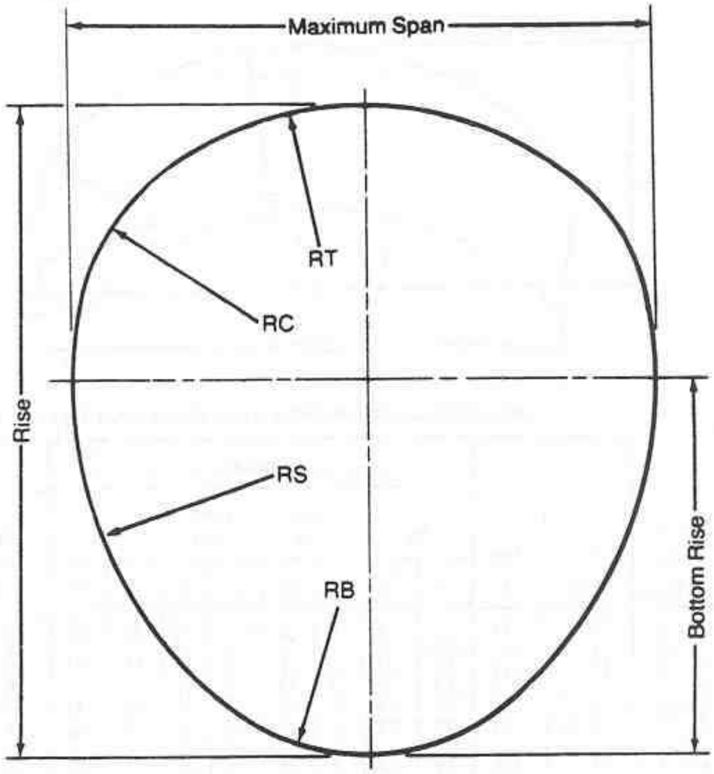
Long Span High Profile Arch Sizes and Layout Details

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: Top N	Top Pi	Corner N	Corner Pi	Side N	Side Pi	Bottom N	Bottom Pi	Total N	Total Pi	Inside Radius: Bottom Radius, ft-in.	Side Radius, ft-in.	Corner Radius, ft-in.	Top Radius, ft-in.
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

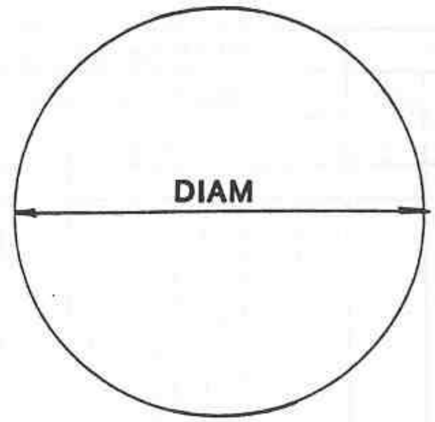
CORR. PATTERN				WEIGHT (Lbs./Lineal Ft.)					
				Equiv. Standard Gauge					
1-1/2 x 1/4	2-2/3 x 1/2	3 x 1	6 x 1	18	16	14	12	10	8
Diameter (In.)									
6				1.4	1.7				
8				1.8	2.2				
10				2.2	2.7				
	12				3.2	4.0	5.5		
	15				3.9	4.9	6.8		
	18				4.7	5.9	8.1		
	21				5.4	6.8	9.4		
	24				6.2	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

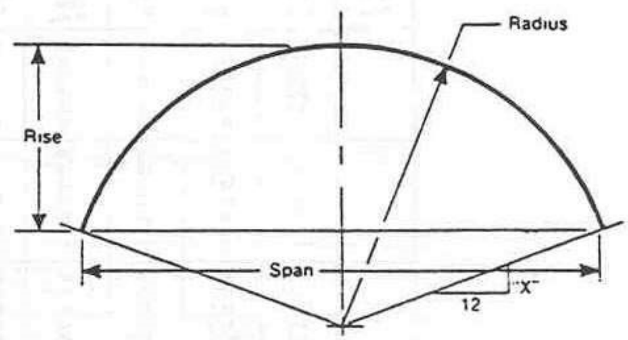
Nom. Diam. In.	Area Sq. Ft.	Total N	Nom. Diam. In.	Area Sq. Ft.	Total N
60	19	20	162	145	54
66	23	22	168	156	56
72	27	24	174	167	58
78	32	26	180	179	60
84	38	28	186	191	62
90	44	30	192	204	64
96	50	32	198	217	66
102	56	34	204	231	68
108	63	36	210	245	70
114	71	38	216	259	72
120	79	40	222	274	74
126	87	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		



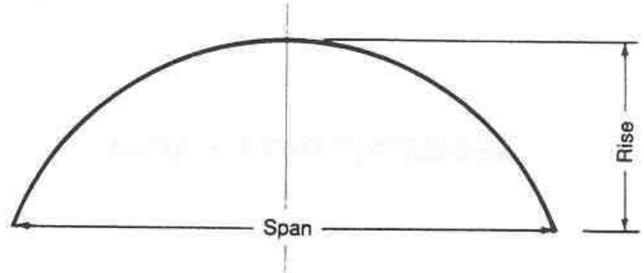
Typical Section

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

Span Ft.In.	Rise Ft.In.	Area Sq.Ft.	Total N	Rise/ Span Ratio	Radius Inches
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



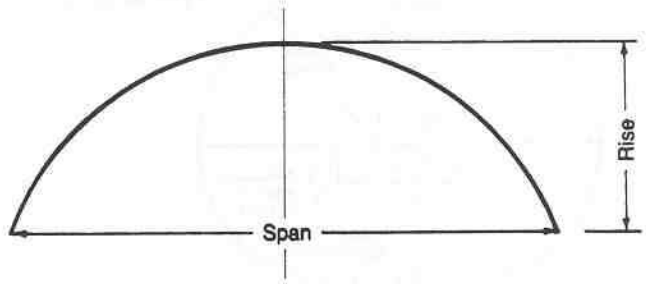
ARCH (CONT'D)

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	125.6	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	206.6	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	256.6	50	.49	156

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

STANDARD SIZES FOR ALUMINUM CULVERTS



ARCH (CONT'D)

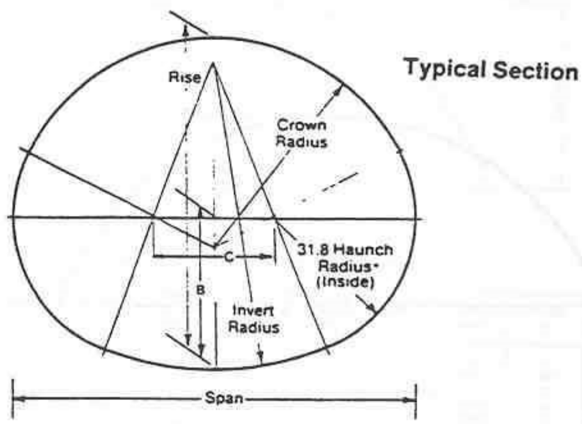
Geometric Data—Arch (Continued)

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

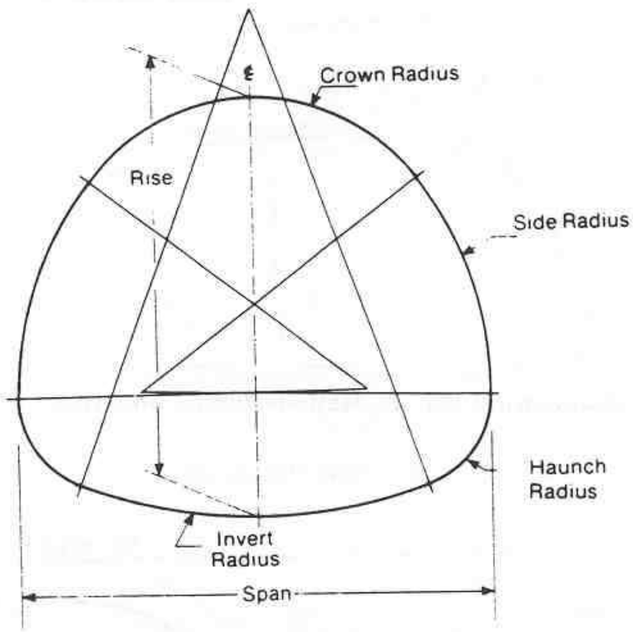
Geometric Data—Pipe Arch



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

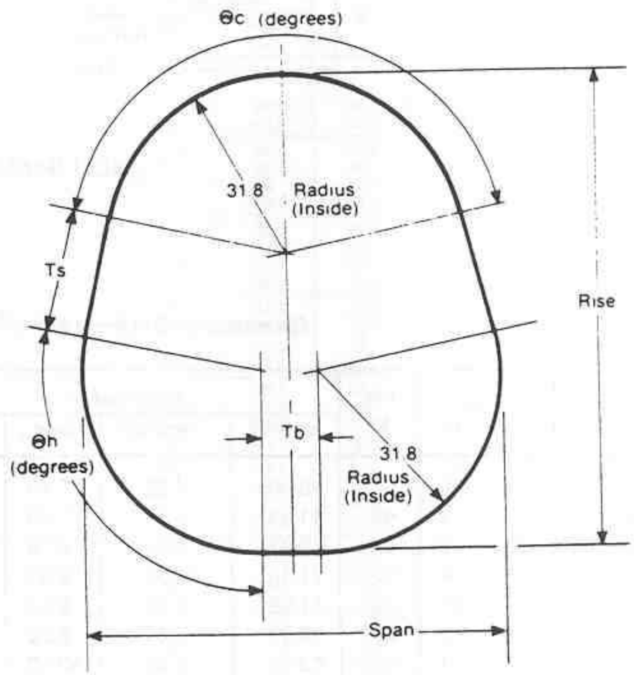
Span Ft	Span In.	Rise Ft	Rise In.	Tot N	Required N Invert	Required N Haunch	Required N Side	Required N Crown	Inside Radius (Inches) Invert	Inside Radius (Inches) Haunch	Inside Radius (Inches) Side	Inside Radius (Inches) Crown
12	1	11	0	47	10.00	4.32	7.69	12.99	135.95	37.95	88.00	67.95
12	10	11	2	49	11.04	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

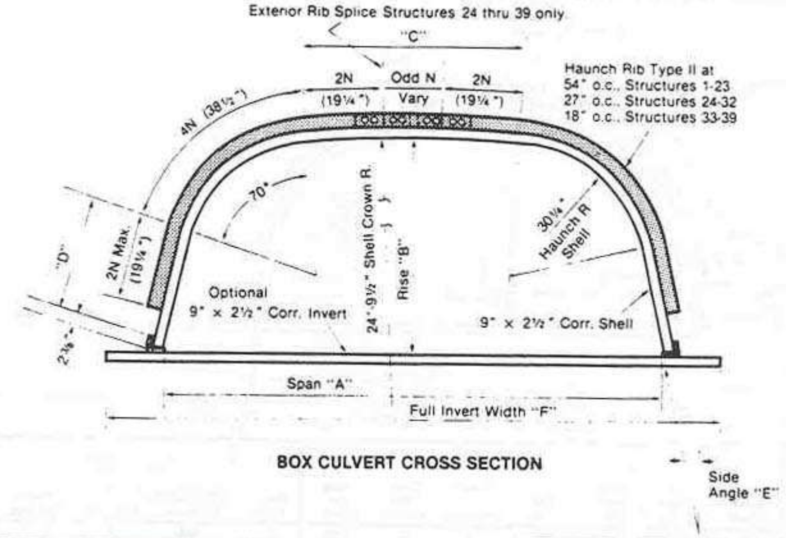


Typical Section

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

				SHELL							FULL INVERT				
												Supplemental/Stub Pl.			
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/Ft.	Width "F" (N)	Thick.	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	6.67
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	6.67
13	12- 1	6- 7	66.4	7	5.5	13-33	26	2 @ 13	—	15.11	17	—	—	28.58	6.37
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	6.37
16	11-11	3- 7	37.4	9	1.5	11-42	20	2 @ 10	—	15.11	17	—	—	28.58	6.37
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	12.49
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	13.13

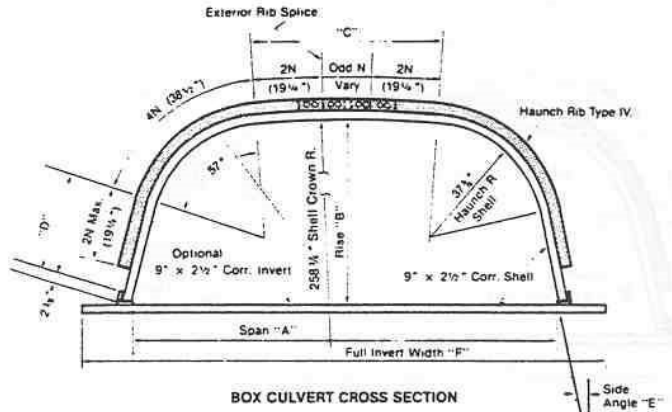
NOTES:

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



BOX CULVERT CROSS SECTION

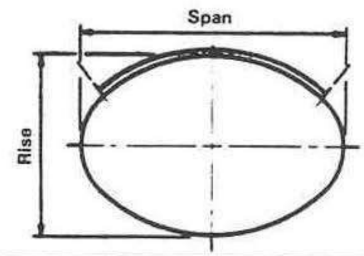
Structure Number	Span "A" (Ft.-In.)	Rise "B" (Ft.-In.)	Area (Sq. Ft.)	SHELL: Crown Width "C" (N)	Leg Length "D" (N)	Side Angle "E" Deg. Min.	Total N	Haunch Plate Length (N)	Crown Plate Length (N)	Bolts Per Foot	FULL INVERT: Width "F" (N)	Supplemental Stub Plates: Thickness	Supplemental Stub Plates: Width (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



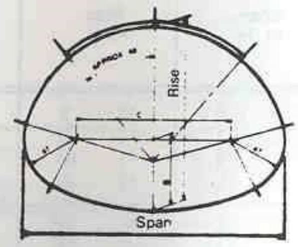
Span Ft.-in		Rise Ft-in.		Area ft²	Required N			Inside Radius	
					Crown or Invert	Haunch	Total	Crown & Invert in.	Haunch in.
19	4	12	9	191	22	10	64	150.3	53.9
20	1	13	0	202	23	10	66	157.2	53.9
20	2	11	10	183	24	8	64	164.1	42.8
20	10	12	2	193	25	8	66	171.0	42.8
21	0	15	1	248	23	13	72	157.2	70.4
21	11	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

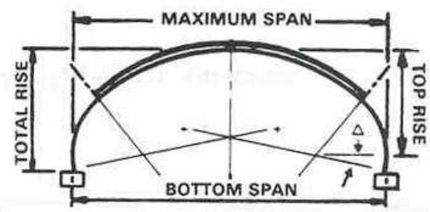


Span Ft-in	Rise Ft-in.	Area ft²	Required N Total	Required N Crown	Required N Invert	Required N Haunch	Inside Radius Crown in.	Inside Radius Invert in.	B	C
20 1	13 11	216	68	34	20	7	122.7	224.2	62.9	146.7
20 7	14 3	229	70	36	20	7	124.9	256.4	61.4	152.8
21 5	14 7	241	72	36	22	7	131.7	237.3	65.4	163.4
21 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



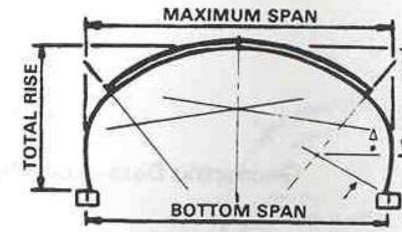
Max. Span Ft-in.		Total Rise Ft-in		Area ft²	Bottom Span Ft-in.		Top Rise Ft-in.		Required N			Inside Radius		Δ	
									Crown	Side	Total	Crown In.	Side In.	Deg.	Min.
20	1	7	6	120	19	10	6	6	23	6	35	157.2	54.0	12	19
19	5	6	9	105	19	2	5	10	23	5	33	157.2	43.0	15	22
21	6	7	9	133	21	4	6	9	25	6	37	171.0	54.0	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	198.6	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



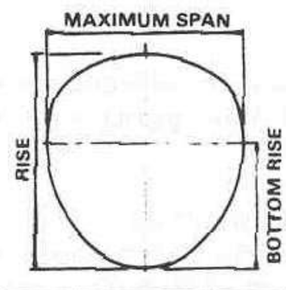
Max Span Ft.-in.		Total Rise Ft.-in.		Area ft²	Bottom Span Ft-in.		Top Rise Ft-in.		Required N Crown	Required N Haunch	Required N Side	Required N Total	Inside Radius Crown in.	Inside Radius Haunch in.	Inside Radius Side in.	Δ Deg.	Δ Min.
20	1	9	1	152	19	6	6	6	23	5	3	39	157.2	54.0	157.2	11	40
20	9	12	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	283	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

Table of Contents

Chapter 15

Advanced Inspection Methods

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Chapter 15
Advanced Inspection Methods

Topic 15.1 Timber

15.1.1 Introduction

Advanced inspection methods give inspectors the ability to further evaluate suspected defects found during a visual inspection. They can also be used to perform inspections on members that are not accessible. Advanced inspection methods usually require calibrated testing equipment, a professionally trained technician to perform the testing, and a professional that has expertise in interpreting the advanced inspection results. However, it is beneficial to have an understanding of the various advanced inspection methods.

There are two main classifications of advanced inspection methods. The first is labeled nondestructive testing or evaluation (NDT or NDE). This classification pertains to advanced inspection methods that do not impair the usefulness of the member being tested. Other testing, the second main classification, covers advanced inspection methods that affect or destroy the structural integrity of the member being tested.

New technology is making the use of these highly technical systems economically feasible for bridge inspection. From this fact, advanced inspection methods are becoming more popular for the routine inspection of bridge members. Current and future studies have been focusing directly on relating results from advanced inspection methods into Bridge Management Systems ratings.

This Topic describes the different types of nondestructive and other test methods for timber bridge members and the general methods for each.

15.1.2 Nondestructive Testing Methods

Sonic Testing

A Sonic Testing device is used to detect decay or other low density regions in timber members. Starting about six inches below the ground line, probes are pressed on opposite sides of the timber member. A trigger trips a hammer that sends a sound wave down one probe, through the member, and up the other probe to a dial (see Figure 15.1.1).

Figure 15.1.1 Sonic Testing Equipment

This method eliminates the need for making holes in timber members. Members testing positive for decay are then drilled or cored to determine the detailed nature of the deficiency. A dial reading that is low, compared with that of a good member of similar diameter, indicates decay or another low density region that delayed the sound wave within the member. However, it is a good idea to take several readings on the member since the readings are nearly instantaneous, and the Sonic Testing equipment needs to be checked frequently for proper calibration.

Used by trained personnel, Sonic Testing works well with Douglas fir and western red cedar. However, it does not work as well with southern pine members because of the high incidence of ring shakes.

Spectral Analysis

Spectral Analysis, sometimes called stress wave, uses sonic waves to produce stress waves in a timber member. The stress waves are then used to locate decay in timber members. The stress waves travel through the timber member and reflect off the timber surface, any flaws, or joints between adjacent members at the speed of sound. It is known that stress waves travel slower in decayed members than in sound members. If the member's dimensions are known, the amount of time it takes for a stress wave to travel the known distance can indicate that deficiencies are evident due to longer stress wave timings.

Stress waves are also used to determine the in-situ strength of timber members. Sound timber members transmit waves at higher velocity than decayed wood. The velocity of the stress wave can be calculated by obtaining time of flight readings over a set length. The velocity can be converted in to a dynamic modulus of elasticity, which in turn, allows properly trained personnel to estimate the strength properties of the wood.

First, a stress wave is induced by striking the specimen with an impact device that is instrumented with an accelerometer that emits a start signal to a timer. A second accelerometer, which is held in contact with the other side of the specimen, serves to detect the leading edge of the propagating stress wave and sends a stop signal to the timer. The elapsed time for the stress wave to propagate between the accelerometers is displayed on the timer.

The use of stress wave velocity to detect wood decay in timber bridges and other structures is limited only by access to the structural members under consideration. It is especially useful on thick timbers or glulam timbers where hammer sounding is not effective. Note that access to both sides of the timber member is required.

The transmission time is affected by such properties as growth ring orientation, decay, moisture content, and preservative treatment.

Figure 15.1.2 Stress Wave Timer

Ultrasonic Testing

Ultrasonic testing (UT) consists of high frequency sound waves introduced by a sending transducer. Discontinuities in the specimen interrupt the sound wave and deflect it toward a receiving transducer. The magnitude of the return signal allows a measurement of the flaw size. The distance from the transducer to the flaw can be estimated from the known properties of the sound wave and of the material being tested. Ultrasonic testing can be used to detect cracks, internal flaws, discontinuities, and sub-surface damage (see Figure 15.1.3).

Figure 15.1.3 Ultrasonic Testing Equipment

In timber bridge members, ultrasonic testing can be used to determine the in-place strength of timber bridge members, both above and below water. The load-carrying capacity of the member is correlated to the member's wave velocity normal to the grain and to its in-place unit weight.

Vibration

A newer type of nondestructive testing that can determine the condition of timber bridge members deals with the use of vibrations (see Figure 15.1.4). This nondestructive evaluation method is based on the philosophy that sound timber members vibrate at a certain frequency. While testing a timber member, if the member vibrates at a different frequency than the established theoretical frequency, the member may have deterioration present. Vibratory testing methods in timber members are basically used to determine the member's modulus of elasticity. From this, other properties of the timber member can be established.

Figure 15.1.4 Vibration Testing Equipment

15.1.3 Other Testing Methods

Boring or Drilling

While drilling and coring are the most common methods for detecting internal deterioration in bridges, boring is seen as the most dependable and widely used method for detecting internal decay in timber. Drilling and coring are used to detect the presence of voids and to determine the thickness of the residual shell when voids are present. Boring permits direct examination of an actual sample from a questionable member. A timber boring tool is used to extract wood cores for examination (see Figure 15.1.5).

Figure 15.1.5 Timber Boring Tool

Drilling is performed using a rechargeable drill or a brace and bit. An abrupt decrease in drilling resistance indicates either decay or a void. However, wet wood and natural voids can falsely suggest decay. Decay can be based on how the auger type drill bit pulls its way through the wood or on measuring the torque resistance on the bit as it penetrates the wood. Drilling is usually done with a power drill or hand-crank drill equipped with a 3/8 inch to 3/4 inch diameter bit. If decay is detected, the inspection hole can be used to add remedial treatments to the wood. While samples are generally not attainable, observation of the wood particles removed during the drilling process can provide valuable information about the member. The depth of preservative penetration, if any, can be determined, and regions of discolored wood may indicate decay.

Coring with timber boring tools also provides information on the presence of decay pockets and other voids, and coring produces a solid wood core that can be carefully examined for evidence of decay. The use of increment cores for assessing the presence and damage due to bacterial and fungal decay requires special care. Cleaning of the timber boring tools is necessary after each core extraction to eliminate transfer of organisms. There are several cleaning agents available to clean the timber boring tools or drill bits that work well. Core samples that do not show visible signs of decay can be cultured to detect the presence of potential decay hazards. Many laboratories can provide this service. Core samples are more commonly used to detect the presence of internal decay pockets and to measure the depth of preservative penetration and retention. Culturing provides a simple method for assessing the potential decay hazard and many laboratories provide routine culturing services. Because of the wide variety of fungi near the surface, culturing is not practical for assessing the hazard of external decay.

A decay detection device is a newer drilling and logging tool. It operates upon the principle that a drill moving through sound wood encounters more resistance than a drill moving through decayed, and/or soft wood. It records the resistance, using a pen, paper, and rotary drum arrangement so that a permanent graphic record of the test is generated. Sound wood produces a series of near vertical markings on the record, however, when decayed wood is encountered, the resistance drops and the markings assume a more horizontal or diagonal pattern. By studying the resulting record, an experienced operator can determine if decay exists and can estimate the approximate location and size of the decayed area (see Figure 15.1.6).

Figure 15.1.6 Inspector Using Decay Detection Device

Bore holes can provide an entrance for bacterial and fungal decay to gain access to the member. Inspection methods that destroy or remove a portion of the wood, splinters, probe holes, and borings may become avenues for decay entry if not properly treated at the conclusion of the inspection. As such, the holes need to be treated with a preservative and plugged after testing. Failure to properly treat the wood may result in accelerated decay development or deterioration in the structure.

Moisture Content

Moisture meters can be used to determine moisture content in a timber member (see Figure 15.1.7). Moisture contents exceeding 20% indicate the condition of the wood is conducive to decay. As a sliding hammer drives two electrodes into the wood, a ruler emerging from the top of the hammer measures the depth. These electrodes can measure moisture content to a depth of approximately 2 1/2 inches. Because the high moisture content of decaying wood causes steeper than normal moisture gradients, the meter is useful for determining the extent of decay.

Figure 15.1.7 Moisture Content Equipment

Probing

Probing consists of inserting a pointed tool, such as an ice pick, into the wood and comparing its resistance with that of sound wood. Lack of resistance or excessive softness to probe penetration may reveal the presence of decay. Two forms of probing are a pick test and a shell-thickness indicator.

A pick test consists of removing a small piece of wood with a pick or pocketknife (see Figure 15.1.8). If the wood splinters, it is probably sound wood, and if it breaks abruptly, it is probably decayed wood. Since the pick test only removes a small portion of the timber member, it may be considered a physical testing method. See Topic 6.1.7 for more information.

Figure 15.1.8 Pick Test: Sound Wood, Decayed Wood

A shell-thickness indicator is a thin, metal, hooked rod used to determine the thickness of solid, but not necessarily sound, wood. The rod is inserted into a hole made by coring or drilling and is then pulled back with pressure against the side of the hole. The hook easily attaches to the edge of a decay pocket, making it possible to determine the depth of the decay and the solid wood.

Field Ohmmeter

The field ohmmeter measures electrical resistance to detect decay in timber members (see Figure 15.1.9). It is best used in wood with a moisture content of at least 27 percent, a value indicative of decaying wood. A probe is used consisting of two twisted, insulated wires with the insulation removed near the tip. This probe is inserted to various depths into a hole with a diameter of 3/32 of an inch. If the electrical resistance changes as the probe goes deeper, this indicates decay or a defect.

While this device effectively detects decay, it can also produce misleading readings on sound timber. Consequently, drilling or coring needs to be done on suspect members to verify results. Like sonic testing, the field ohmmeter needs to be recalibrated frequently.

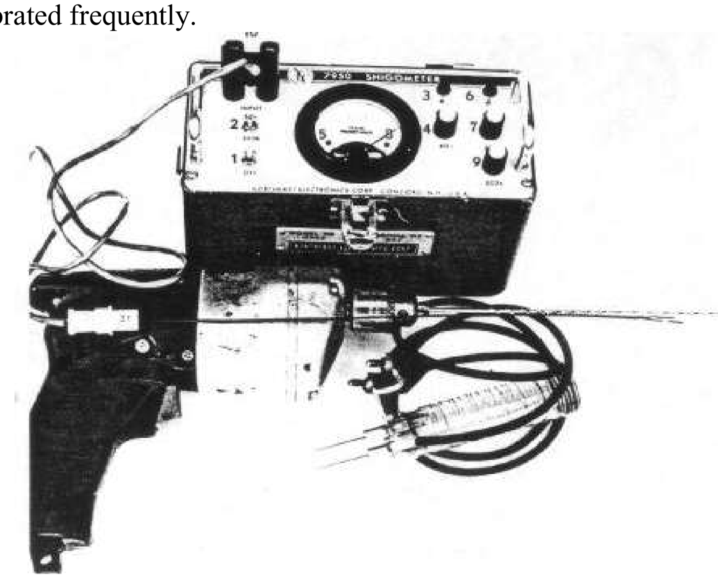

Figure 15.1.9 Field Ohmmeter Equipment

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Chapter 15

Advanced Inspection Methods

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Topic 15.2 Concrete

15.2.1 Introduction

Advanced inspection methods give inspectors the ability to further evaluate suspected deficiencies found during a visual inspection. They can also be used to perform inspections on members that are not accessible. Advanced inspection methods usually require calibrated testing equipment, a professionally trained technician to perform the testing and a professional that has expertise in interpreting the advanced inspection results. Bridge inspectors need to have an understanding of the various advanced inspection methods.

There are two main classifications of advanced inspection methods. The first is labeled nondestructive testing or evaluation (NDT or NDE). This classification pertains to advanced inspection methods that do not impair the usefulness of the member being tested. Other testing, the second main classification, covers advanced inspection methods that may affect the structural integrity of the member being tested.

New technology is making the use of these highly technical systems more economically feasible for bridge inspection. From this fact, advanced inspection methods are becoming more popular for supplementing visual inspection methods predominately used for routine inspection of bridge members. Current studies have been focusing directly on relating results from advanced inspection methods into Bridge Management Systems ratings.

This Topic describes the different types of nondestructive and other test methods for concrete bridge members and the general methods for each.

15.2.2 Nondestructive Testing Methods

Acoustic Wave Sonic/Ultrasonic Velocity Measurements

An evaluation of concrete decks can be accomplished with sonic or ultrasonic acoustic wave velocity measurements. This method delineates areas of internal cracking (including delaminations) and deteriorated concrete, including the estimation of strength and elastic modulus. A mobile automated data acquisition device with an impact energy source and multiple sensors is the principle part of a computer-based monitoring and recording system for detailed evaluation of bridge decks. Bridge abutments and concrete support members are tested using the same recording system with a portable, hand-held sensor array (see Figure 15.2.1 and 15.2.2). The system works directly on either bare concrete or through wearing surfaces such as asphalt. It can distinguish between debonded asphalt and delaminations, and it is effective for a detailed evaluation of large areas.

Figure 15.2.1 Portable Hand Held Sonic/Ultrasonic Testing Sensor Array System

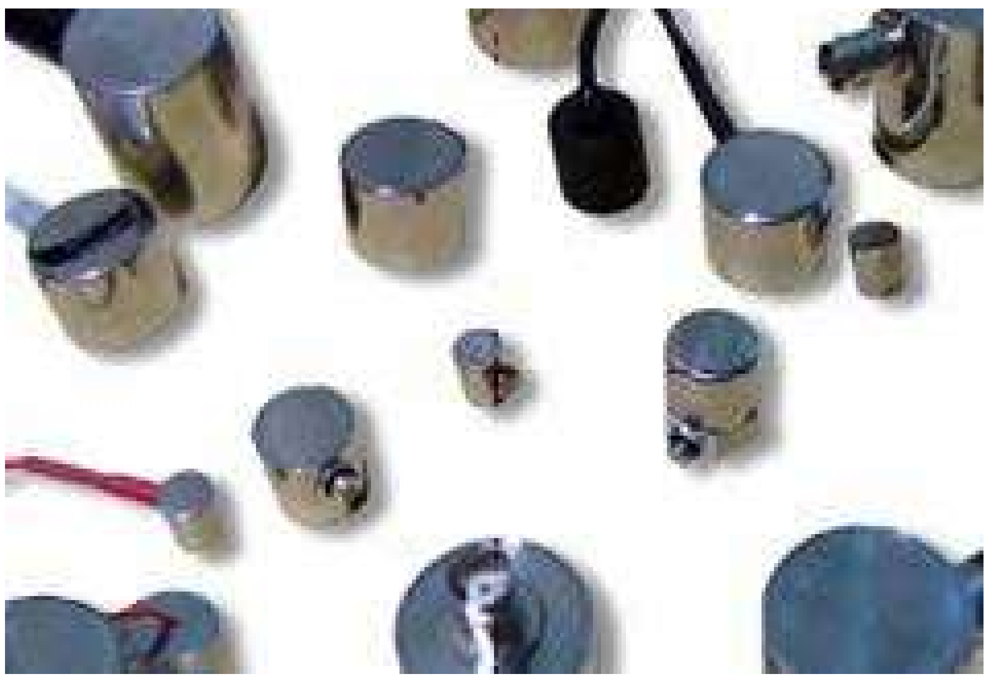

Figure 15.2.2 Acoustic Emission Sensors

Electrical Methods

Half-cell potentials are used to evaluate the corrosion activity of reinforcing steel embedded in concrete (See Figure 15.2.3). Commonly known as CSE (Copper Sulfate Electrode) tests, reinforcing bar networks are physically accessed and wired for current detection. Half-cell electrical potentials of reinforcing steel are measured by moving the CSE about the concrete surface. As the CSE contacts concrete over an actively corroding rebar, voltage is registered. Measured potential values reflect levels of corrosion activity in the rebar. Higher potential measurements indicate corrosion activity. This kind of survey can be used to determine core sample locations.

Figure 15.2.3 Half-Cell Potential

Delamination Detection Machinery

Delamination detection machinery is based on sonic responses and can be used to inspect concrete decks (see Figure 15.2.4). The portable electronic instrument consists of three components: a tapping device, a sonic receiver, and a signal interpreter. The instrument is moved across the deck as acoustic signals are passed through the deck. These signals are then received and electronically interpreted, and the output is used to generate a plan of the deck showing delaminated areas. This method can be used on concrete decks with asphalt covered surfaces, although accuracy decreases.

Figure 15.2.4 Delamination Detection Machinery

Ground-Penetrating Radar

Ground-Penetrating Radar (GPR) is a geophysical method that uses high-frequency pulsed electromagnetic waves to acquire subsurface information. An important benefit of this method is the ability to measure the thickness of asphalt covering. It can also be used to examine the condition of the top flange of box beams that may otherwise be inaccessible.

An electromagnetic wave is radiated from a transmitting antenna, and travels through the material at a velocity which is determined primarily by the electrical properties of the material. The wave spreads out and travels downward; however, materials with different electrical properties can alter its path. Upon encountering a buried object or boundary with different electrical properties, part of the wave energy is reflected or scattered back to the surface while part of its energy continues its downward path. The wave that is reflected back to the surface is captured by a receiving antenna, and recorded on a digital storage device for later interpretation (see Figure 15.2.5). The most common display of GPR data is one showing signal versus amplitude, and is referred to as a trace. A single GPR trace consists of the transmitted energy pulse followed by pulses that are received from reflecting objects or layers.

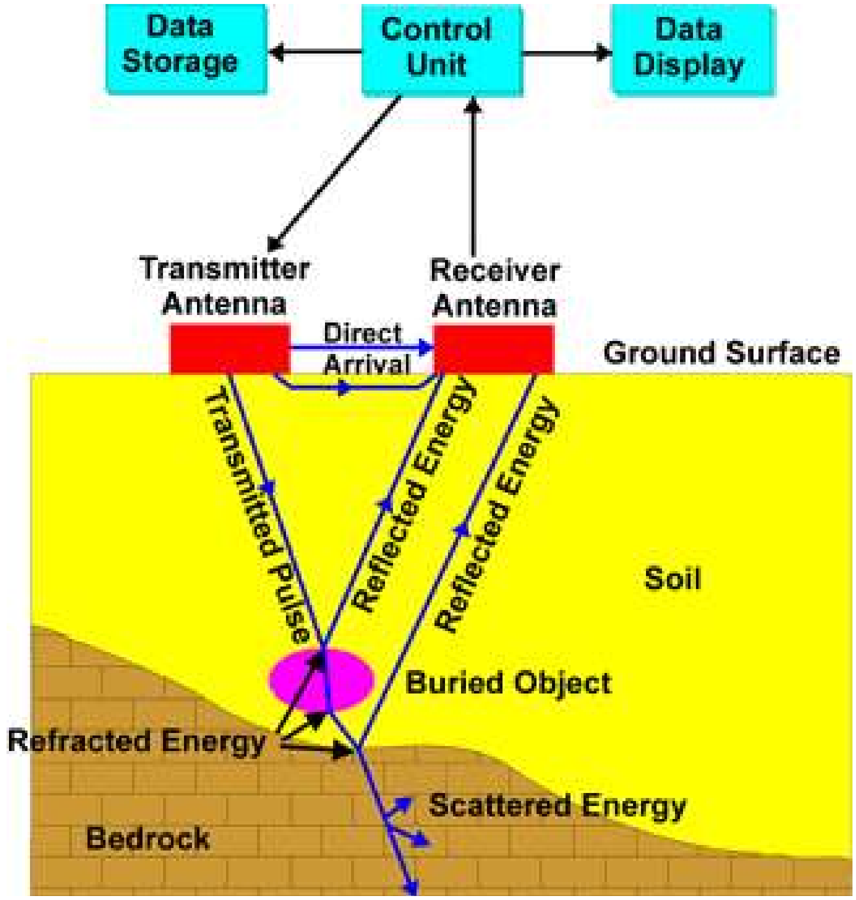

Figure 15.2.*5* Schematic of Ground-Penetrating Radar

GPR is used to map geologic conditions that include depth to bedrock, depth to the water table, depth and thickness of soil and sediment strata on land and under fresh water bodies, and the location of subsurface cavities and fractures in bedrock.

Other applications include the detection of delaminations and flaws in reinforced concrete bridge elements; location of post-tensioning ducts in prestressed concrete elements; location of objects such as pipes, drums, tanks, cables, and boulders; mapping landfill and trench boundaries; mapping contaminants; and conducting archeological investigations. GPR has been used for concrete bridge element and tunnel lining inspections.

Ground Penetrating Radar for Bridge Decks

Ground penetrating radar (GPR) technology is nearing full acceptance as a method to assess the condition of bridge decks, in particular, delaminations between concrete and rebar.

Importantly, GPR is an NDE technology, as opposed to cutting core samples from concrete decks. It can provide information on asset condition that can be used to plan and execute effective and efficient repair programs. The principal issue with GPR technology is slow rate of data capture when the depth of evaluation is more than approximately 3 inches.

Electromagnetic Methods

Advancements in ground penetrating radar have led to the development of the High Speed Electromagnetic Roadway Measurement and Evaluation System (HERMES) Bridge Inspector. This system was built by the Lawrence Livermore National Library to detect delaminations in concrete decks caused by reinforcement corrosion. The HERMES Bridge Inspector sends high frequency electromagnetic pulses from sixty-four radar antennas into a bridge deck while travelling over the structure. The device is set up in a trailer mounted towing vehicle and is made up of a computer workstation, storage device, survey wheel, control electronics, and the sixty-four antenna modules or transceivers (see Figures 15.2.6 and 15.2.7). The system can inspect up to a 6 foot 3 inch width at a time with maximum speeds of up to sixty miles per hour. At speeds of around twenty miles per hour, the system can sample the concrete deck every 9/16 inch in the direction of travel. Output information can be reconstructed to show cross-sections of the deck being inspected. The depth of penetration depends on time and the material type. An 11-13/16 inch penetration in concrete can be accomplished in about six nanoseconds.

Figure 15.2.6 The HERMES Bridge Inspector (Outside)

Figure 15.2.7 The HERMES Bridge Inspector (Inside)

Pulse Velocity

Pulse velocity methods are used to evaluate relative quality of concrete and estimate compressive strength. The pulses pass through the concrete and the transit time is then measured. The pulse velocity is then interpreted to evaluate the quality of the concrete and to estimate in-place concrete compressive strength.

This equipment analyzes concrete in decks by measuring velocity of sound waves. Some equipment generates sound waves by shooting BB's on to the deck. The time for the waves to return depends on the integrity of the concrete.

Flat Jack Testing

The flat jack method was originally developed to test the in situ stress and deformation of rock and is now being applied to masonry structures. A portion of the horizontal mortar joint is removed, and the flat jack (an envelope made of metal) is inserted and pressurized to determine the state of stress. For deformation testing, two flat jacks are inserted, one directly above the other and separated by five or six courses.

Impact-Echo Testing

Sound wave reflection is a method for nondestructive evaluation of concrete and masonry, based on the use of impact-generated stress (sound) waves that propagate through the structure and are reflected by internal flaws and external surfaces.

This method can be used to determine the location and extent of flaws such as cracks, delaminations, voids, honeycombing and debonding in plain, reinforced and post-tensioned concrete structures. It can locate voids in the subgrade directly beneath slabs and pavements. It can be used to determine member thickness or locate cracks, voids and other defects in masonry structures where the brick or block units are bonded together with mortar. This method is not adversely affected by the presence of steel reinforcing bars.

A short-duration mechanical impact, produced by tapping a small steel sphere against a concrete or masonry surface, produces low-frequency stress waves that propagate into the structure and are reflected by flaws and/or external surfaces (see

Figure 15.2.8). The wavelengths of these stress waves propagate through concrete almost as though it were a homogeneous elastic medium. Multiple reflections of these waves within the structure excite local modes of vibration, and the resulting surface displacements are recorded by a transducer located adjacent to the impact. The piezoelectric crystal in the transducer produces a voltage proportional to displacement, and the resulting voltage-time signal (called a waveform) is digitized and transferred to a computer, where it is transformed mathematically in to a spectrum of amplitude vs. frequency. Both the waveform and spectrum are plotted on the computer screen. The dominant frequencies, which appear as peaks in the spectrum, are associated with multiple reflections of stress waves within the structure, or with flexural vibrations in thin or delaminated layers.

Figure 15.2.8 Impact-Echo Testing Equipment

Infrared Thermography

NDE inspection using thermography is based on imaging surface temperatures of a specimen in order to infer subsurface delaminations or defects (see Figure 15.2.10). The basic theory is that heat conduction through a material is altered if a delamination is present (see Figure 15.2.11). In this example the temperature of the deck is greater than the surrounding air. With no internal defect, heat flow through the deck is relatively uniform. An image of the surface temperature of the deck then produces an image that is relatively uniform. If a delamination is now present inside the specimen, the heat flow is altered. In this example, the surface of the deck above the delamination appears to be higher in temperature than the remainder of the deck. The rest of the deck that is not delaminated appears cooler than the delaminated area (see Figure 15.2.9).

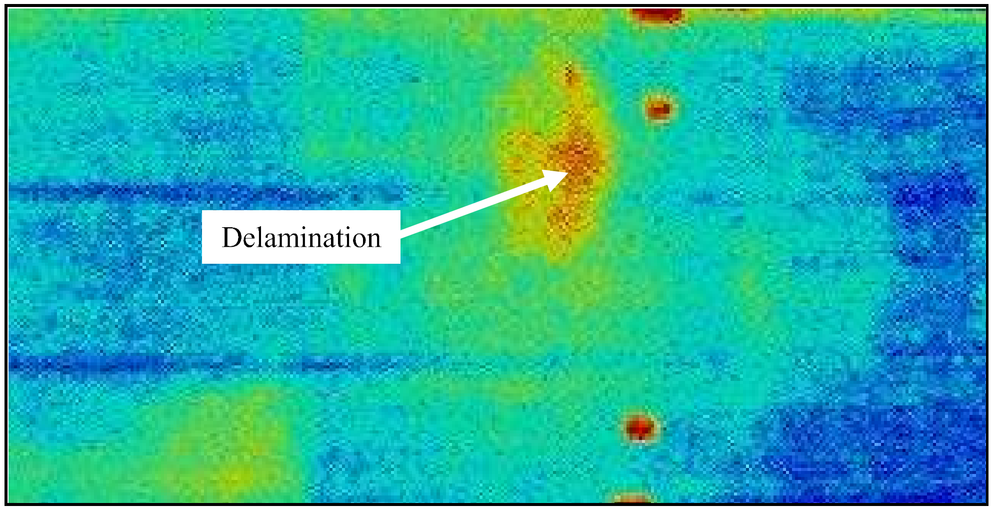

Figure 15.2.9 Deck with Area of Delamination (Warmer Colors)

Figure 15.2.10 Infrared Thermography Testing Equipment

Thermographic measurements are complicated by a number of issues. Probably the most significant is that a thermal camera does not directly measure the temperature of a specimen. The camera measures radiant flux that needs to be converted to temperature. The measured radiant flux is not only a function of the surface temperature, but is a function of the emissivity of the specimen. Emissivity is a material property that describes how well an object emits or absorbs energy. Two objects at the same temperature but with different emissivities appear as different intensities in an infrared image. Shadows or other uneven heating of a specimen are also a concern. Other environmental factors, such as water, snow, or ice on a specimen, alter results as well. Also, the method is sensitive to material property differences on the specimen surface. Surface defects, such as oil stains, water, and skid marks, show up in the infrared data.

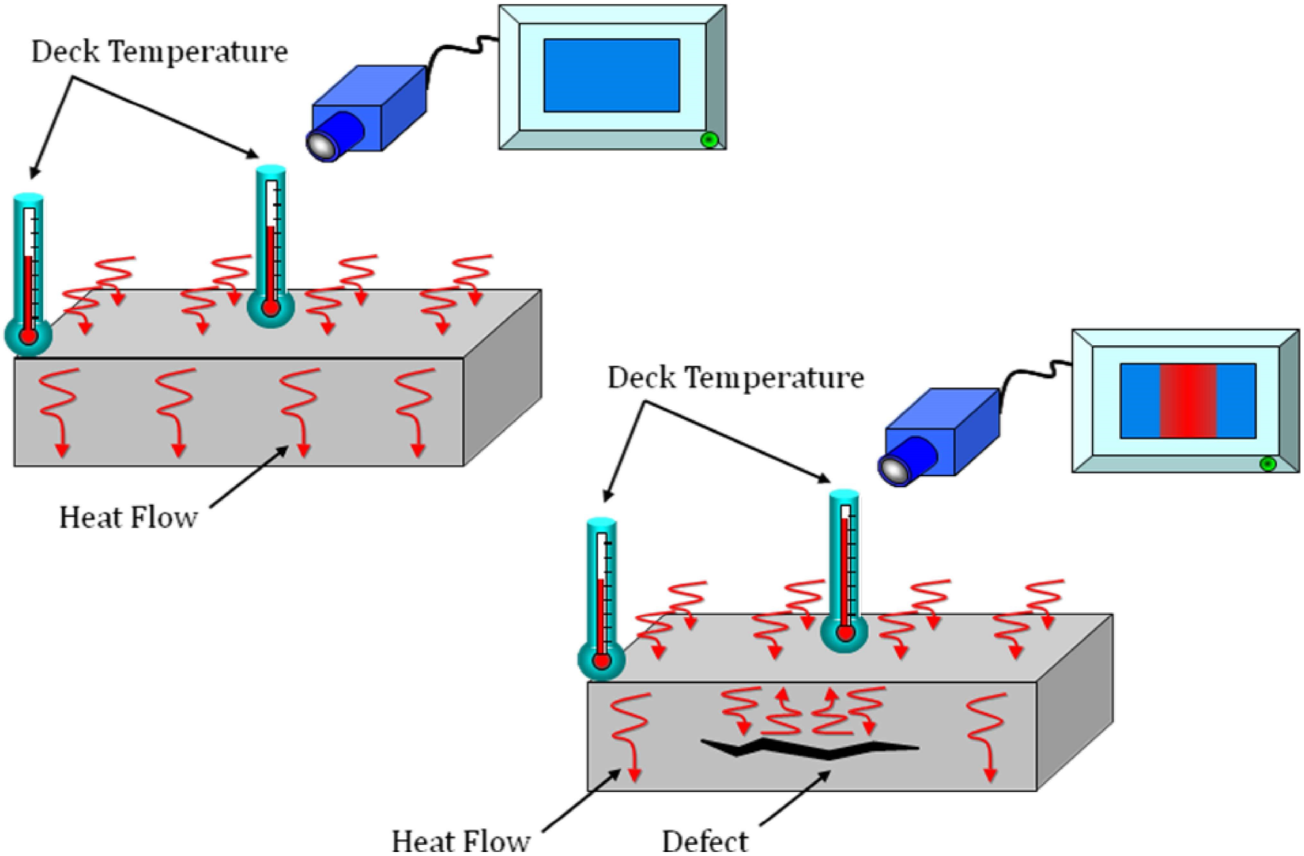

Figure 15.2.11 Schematic of Thermal Imaging

Laser Ultrasonic Testing

Laser ultrasonic testing provides information about flaws in concrete and about the position of steel reinforcement bars, which cannot be obtained with the non-laser ultrasonic testing described in this Subtopic. Laser-generated acoustic wave measurements with high stress amplitudes provide information about the quality of the concrete at various depths from the surface. Reinforcing steel does not cause misleading results in laser ultrasonic testing as it does in non-laser ultrasonic testing.

Magnetic Field Disturbance

Advanced inspection methods have been developed that can evaluate fatigue damage to steel reinforcement in concrete members. The device is known as the magnetic field disturbance (MFD) system and can be used on reinforced and prestressed concrete. The system maps the magnetic field across the bottom and sides of the beam. A discontinuity in magnetized steel, such as a fracture in a rebar or a broken wire in a steel strand, produces a unique magnetic signal. Research has been encouraging for detecting fatigue-related damage due to the significantly different magnetic signals for corroded reinforcing.

Neutron Probe for Detection of Chlorides

A neutron probe can be used to detect chlorides in construction materials. The materials are bombarded with neutrons from a small portable source. Measuring the gamma rays bouncing back provides a spectrum showing different elements, one of which is chloride. A major potential application that remains to be tested is measuring chlorides in reinforced concrete to determine corrosion hazard. Another potential application includes inspecting suspension bridge cables.

Nuclear Methods

The primary use of nuclear methods is to measure the moisture content in concrete by neutron absorption and scattering methods. These moisture measurements are then used to determine if corrosion of reinforcement is likely to occur. A more direct measurement of the rate of corrosion is more useful to the bridge inspector,

Pachometer

A pachometer is a magnetic device used in determining the position of reinforcement (see Figure 15.2.12). Magnetic methods do not detect concrete defects or deterioration directly. However, they can detect regions of inadequate cover, which is often associated with corrosion-induced deterioration. Magnetic methods can be used to measure cover in the range of 0 to 3 inches to an accuracy of about 1/4 inch.

Figure 15.2.12 Pachometer Testing Equipment

Rebound and Penetration Methods

Rebound and penetration methods measure the hardness of concrete and can be used to predict the strength of concrete. The rebound hammer (also known as the Swiss hammer) is probably the most commonly used device to measure the penetration resistance of hardened concrete. A spring-loaded device strikes the surface of the concrete, and based on the response, the compressive strength of the concrete can be determined. This inspection method can be used to compare the quality of the concrete in different parts of concrete bridge components. However, only the surface of the concrete is being tested, and the strength value is relative.

Another common penetration device utilizes a pistol-like driving device that fires a probe into the surface of the concrete. The probe is specifically designed to crack aggregate particles and to compress the concrete being tested.

Both of these tests are considered practical primarily with concrete that is less than one year old. However, when used in conjunction with core sampling, these tests can also be used to determine significant differences in concrete strength of older bridges.

Ultrasonic Testing

Ultrasonic testing can provide valuable information regarding the condition of concrete bridge members. However, the method can be difficult to use with reinforced concrete members, and some skill is required to obtain usable results.

Large cracks and voids can be detected since the path of the pulse travels around any cavity in the concrete and time of transmission is therefore lengthened. The presence of steel parallel to the line of transmission provides a path along which the pulse can travel more rapidly, causing misleading results. Therefore, it is generally desirable to choose paths that avoid the influence of reinforcing steel.

Smart Concrete

Carbon fiber-reinforced cement can be used as a strain-sensing coating on conventional concrete. This coating allows the sensing of strain similar to strain gauges. The resistance can be measured by having electrical contacts attached to the member.

Strain gauges are expensive compared to the structural material, and they often become detached during use. This method could be much more reliable in sensing strain in structures.

Smart concrete is in early stages of development.

Radiography

Radiographic inspection is a nondestructive testing technique used to evaluate concrete for signs of hidden flaws which could interfere with its function. It is accomplished with the use of radiographs, images generated by bombarding the concrete under inspection with radiation. X-ray and gamma ray radiographic inspection are the two most common forms of this inspection method.

Carbonation

Carbonation of concrete is the result of the reaction of carbon dioxide and other acidic gases in the air, and it can cause a loss of protection of the reinforcing steel against corrosion. The depth of carbonation in a concrete bridge member can be measured by exposing concrete samples to a solution. Uncarbonated concrete areas change color, while carbonated concrete areas remain colorless.

15.2.3 Other Testing Methods

Core samples can be used for many of the following other advanced inspection tests. Usable cores can normally be obtained only if the concrete is relatively sound. If possible, cores need to have a diameter three times the maximum aggregate size. Core holes need to be filled with non-shrink concrete grout. Since removing a concrete core may weaken the member, exercise caution and do not remove from high stress areas.

Concrete Permeability

Air and water permeability can be measured by drilling a small hole into the concrete, sealing the top with liquid rubber, and inserting a hypodermic needle. Air permeability can then be determined by filling the hole with water and measuring the flow in to the concrete at a pressure similar to that of rainfall. However, this method is seldom used in bridge inspections.

Concrete Strength

Actual concrete strength and quality can be determined only by removing a concrete core and performing such laboratory tests as:

- Compressive strength
- Cement content
- Air voids
- Static modulus of elasticity
- Dynamic modulus of elasticity
- Splitting tensile strength

Endoscopes and Videoscopes

Endoscopes and videoscopes are viewing tubes that can be inserted into holes drilled into a concrete bridge member (see Figure 15.2.13). Light can be provided by glass fibers from an external source. Some applications of this method include the inspection of the inside of a box girder and the inspection of hollow post-tensioning ducts. Although this is a viewing method, it is considered to be a destructive method because some destruction is necessary for its proper use in concrete.

Figure 15.2.13 Remote Video Inspection Device

Moisture Content

Moisture content in concrete serves as an indicator of corrosion activity. Moisture content can be determined using nuclear methods (refer to Topic 15.2.2) or from concrete samples taken from the bridge and oven dried in a laboratory

Petrographic Examination

Petrographic examination is a laboratory method for determining various characteristics of hardened concrete, which are useful in determining the existing condition and predicting future performance. This advanced inspection method is able to detect Alkali-Silica Reaction (ASR) products.

Reinforcing Steel Strength

The actual properties of reinforcing steel can only be determined by removing test samples. Such removal of reinforcing steel can be detrimental to the capacity of the bridge and needs to be done only when such data is essential.

Chloride Test

One of the current standard test methods used to assess the resistance of concrete to penetration of chloride ions is the rapid chloride permeability test. This test, officially known as AASHTO T 277-93, “Electrical Indication of Concrete’s Ability to Resist Chloride,” measures the charge passed through a concrete specimen subjected to sixty volts (direct current) for six hours. Variable results have been reported with the rapid chloride permeability test when certain mineral admixtures such as silica fume were included in the concrete mixture and when calcium nitrite (included in some corrosion inhibitors) or reinforcing steel have been present. The test specimens are two inches long and four inches in diameter in the rapid chloride test. The rapid chloride test uses sodium hydroxide ponded on the top of the specimen, and a solution of sodium chloride at the bottom of the specimen. The specimen is initially subjected to thirty volts (direct current), and the resulting current determines the voltage to be applied for the duration of the test. The voltage is applied for three different time periods varying anywhere from 2 to 96 hours. Following the test, the specimen is split in half and a silver nitrate spray is applied to identify the depth of chloride penetration in to the specimen.

ASR Evaluation

One test for ASR evaluation, often referred to as the accelerated mortar bar test, has been accepted by ASTM and AASHTO. The test involves casting mortar bars that contain the subject aggregate (either coarse or fine), which is processed to a standard gradation. The mortar bars are then removed from their molds after 24 hours and placed in water at room temperature. The temperature of the water is then raised to 176 degrees Fahrenheit in an oven, and the mortar bars are stored in this condition for the next 24 hours. After the bars are removed from the water, they are measured for initial length and then submersed in a 1 normal (N) NaOH solution at 176 degrees Fahrenheit, where they are then stored for 14 days. Length change measurements are made periodically during this storage period. The total expansion at the end of the 14-day soaking period typically is used in specifications, although the expansion limits specified by different agencies vary.

Another method is a qualitative ASR field test that utilizes colored dyes. This test is performed on a broken surface of a concrete core, where reagents are then applied. If ASR is present, the reagents turn different colors indicating if ASR is just beginning or if ASR is in an advanced stage. This field test is relatively inexpensive and can be carried out completely on-site with easy-to-interpret results.

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Chapter 15

Advanced Inspection Methods

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Topic 15.3 Steel

15.3.1 Introduction

Advanced inspection methods give inspectors the ability to further evaluate suspected deficiencies found during a visual inspection. They can also be used to perform inspections on members that are not accessible. Advanced inspection methods usually require calibrated testing equipment, a professionally trained technician to perform the testing and a professional that has expertise in interpreting the advanced inspection results. However, bridge inspectors will have an understanding of the various advanced inspection methods.

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This Topic describes the different types of nondestructive and other test methods for steel bridge members and the general methods for each.

15.3.2 Nondestructive Testing Methods

Acoustic Emission Testing

Acoustic emission (AE) testing has been used for many years, but is now becoming a more standardized and available method.

This inspection method detects elastic waves generated by the rapid release of energy from within a test object by such mechanisms as plastic deformation, fatigue and fracture. When a structure is under certain load levels, it will produce an acoustic sound that ranges between 20 KHz and 1 MHz. The sound that is generated is known as acoustic emissions. Acoustic emission testing uses ultrasonic microphone to listen for sounds from active deficiencies and is very sensitive to deficiency activity when a structure is loaded beyond its service load in a proof test. This process can detect flaws and imperfections such as the initiation, growth and growth rate of fatigue cracks in steel structural members, friction, corrosion, deformation, cracks opening and closing, weld discontinuities, the failure of bonds, fibers and filaments in composite materials and the appearance of potentially hazardous flaws in metal or synthetic pressure vessels.

Most sounds produced by materials under stress are inaudible; however there may be a portion that exists as audible sound, based on the magnitude and type of deformation, flaw growth or failure.

Bridges contain a large number of joints, welds and connections that are potential initiation points for fatigue cracks. Acoustic emission monitoring is used for early detection of fatigue cracks in fracture critical bridge members and to monitor the relative activity of existing fatigue cracks. Advanced signal processing and correlations to parametric measurements are used to separate noises generated by dynamic loading, loose connections, rivets and crack growth (see Figure 15.3.1).

Commercial systems are available, based on wave propagation properties. When energy is released (for example: high-tensile wire failures or concrete cracks), waves propagate in the material. Acoustic sensors distributed along the structure can detect and record the signal. Computer processing of the signal will then provide valuable information about the event including: location, origin, energy, and frequency (see Figure 15.3.1).

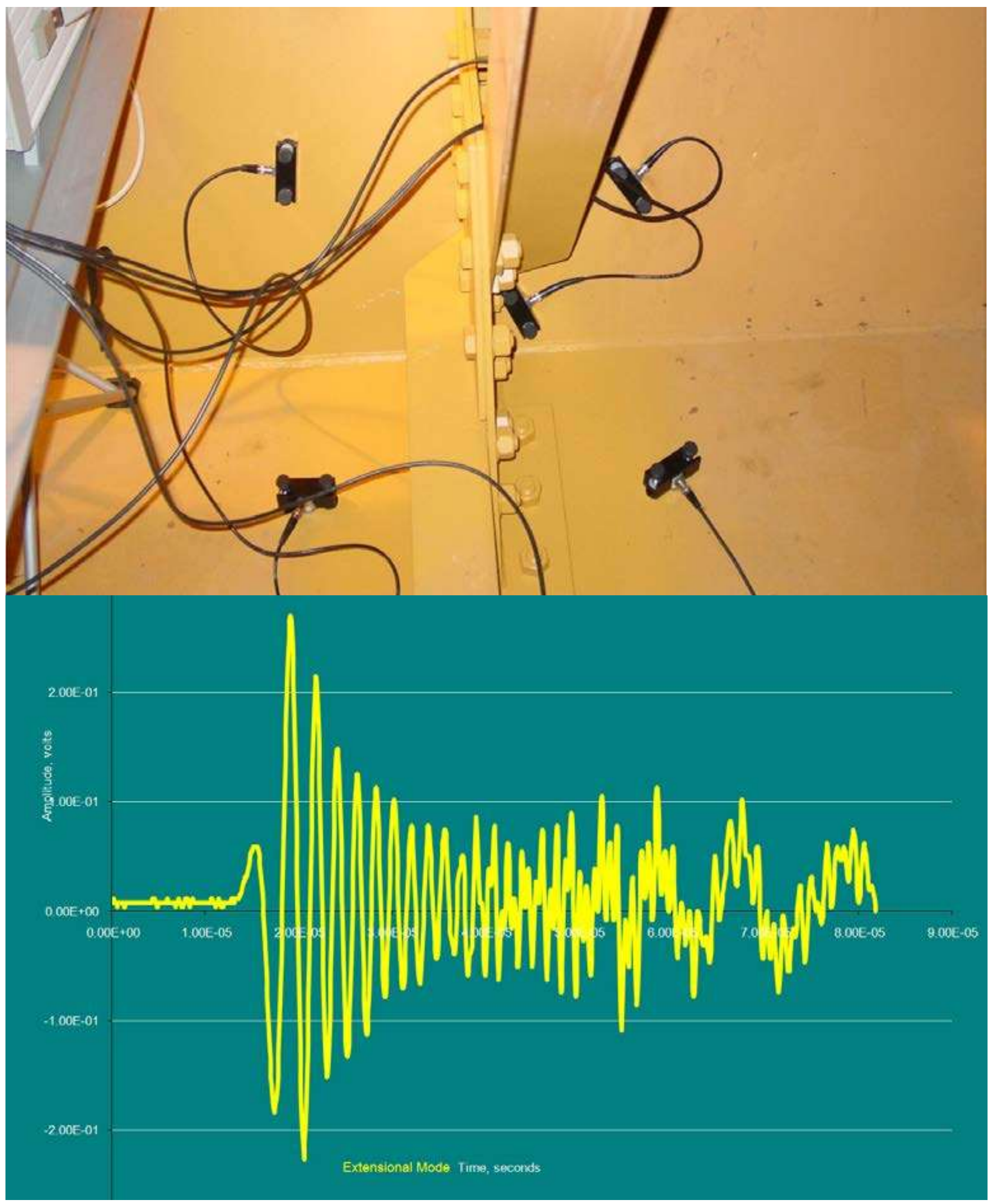

Figure 15.3.1 Acoustic Sensors Used to Determine Crack Propagation

The main advantage of these systems is the recording and real-time analysis of the waves themselves, allowing automatic filtering by the acquisition unit according to preset criteria. The events of interest are stored in the acquisition unit and automatically available for analyses.

Devices can be used to monitor areas that already are cracked or cracked areas that have been retrofitted. The device is a portable, modular multi-channel system that can be mounted close to the area being monitored (see Figure 15.3.2). The system can be directly connected to a computer or it can be accessed through wired or wireless modems for data collection.

Figure 15.3.2 Inspector Using Acoustic Emissions to Determine Crack Propagation

Limitations of acoustic emission testing include AE being a non-repeatable test. Once a test is completed, it cannot be repeated due to the flaw growth being an irreversible process. Also, deficiencies are not detectable if they are not growing or flexing. Therefore, if the deficiency is not increasing in size, acoustic emission testing will not be able to locate the crack. The bridge may also cause interference with testing. If background noise exists, that noise would be similar to the sound energy released by a flaw. For this reason, the wires need to be properly shielded against background noise. Lastly, the acoustic emission testing unit is relatively expensive and also requires the additional cost of an operator.

Corrosion Sensors

Corrosion sensors are being developed that use environmental variables such as dirt and duration of wetness to indicate the degree of corrosion of a steel structure.

Smart Coatings

The National Science Foundation's Advanced Technology for Large Structural Systems (ATLSS) Engineering Research Center has developed "Smart Paint" – paint with microencapsulated dyes that outline a fatigue crack in a bridge or other highway structure as the crack forms and propagates.

Japanese scientists have also developed paint that sends out electrical signals which are picked up by electrodes placed on either side of the paint's resin layer if the structure or material begins to vibrate. The greater the vibration, the greater the electrical signal. This paint could enable engineers to monitor vibrations throughout the lifetime of a structure, allowing them to calculate much more accurately when fatigue is becoming a problem. The new paint is a much easier way of measuring vibrations than conventional strain gauges.

Dye Penetrant

A dye penetrant test (PT) can be used to define the extent and size of surface flaws in steel members (see Figure 15.3.3). The test area is cleaned to bare metal to remove all contaminants, a penetrant is applied to the surface by spray or brush, and excess penetrant is removed by wiping or water rinsing. Once the penetrant has dried, a white developer is applied, which draws the dye out of the irregularities and defines the extent and size of surface flaws. Bridge inspectors commonly use this method since it does not require extensive training or expensive equipment. A limitation of this method, however, is that it reveals neither the depth of cracks nor any subsurface flaws. Another important factor when performing dye penetrant testing is the penetrant dwell time. This is the amount of time that the penetrant is allowed to remain on the surface before the excess is wiped off. Factors that effect the dwell time include:

- Temperature of the member being tested and the penetrant type
- Ambient air temperature (higher temperatures require shorter dwell times)
- Humidity (low humidity causes penetrant to dry out rapidly)
- Size and shape of the discontinuity (hairline cracks need more time than large ones)
- Material type
- Penetrant removal type and manufacturer's recommendations

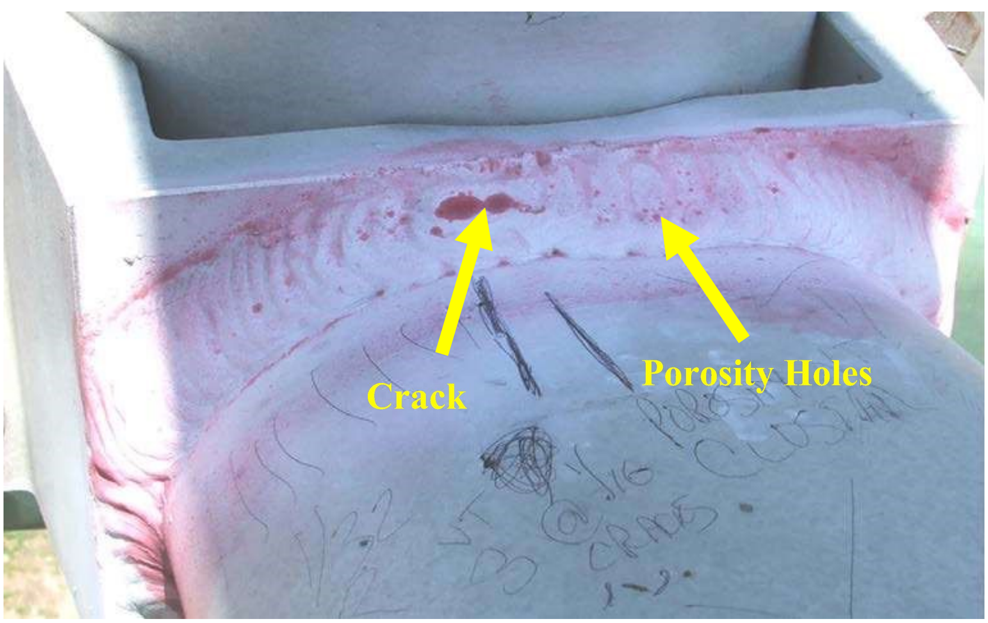

Figure 15.3.3 Detection of a Crack Using Dye Penetrant

Limitations of dye penetrant testing include only showing what defect is on the surface and nothing further in on the specimen. For a proper reading, clean the surface, which includes the paint. In order to see if there is a crack present, the inspector needs good visual acuity. In addition, a recommended temperature of over 40 degrees Fahrenheit is required to achieve acceptable results using dye penetrant testing.

Magnetic Particle

Magnetic particle testing is useful in detecting surface gouges, cracks, and holes in ferromagnetic materials. It can also detect subsurface deficiencies, such as voids, inclusions, lack of fusion, and cracks, which lie near the surface. Magnetic particle inspection is primarily used to find surface breaking flaws (see Figure 15.3.4) and can also be used to located subsurface flaws. Its effectiveness, however, diminishes quickly depending on the depth and type of flaw. The method consists of magnetizing the member, applying iron filings, and then interpreting the pattern formed by the filings, which are attracted by the magnetic leak.

A magnetic field is induced into the member, and cracks or other irregularities in the surface of the member cause irregularities in the magnetic field (see Figure 15.3.5). This method is also referred to as magnetic field disturbance.

Figure 15.3.4 Magnetic Particle Device Used to Detect Subsurface Flaws

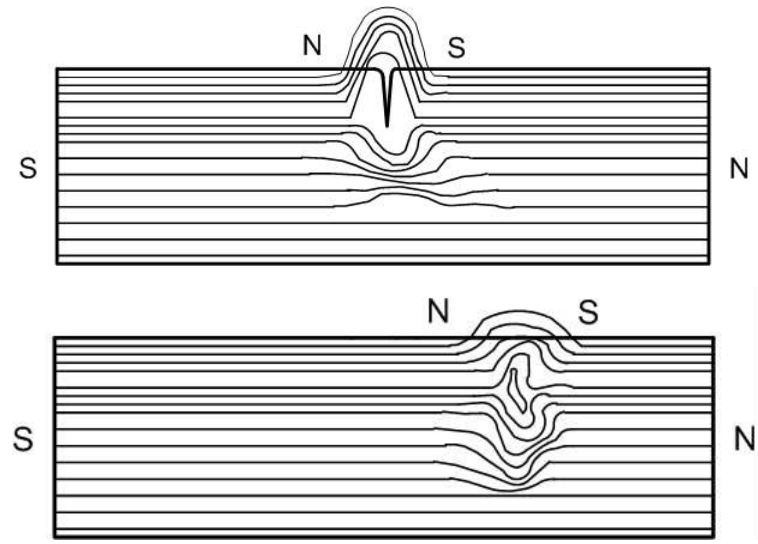

Figure 15.3.5 Schematic of Magnetic Field Disturbance

Limitations of magnetic particle testing include applicability only for members composed of a ferromagnetic material. For some test pieces, removal of the residual magnetism is necessary for an additional expense. The magnetic field requires perpendicular orientation to the principle plane of the defect for detection. In addition, smaller subsurface deficiencies are generally harder to detect than larger deficiencies. Lastly, clean unpainted surfaces help to ensure the maximum sensitivity of the magnetic particle testing unit.

Radiography Testing

Radiography testing (RT) is used to detect and locate subsurface deficiencies such as cracks, voids, and inclusions throughout the internal structure of the material in the fabrication shop and in the field.

Radiography testing requires that the inspector have access to both sides of the structure, with the radiation source on one side and the film on the other side. X-rays or gamma rays are passed through the member and are absorbed differently by the various flaws. When a piece of radiographic film is exposed to the rays, the deficiencies appear as shadows on the film (see Figures 15.3.6). This type of advanced inspection is typically used for full penetration groove welds during fabrication and construction.

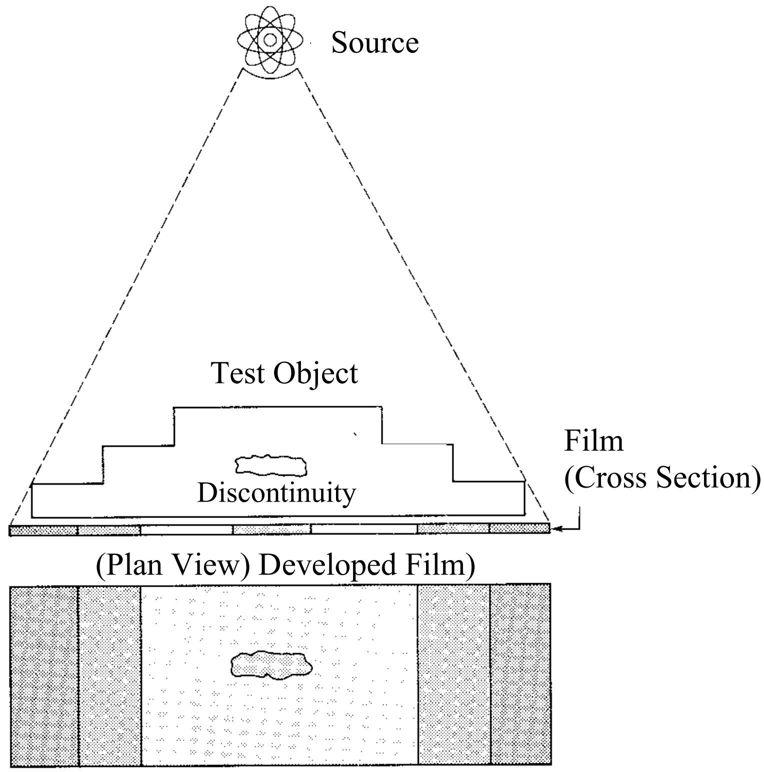

Figure 15.3.6 Radiography Testing

Limitations of radiography testing include requiring access to both sides of the test member for a proper reading. It is necessary to have a high skill level to interpret the readings. Lastly, radiography testing is relatively expensive, especially for thicker members. The cost of an operator needs to be factored into the total cost of radiography testing.

Computed Tomography

Computed tomography uses X-ray and gamma radiation to visualize and produce 2-D and 3-D cross-sectional images of the interior deficiencies of a steel member. The image is captured by a detector array, it is processed by a computer, and it is then reconstructed. This method is similar in many ways to medical CAT scans, and it has great potential for locating discontinuities of all types in steel members (as well as concrete members).

Robotic Inspection

Several companies are currently developing and marketing systems which use high-resolution video cameras on robotic arms attached to permanent falsework underneath the bridge. By remote telescanning, details can be visually monitored, with magnification if needed, without the inspector having to climb to gain access to a detail each time an inspection is desired. While the primary material application for robotic inspection is steel, it can also be used on timber and concrete bridges.

In recent years, the California Department of Transportation (Caltrans) has been working on an aerial robotic inspection system. This system, in the testing and development stage, can allow bridge inspectors to view elevated bridge members from the ground. It is controlled by a remote control that is connected to the system through a 100 ft electrical cord. A fiber optics cable transfers information and images from the aerial device to the ground station. This type of inspection may reduce traffic delays and increase the level of safety for motorists and bridge inspectors.

There have also been robotic inspections performed by unmanned vehicles. Since Hurricane Ike in 2008, the Texas Transportation Institute and the Texas Department of Transportation (TxDOT) gave permission to the Center for Robot-Assisted Search and Rescue for bridge inspection using robotic means. This is achieved by using an unmanned surface vehicle and underwater vehicles (see Figure 15.3.7) that were used to inspect the substructures. The surface vehicle is battery powered and can run for four to six hours based upon the current. It contains an acoustic camera for subsurface inspections and three video cameras to record above the water. The underwater inspection robots can be used for the underwater visual inspection of bridges and debris and mapping debris fields.

Figure 15.3.7 Robotic Inspection: Unmanned and Underwater Inspection Vehicles

Ultrasonic Testing

Ultrasonic testing is frequently used in steel applications and can be used to detect cracks in flat, relatively smooth members, as well as pins by using high-frequency sounds (range of 20 KHz to 25 MHz) pulsed through a material to generate images (see Figure 15.3.8). It can also be used to measure the thickness of steel members, providing detailed information concerning loss of cross section. Ultrasonic testing also has many applications in the inspection of welds, detecting porosity, voids, inclusions, corrosion, cracks, and other discontinuities. This method will involve applying a couplant to the area that is to be inspected and then scanning the area with a transducer, which is attached to the UT machine. Refer to Topic 15.1 for further details about the principles of ultrasonic testing.

Figure 15.3.8 Ultrasonic Testing of a Pin in a Moveable Bridge

Limitations of ultrasonic testing include inaccurate readings for members with a rough surface or complicated geometry. Parallel plates or angles (including built-up members) with a small gap between the elements may also produce inaccurate readings. In additional, flaws that are parallel to the sound waves will not be detected. Skilled operators are required to administer ultrasonic testing, adding to the cost of this NDE method.

Ultrasonic thickness depth meters (D-meters) are miniature versions of an ultrasonic tester which uses a dedicated straight beam transducer (see Figure 15.3.9). The primary difference between an average ultrasonic tester and a D-meter is that ultrasonic testers can determine internal flaws while D-meters can only detect the thickness of the part being tested.

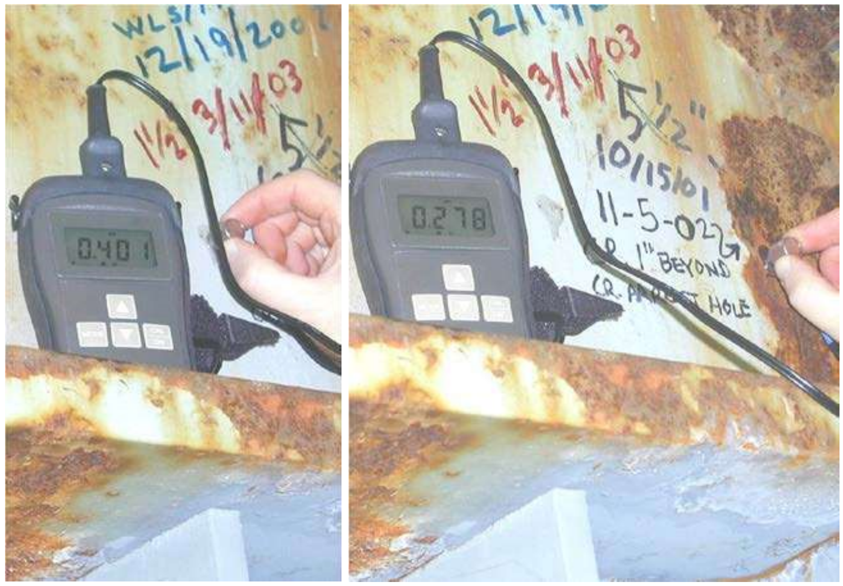

Figure 15.3.9 Ultrasonic Thickness Depth Meter (D-meter)

Portable ultrasonic testing (UT) or phased array units are another form of ultrasonic testing that can be used to test for discontinuities on steel members (see Figure 15.3.10). They are arrays that consist of a series of individual elements, transducers, that are separately pulsed, time delayed and processed. Software will allow the operator to modify the beams time delay or phasing. The portable UTs and phased arrays can be controlled electronically to scan, sweep, steer, and focus the beam.

Figure 15.3.10 Ultrasonic Testing of a Gusset Plate Using a Portable UT

Advantages of this type of testing include considerably faster scanning rates (5 to 10 times faster) compared to traditional ultrasonic testing. Multiple angles and frequencies also produce better images, which results in less user-interpretation required by the operator.

Limitations of portable units include some uncertainty in the technology, as this method is relatively new and not completely proven. For this reason, this method may not be universally accepted by bridge owners as a legitimate way to test for deficiencies. Training courses are also required, due to the difficulty in using this equipment. Lastly, the units are expensive and require an additional cost for a qualified operator.

Eddy Current

This type of electromagnetic method uses AC currents. Eddy current testing (ET) can only be performed on conductive materials and is capable of detecting cracks and flaws as well as member dimensions and variations. This method can be used on painted or untreated surfaces. The system works by monitoring the voltage across a coil that has an AC current flowing through it. When the coil is placed next to the conductive member, the member produces eddy currents that flow opposite to the direction of flow from the coils. Deficiencies in the member disturb the eddy currents, which, in turn, affect the induced current. The affected induced current is monitored through the voltage across the coil. Eddy current testing devices can be hand held devices (see Figure 15.3.11).

Figure 15.3.11 Hand Held Eddy Current Testing (ET) Instruments

Limitations in eddy current testing include the inability to determine the depth of the crack. This NDE method also does not work with galvanized steel members. Lastly, eddy current testing requires operators with the proper training to correctly interpret the test results, which adds to the cost of the method.

Electrochemical Fatigue Sensor (EFS)

Electrochemical Fatigue Sensors (EFS) is a new nondestructive evaluation method that is used to determine if actively growing fatigue cracks are present in the steel. Data collection and analysis software is provided within the EFS system. The system also consists of an electrolyte, sensor array, and potentiostat. These components are used to apply a constant polarizing voltage between the bridge and the sensor. The sensor is placed near the suspected fatigue crack location on the bridge and then injected with the electrolyte. A small voltage is then applied. The current response of the sensor array, comprised of a crack measurement sensor and a reference sensor, is collected, analyzed and compared with the software. The software will automatically indicate the level of any fatigue crack activity (see Figure 15.3.12).

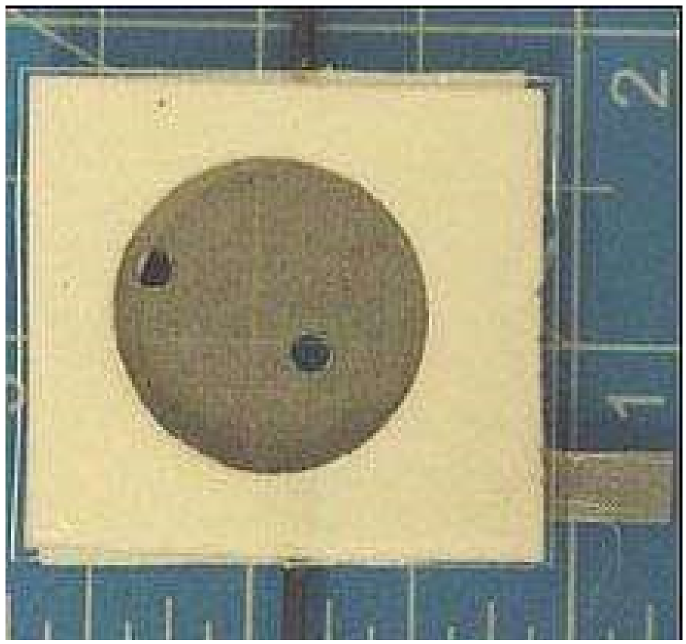

Figure 15.3.12 Electrochemical Fatigue Sensor

Magnetic Flux Leakage

Magnetic flux leakage testing, similar to magnetic particle testing, is a form of nondestructive evaluation developed in Great Britain that has been used over the past few decades on stay cables. This method uses a magnet to magnetize the steel to help detect any corrosion and pitting in steel. Any crack will be detected by sensors that will pick up any distortion of the magnetic field which causes the field to leak from the rope. Various types of sensors, placed close to the rope, are used to help sense and measure any magnetic flux leakage. The types of sensors include coils, Hall sensors or fluxgate sensors.

Laser Vibrometer

Laser vibrometers are used to measure small non-contact vibrations of a stay cable from a large distance. Nothing special needs to be placed or done to the cable. Instead, a low-power laser beam is used, directed at the cables. The response that is measured will be vibration amplitude and frequencies which will be used to determine any vibration of the cables. Those frequencies detected will then be used to calculate the forces that the vibrations are placing upon the cables.

Information concerning various nondestructive testing can be found on the American Society of Nondestructive Testing website: **www.asnt.org**.

15.3.3 Other Testing Methods

Strength tests are considered destructive since they usually involve removing pieces of steel from the bridge. Small pieces cut out of steel members are called test "coupons." The removal method and coupon size have to be suitable for the planned tests. If a coupon is required, consult the bridge engineer to determine the most suitable area of removal. For instance, an inspector will not remove a coupon from the web area over a bearing. An inspector will not recommend removal of a coupon from a high stress zone such as the bottom flange at midspan. Tests may be necessary to determine the strength or other properties of existing iron or steel on bridges for which the steel type is unknown.

The following tests can be conducted only by the destructive method of removing a sample and evaluating it in a laboratory.

Brinell Hardness Test

The Brinell hardness test measures the resistance to penetration of the steel. A hardened steel ball is pressed into the test coupon by a machine-applied load. The applied load and the surface area of the indentation are used to calculate the hardness of the steel. For steel that has not been hardened by cold work, its hardness is directly related to its ultimate tensile strength.

Charpy Impact Test

An impact test determines the amount of energy required to fracture a specimen. A common impact test for steel coupons is the Charpy V-notch test (see Figure 15.3.13). A notched test coupon is placed in a vise, and a hammer is then released from an elevated position, swinging down and hitting the coupon. Since the force of the hammer is concentrated in a notch in the coupon, the stress goes into fracturing the specimen and not into strain. The energy required for fracture is determined based on the mass of the hammer and the distance that it fell and is recorded on the dial located on the striking hammer. This test can be performed at different temperatures to determine if the steel is susceptible to brittle failure.

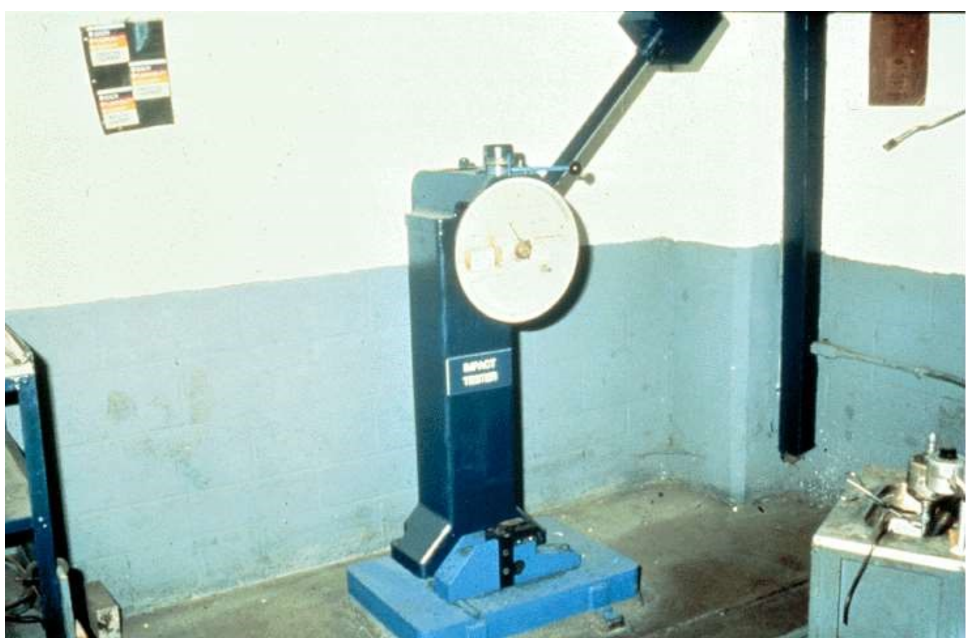

Figure 15.3.13 Charpy V-Notch Test

Chemical Analysis

The chemical composition of the steel is an important indication of whether a weld will crack, either from cold cracking or hot cracking. Tests can be performed on coupons to determine the chemical composition of the steel.

Cold, or delayed, cracking can be approximated using a carbon equivalent (C.E.) equation that is based on the chemical composition of the steel. One such equation, based on the relative proportions of various elements in the steel, is presented in the ASTM A706 rebar specification:

$$C.E. = C\% + \frac{Mn\%}{6} + \frac{Cu\%}{40} + \frac{Ni\%}{20} + \frac{Cr\%}{10} - \frac{Mo\%}{50} - \frac{V\%}{10}$$

C – Carbon	Cr – Chromium
Mn – Manganese	Mo – Molybdenum
Cu – Copper	V – Vanadium
Ni – Nickel	

When the C.E. is below 0.55, the steel is generally not susceptible to cold cracking, and no special precautions are required for welding. However, when the C.E. is above 0.55, the steel is susceptible to cold cracking, and special precautions are required for welding.

Hot cracking occurs as the weld begins to solidify. Hot cracks have almost been eliminated today due to modern welding material formulation.

Tensile Strength Test

The tensile strength is the highest stress that can be applied to the coupon before it breaks Once the test is complete, the tensile strength of the steel can be easily determined. See Topic 5.1, Bridge Mechanics.

The ends of the test coupon are placed in vises on a testing machine. The machine then applies a tensile load to the ends of the coupon. The machine measures the load at which the coupon fails or breaks. This load and the cross-sectional area of the coupon determine the tensile strength of the steel.

Brittle fractures occur without plastic deformation once the yield strength is exceeded. Since there is no plastic deformation, there is no warning that a fracture will occur. The fracture that is formed on a brittle fracture will be flat (see Figure 15.3.14).

Ductile fractures occur once the yield strength has been exceeded, causing the specimen to elongate and "neck down" (also known as plastic deformation) and eventually breaking if the load is not removed (see Figure 15.3.15). Plastic deformation results in distortion of the member, which will provide a visual warning before the member would fracture. The reduced cross section is caused by plastic distortion rather than section loss. The fracture produces shear lips that are tilted at 45 degrees.

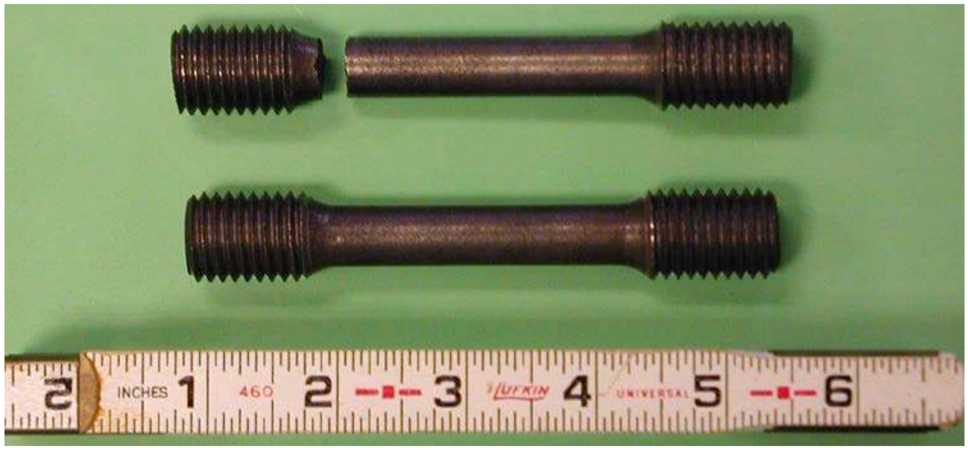

Figure 15.3.14 Brittle Failure of Cast Iron Specimen

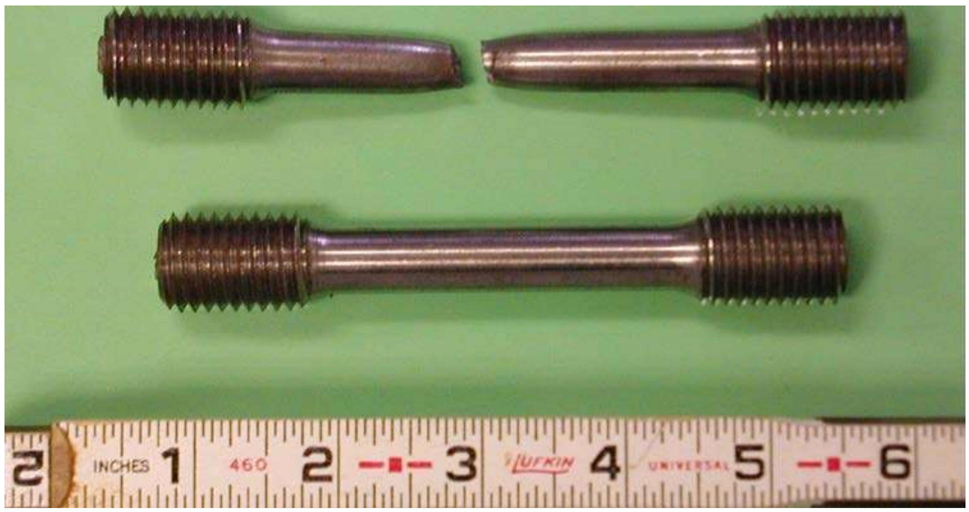

Figure 15.3.15 Ductile Failure of Cold Rolled Steel

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Chapter 15
Advanced Inspection Methods

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Topic 15.4 Advanced Bridge Evaluation

15.4.1 Introduction

Today’s sensing devices capture and report highly accurate and objective data, which can be used to make “fact-based” evaluations for bridge condition and provide decision support for serviceability, repair or replacement actions, optimizing the owner’s overall bridge management plan.

Advanced bridge evaluation technologies allow the owner to more objectively capture and evaluate known or suspect deficiencies found during a visual inspection. They may also be used to perform periodic or continuous inspections on members that are not readily accessible. Advanced bridge evaluation technologies usually require customized hardware and software, an experienced technician to install sensing devices or perform the testing, and an engineering professional that has expertise in interpreting the results (see Figure 15.4.1). Generally, bridge inspectors and engineers have a basic understanding of the advanced bridge evaluation technologies available. This basic knowledge allows them to participate in the selection and use of the appropriate technologies to better determine the bridge's condition.

Figure 15.4.1 Installation of Sensors

There are two main classifications of advanced bridge evaluation technologies. The first is known as nondestructive evaluation (NDE). This classification pertains to technologies that do not impair the usefulness (short term or long term) of the member being tested. The other classification consists of advanced bridge evaluation technologies that negatively affect the member by reducing the structural integrity of the member being tested. For example, removing a part of a member for testing therefore reduces its capacity. Most practitioners and owners today prefer the nondestructive technologies for obvious reasons.

The proper use of these advanced bridge evaluation technologies can supplement routine bridge inspections and can be useful for optimizing an owner's bridge management program. Methods are being developed to transfer near real-time results from these technologies directly into Bridge Management Systems ratings and bridge management protocols (e.g. overload permitting.) (see Figure 15.4.2).

Near real-time solutions are made possible by the combination of a variety of sensing devices, wireless communication and internet technologies. The ability to capture data on member strains, relative movement between members, crack growth and propagation, and other relevant structural parameters are the result of digital technology being applied to structural bridge evaluations.

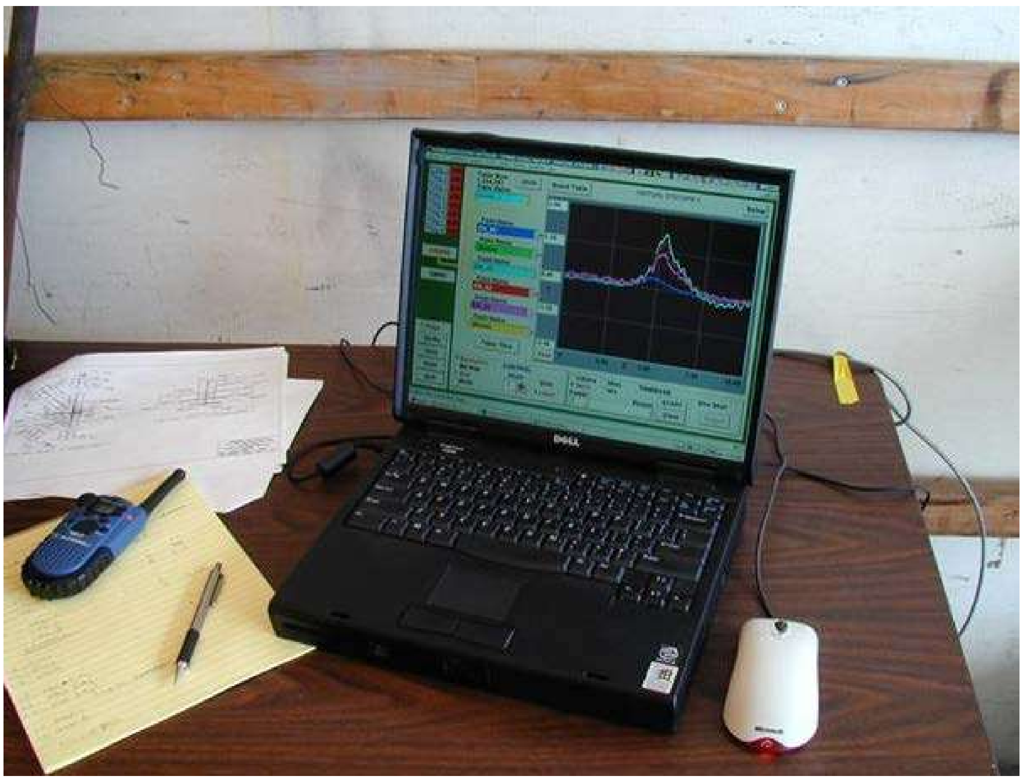

Figure 15.4.2 Viewing Real Time Data

15.4.2 Advanced Bridge Evaluation Methods

Strain or Displacement Sensors

Strain or displacement sensors can be used to monitor the response of a member to a live load and/or temperature changes. These type sensors are available and include foil type, vibrating wire, fiber optic, and a sensor that measures both current and peak strains in one device (see Figure 15.4.3). Foil-type sensors are only used in the axial direction of flat members. Single wire filament “vibrating wire” sensors can be used on flat members or cables. Portable strain reading instruments can be used to monitor sensors from a central location on or near the bridge in a manual data collection mode or fully automatic monitoring can be installed, allowing readings to be taken at user defined intervals and sent wirelessly to a central location for viewing over the internet.

Figure 15.4.3 Strain Gage Used on the Hoan Bridge, Milwaukee, Wisconsin

Locations for strain sensors are selected based on the condition of individual members, accessibility, and the objectives of the monitoring program. Strain/displacement sensors can provide valuable information about:

- The actual transverse load distribution through the structural member
- The load sharing between elements of a multi-element member
- The effectiveness of the various members of the primary structural system
- The influence of deteriorated or defective members
- The growth and/or propagation of cracks in steel or concrete members
- The relative movement of members to fixed points due to loss of section (chemical) or load-induced deterioration

The principal use of strain sensors today is to ascertain the actual condition of a member or series of members and use that information to infer the safe load-carrying capacity of the structure. In essence, sensors are used to provide data to allow additional decision making combined with a visual inspection. Strain sensor data can be used to ascertain the weight of vehicles crossing a bridge. This is known as a "weigh-in-motion" system.

Sensing devices, coupled with electronic control equipment, can be used to update owners and bridge inspectors about ongoing deterioration of the structure. Such configured solutions, which can be integrated into one system, generally include strain or displacement sensors, a system controller on the structure, wireless data transmission, customized software, and other features. This allows for secure data capture, data graphing, viewing over the internet and alerts (by e-mail, cell phone or other method) if strains or displacements exceed predetermined values.

Other Available Sensors

To complement strain or displacement sensors, newer sensors are being developed and deployed to enhance bridge evaluation. Typical sensing devices include tiltmeters (foundation movements), accelerometers (earthquake-induced movements), temperature and humidity sensors, and even global positioning satellite (or GPS) systems to monitor movement of piers, towers, and decks on long bridges to an accuracy of 3/16 of an inch. Other, more esoteric sensing devices include those to detect onset of fatigue cracking, actual stress in cables via electromagnetic fields, corrosion, and other member condition parameters.

Generally speaking, price and functionality are directly related. That is, sensors meant to be used in outdoor environments for long periods of time (years) are more expensive than those meant for controlled environments (laboratories) or short duration use (weeks). Sensing devices can be utilized individually or as part of a system that is configured to provide a total solution. Specialized personnel are required to integrate the variety of sensing devices with controller hardware and software for advanced bridge evaluations.

Dynamic Load Testing

In recent years, an increasing number of short-span bridges have been evaluated using measured response data from known loads. These bridge evaluations have provided useful information and, in some instances, have revealed bridges that required closure or restrictions and those that could be safely upgraded (load restrictions removed).

Use of this method involves a combination of strain sensors, on-site data capture, and response modeling. A known load (weighed dump truck) is driven across a short-span bridge with no other traffic (see Figure 15.4.4). GPS technology is used to precisely spot the truck's position while strain sensors capture member displacements/strains. Data capture typically occurs in one day or less. The data is then used to "build" a rudimentary structural model for evaluation of actual load-carrying capacity. The model is fitted to the actual structural response, allowing engineers to determine actual load-carrying capacity.

This technology gains advantage over current load capacity protocols in that it can consider composite action of the members and contributions to load-carrying capacity from other structural components (sidewalks and parapets) that are typically ignored with traditional analysis methods. Dynamic load testing has been used for over twenty years and has proven its ability to provide accurate load-carrying capacity determinations.

Figure 15.4.4 Dynamic Load Testing Vehicle

System Identification

Using actual structural response data, the properties of the structure (e.g., areas and moments of inertia of structural members) can be calculated. The process of building a structural model from response data is called system identification. The primary use of system identification in structural engineering has been for earthquake engineering research. The historical accuracy achieved in this advanced bridge evaluation methodology indicates that system identification can also provide a tool for detecting unseen structural flaws.

System identification can be performed using a variety of response data, such as modal and time history response. For modal response, the frequencies and mode shapes of the structure are obtained either from ambient vibration data or from the results of harmonic excitation. A time history response is the response (i.e., displacements or acceleration) of one or more points on the structure as a function of time due to a known loading function. For either type of response data, the results are used to determine structural parameters representing the structural integrity of the bridge.

Initially, system identification is used to create a structural model, which accurately represents the in-service condition of the structure (see Figure 15.4.5). Subsequent analyses are then performed to determine which parameters are changing. Since the parameters represent structural properties (e.g., areas and moments of inertia), the changes are indicative of structural deterioration.

Since bridge inspections focus on individual members and system identification considers the entire structure, they are complementary processes. Therefore, system identification can be used to define the structural integrity of the entire bridge structure.

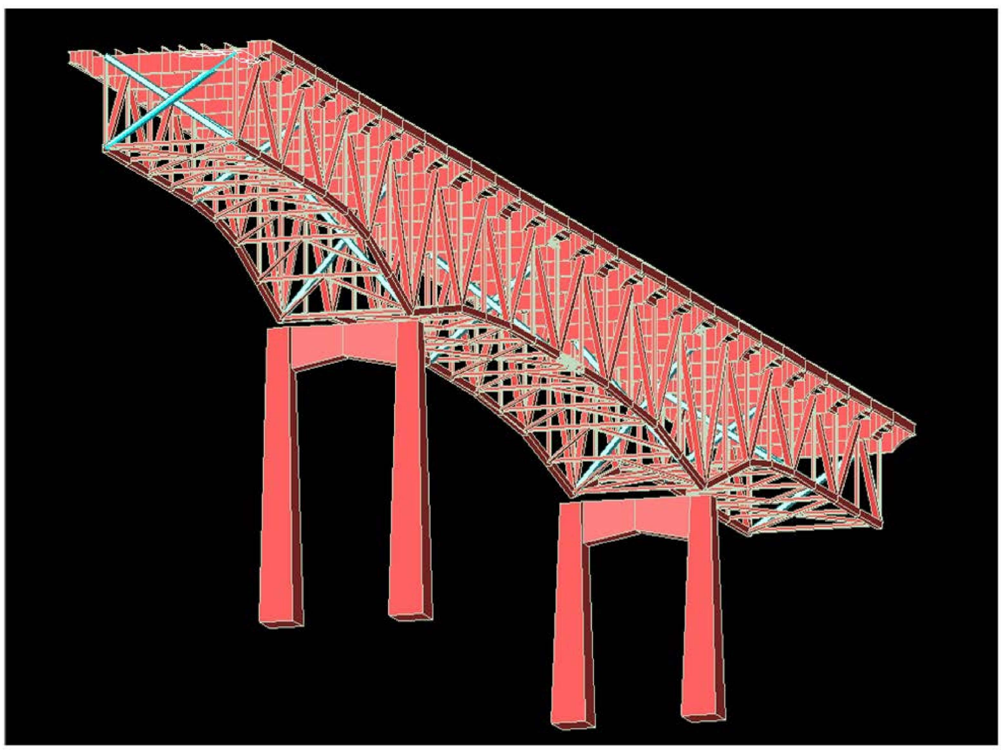

Figure 15.4.5 Structural Model

Practical Considerations for Selection and Use of Advanced Bridge Evaluation Technologies

Any advanced bridge evaluation technology typically provides a reasonable return on investment. There is no reason to pay for technology unless that technology can provide a sufficient return for the Bridge Owner. Over the past several years, significant research has been conducted to demonstrate new advanced bridge evaluation technologies. Some worked well; others did not. But given the current advanced bridge evaluation technologies, owners can typically expect adequate returns on projects. Returns can be calculated using a variety of financial metrics, but some of the more useful are provided below:

- Safe extension of bridge life span, lowering life cycle cost of ownership
- Safe deferral of bridge maintenance or repair programs
- Safe deferral of bridge replacement programs
- Improved prioritization of limited funds
- Removal of unnecessary load restrictions to support commercial traffic and reduce detours, congestion and air pollution
- Identification of bridges that are to be replaced or repaired immediately, thereby lowering liability exposure and increasing safety

Other issues to consider before utilizing an advanced bridge technology:

- Is the advanced bridge evaluation technology being used for a few bridges or across the entire system?
- Is the advanced bridge evaluation technology capturing the "right" information to aid decision making and not a lot of extraneous information?
- Can the advanced bridge evaluation solution be expanded easily and cost effectively if it is later decided to capture more data?
- Should a solution provider be used, capable of system configuration and installation, or integrate the hardware and software internally?
- Should the captured information be able to integrate with the existing information system?
- How long is the technology expected to be deployed – what is the reliability and durability of the hardware and software?
- Can the confidentiality of captured data, both on-site and for later viewing and downloading, be assured?
- Who has the responsibility for conversion of the structural data into useful information and subsequent analysis of that information?
- Can the hardware be used on other structures after project completion?

In summary, the use of advanced bridge evaluation technologies can provide owners with information that promotes "fact-based" decisions. Care and judgment are utilized when specifying and purchasing improved technologies, as well as use in the field. To obtain the best return on investment, defer to those with experience and earned reputation to provide alternative solutions for consideration

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Complex Bridges

Chapter 16
Complex Bridges

Topic 16.1 Cable-Supported Bridges

16.1.1 Introduction

There are several bridge types which feature elements which require special inspection procedures. The most notable bridge types are:

- Suspension bridges (see Figure 16.1.1)
- Cable-stayed bridges (see Figure 16.1.2)

Figure 16.1.1 Golden Gate Bridge

This topic is limited to the cable and its elements. All other members of a cable-supported bridge have been described in earlier topics and are to be referred to for the appropriate information. For each of the above bridge types, this topic provides:

- A general description
- Identification of special elements
- An inspection procedure for special elements
- Methods of recordkeeping and documentation

Figure 16.1.2 Maysville Cable-Stay Bridge

16.1.2 Design Characteristics

A cable-supported bridge is a bridge that is supported by or "suspended from" cables.

Suspension Bridges

A suspension bridge has a deck, which is supported by vertical suspender cables that are in turn supported by main suspension cables. The suspension cables can be supported by saddles atop towers and are anchored at their ends or self-anchored to the bridge superstructure. Suspension bridges are normally constructed when intermediate piers are not feasible because of long span requirements (see Figure 16.1.3). Modern suspension bridge spans are generally longer than 1400 feet.

Cable-Stayed Bridges

A cable-stayed bridge is another long span cable-supported bridge where the superstructure is supported by cables, or stays, passing over or anchored to towers located at the main piers. Cable-stayed bridges are the more modern version of cable-supported bridges. Spans generally range from 700 to 1400 feet (see Figure 16.1.4). Evolving for approximately 400 years, the first vehicular cable-stayed bridge in the United States was constructed in Alaska in 1972 (John O'Connell Memorial Bridge at Sitka, Alaska).

In suspension bridges, vertical suspender cables attach the deck and floor system to the main suspension cables. Cable-stayed bridges are much stiffer than suspension bridges. In cable-stayed bridges, the deck and floor system is supported directly from the tower with fairly taut stay cables.

Figure 16.1.3 Roebling Bridge

Figure 16.1.4 Sunshine Skyway Cable-Stayed Bridge in Tampa Bay, Florida

Types of Cables

A cable may be composed of one or more structural wire ropes, structural wire strands, locked coil strands, parallel wire strands, or parallel wires.

Parallel Wire Cable

Parallel wire cable consists of a number of parallel wires (see Figure 16.1.5 and Figure 16.1.10). The diameter varies depending on the span length and design loads. Parallel wire cables used in cable-stayed bridges conforms to ASTM A421, Type BA, low relaxation. It is basically stress-relieved wire used for prestressed concrete.

Structural Wire Strand

Structural wire strand is an assembly of wires formed helically around a center wire in one or more symmetrical layers. Sizes normally range from 2 to 4 inches in total diameter (see Figure 16.1.6).

Structural Wire Rope

Structural wire rope is an assembly of strands formed helically around a center strand (see Figure 16.1.7).

Parallel Strand Cable

Parallel strand cable is a parallel group of strands (see Figure 16.1.8). Seven-wire strand commonly used for cable-stayed bridges conforms to ASTM A416, low relaxation steel (see Figure 16.1.11). It is basically seven-wire stress-relieved strand for prestressed concrete.

Locked Coil Strand

Locked coil strand is a helical type strand composed of a number of round wires, and then several layers of wedge or keystone shaped wires and finally several layers of Z- or S-shaped wires (see Figure 16.1.9). Locked coil strand has not been used for cable-stayed bridges in this country, but it is commonly used for cable-stayed bridges in Europe.

Several types of cables have been used for cable-stayed bridges. The three most common are locked-coil strand, parallel wire, and parallel seven-wire strand. The majority of existing cable-stayed bridges in the world, other than the United States, use preformed prestretched galvanized locked-coil strand. The cable-stayed bridges in the United States incorporate parallel wire or seven-wire prestressing strand in the cables.

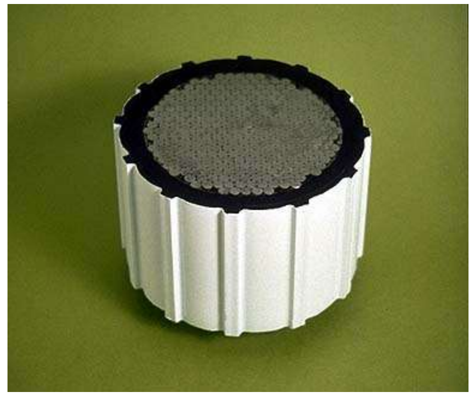

Figure 16.1.5 Parallel Wire

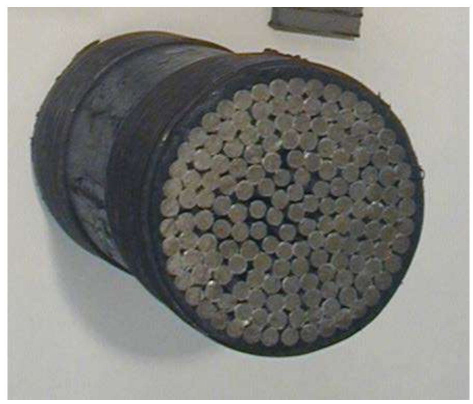

Figure 16.1.6 Structural Wire Strand

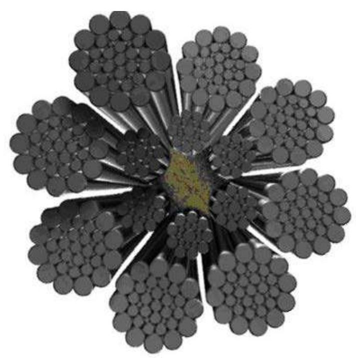

Figure 16.1.7 Structural Wire Rope

Figure 16.1.8 Parallel Strand Cable

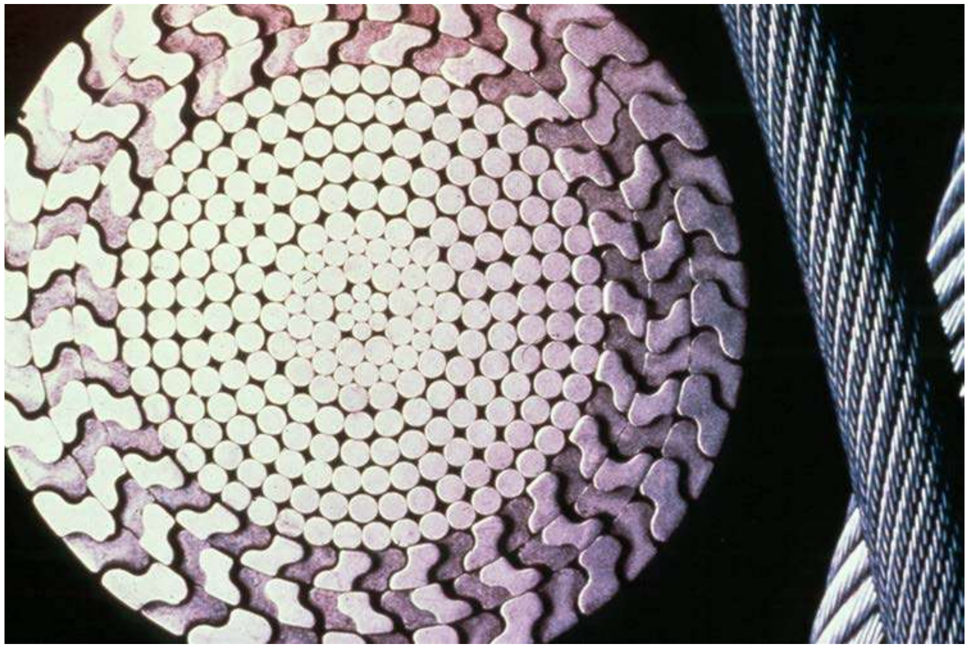

Figure 16.1.9 Locked Coil Strand Cross-Section

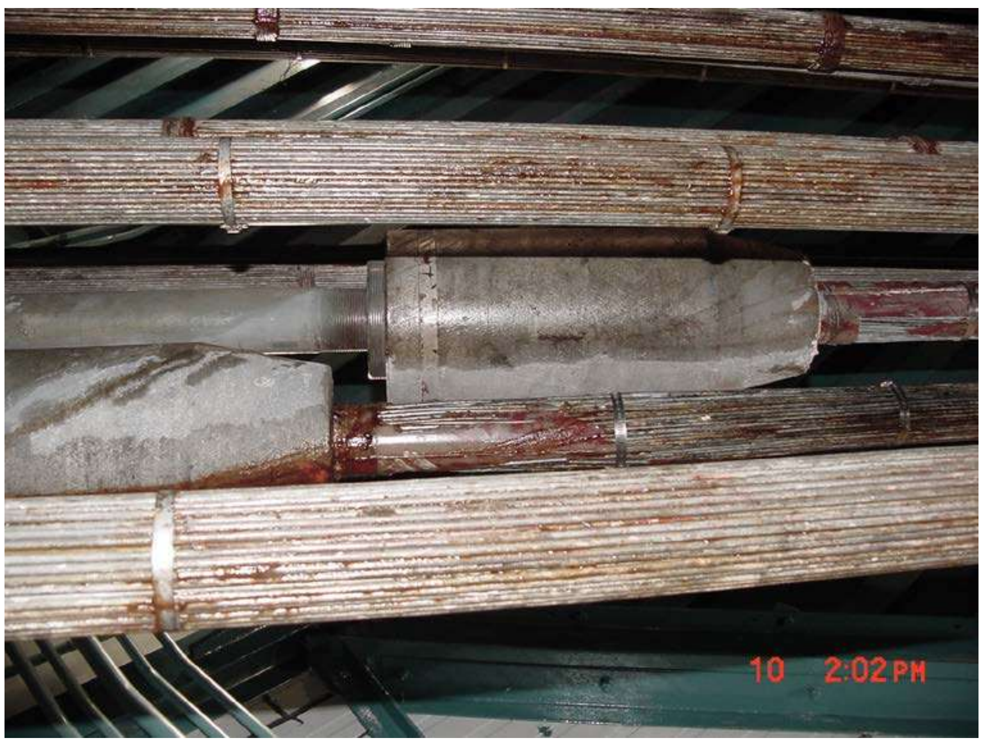

Figure 16.1.10 Parallel Wire

Figure 16.1.11 Parallel Strand

Corrosion Protection of Cables

Methods used for corrosion protection include:

- Galvanizing the individual wires
- Painting the finished cable
- Wrapping the finished cable with spirally wound soft galvanized wire, neoprene, or plastic wrap type tape
- Polyethylene sheathing filled with cement grout or grease
- Polyethylene sheathing filled with no grouting
- Any combination of the above systems (see Figure 16.1.12).

Figure 16.1.12 Cable Wrapping on the Wheeling Suspension Bridge

Types of Towers

- Portal tower – typical of suspension bridges (see Figure 16.1.13 (a))
- Towers fixed to pier (see Figure 16.1.13 (b))
- Towers fixed to superstructure (see Figure 16.1.13 (c))
- Single column tower (see Figure 16.1.13 (d))
- A-frame tower (see Figure 16.1.13 (e))
- Laterally offset tower fixed to pier (see Figure 16.1.13 (f))
- Diamond shaped tower (see Figure 16.1.13 (g))

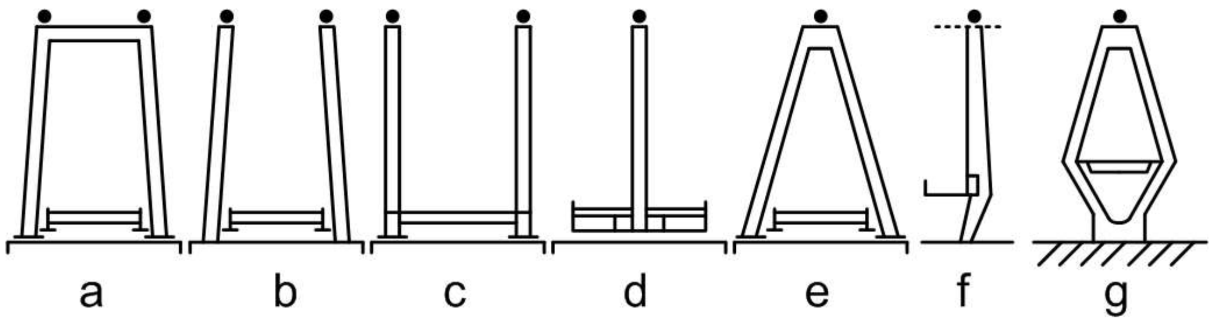

Figure 16.1.13 Shapes of Towers Used for Cable-Stay Bridges

Towers are constructed of reinforced concrete or steel or a combination of the two materials (see Figures 16.1.14 and 16.1.15).

Figure 16.1.14 Tower Types: Concrete "Portal Tower" and "A-Frame Tower"

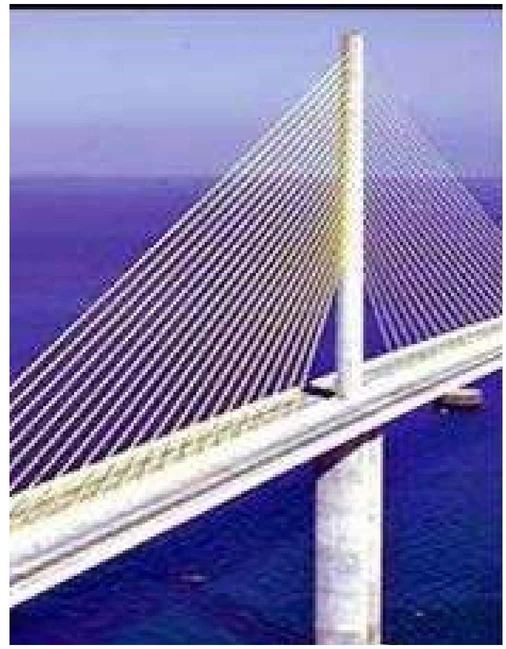

Figure 16.1.15 Tower Types: Steel "Portal Tower" and Concrete "Single Column Tower"

The deck structures are also constructed of concrete or steel.

16.1.3 Suspension Bridges

In this subtopic, only those bridge elements that are unique to suspension bridges are presented. Refer to the appropriate topic for other bridge elements that are common to similar bridge types (i.e. floor systems, open web girders, box sections, etc.).

Main Suspension Cables and Suspender Cables

Main suspension cables are generally supported on saddles at the towers and are anchored at each end. Sometimes, main suspension cables are referred to as catenary cables. Suspender cables are vertical cables that connect the deck and floor system to the main suspension cables (see Figure 16.1.16). .

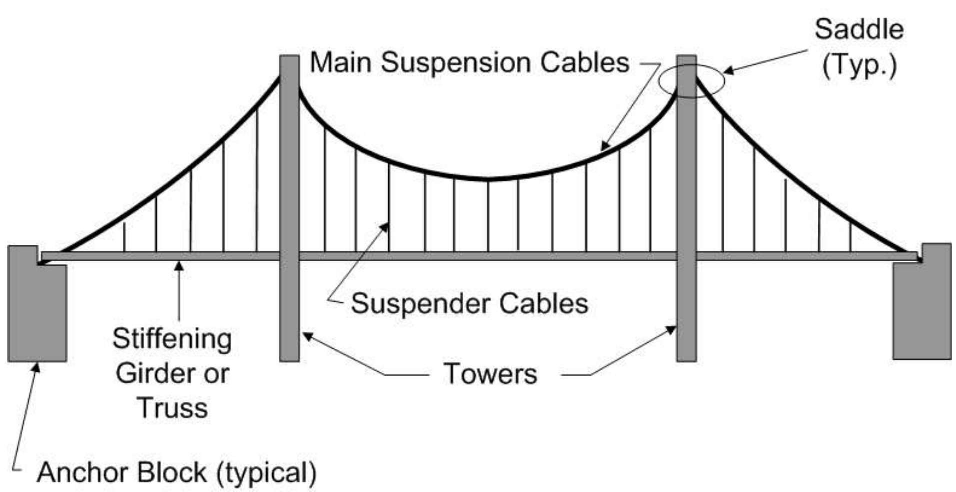

Figure 16.1.16 Three-Span Suspension Bridge Schematic

If a suspension bridge has only two main suspension cables, the cables are considered to be fracture critical members since there is no load path redundancy. Refer to Topic 6.4 for a detailed description of fracture criticality and redundancy.

Another type of suspension bridge uses a self-anchoring system where the main suspension cables are anchored into the edge girders that span continuously from end to end in the suspension spans. The force from the main suspension cables puts the edge girders into compression. The edge girders support the floor system and the suspender cables support the edge girders in this arrangement.

This type suspension bridge may be used to create long clear spans for navigation and not have to continue the suspension spans to the shorelines for anchorage. The alignment for the approach spans can be different than the suspension spans. These benefits are seen in the new Oakland Bay View Bridge in California, where the approach alignment is on a curve, the suspension span creates the wide navigation channel and the anchoring is self contained within the superstructure of the suspension spans.

Anchorage and Connections

Anchorages

In bridges with common earth anchored cable systems, either above or below ground, the total force of the main suspension cable has to be transferred into the anchor block (see Figure 16.1.17). The void area inside the anchor block is referred to as the Chain Gallery. The force from the main cable is distributed through the splay saddle, bridge wires, strand shoes and anchor bars. The anchor bars are embedded and secured in the concrete of the anchor block. The anchor bars may consist of steel bars, rods, pipes, or prestressed bars / strands.

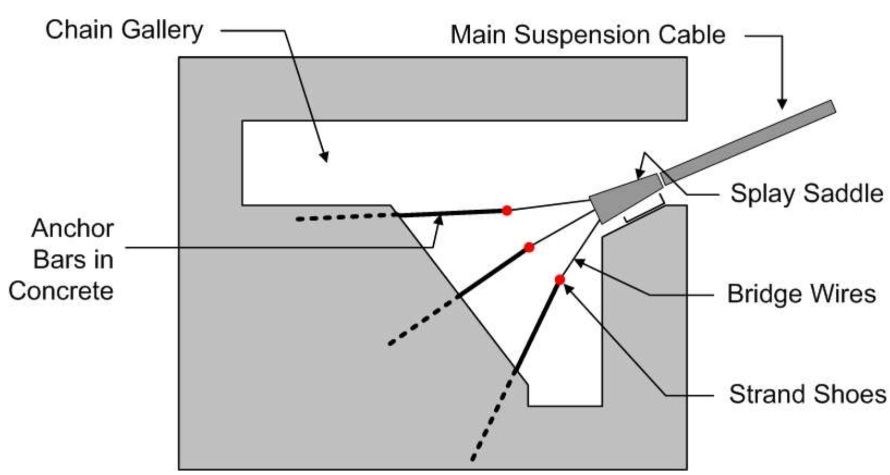

Figure 16.1.17 Anchor Block Schematic

Saddles

The connection between main cable and tower is usually made through saddles. The saddle supports the main cable as it crosses over the tower (see Figure 16.1.18). Saddles are commonly made from fabricated steel or castings.

Figure 16.1.18 Cable Saddles for Manhattan Bridge, NYC (Main Span 1,480 ft)

Suspender Cable Connections

The connection between the main suspension cable and suspender cable is made by means of a cable band. The cable band consists of two semi-cylindrical halves connected by high-tensile steel bolts to develop the necessary friction.

Grooved cable bands have been used in the majority of suspension bridges (see Figure 16.1.19). The top surfaces of the bands are grooved to receive the suspender cables, which are looped over the band.

Instead of looping the hanger cables around the main suspension cable, the hanger might be socketed at the upper end and pin connected to the cable band. This connection is called an open socket (see Figure 16.1.20). Connection to the deck and floor system can also be a similar open socket arrangement or it can be connected directly to a floorbeam - similar to the tied arch bridge.

Figure 16.1.19 Grooved Cable Bands

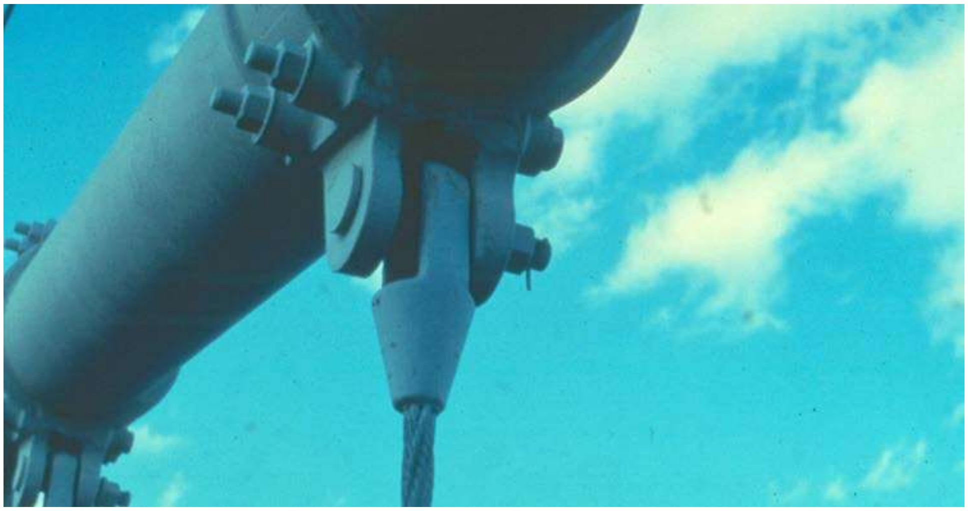

Figure 16.1.20 Open Socket Suspender Cable Connection

Vibrations

The flexibility of cable-supported structures, associated with high stress levels in the main load carrying members, makes these structures especially sensitive to dynamic forces caused by earthquake, wind, or vehicular loads. The term local vibration is used when dealing with the vibration in an individual member (see Figure 16.1.21). When the vibration of the entire structure as a whole is analyzed, it is known as global vibration (see Figure 16.1.22). Due to the amount of vibration in cable-supported structures, it may be common to see various types of damping systems attached to cables. Damping systems may be a tie between two cables, neoprene cushions, shock absorbers mounted directly to the cables, or other systems that act to dampen the cable vibrations (see figures 16.1.23 and 16.1.24).

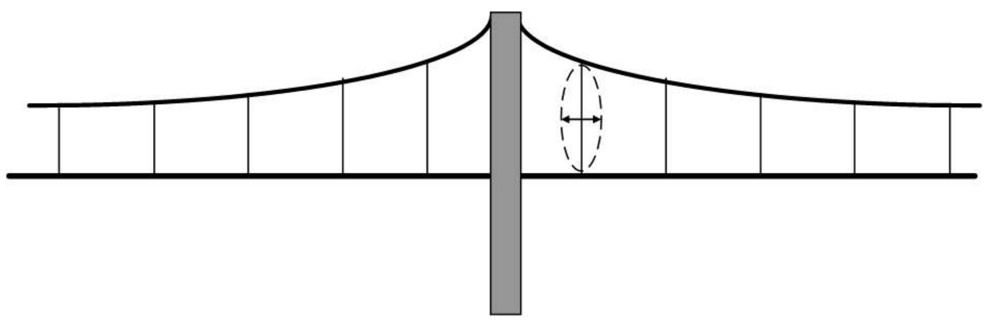

Figure 16.1.21 Cable Vibrations Local System Schematic

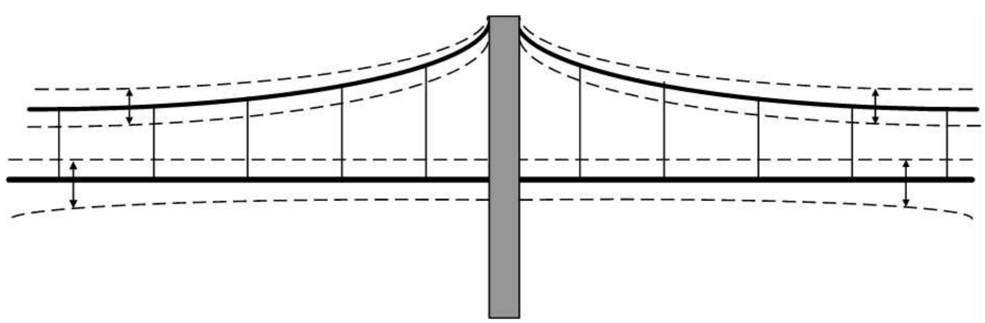

Figure 16.1.22 Cable Vibrations Global System Schematic

Vibrations can affect suspension cables in several ways. Vibration opens cable wires allowing entry of corrosive chemicals and accelerates corrosion. Vibrations create fretting, cracks in the protective coating and cement grout, and accelerate corrosion and possibly fatigue.

Figure 16.1.23 Cable Damping System - Wheeling Suspension Bridge (Photo Courtesy of Geoffrey H. Goldberg, 1999)

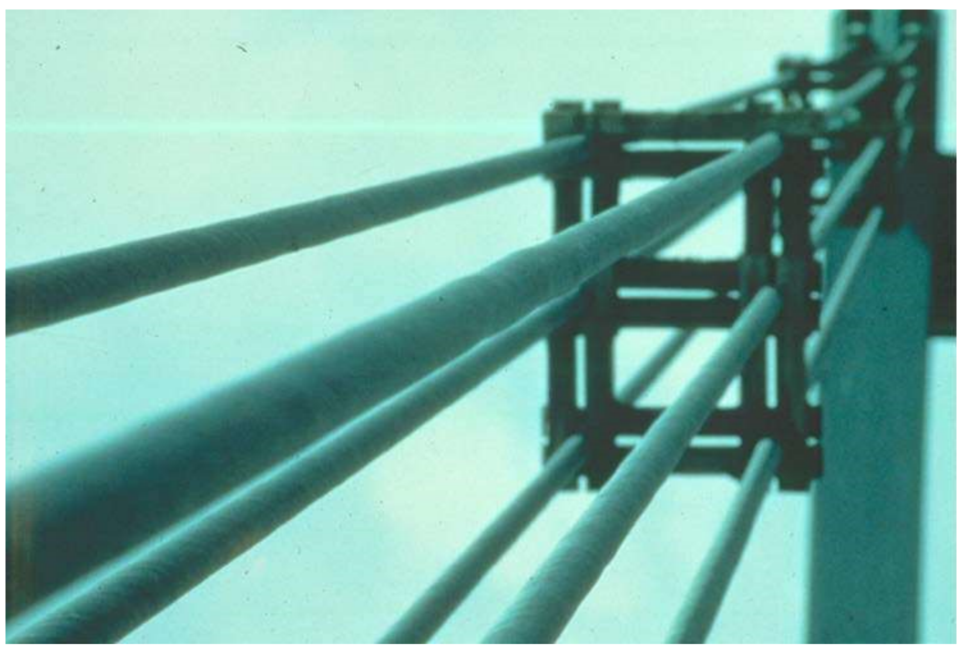

Figure 16.1.24 Cable Tie Damper System

16.1.4 Cable-Stayed Bridges

Only the cable and its elements are described in this subtopic. Refer to the appropriate topic for other bridge elements that are common to similar bridge types (i.e. floor systems, open web girders, box sections, etc.).

Due to the complexity of the various cable arrangements and systems, fracture criticality for individual cable-stayed structures can only be determined through a detailed structural analysis.

Cable Arrangements and Systems

Cable-stayed bridges may be categorized according to the various longitudinal cable arrangements. These cable arrangements are categorized into the following four basic systems:

- Radial or Converging Cable System
- Harp Cable System
- Fan Cable System
- Star Cable System

Radial or Converging Cable System

In this system, all cables are leading to the top of the tower at a common point. Structurally, this arrangement is the most effective. By anchoring all the cables to the tower top, the maximum inclination to the horizontal is achieved (see Figure 16.1.25).

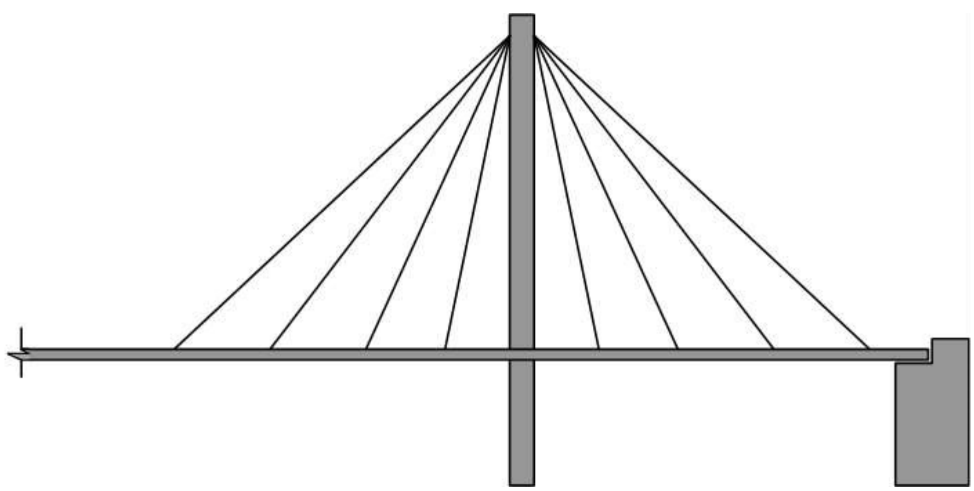

Figure 16.1.25 Radial or Converging Cable System Schematic

Harp Cable System

The harp system, as the name implies, resembles harp strings. In this system, the cables are parallel and equidistant from each other. The cables are also spaced uniformly along the tower height and connect to the deck floor system or superstructure at the same spacing (see Figure 16.1.26).

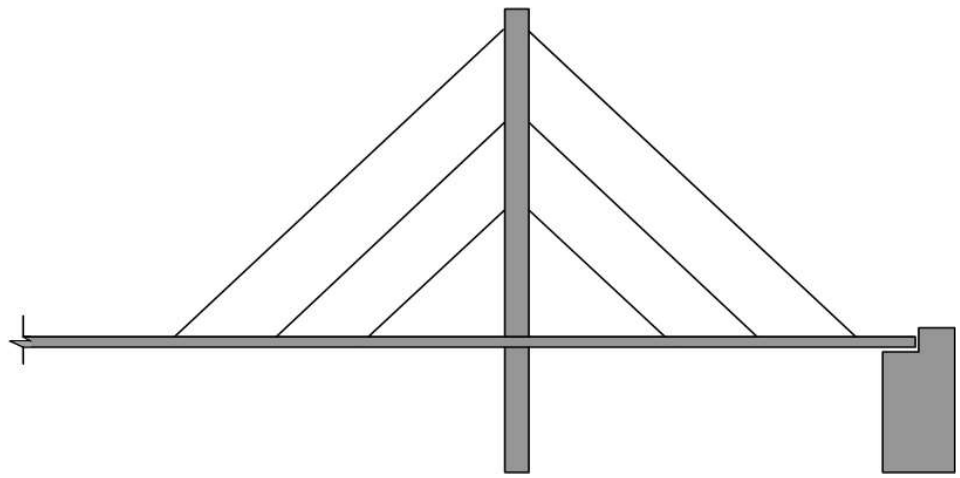

Figure 16.1.26 Harp or Parallel Cable System Schematic

Fan Cable System

The fan system is a combination of the radial and the harp systems. The cables emanate from the top of the tower at equal spaces and connect to the superstructure at larger equal spaces (see Figure 16.1.27).

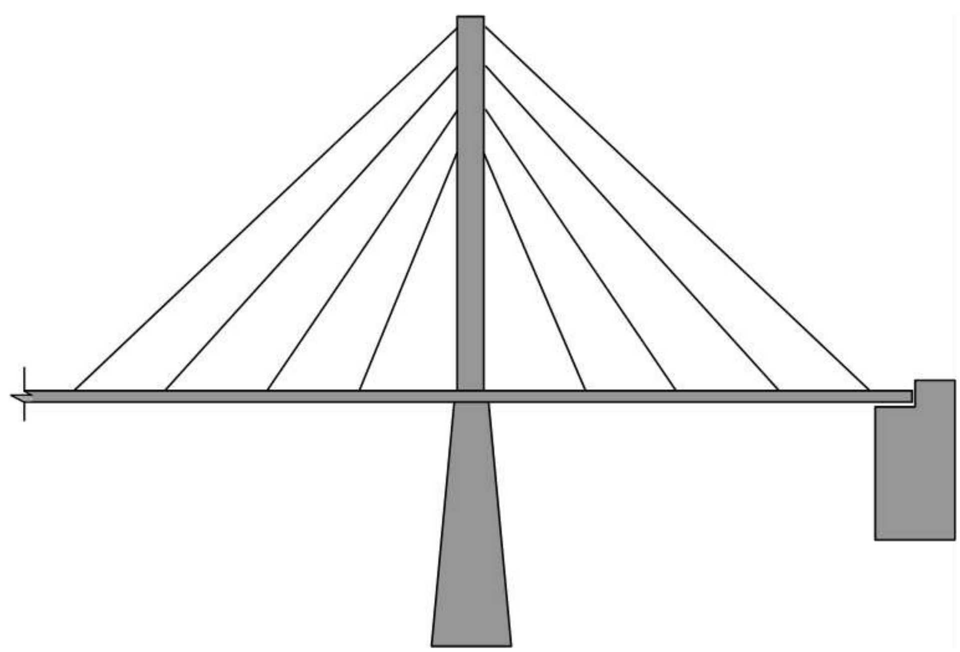

Figure 16.1.27 Fan or Intermediate Cable System Schematic

Star Cable System

In the star system, the cables intersect the tower at different heights and then converge on each side of the tower to intersect the deck structure at a common point. The common intersection in the anchor span is usually located over the abutment or end pier. The star system is uncommon compared to the three systems previously presented. The star system requires a much stiffer superstructure since the cables are not distributed longitudinally along the deck and superstructure (see Figure 16.1.28).

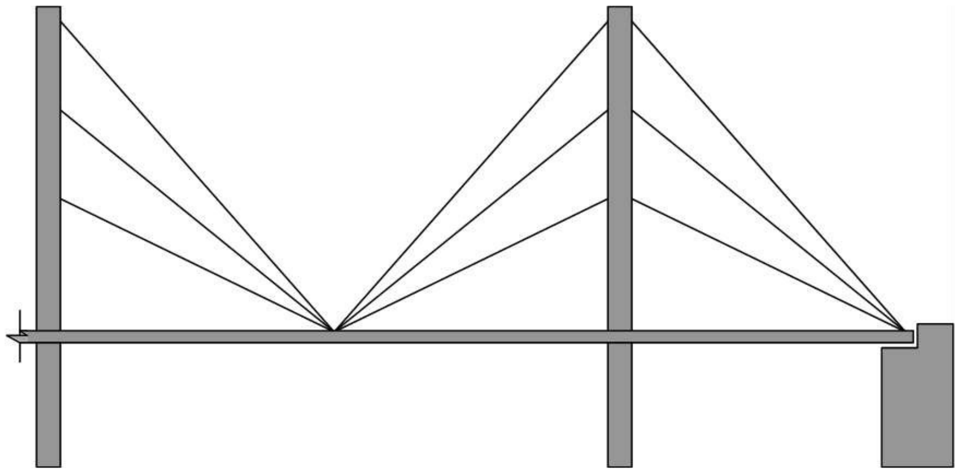

Figure 16.1.28 Star Cable System Schematic

Cable Planes

The cables may lie in either a single or a double plane, may be symmetrical or asymmetrical, and may lie in oblique or vertical planes.

Single Plane

The single-plane cable arrangement is used with a divided deck structure with the cables passing through the median area and anchored below the deck. A single-plane cable system generally utilizes single column or A-frame towers (see Figure 16.1.29).

Figure 16.1.29 Single Vertical Plane Cable System

Double Vertical Plane

The double vertical plane system incorporates two vertical cable planes connecting the tower to the edge girders along the deck structure. The structure may utilize twin towers or a portal frame tower (see Figure 16.1.30). The portal frame tower is a twin tower with a connecting strut at the top. Wider bridges may utilize a triple plane system that is basically a combination of the single and double plane systems.

Figure 16.1.30 Double Vertical Plane Cable System

Double Inclined Plane

In this two plane system the cable planes are oblique, sloping toward each other from the edges of the deck and intersecting at the tower along the longitudinal centerline of the deck (see Figure 16.1.31). Generally the tower is an A-frame type, receiving the sloping cables that intersect close to the centerline on the tower.

Figure 16.1.31 Double Inclined Plane Cable System

Anchorages and Connections

The cables may be continuous and pass through or over the tower or be terminated at the tower. If continuous across the tower, a saddle is incorporated.

Saddles

The cable saddles are constructed from fabricated plates or steel castings with grooves through which the cables pass (see Figure 16.1.32). Between the end and center spans differential forces will occur at the cable saddles unless they are supported by rollers or rocker bearings. When the saddles are fixed, the rigidity of the system is at the maximum.

Figure 16.1.32 Cable Saddle

End Fittings

If terminated at the tower, an end fitting or anchorage is incorporated. A similar end fitting is utilized at the edge girder (see Figure 16.1.33).

Figure 16.1.33 Cable Deck Anchorage

Socket

A socket widely used for the anchoring of parallel-wire strands is a poured zinc socket. The wires are led through holes in a locking plate at the end of the socket and have the bottom heads providing the resistance against slippage of wires. The cavity inside the socket is filled with hot zinc alloys. To improve the fatigue resistance of the anchor, a cold casing material is used. The zinc cools and locks the wire strands into the socket.

Figure 16.1.34 Anchor Inspection on Veterans Bridge

The problems encountered with low fatigue strength of zinc-poured sockets lead to the development of HiAm sockets in 1968 for use with parallel wire stays.

This anchorage incorporates a flat plate with countersunk radial holes to accommodate the geometry of flared wires that transition from the compact wire bundle into the anchorage. The anchorage socket is filled with zinc dust and with an epoxy binder. This method of anchoring the stays increases the magnitude of fatigue resistance to almost twice that for the zinc-poured sockets.

A common anchorage type for strands is the Freyssinet type anchor.

In the Freyssinet socket the seven wire strand is anchored to an anchor plate using wedges similar to prestressing wedges. This wedge anchor is used during erection. After application of the permanent dead load, the anchor tube is filled with an epoxy resin, zinc dust, and steel ball composition. Under transient live load, the additional cable force will be transformed by shear from the cable strand to the tube.

Vibrations

Several of the primary causes of vibration in stay cables consist of rain-wind induced vibrations, sympathetic vibration of cables with other bridges elements excited by wind, inclined cable galloping, and vortex excitation of single cable or groups of cables. Due to the amount of vibration in cable-supported structures, it may be common to see various types of damping systems attached to cables. Damping systems may be a tie between two cables, neoprene cushions, shock absorbers mounted directly to the cables, or other systems that act to dampen the cable vibrations (see Figure 16.1.35).

Vibrations can affect stay cables in several ways. Vibration opens cable wires allowing entry of corrosive chemicals and accelerates corrosion. Vibrations create fretting, cracks in the protective coating and cement grout, and accelerate corrosion and possibly fatigue.

Figure 16.1.35 Damper on Cable-Stayed Bridge

16.1.5 Overview of Common Deficiencies

Common deficiencies that can occur on steel cable members:

- Corrosion
- Fatigue Cracking
- Overloads
- Collision Damage
- Heat Damage
- Paint Failure

Refer to Topic 6.3.5 for a more detailed presentation of the properties of steel, types and causes of steel deficiencies, and the examination of steel.

16.1.6 Inspection Locations and Methods for Suspension Bridge Cable System Elements

The inspection and maintenance methods presented in this Topic are not exhaustive, but are unique to the particular bridge type. Therefore, include both the procedures presented in this Topic as well as the general procedures previously presented in this manual during the inspection of special bridges.

These bridges are considered to be complex according to the NBIS regulations. The NBIS requires identification of specialized inspection procedures, and additional inspector training and experience required to inspect these complex bridges. The bridges are then to be inspected according to these procedures.

Due to the specialized nature of these bridges and because no two cable-supported bridges are identical, the inspection should be led by someone very familiar with the particular bridge. Many major bridges, such as cable-supported bridges, will have individual inspection and maintenance manuals developed specifically for that bridge, like an "owner's" manual. If available, use this valuable tool throughout the inspection process and verify that specified routine maintenance has been performed. Use customized, preprinted inspection forms wherever possible to enable the inspector to report the findings in a rigorous and systematic manner.

Main Cable Anchorage Elements

The anchorage system, at the ends of the main cables, consists of a number of elements that require inspection (see Figure 16.1.36).

- Splay saddle
- Bridge Wires
- Strand shoes or sockets
- Anchor bars
- Chain Gallery

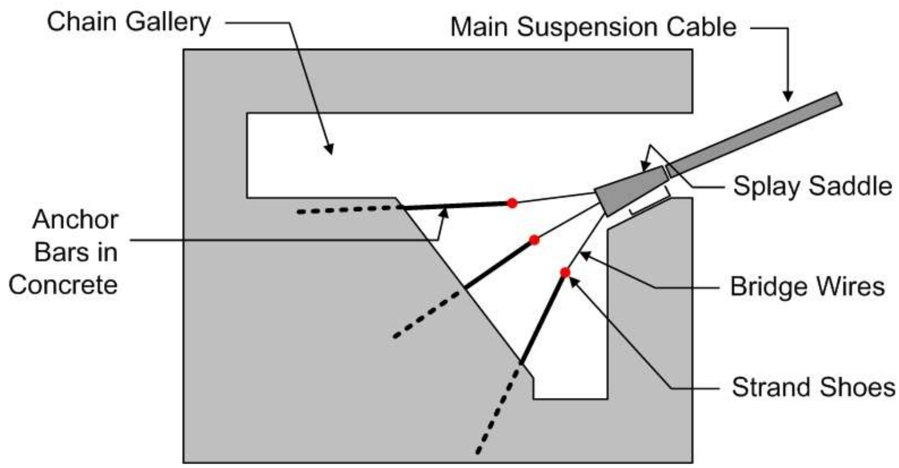

Figure 16.1.36 Anchor Block Schematic

Splay Saddle

Inspect the splay saddles for missing or loose bolts and the presence of cracks in the casting itself. There is a possibility of movement up the cable away from the splay. Signs of this movement may be the appearance of unpainted strands on the lower side or "bunched up" wrapping on the upper side

Bridge Wires

In parallel wire type suspension bridges, inspect the unwrapped wires between the strand shoes and the splay saddle. Carefully insert a large screwdriver between the wires and apply leverage. This will help reveal broken wires. Inspect the wires for abrasion damage, corrosion, and movement.

Strand Shoes or Sockets

At the anchorages of parallel wire type suspension bridges, inspect the strand shoes for signs of displaced shims, along with movement, corrosion, misalignment, and cracks in the shoes.

At the anchorages of prefabricated strand type suspension bridges, inspect the strand sockets for signs of movement, slack or sag, corrosion, and broken sockets. Unpainted or rusty threads at the face of the sockets may indicate possible "backing off" of the nuts.

Anchor Bars

Inspect the anchor bars or rods for corrosion (section loss), deficiencies, or movement at the face of their concrete embedment. Check for corrosion or other signs of distress over the entire visible (unencased) portion.

Chain Gallery

Inspect the interior of the anchorage for corrosion and deficiencies of any steel hardware, and cracks and spalls in the concrete anchor. Note if there is protection against water entering or collecting where it may cause corrosion, and also if there is proper ventilation (see Figure 16.1.37).

Figure 16.1.37 Anchorage Interior of Ben Franklin Bridge, Philadelphia, PA

Main Suspension Cables

Inspect the main suspension cables as follows:

Cables

Inspect the main suspension cables for indications of corroded wires. Inspect the condition of the protective covering or coating, especially at low points of cables, areas adjacent to the cable bands, saddles over towers, and at anchorages.

Cable Wrapping

Inspect the wrapping wire for cracks, staining, and dark spots. Check for loose wrapping wires. If there are cracks in the caulking where water can enter, this can cause corrosion of the main suspension cable. Check for evidence of water seepage at the cable bands, saddles, and splay castings (see Figure 16.1.38).

Figure 16.1.38 Tape and Rubber Seal Torn Around Cable Allowing Water Penetration into Top of Sheath

Hand Ropes

Inspect the hand ropes and connections along the main cables for loose connections of stanchion (hand rope supports) to cable bands or loose connections at anchorages or towers. Check also for corroded or deteriorated ropes or stanchions, bent or twisted stanchions, and too much slack in rope.

Vibration

Note and record all excessive vibrations.

Saddles

Inspect the saddles for missing or loose bolts, and corrosion or cracks in the casting. Check for proper connection to top of tower or supporting member and possible slippage of the main cable.

Suspender Cables and Connections

Inspect the suspender cables for corrosion or deficiencies, broken wires, and kinks or slack. Check for abrasion or wear at sockets, saddles, clamps, and spreaders. Be sure to note excessive vibrations.

Sockets

Inspect the suspender rope sockets for:

- Corrosion, cracks, or deficiencies
- Abrasion at connection to bridge superstructure
- Possible unanticipated movement

Cable Bands

Inspect the cable bands for missing or loose bolts, or broken suspender saddles. Signs of possible slippage are caulking that has pulled away from the casting or "bunching up" of the soft wire wrapping adjacent to the band. Check for the presence of cracks in the band itself, corrosion or deficiencies of the band, and loose wrapping wires at the band.

Recordkeeping and Documentation

Prepare a set of customized, preprinted forms for documenting all deficiencies encountered in the cable system of a suspension bridge. A suggested sample form is presented in Figure 16.1.39. Separate forms are to be used for each main suspension cable. Designations used to identify the suspender ropes and the panels provide a methodology for locating the problems in the structure. Note and describe vibrations whether local or global, while performing inspections of cable-supported structures.

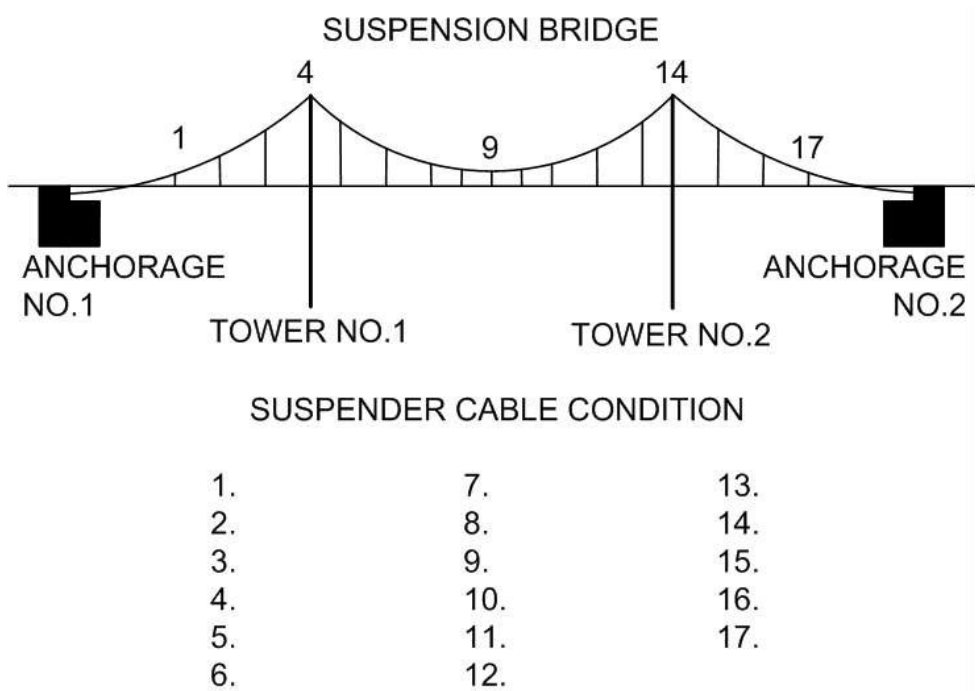

Figure 16.1.39 Form for Recording Deficiencies in the Cable System of a Suspension Bridge

16.1.7 Inspection Locations and Methods for Cable-Stayed Bridge Cable System Elements

A cable-stayed bridge is a bridge in which the superstructure is supported by cables, or stays, passing over or attached directly to towers located at the main piers (see Figure 16.1.40 and 16.1.41). There are several special elements that are unique to cable-stayed bridges.

See the National Cooperative Highway Research Program (NCHRP) Synthesis 353 "Inspection and Maintenance of Bridge Cable Systems", 2005 for a detailed description of inspection locations and procedures for cable-stayed bridge cable element systems.

These bridges are considered to be complex according to the NBIS regulations. The NBIS requires identification of specialized inspection procedures, and additional inspector training and experience required to inspect these complex bridges. The bridges are then to be inspected according to these procedures.

Figure 16.1.40 Cable-Stayed Bridge

Figure 16.1.41 Cable-Stayed Bridge Cables

Inspection Elements

Cable element inspection includes:

- Cable wrappings and wrap ends near the tower and deck
- Cable sheathing assembly
- Dampers
- Anchorages

Cable Wrapping

Common wrapping methods for corrosion protection of finished cables include spirally wound soft galvanized wire, neoprene, or plastic wrap type tape (see Figure 16.1.42). Inspect the wrappings for corrosion and cracking of soft galvanized wire, staining and dark spots indicating possible corrosion of the cables, and loose wrapping wires or tape. Bulging or deforming of wrapping material may indicate possible corrosion or broken wires (see Figure 16.1.43). Check for evidence of water seepage at the cable bands, saddles, and castings.

Figure 16.1.42 Cable Wrapping Placement

Figure 16.1.43 Deformed Cable Wrapping

Cable Sheathing Assembly

The most common types of cable sheathing assemblies are steel sheathing and polyethylene sheathing.

Steel Sheathing

If steel sheathing is used, inspect the system for corrosion (see Figure 16.1.44), condition of protective coatings, and weld fusion. Bulging may indicate corrosion or broken wires (see Figure 16.1.45). Splitting may be caused by water infiltration and corrosive action. Cracking is sometimes caused by fatigue (see Figure 16.1.46).

Polyethylene Sheathing

If polyethylene sheathing is used, inspect the system for nicks, cuts, and abrasions. Check for cracks and separations in caulking and in fusion welds. Bulging may indicate broken wires (see Figure 16.1.45). Splitting is sometimes caused by temperature fluctuations (see Figure 16.1.47). Coefficient of the thermal expansion for polyethylene is three times higher than the value for steel or concrete. Cracking is sometimes caused by fatigue.

Figure 16.1.44 Corrosion of Steel Sheathing

Figure 16.1.45 Bulging of Cable Sheathing

Figure 16.1.46 Cracking of Cable Sheathing

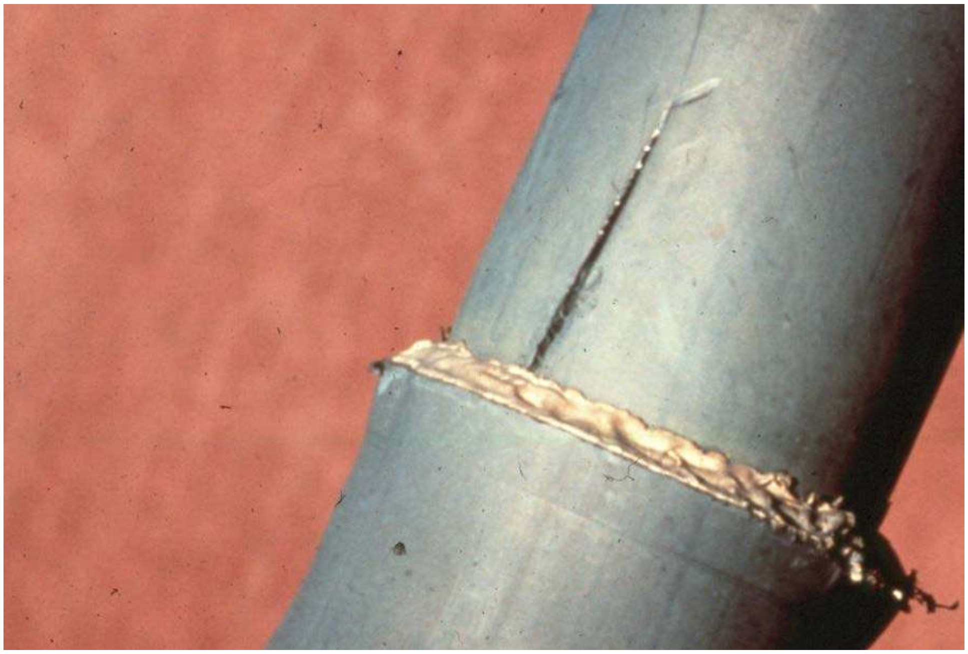

Figure 16.1.47 Splitting of Cable Sheathing

Dampers

Shock Absorber Type

A variety of damper types may have been installed (see Figure 16.1.48 and 16.1.49). If shock absorber type dampers are used, inspect the system for corrosion, oil leakage in the shock absorbers, and deformations in the bushings. Check for tightness in the connection to the cable pipe, and torque in the bolts.

Figure 16.1.48 Shock Absorber Damper System

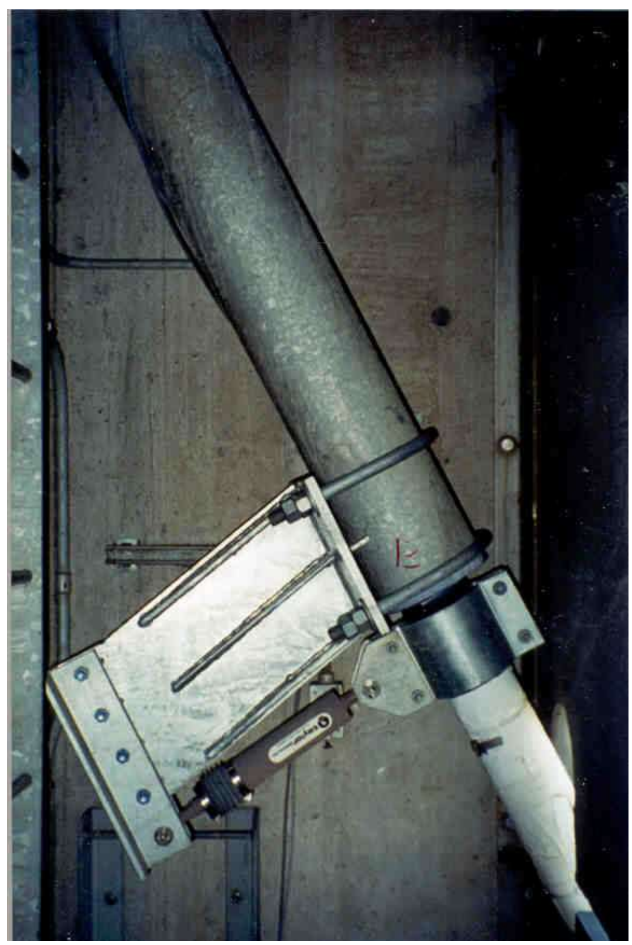

Figure 16.1.49 Shock Absorber Damper System

Tie Type

Inspect the tie type dampers (see Figure 16.1.50) for corrosion, and deformations in the bushings. Check for tightness in the connection to the cable pipe, and torque in the bolts.

Figure 16.1.50 Cable Tie Type Damper System

Tuned Mass Type

Inspect the tuned mass dampers (see Figure 16.1.51) for corrosion, and deformations in the bushings. Check for tightness in the connection to the cable pipe, and torque in the bolts.

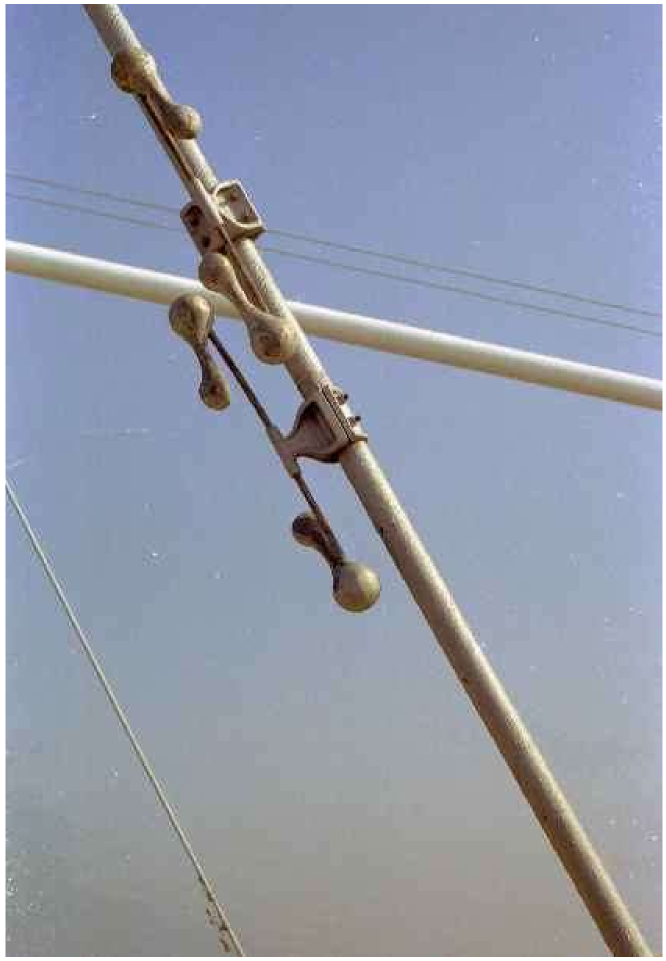

Figure 16.1.51 Tuned Mass Damper System

Anchorages

End Anchorage

Inspect the transition area between the steel anchor pipe and cable for water tightness of neoprene boots at the upper ends of the steel guide pipes (see Figure 16.1.52). Check for drainage between the guide pipe and transition pipe, and deteriorations, such as splits and tears, in the neoprene boots (see Figure 16.1.53). Check for sufficient clearance between the anchor pipe and cable, noting rub marks and kinks.

Figure 16.1.52 Neoprene Boot at Steel Anchor Pipe Near Anchor

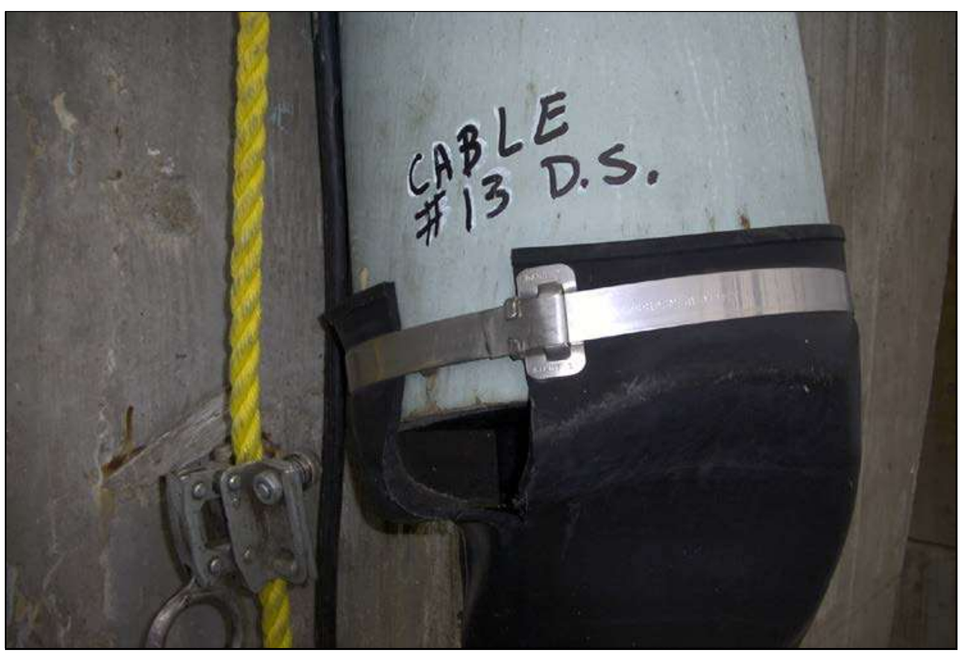

Figure 16.1.53 Split Neoprene Boot

Tower Anchorage

Inspect the cable anchorages for corrosion of the anchor system (see Figure 16.1.54). Check for cracks and nut rotation at the socket and bearing plate, and seepage of grease from the protective hood.

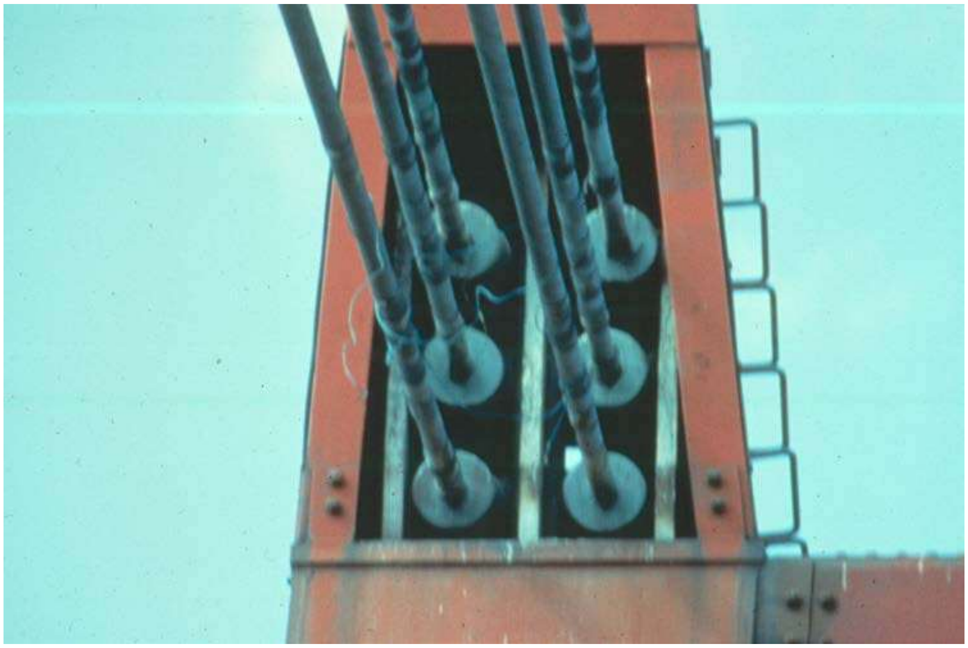

Figure 16.1.54 Corrosion of the Anchor System

Other Inspection Items

Include anchor pipe clearances, flange joints, and polyethylene expansion joints within the inspection of the cable system. Read the load cells and record the forces in the cables. Note and record all excessive vibrations including amplitude and type of vibration along with wind speed and direction, or other forces including vibrations such as traffic. Also evaluate cable and tower lighting systems.

Recordkeeping and Documentation

Prepare a set of customized, preprinted forms for documenting all deficiencies encountered in the cable system of a cable-stayed bridge. A suggested sample form is presented in Figure 16.1.55. Use a separate form for each plane or set of cables. Designations used to identify the cables and the panels provide a methodology for locating the deficiencies in the structure. Note and describe vibrations whether local or global, while performing inspections of cable-supported structures.

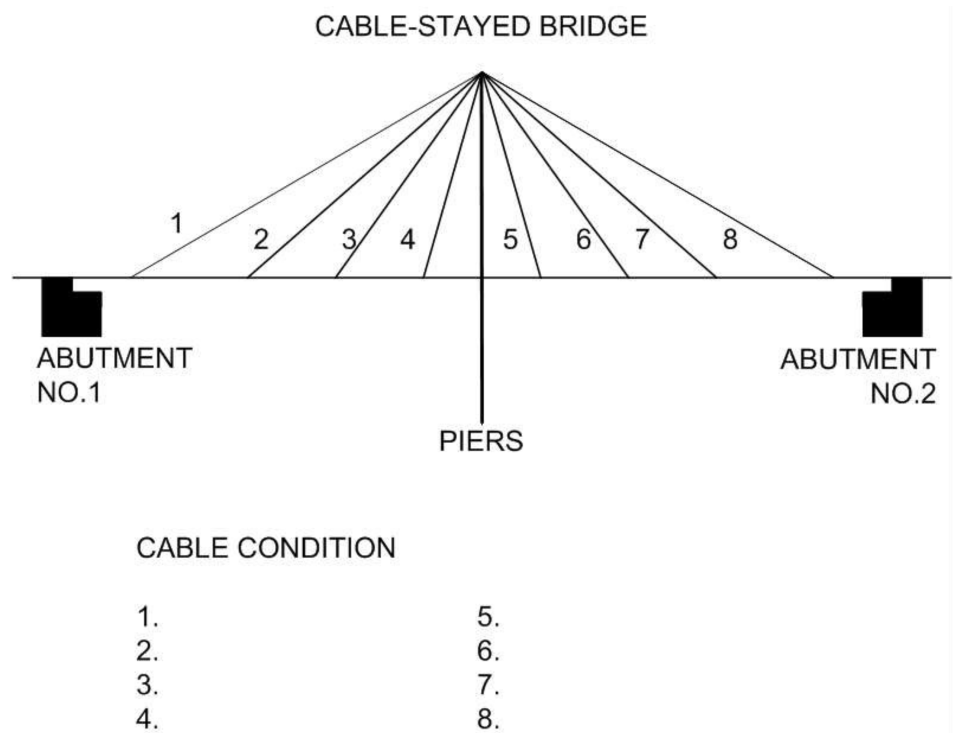

Figure 16.1.55 Form for Recording Deficiencies in Cable System of a Cable-Stayed Bridge

16.1.8 Advanced Inspection Methods

In bridge cables, whether a suspension bridge or cable-stayed bridge, the greatest problems generally occur due to corrosion and fracture of individual wires. Visual inspection of unwrapped cables is limited to the outer wires, while visual inspection of wrapped cables is limited to the protective sheathing. Therefore, advanced inspection methods are used to achieve a more rigorous and thorough inspection of steel bridges, including:

- Acoustic Emissions Testing
- Corrosion Sensors
- Smart Coatings
- Dye Penetrant
- Magnetic Particle
- Radiography Testing
- Computed Tomography
- Robotic Inspection

- Ultrasonic Testing
- Eddy Current
- Electrical fatigue sensor (EFS)
- Magnetic flux leakage
- Laser vibrometer

See Topic 15.3 for Advanced Inspection Procedures for steel.

Other methods specific to cables include:

- Cable force measurements using the precursor transformation matrix - this method uses a linearly elastic finite-element analysis (FEA) model of the cable-supported bridge. Through the model, the temperature each of cable is raised to simulate loss of stiffness one cable, noting the resultant changes in force of the other cables. Field measurements are then taken and compared with the matrix to identify cables that have suffered a loss of stiffness. Alternatively, a matrix may be formed using resultant deck elevations instead of resultant cable stiffnesses from the single cable temperature change.
- Accelerometer - this method operates on the vibrating string theory and is an alternative to the laser vibrometer for vibration-based cable force measurements. The accelerometer measures the natural frequency of the cable, which is then used to calculate the tension in the cable from the known length and mass per unit length. This method is generally taken as an estimate, since the vibrating string theory does not take into consideration cable bending stiffness, cable sag, neoprene rings, viscous dampers, and variable stiffness.
- Vibration decay - this method measures the cable damping by inducing high-vibration amplitudes. The cable is then allowed to slow down, decaying the signal of the accelerometer and providing the damping ratio.

16.1.9 Evaluation

State and Federal rating guideline systems have been developed to aid in the inspection of steel superstructures. 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 the NBIS component condition rating guidelines, a one-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the superstructure. Component condition rating codes range from 9 to 0 where 9 is the best rating possible. See Topic 4.2 (Item 59) for additional details about NBIS component condition rating guidelines.

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 cable-supported bridge, possible AASHTO National Bridge Elements (NBEs) and Bridge Management Elements (BMEs) are:

NBE No.	Description
Superstructure	
147	Steel Main Cables (not embedded in concrete)
148	Secondary Steel Cables (not embedded in concrete)

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

The unit quantity for cables is feet. The total length cable is distributed among the four available condition states depending on the extent and severity of the deficiency. The unit quantity for protective coating is square feet, and the total area is distributed among the four available 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 cable-supported bridges:

Defect Flag No.	Description
356	Steel Cracking/Fatigue
357	Pack Rust
362	Superstructure Traffic Impact (load capacity)

See Chapters 9 and 10 for the inspection and evaluation of concrete and steel girders, floorbeams and stringers.

See Chapter 7 for the inspection and evaluation of decks.

See Chapter 12 for the inspection and evaluation of abutments, piers and bents.

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Chapter 16
Complex Bridges

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Topic 16.2 Movable Bridges

16.2.1 Introduction

This topic serves as an introduction to the highly specialized area of movable bridge inspection. It focuses on the types of movable bridges and special elements associated with the various bridge types.

Each of these specialized bridge types has their unique features and unique mechanisms for movement. The following sections cover common types of movable bridges, including information on the operation, maintenance and inspection of the structure and the movement mechanisms. The inspection of these specialized bridges requires a diverse team collectively capable of inspecting the structure as well as the mechanical, electrical, pneumatic or other movement mechanisms. The duties of the bridge inspector are defined by the bridge owner for the inspection of these type structures and should be complemented, as necessary, by duties of other inspectors for the inspection of the movement mechanisms and by the duties for maintenance and operation personnel. The bridge inspector should confirm with the owner their role in the inspection of these specialized structures (see Figure 16.2.1).

Figure 16.2.1 Movable Bridge

Movable bridges are normally constructed only when fixed bridges are either too expensive or impractical. Movable bridges are constructed across designated "Navigable Waters of the United States", in accordance with "Permit Drawings" approved by the U.S. Coast Guard. When a movable bridge is fully open, it must provide the channel width and the underclearance shown on the Permit Drawings (see Figure 16.2.2). If the bridge cannot be opened to provide these clearances, notify the U.S. Coast Guard immediately and take action to restore the clearances. If that is impossible, an application must be submitted to revise the Permit Drawings.

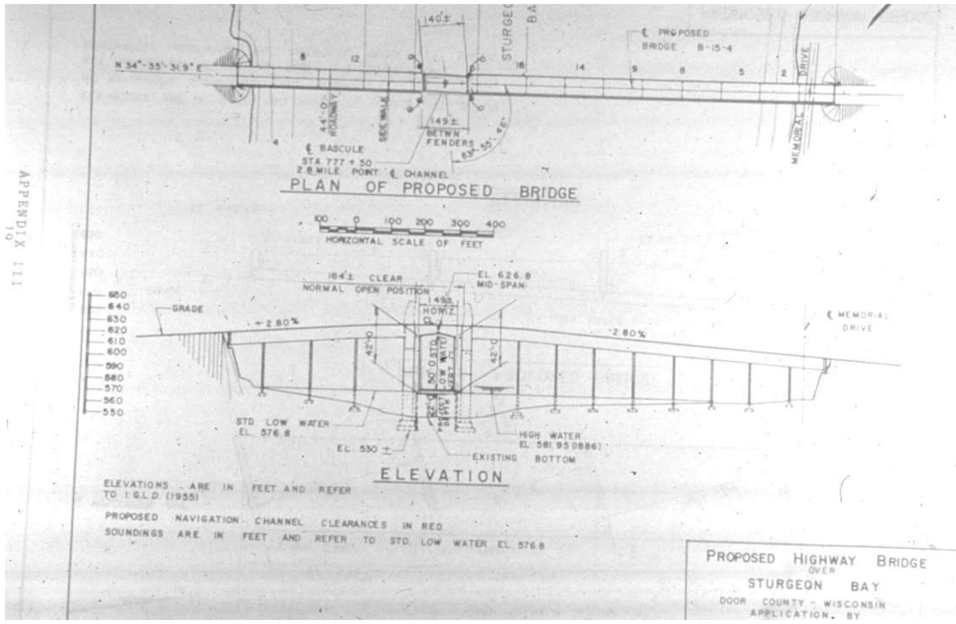

Figure 16.2.2 Typical "Permit Drawing" Showing Channel Width and Underclearance in Closed and Open Position

If any work is to be done in the channel or on the movable span to reduce the clearances from those shown on the Permit Drawing, obtain an additional permit, from the U.S. Coast Guard District covering the scheduled time for the work.

The U.S. Coast Guard publishes Local Notices to Mariners to keep waterway users informed of work in progress that may affect navigation. The permittee keeps the U.S. Coast Guard informed of all stages of construction.

Verify that the bridge conforms to the Permit Drawing and that the operator is instructed to open the bridge to the fully open position every time the bridge is operated. Failure to do this would establish a precedent that a vessel is expected to proceed before the green navigation lights have turned "on". Any accident caused as a result of this practice could be ruled the fault of the bridge owner.

Early America's engineering literature did not establish where the first iron drawbridge was built. The first all-iron movable bridge in the Midwest was completed in 1859 carrying Rush Street over the Chicago River (see Figure 16.2.3). The bridge was a rim bearing swing span and was probably operated by steam. It was destroyed on November 3, 1863 when it was opened while a drove of cattle was on one end. It was rebuilt but destroyed by the great Chicago fire of 1871.

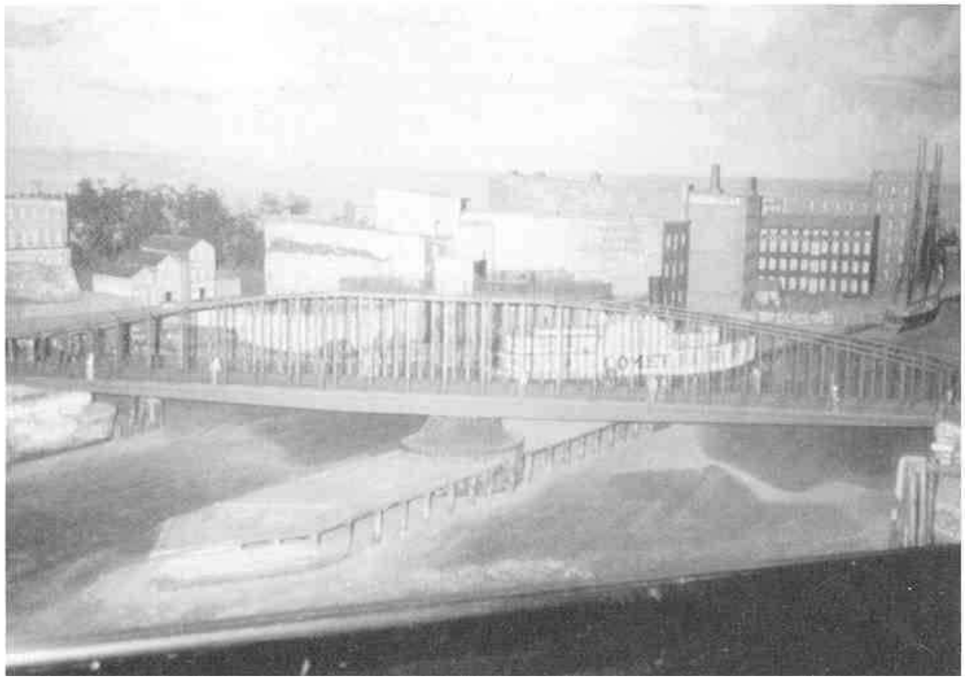

Figure 16.2.3 The First All-Iron Movable Bridge in the Midwest was Completed in 1859 (Photo on File at the Chicago Historical Society)

All categories of movable bridges are powered by electric-mechanical or hydraulic-mechanical drives with power driven pinions operating against racks, or by hydraulic cylinders. A small number are hand powered for normal operation. A few bridges use hand power for standby operation. Three categories of movable bridges comprise over 95 percent of the total number of movable bridges within the United States. These categories include:

- Swing bridges
- Bascule bridges
- Vertical lift bridges

16.2.2

Swing Bridges Design Characteristics

Swing bridges consist of two-span trusses or continuous girders, which rotate horizontally about the center (pivot) pier (see Figure 16.2.4). The spans are usually, but not necessarily, equal. When open, the swing spans are cantilevered from the pivot (center) pier and must be balanced longitudinally and transversely about the center. When closed, the spans are supported at the pivot pier and at two rest (outer) piers or abutments. In the closed condition, wedges are usually driven under the outer ends of the bridge to lift them, thereby providing a positive reaction sufficient to offset any possible negative reaction from live load and impact in the other span. This design feature prevents uplift and hammering of the bridge ends under transient live load conditions.

Figure 16.2.4 Center-Bearing Swing Bridge

Swing spans are subdivided into two types:

- Center-bearing
- Rim-bearing

Center-Bearing

Center-bearing swing spans carry the entire load of the bridge on a central pivot (usually metal discs). Balance wheels are placed on a circular track around the outer edges of the pivot pier to prevent tipping (see Figures 16.2.5 and 16.2.6). When the span is closed, wedges similar to those at the rest piers are driven under each truss or girder at the center pier. This relieves the center bearing from carrying any live load. However, these wedges do not raise the span at the pivot pier, but are merely driven tight.

The latest swing spans built are nearly all of the center-bearing design. Center-bearing swing spans are less complex and less expensive to build than rim-bearing swing spans.

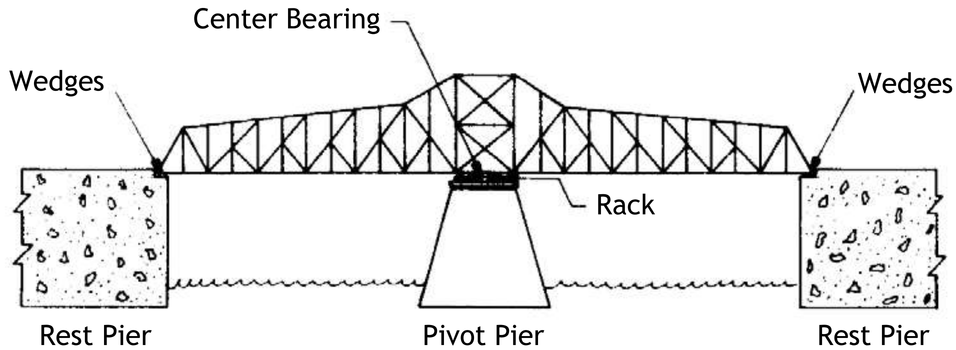

Figure 16.2.5 Center-Bearing Swing Span in Closed Position

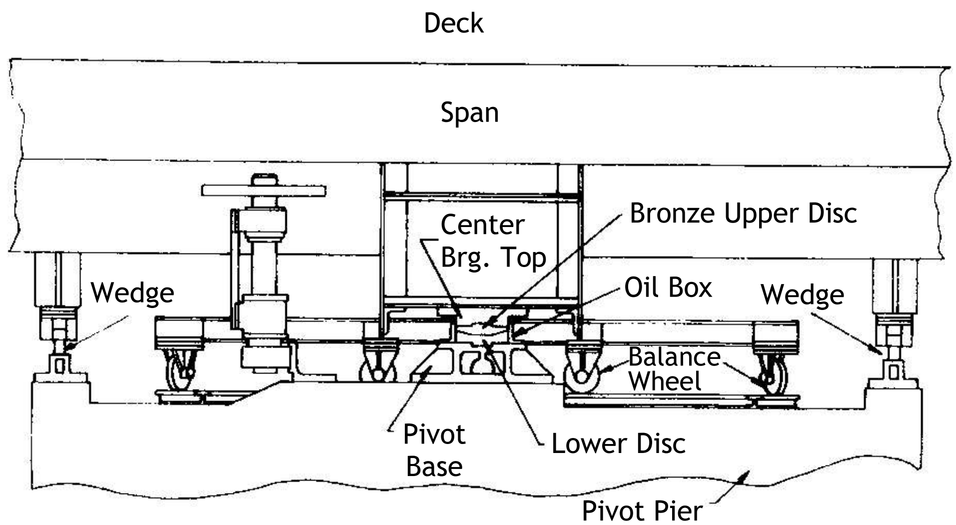

Figure 16.2.6 Layout of Center-Bearing Type Swing Span with Machinery on the Span

Rim-Bearing

Rim-bearing swing spans transmit all loads, both dead and live, to the pivot pier through a circular girder or drum to beveled rollers. The rollers move on a circular track situated inside the periphery of the pier. The rollers are aligned and spaced on the track by concentric spacer rings. This type of swing span bridge also has a central pivot bearing which carries part of the load. This pivot bearing is connected to the rollers by radial roller shafts and keeps the span centered on the circular track.

On both types of swing bridges, the motive power is usually supplied by electric motor(s), hydraulic motor(s), or hydraulic cylinder(s), although gasoline engines or manual power may also be used. The bridge is rotated horizontally by a circular rack and pinion arrangement, or cylinders.

16.2.3 Bascule Bridges Design Characteristics

Bascule bridges open by rotating a leaf or leaves (movable portion of the span) from the normal horizontal position to a point that is nearly vertical, providing an open channel of unlimited height for marine traffic (see Figure 16.2.7).

Figure 16.2.7 Bascule Bridge in the Open Position

If the channel is narrow, a single span may be sufficient. This is called a single-leaf bascule bridge. For wider channels, two leaves are used, one on each side of the channel. When the leaves are in the lowered position, they meet at the center of the channel. This is known as a double-leaf bascule bridge.

A counterweight is necessary to hold the raised leaf in position. In older bridges, the counterweight is usually overhead, while in more modern bascule bridges, the counterweight is placed below the deck and lowers into a pit as the bridge is opened.

The leaf lifts up by rotating vertically about a horizontal axis. The weight of the counterweight is adjusted by removing or adding balance blocks in pockets to position the center of gravity of the moving leaf at the center of rotation. When the bridge is closed, a forward bearing support located in front of the axis is engaged and takes the live load reaction. On double-leaf bascule bridges, a tail-lock behind the axis and a shear lock at the junction of the two leaves are also engaged to stiffen the deck.

There are many types of bascule bridges, but the most common are the following three types:

- Rolling lift (Scherzer) bridge
- Simple trunnion (Chicago) bridge
- Multi-trunnion (Strauss) bridge

Rolling Lift (Scherzer) Bridge

The first rolling lift bridge was completed in 1895 in Chicago, and was designed by William Scherzer. The entire moving leaf, including the front arm with the roadway over the channel and the rear arm with the counterweight, rolls away from the channel while the moving leaf rotates open (see Figures 16.2.8 and 16.2.9). On this type of bridge, curved tracks are attached to each side of the tail end of the leaf. The curved tracks roll on flat, horizontal tracks mounted on the pier. Square or oblong holes are machined into the curved tracks. The horizontal tracks have lugs (or teeth) to mesh with the holes preventing slippage as the leaf rolls back on circular castings whose centerline of roll is also the center of gravity of the moving leaf.

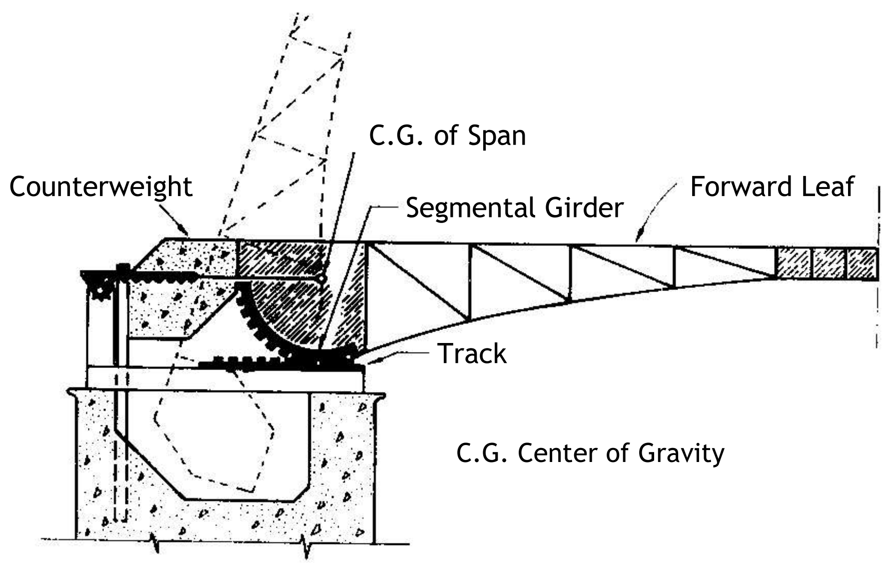

Figure 16.2.8 Rolling Lift Bascule Bridge Schematic

Figure 16.2.9 Double-Leaf Rolling Lift Bascule

The simple principal of this type of bridge can be seen easiest with a railroad bridge. The dead load of the bridge is balanced about the centerline of the drive pinion (center of roll). The pinion teeth are engaged with the teeth on the rack casting. When the pinion turns it moves along on the fixed rack and causes the span to rotate on the circular tread casting as it rolls back on the track casting.

The weight of the leaf, including the superstructure and counterweight, is supported by the curved tracks resting on the horizontal tracks. The counterweight is positioned to balance the weight of the leaf.

On one variation of this type, the trusses on the two leaves acted as three-hinged arches when closed. Locks are engaged in the closed position, allowing the bridge to function as a simple span. In the open position, the leaves operate as a cantilever span. There is a 310 feet span between the centerline of bearings. This bridge was built across the Tennessee River at Chattanooga in 1915, and it is believed to be the third longest double-leaf bascule in the world. It provides an 295 foot channel, which is the widest channel spanned by a bascule bridge.

Simple Trunnion (Chicago) Bridge

The Chicago Bridge Department staff of Engineers built the first Chicago type simple trunnion bascule bridge in 1902. This type of bascule bridge consists of a forward cantilever arm out over the channel and a rear counterweight arm (see Figure 16.2.10). The leaf rotates about the trunnions. Each trunnion is supported on two bearings, which in turn, are supported on the fixed portion of the bridge such as trunnion cross-girder, steel columns, or on the pier itself (see Figures 16.2.11, 16.2.12 and 16.2.13). Forward bearing supports located in front of the trunnions are engaged when the leaf reaches the fully closed position. They are intended to support only live load reaction. Uplift supports are located behind the trunnions to take uplift until the forward supports are in contact (if misadjusted) and to take the live load uplift that exceeds the dead load reaction at the trunnions. If no forward live load supports are provided or if they are grossly misadjusted, the live load and the reaction at the uplift supports are added to the load on the trunnions. A double-leaf bascule bridge of this type in Lorain, Ohio has 333 feet between trunnions. Of the three types of movable bridges, the simple trunnion is by far the most popular.

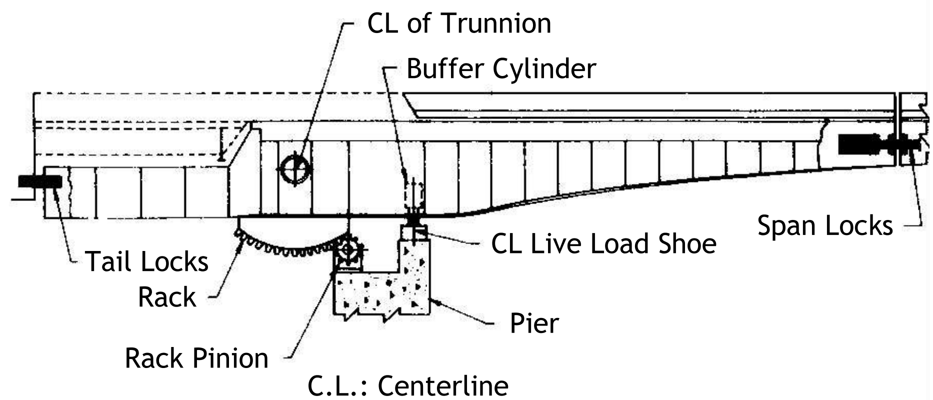

Figure 16.2.10 Trunnion Bascule Bridge Schematic

Figure 16.2.11 Double-Leaf Trunnion Bascule Bridge

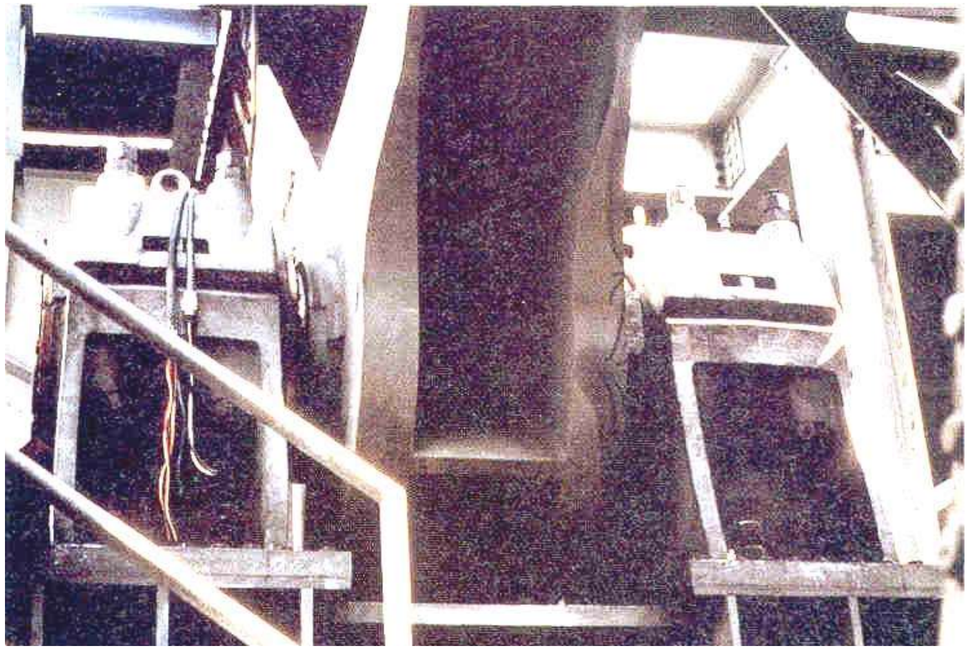

Figure 16.2.12 Each Trunnion is Supported on Two Bearings

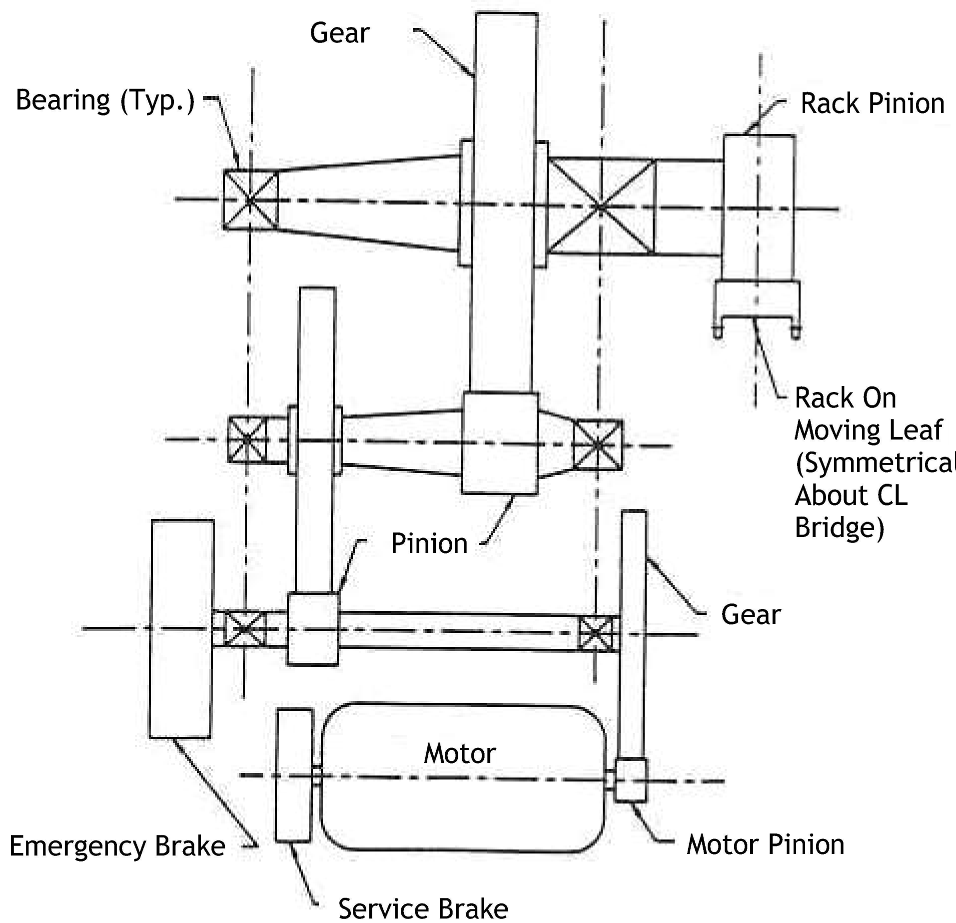

Figure 16.2.13 Trunnion Bascule Bridge Machinery (One Quarter Shown) is Located Outside of the Bascule Trusses on the Pier

Multi-Trunnion (Strauss Bridge)

The first multi-trunnion (Strauss) bascule bridge was designed by J.B. Strauss and completed during 1905 in Cleveland, Ohio. There are many variations of multi-trunnion bascule bridges, but basically one trunnion supports the moving span, one trunnion supports the counterweight, and two link pins are used to form the four corners of a parallelogram-shaped frame that changes angles as the bridge is operated. The counterweight link keeps the counterweight hanging vertically from the counterweight trunnions while the moving leaf rotates about the main trunnions (see Figure 16.2.14). One variation of this parallelogram layout is the heel trunnion. A double-leaf bascule bridge of this type in Sault St. Marie, Michigan has 336 feet between the span trunnions. It was built across the approach to a lock in 1914, and it is believed to be the longest double-leaf bascule in the world.

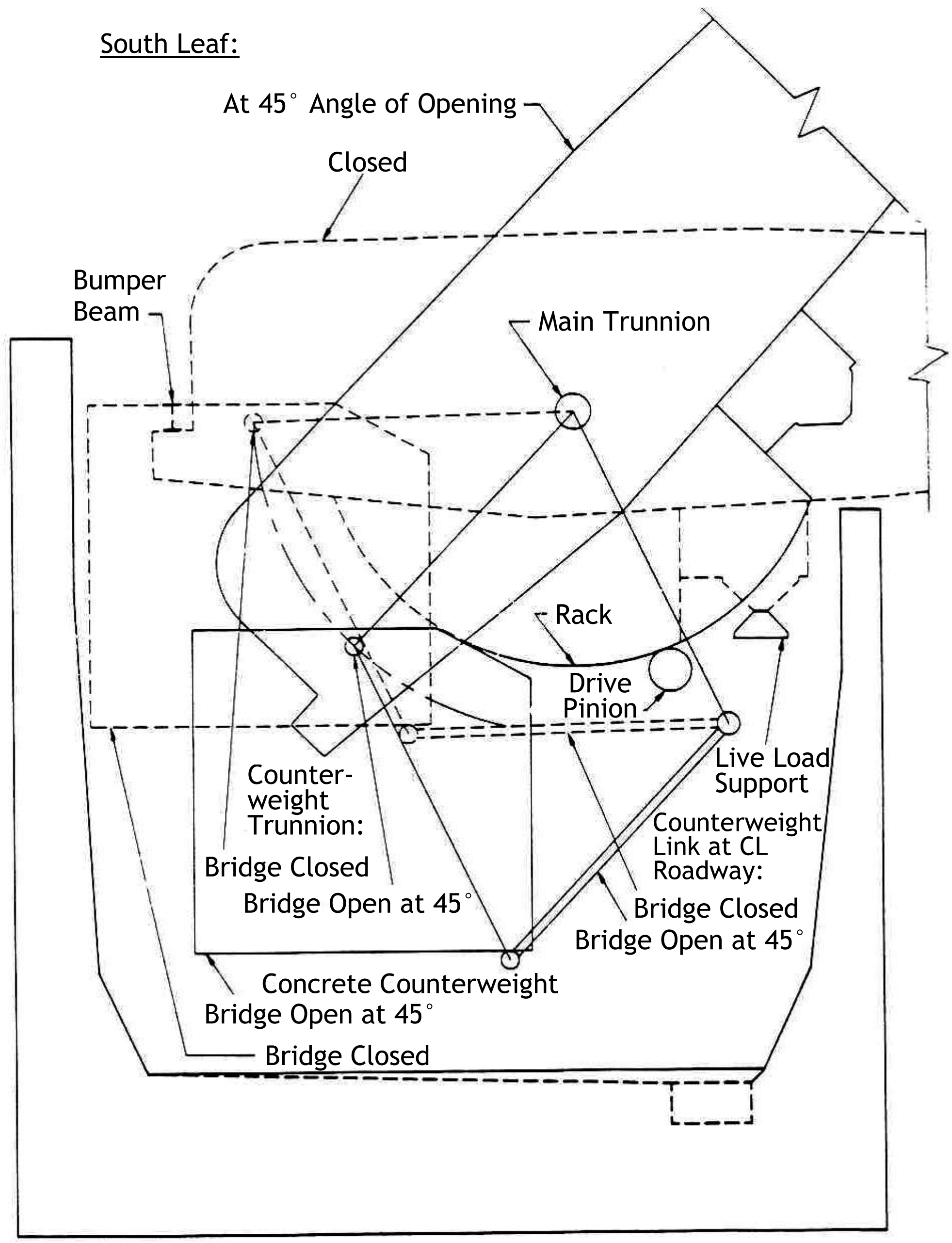

Figure 16.2.14 Multi-Trunnion, Strauss Type Bascule Bridge

16.2.4 Vertical Lift Bridges Design Characteristics

Vertical lift movable bridges have a movable span with a fixed tower at each end. The span is supported by steel wire ropes at its four corners. The ropes pass over sheaves (pulleys) atop the towers and connect to counterweights on the other side. The counterweights descend as the span ascends (see Figure 16.2.15).

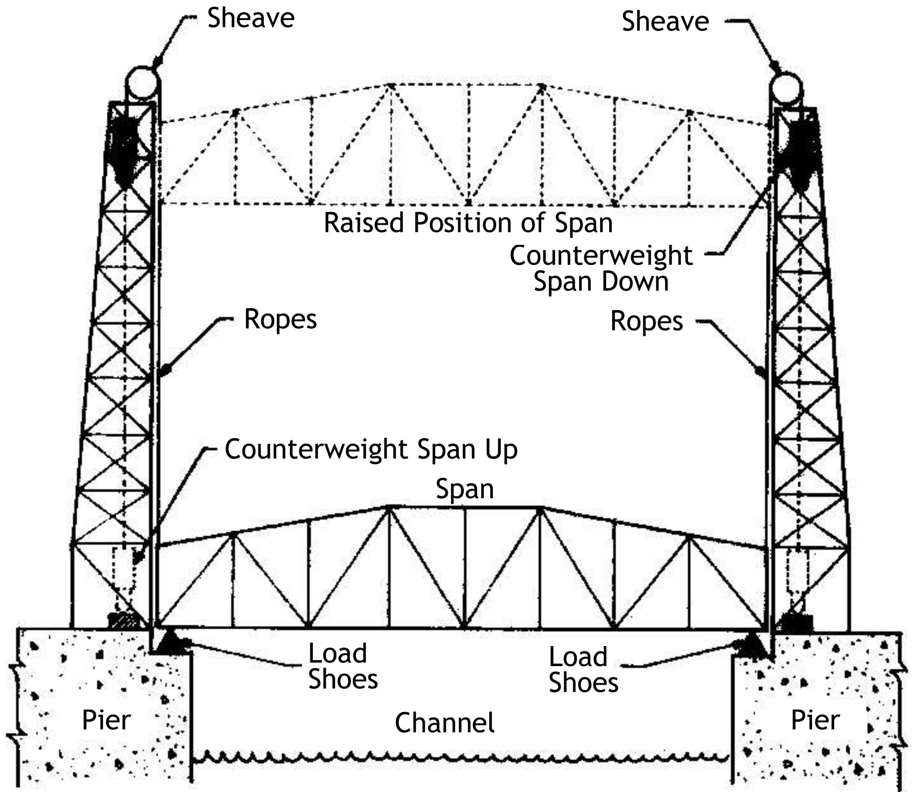

Figure 16.2.15 Vertical Lift Bridge Schematic

There are two basic types of vertical lift bridges:

- Power and drive system on lift span
- Power and drive system on towers

Power and Drive System on Lift Span

The first vertical lift bridge completed during 1894 in Chicago was designed by J.A.L. Waddell. This bridge type locates the power on top of the lift truss span. The actual lifting is accomplished using “up-haul and down-haul ropes” where turning drums wind the up-haul (lifting) ropes as they simultaneously unwind the down-haul ropes. Vertical lift bridge machinery is located on top of the lift truss span, and the operating drums rotate to wind the up-haul (lifting) ropes as they simultaneously unwind the down-haul ropes (see Figure 16.2.16). A variation of this type provides drive pinions at both ends of the lift span which engage racks on the towers.

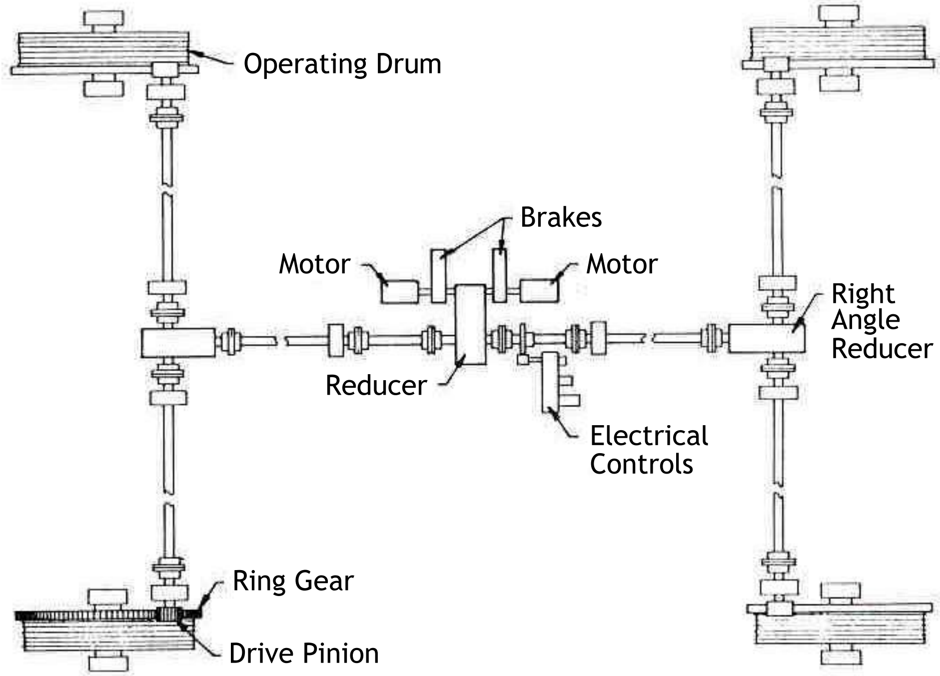

Figure 16.2.16 Vertical Lift Bridge Machinery is Located on Top of the Lift Truss Span, and the Operating Drums Rotate to Wind the Up-Haul (Lifting) Ropes as They Simultaneously Unwind the Down-Haul Ropes

Power and Drive System on Towers

The other basic type of vertical lift bridge locates the power on top of both towers, where drive pinions operate against circular racks on the sheaves. The lifting speed at both towers must be synchronized to keep the span horizontal as it is lifted (see Figures 16.2.17 and 16.2.18).

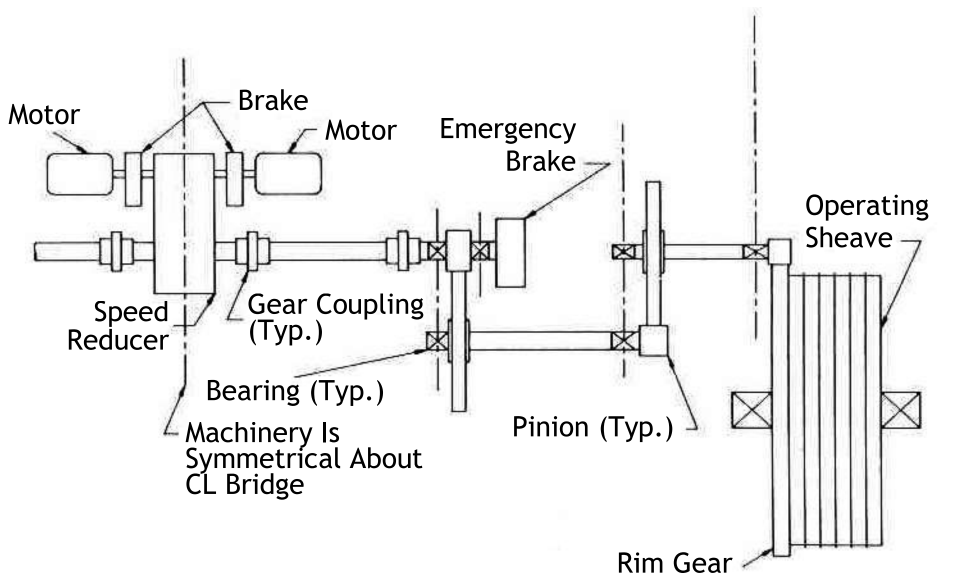

Figure 16.2.17 Vertical Lift Bridge Machinery is Located on the Towers, and the Rim Gears (and Operating Sheaves) are Rotated to Raise and Lower the Bridge