Figure 13.1.12 Gabion Basket Serving as Slope Protection

Figure 13.1.13 Slope Stabilization

Figure 13.1.14 Concrete Revetment Mat

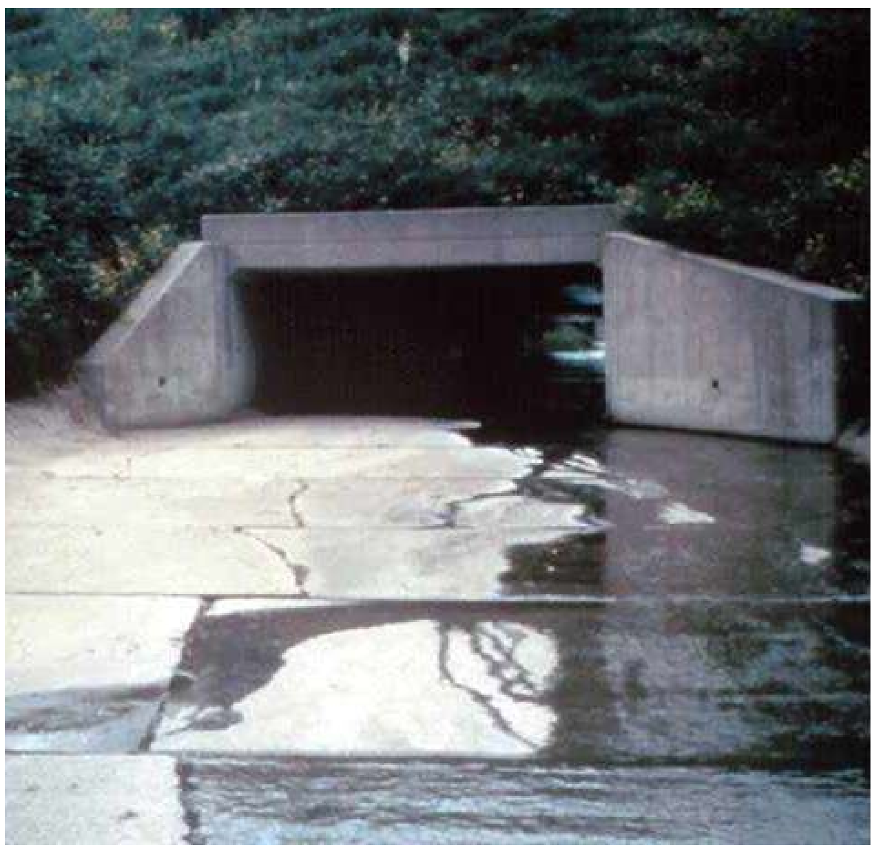

Figure 13.1.15 Formed Concrete Channel Lining

Figure 13.1.16 Concrete Footing Apron on a Masonry Abutment

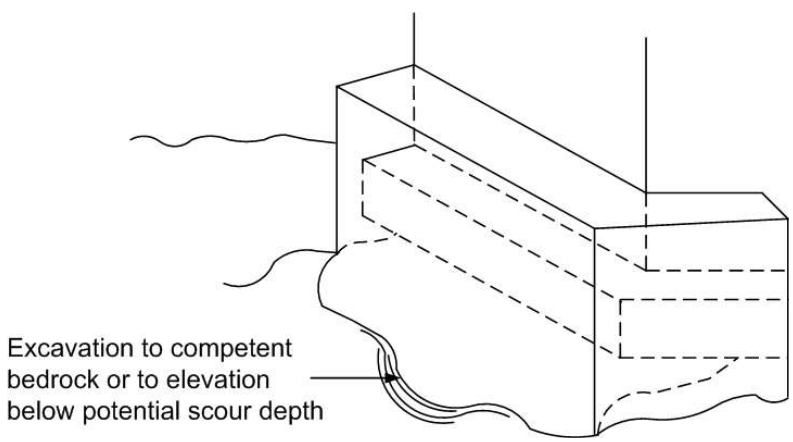

Figure 13.1.17 Concrete Footing Apron to Protect a Spread Footing from Undermining

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Chapter 13
Inspection and Evaluation of Waterways

Topic 13.2 Inspection of Waterways

13.2.1 Introduction

The bridge inspector needs to be able to correctly identify and assess waterway deficiencies when performing a bridge waterway inspection. Accurate bridge waterway inspections are vital for the safety of the motoring public. For this to happen, have a thorough understanding of the different types of waterway elements and deficiencies, as well as the various inspection techniques. See Topic 13.1 for detailed descriptions of various waterway elements.

Waterway deficiencies are properties of the waterway or substructure members that work to act negatively on the structural integrity of the bridge. They are mostly interrelated and when a change in one of these properties occurs, others are also often affected.

13.2.2 Waterway Performance Factors

Waterway Alignment

In general, bridges are designed so that the flow passes through the waterway parallel to the axes of the abutments and the piers. If the path of flow shifts in direction as a result of continued lateral movement so that it approaches the abutments and the piers at a significant skew angle, the capacity of the waterway can be reduced. More significantly, local scour will be increased and may lead to the failure of the structure. This depends upon the original design conditions and the degree of change resulting in misalignment in the flow with the critical elements supporting the structure. Carefully note any change in direction of the approach of the flow to the bridge and any change in the angle at which the flow hits or impinges on the abutments and piers. Also make observations of local change in flow directions and surveys of changes in bed and bank elevations. Evaluation of aerial photographs over time is extremely useful in assessing changes in waterway alignment. All of this information may be utilized to rate the severity of increasing misalignment in the flow on bridge safety.

Example of channel misalignment: If the approaching flow impinges on rectangular piers at an angle of 45 degrees versus flowing parallel to the axis of the piers, the depth of scour may be increased by a factor of two or more. The actual factor of increase depends upon the characteristics of the bed material, the pier type, and the duration of the flood.

For bridges spanning over wide floodplains, the approach angle of the low flow channel may not be significant. In these cases it is the alignment of the floodplain flow during the larger floods that will determine the magnitude of local scour.

Streamflow Velocity

Streamflow velocity is a major factor in the rate and depth of scour. During flood events, the streamflow velocity is increased, which produces accelerated scour rates and depths. At high streamflow velocities, bridge foundations have the greatest chance to become undermined (see Figure 13.2.1).

Figure 13.2.1 Flood Flow Around a Pier Showing High Streamflow Velocity

The streamflow velocity depends on many variables. One of these variables is the stream grade. A steep stream grade will produce high streamflow velocities, while a flat stream grade produces low streamflow velocities. Other variables that affect the streamflow velocity include the waterway alignment, the hydraulic opening, any natural or man-made changes to the stream, flooding, etc.

Hydraulic Opening

It is necessary to consider the adequacy of the hydraulic opening (the cross-sectional area under the bridge) to convey anticipated flows, including the design flood, without damage to the bridge. It is essential to maintain a bridge inspection file comparing original conditions in the waterway at the time the bridge was constructed to changes in the cross-sectional area of the channel under the bridge over time.

The primary method of assessing loss of cross-sectional area of the hydraulic opening is to determine channel bed elevation changes. This can be determined by a periodic survey of the channel bed or by taking soundings from the bridge. Typically, a number of survey or sounding points spaced across the bridge opening are established to determine changes in cross-sectional area. Note the lateral location of these surveyed points so that as subsequent inspections are conducted, the survey points can be repeated to maintain consistency. Photographs from key locations can be used to document debris and vegetation that can block the bridge opening.

Stream gages in the vicinity of the bridge may be useful in evaluating the adequacy of the waterway in relationship to changing hydraulic conditions. For example, stage-discharge curves based on discharge measurements by the United States Geological Survey (USGS) or other agencies and shifts in rating curves may indicate changes in channel bed elevation and cross section.

Streambed Material

The size, gradation, cohesion, and configuration of the streambed material can affect scour rates. When comparing sands and cohesive soils, such as clays, the size of the streambed material has little effect on the depth of scour, but can affect the amount of time needed for this depth to be attained. Cohesive streambed materials that are fine usually have the same ultimate depth of scour as sand streambeds. The difference is that the cohesive streambeds take a longer period to reach this ultimate scour depth. For these reasons, the streambed type is important and correctly evaluated by the bridge inspector. Streambed rates of scour for different types of material are described later in this topic.

Substructure Shape

Substructure members on old bridges were not necessarily designed to withstand the effects of scour. Wide piers and piers skewed to the flow of the stream can contribute to an increase the depth of scour. Due to increased awareness of bridge waterway scour, recent substructure members have been designed to allow the stream to pass through with as little resistance as possible. Many newer piers have rounded or pointed noses, which can decrease the scour depth by up to 20%.

Foundation Type

Footings that are undermined, but founded on piles are not as critical as spread footings that are undermined. Determine the substructure foundation type, in order to properly evaluate the substructure and the waterway. The foundation type may often be determined from design and/or construction drawings. In some older bridges, the foundation type is not known. In this case, advanced inspection techniques by a trained professional may be required to verify the foundation type.

13.2.3 Waterway Deficiencies

Total Scour

The most common bridge waterway deficiency is scour, which may adversely impact bridge substructure units. Scour is the removal of material from the streambed or embankment as a result of the erosive action of streamflow.

The rate of scour will vary for different streambed materials, and for different streamflow rates. For a given streamflow rate, a streambed material will scour to a maximum depth in a given time. The following are examples for different types of streambeds and their corresponding scour rate:

- Dense granite: centuries
- Limestone: years
- Glacial tills, sandstone and shale: months
- Cohesive soils (clay): days
- Sand and gravel: hours

There are three forms of scour considered in evaluating the safety of bridges:

- Aggradation and degradation
- General scour (which includes contraction scour)
- Local scour

Aggradation and Degradation

Aggradation and degradation are long-term streambed elevation changes. Aggradation is the general and progressive buildup of the longitudinal profile of a channel bed due to the sediment deposition. (see Figure 13.2.2). Degradation is the general and progressive (or long-term) lowering of the channel bed due to erosion, over the relatively long channel length (see Figure 13.2.3).

Aggradation and degradation may be a result of the natural erosion and downcutting process that rivers experience through the years. This scour type may be accelerated by natural cutoffs in a meandering river, which steepens the channel gradient, increasing both the velocity of flow and hence scour. These changes may also be accelerated by various types of development or river modification, such as:

- Upstream dam construction
- Dredging
- Straightening or narrowing of the river channel
- Upstream development resulting in an increase of precipitation into the channel

Since aggradation and degradation of the channel bed is along some considerable distance of channel, major facilities are sometimes used to control scour. These facilities can include a series of drop structures (small dam-like structures) or other scour protection of the riverbed. Presence of such structures may be indicative that the channel is experiencing scour.

Factors that may cause changes in the elevation of the streambed include:

- Water resources development, such as upstream diversions and upstream dams
- Changes in channel alignment or dimensions
- Urbanization of the watershed (conversion of a more natural or agricultural area to a city)

Headcut migration is the degradation of the channel that is associated with abrupt changes in the bed elevation and then migrates upstream. Headcutting tends to form in more cohesive materials in a streambed. Cohesive materials are discussed on page 13.2.18.

Figure 13.2.2 Streambed Aggradation

Figure 13.2.3 Streambed Degradation

General Scour

General scour can occur in a short time with the right conditions (see Figure 13.2.4 and 13.2.5). It is the lowering of the streambed across the waterway at the bridge which may or may not be uniform. This means it could be deeper in some parts than in others. General scour could be the result of contraction of the flow, which will result in the removal of the streambed material across all or most of the channel width or from other general scour conditions, such as flow around a bend where the scour will be concentrated near the outside of the bend.

Figure 13.2.4 General Scour

Figure 13.2.5 Close-up of General Scour of a Pier

Changes in downstream elevation, such as at the confluence with another river which is undergoing scour of its own, can cause general scour in the upstream river. Weather events such as hurricanes can also cause general scour (see Figures 13.2.4 and 13.2.5).

General scour may reduce the degree of safety experienced by the substructures, because of the changed hydraulic conditions and the changed channel geometry. In this case, it is essential to refer to the bridge inspection file and study historical changes that have occurred in the bed elevation through the waterway. If possible, these changes are related to specific causes to assess the present safety of the bridge. These changes also provide insight as to future conditions that may be imposed by changed flow conditions, watershed development, or other conditions affecting the safety of the bridge.

Contraction Scour

Contraction scour results from the acceleration of flow due to a natural contraction, a bridge contraction, or both (see Figures 13.2.6 and 13.2.7). When the available area for stream flow at the bridge is reduced compared with the available area upstream from the bridge, velocity will increase at the bridge. Less area for flow results in faster moving water. The lowering of the streambed under the bridge due to this accelerated stream velocity is known as contraction scour. A bridge length may be shortened to reduce the initial cost of the superstructure. However, this shortened bridge results in a smaller hydraulic opening which can lead to contraction scour (see Figure 13.2.8).

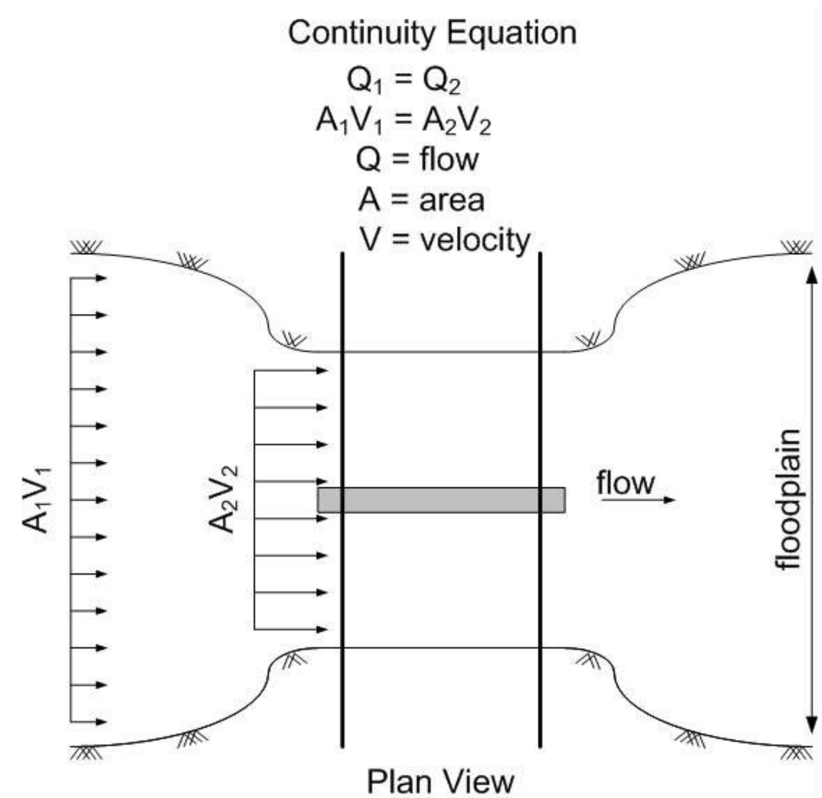

Figure 13.2.6 Stream Contraction Schematic

Figure 13.2.7 Contraction Scour Photograph

Figure 13.2.8 Large number of Piers Combine to Reduce the Hydraulic Opening

Some common causes that can lead to contraction scour include:

- A natural stream constriction such as hard rock on embankment slopes.
- Excessive number of piers in the waterway (see Figure 13.2.8)
- Heavy vegetation in the waterway or floodplain (see Figure 13.2.9).
- Bridge roadway approach embankments built in the floodplain constricting the waterway opening. The overbank area of the floodplain is restricted by the bridge approach embankments extending partially across the floodplain.
- Formation of sediment deposits within the waterway along the inside radius of curved waterways (sandbars), and along embankments that constrict or reduce the available waterway opening (see Figure 13.2.10).

- Ice formation or ice jams that temporarily reduce the waterway opening and produce contraction (see Figure 13.2.11).
- Flow under an ice sheet or flow contracting down under bottom of the superstructure.
- Debris buildup, which often reduces the waterway opening (see Figure 13.2.12).

The effects of contraction scour can be very severe.

Figure 13.2.9 Vegetation Constricting the Waterway

Figure 13.2.10 Sediment Deposits Within the Waterway Opening

Figure 13.2.11 Ice in Stream Resulting in Possible Contraction Scour

Figure 13.2.12 Debris Build-up in the Waterway

Other General Scour

Other general scour conditions result from erosion due to streams which are meandering, braided, or straight, variable downstream control, flow around a bend or any other changes which may cause a decrease in the bed elevation. This could also result from a short-term change in downstream water surface elevation which can control the velocity through the bridge. This may occur at bridges located upstream or downstream from a confluence.

Local Scour

Local scour occurs around an obstruction that has been placed within a stream, such as a pier or an abutment which causes an acceleration of the flow and results in induced by the obstruction. Local scour can either be clear-water scour or live-bed scour.

Clear-water scour occurs when there is no bed material transport upstream of the bridge. It occurs in streams where the bed material is coarse, the stream grade is flat, or the streambed is covered with vegetation except in the location of substructure members.

Live-bed scour occurs when local scour at the substructure is accompanied by bed material transport in the upstream waterway.

The cause of local scour is the acceleration of streamflow resulting from vortices induced by obstructions (see Figure 13.2.13). Some common obstructions are:

- Abutments – floodplain overbank flow is collected along and forced around abutments at high velocities (see Figure 13.2.14).
- Wide Piers - scour depth is proportional to width (see Figure 13.2.15).
- Long Piers - can produce multiple vortices and greater scour depth if the pier is at an angle to the flow direction (see Figure 13.2.16).Unusually Shaped Piers - can increase vortex magnitude. A square-nosed pier will have maximum scour depth, about 20 percent deeper than a sharp-nosed pier and 10 percent deeper than a cylinder or round-nosed pier.
- Bridge Piers Skewed to the Direction of Streamflow - can increase both contraction scour and local scour because of increased (projected) pier width effects. This skew can be dramatically different during low flow versus high flows.
- Depth of Streamflow - increases vortex effect on the streambed. An increase in flow depth can increase scour depth by a factor of 2 or more (see Figure 13.2.13).
- Streamflow Velocity - as streamflow velocity increases vortex action can be magnified considerably.
- Unstable Streambed Material - can contribute to the occurrence of local scour.
- Irregular Waterway Cross Section - can result in local scour at substructure units in the waterway.
- Debris Accumulation - and ice piled up against piers can produce the same effect as a wider pier, increasing both contraction and local scour effects. Debris needs to be removed as a safety precaution to prevent pier failure

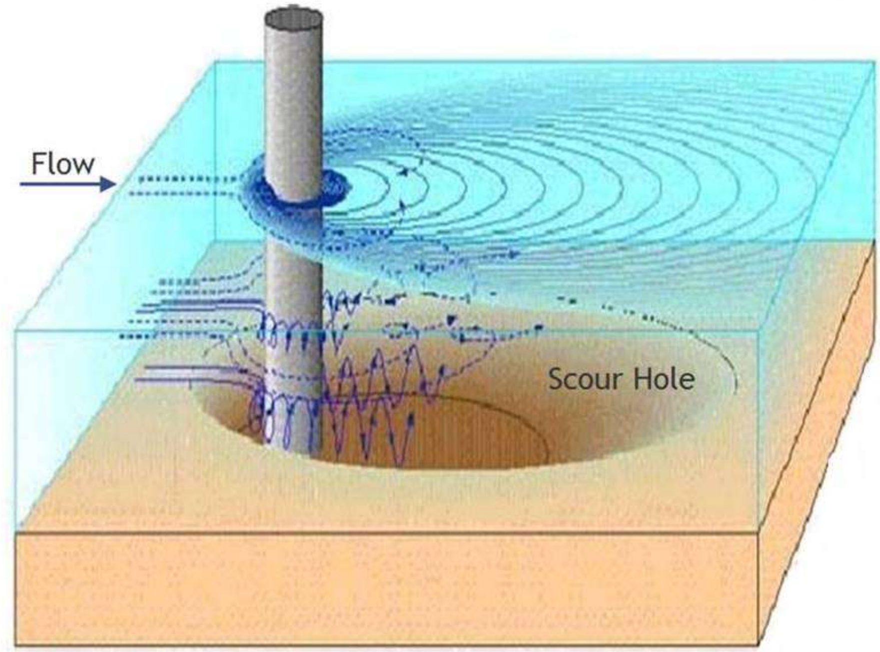

Figure 13.2.13 Local Scour at a Pier

Figure 13.2.14 Local Scour at a Pier

Figure 13.2.15 Wide Pier

Figure 13.2.16 Long Pier

Scour depths resulting from local scour are normally deeper than those from general scour, often by a factor of ten. However, if there are major changes in hydrologic conditions resulting from such factors as construction of large dams and water resources development, the general scour can be the larger element in the total scour.

Bridges in tidal situations are particularly vulnerable to local scour. A strong tidal current whose direction reverses periodically causes a complex local scour phenomenon around a bridge substructure. This local scour is caused by an imbalance between the input and output sediment transport rates around the pier, and it has a negative influence on the stability of the bridge.

To properly evaluate local scour and impacts of changes in hydrologic and hydraulic conditions on local scour, it is essential to develop and refer to that component of the bridge inspection file which deals with local scour. With each inspection, subject the critical supporting elements of the bridge to careful survey to determine the degree of local scour that has developed over time. By referring to this history of change in local scour, it can be determined whether or not the maximum local scour has occurred and the relationship of this maximum local scour to bridge safety.

If the survey of the magnitude of local scour indicates increased local scour with time and furthermore verifies that the local scour exceeds the anticipated maximum local scour when the bridge was designed, take remedial measures to protect the bridge. Surveys of local scour along the abutments and around the piers are most often done during periods of low flow when detailed measurements can be made, either by wading and probing, by probing from a boat, by the use of divers, or by sonic methods. The pattern of survey has to be established and remain the same during the life of the bridge, following either a fixed radial or a rectangular grid. Changes in magnitude of local scour can then be compared at specific points over time.

The greatest problem associated with determining the magnitude of local scour relates to maximum local scour occurring at flows near flood peak followed by a period of deposition of sediments in the scour hole after the flood peak has passed and during low-flow periods. Consequently, base the bridge rating upon maximum scour that occurred during floods but not based upon examination of bed levels around abutments and piers during low-flow periods. Hence, it is necessary to use a variety of techniques to differentiate between maximum scour that may have occurred during flood periods and apparent scour after periods of low flow.

Consider utilizing straight steel or aluminum probing rods to probe loose sediments deposited along abutments and around footings; if sediment is finer than average bed material sizes or if the sediment is easily penetrated by the rod, it is indicative that the present sediment has accumulated in the scour hole and local scour is more severe than indicated by present accumulations of sediments. Core samples may also be used to differentiate between backfill in the scour hole and the bottom of the scour hole. It may be possible to use geotechnical means as another alternative to differentiate between materials that have deposited in the scour hole and the bottom of the scour hole. It may also be necessary to use underwater surveys using divers, or perhaps to even divert water away from critical elements to allow removal of loose backfill material. The inspector can then determine the true level of maximum scour in relationship to the bridge's supporting structural elements.

The problem of accurately determining maximum local scour and rate of change of local scour over time is one of the most difficult aspects of bridge inspection and is one of the most important aspects of evaluating bridge safety. Additional research is being conducted to provide better guidelines for investigating local scour in relationship to bridge safety.

Lateral Stream Migration

Lateral stream migration or horizontal change in the waterway alignment is another type of erosion that can also threaten the stability of bridge crossings. Embankment instability typically results from lateral stream movement at a bridge opening and has often been the primary cause in a number of bridge collapses around the country. Bridge abutments and piers are often threatened by this type of erosion (see Figure 13.2.17).

Figure 13.2.17 Lateral Stream Migration Endangering an Abutment

Lateral stream migration often threatens bridge abutments, piers and approach roadways, particularly those that are along upstream banks at the bridge opening. Lateral stream migration can occur in four modes of bank failure:

- Streambank damage – onset of lateral stream migration. The toe of the slope of the embankment will exhibit lateral scour and the streambank protection will be failing. (see Figure 13.2.18)
- Sloughing streambank – next level of streambank damage where lateral scour has removed enough of the slope that the streambank slides down into the channel. This occurs most often when streambanks are unprotected. (see Figure 13.2.19)
- Undermined streambank – an advanced state of lateral scour where the overbank area is undercut. The original embankment slope is gone. This occurs because the streambank and/or overbank protection at the surface is able to support itself without the underlying streambank material. (see Figure 13.2.20)
- Channel misalignment – an adverse channel offset where the stream flow now impacts one of the bridge abutments or flows through the under bridge waterway at a skew angle incompatible with the span opening(s).

This results when earlier stages of lateral stream migration are allowed to advance unchecked, and leads to local scour conditions that result in undermining and substructure distress. (see Figure 13.2.21)

Figure 13.2.18 Streambank Damage

Figure 13.2.19 Sloughing Streambank

Figure 13.2.20 Undermined Streambank

Lateral stream migration is very common and can result from a variety of causes. Channel changes contributing to lateral stream migration include:

- Stream meander changes due to slope instability, cuts or additional exposure that was not visible before (see Figure 13.2.21)
- Channel widening (see Figure 13.2.22)

Series of aerial photographs over time could be a way to check for lateral stream migration.

Figure 13.2.21 Stream Meander Changes

Figure 13.2.22 Channel Widening

When inspecting for lateral stream instability, some visual indicators are:

- Steep eroding banks on the outside of bends
- Tension cracks in the soil at the top of the bank
- Active undercutting of trees and riparian vegetation along the banks
- Bank sloughing due to undercutting of the toe
- Wide point bars on the inside of meander bends
- Alternate point bars developing in an otherwise straight channel
- Piers that were originally on the floodplain are now in the main channel
- Oxbow lakes or evidence of recent meander cutoffs in the floodplain

The resistance that a streambank has to erosion is closely related to several characteristics of the bank material. The bank material that is deposited in the stream can be classified as:

- Noncohesive bank material - can be removed grain by grain from the streambank. The rate of the streambank erosion are affected by factors which include the particle size, streambank slope, the direction and magnitude of the velocity adjacent to the streambank, turbulent velocity fluctuations, the magnitude of and fluctuations in the shear stress exerted on the streambanks, seepage force, piping and wave forces (see Figure 13.2.23).
- Cohesive bank material - Cohesive bank material is more resistant to erosion than noncohesive bank material. It has low permeability which will reduce the effect of seepage, piping, frost heaving and subsurface flow on the stability of the streambanks. However, if the streambank is undercut and/or saturated, they are more likely to fail due to the mass wasting processes (see Figure 13.2.24).

- Composite bank material - Composite bank material consists of layers of various sizes, permeability and cohesive material. The noncohesive layers will be subjected to surface erosion, but may be partially protected by adjacent layers of cohesive materials. However, this type of bank material is vulnerable to erosion and sliding due to subsurface flows and piping (see Figure 13.2.25).

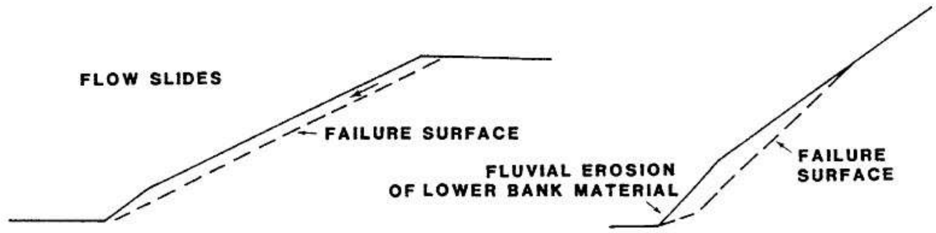

Figure 13.2.23 Schematic of Noncohesive Bank Material

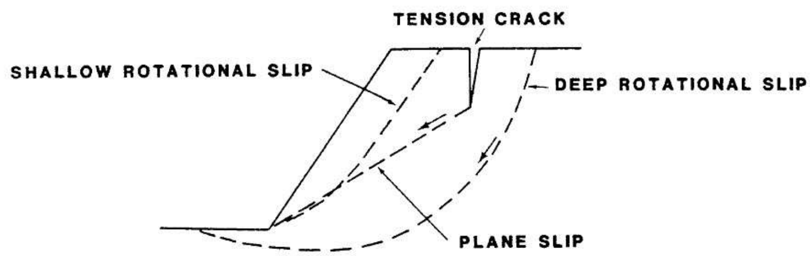

Figure 13.2.24 Schematic of Cohesive Bank Material

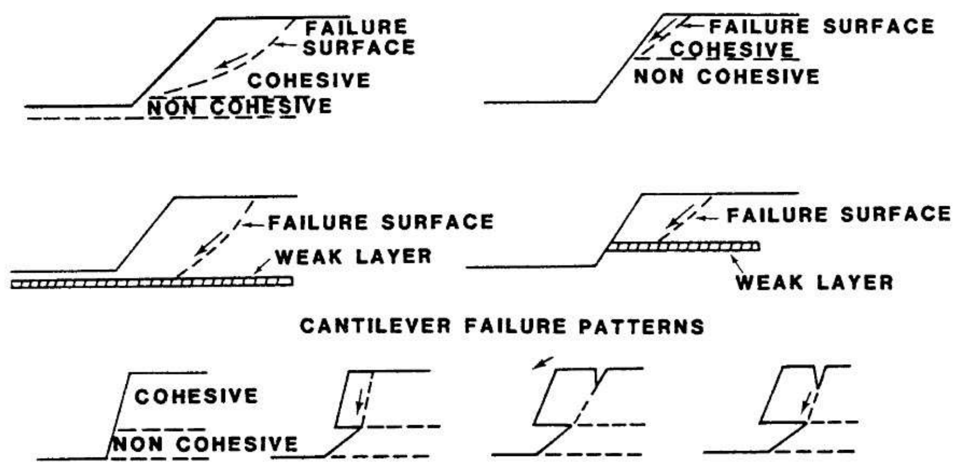

Figure 13.2.25 Schematic of Cohesive Bank Material

13.2.4 Effects of Waterway Deficiencies

Material Defects

Material defects that can be caused by waterway deficiencies include the deterioration and damage (i.e. abrasion, corrosion, scaling, cracking, spalling, and decay) to channel protection devices and substructure members.

As an integral part of the waterway inspection, give careful consideration to the identification of material defects. A loss of quality and quantity of materials required to provide bridge safety may occur in a variety of ways. Carefully record the changes in characteristics of materials in the bridge inspection file. Changes over time can be compared and any decision concerning maintenance requirements or replacement becomes more straightforward with historic information available.

Bridge Damage

Waterway deficiencies that are severe have the capability to cause damage to bridges. Effects of waterway deficiencies on bridge members include undermining, settlement, and failure.

Undermining

Undermining is the scouring away of streambed and supporting foundation material from beneath the substructure (see Figure 13.2.26). Excessive scour often produces undermining of both piers and abutments. Such undermining is a serious condition, which requires immediate correction to assure the stability of the substructure unit. Undermining is especially serious for spread footings, but may also be cause for concern for pile foundations because loss of supporting soil around piling can reduce pile capacity. Substructure stability may be compromised, potentially leading to total bridge collapse.

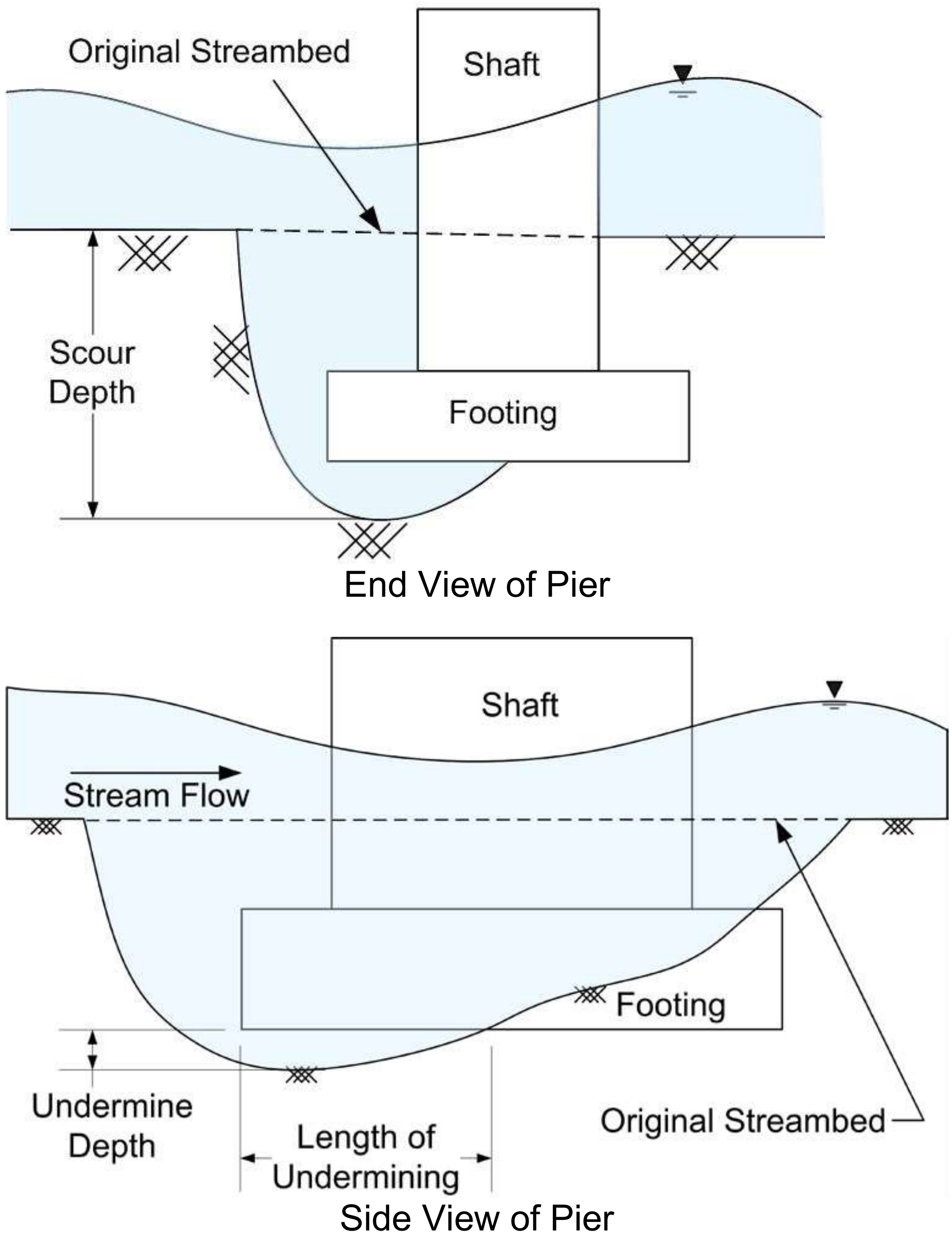

Figure 13.2.26 End and Side View of Scour and Undermining

The undermining of structural elements is basically an advanced form of scour. It is essential to determine whether or not undermining has a potential to develop, as well as whether it has already occurred. Address undermining immediately since it can pose an immediate threat to safety.

With small bridges, L-shaped rods can be used to probe at the base of footings to determine possible undermining. On the other hand, undermining may be very difficult to identify due to the redeposition of sediments during periods of low flow after undermining has occurred. However, in those channels where the bed is formed of coarse rock and the sediment supply to the bridge crossing is small, it is possible to inspect the footings because the backfill with fine sediments during periods of low flow generally does not occur.

For areas not accessible to effective probing from above water, it is essential to employ underwater inspection techniques utilizing divers. Whenever possible, take detailed measurements, showing the height, width, and penetration depth of the undermined cavities. Refer to Topic 13.3 for a more detailed description of underwater inspections.

Settlement

Local scour and undermining is typically most severe at the upstream end of the substructure and, if not corrected, may result in differential settlement (see Figure 13.2.27).

Figure 13.2.27 Pier Settlement due to Undermining

Failure

When undermining and settlement go undetected for some length of time, the bridge may become unstable, and be subject to failure or collapse. Failure may occur over a period of time, or it may be a very rapid process occurring during a flood event.

13.2.5 Inspection Preparation

It is necessary to identify and assemble the documentation and equipment required to conduct the waterway inspection. The required equipment will depend upon the characteristics of the river, the characteristics of the bridge, and the accessibility of the site.

Information Required

Necessary information is required for a comprehensive, well-organized inspection of waterways.

Examine any previous hydraulic engineering scour evaluation studies on the bridge. These studies provide theoretical ultimate scour depths for the bridge substructure elements. Review original drawings and previous inspection report data taken from successive inspections to determine the foundation type and streambed material. Establish whether the waterway is stable, degrading or aggrading.

Become familiar with site conditions and channel protection installations. Verify if there is a change in the hydraulic opening by reviewing previous channel cross sections and profiles. Examine the photographs to determine any changes in the channel alignment.

Considering the complexity of the inspection and the equipment and materials needed to execute the inspection, develop a detailed plan of investigation, as well as forms for recording observations. Use a systematic method each time the bridge is surveyed to provide a means of accurately identifying changes that have occurred at the bridge site, which may affect the safety of the bridge.

Inspection Methods

Prior to beginning the inspection, the bridge inspector needs to understand the type and extent of the inspection required. Waterway inspections are typically accomplished by either surface inspection or underwater diving inspection.

Surface or “wading” inspection is conducted on shallow depth foundations. Submerged substructure, streambed and embankments are often accessible by inspectors using hip boots or chest waders and probing rods (see Figure 13.2.28). Additionally, boats are often used as a surface platform from which to gather waterway data, including channel cross-sections, pier soundings, etc.

Underwater diving inspection is required when the foundations are deep into water. Site conditions often require waterway and submerged substructure units to be evaluated using underwater divers, in order to obtain complete, accurate data. This is especially true when water depths are too great for wading inspection, and/or undermining of substructure elements is suspected.

Equipment

Equipment required to inspect bridges is listed and described in Topic 2.4. Additional equipment may be required for the inspection of waterways. The type of equipment needed for a waterway inspection is dependent on the type of inspection. The following is a list that represents the most common waterway inspection equipment.

- Probing rods and waders (see Figure 13.2.28)
- Sounding line (lead line to measure depths of scour)
- Fathometer to determine water depth

- Diving equipment (see Figure 13.2.29 and Topic 13.3)
- Boat, oars, motor, and anchor
- Surveying equipment (level or transit)
- Survey tapes and chains
- Level rod
- Compass
- Underwater camera and video recorder
- Underwater to surface communication equipment
- Past climatic and hydrologic records
- Stopwatch to time stream velocity and record diver durations under water

Refer to Topic 13.3 for additional information on underwater inspection equipment.

Figure 13.2.28 Probing Rod and Waders

Figure 13.2.29 Surface Supplied Air Diving Equipment

Special Considerations

Give special considerations to the site conditions and the navigational controls that may adversely affect the safety of the bridge inspector and others.

Site conditions such as rapid stream flow velocity, pollution levels, safety concerns, and conditions requiring special attention need to be accounted for during a waterway inspection (see Figure 13.2.30).

Navigational control is necessary when inspecting large waterways. Notify the Coast Guard in advance of inspections where navigational controls are needed. Other navigational controls include boat traffic, operational status and condition of dolphins and fenders, dam releases (see Figure 13.2.31).

Figure 13.2.30 Rapid Flow Velocity

Figure 13.2.31 Navigable Waterway

13.2.6 Inspection Methods and Locations

Methods

Visual

The primary method used to inspect waterways is visual. Look at the site in the vicinity of the bridge. Also, look at the floodplain. This observation may have to be done during periods of high water flow.

Physical

After the inspector gets the general condition by visually inspecting the bridge site, the next step is to probe for any scour or undermining. Take care to adequately press the probing rod into the soil in the streambed. Sometimes scour holes are loosely filled with silt. This silt may be washed away quickly during the next period of high stream flow velocity, permitting additional scour.

Advanced Inspection Methods

Take measurements to obtain the cross section and profile. These measurements are used to analyze the area of the hydraulic opening and help determine need for and design of mitigation measures. The cross section under the bridge can be measured with a surveyor's tape or rod. The stream profile can be measured with a hand level, survey tape and surveying rod (see Figures 13.2.32 and 13.2.33). Compare the streambed profile and hydraulic opening to previous inspections.

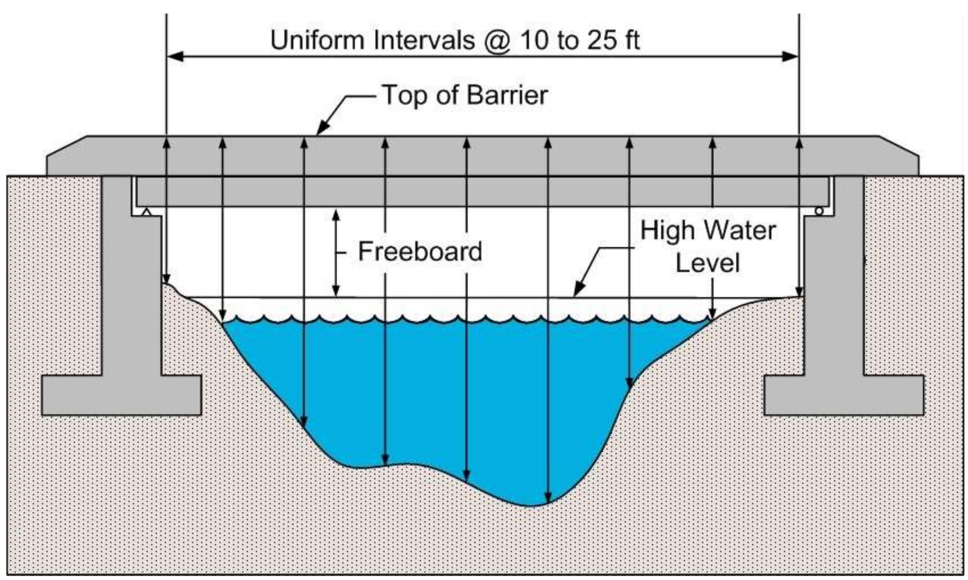

Figure 13.2.32 Streambed Cross-Section

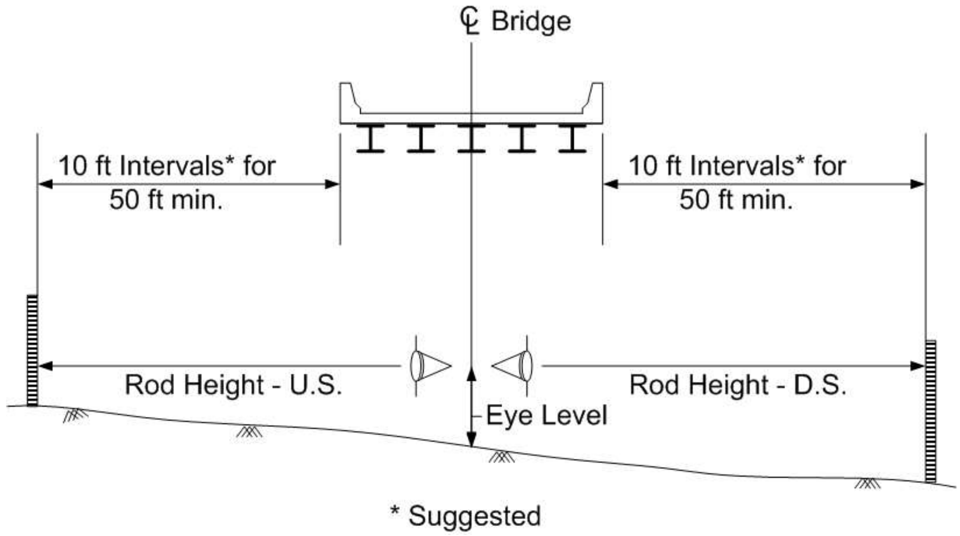

Figure 13.2.33 Streambed Profile

An alternative to the sounding and scour sensing devices used during inspections is to permanently install fixed instrumentation directly on the bridge substructure. With fixed instrumentation, local scour is continuously monitored and recorded as it occurs, unaffected by washing back of silts and sands, and making information readily available to the bridge owner by setting off a beacon-type alarm on the bridge deck (or relayed back to an office). One such instrument consists of a steel rod inside of a conduit attached to the substructure unit. The rod acts as a probe, resting on the vulnerable soil supporting the substructure. As local scour occurs the soil is washed away and the rod drops a measured distance.

Other fixed instrumentation includes fixed sonar units, sliding magnetic collars, and buried "float-out" buoys, which float to the water surface after being uncovered by local scour, activating an electronic alarm system (see Figure 13.2.34).

Researchers are studying a new method for scour detection and monitoring. The new method is based on time domain reflectometer (TDR) technology, which uses pulse transmissions to show changes in a particular environment. The TDR bridge scour monitoring system consists of a probe, which is completely buried in the sediment at appropriate locations around and near the bridge pier and footings. As erosion occurs, part of the probe is exposed to water. Then, the probe reflects a specific pulse back to the TDR box, which is on the surface, indicating how much of the probe is exposed and producing wave forms to show scour depth. The probes are designed to be left at bridge sites to detect/monitor scour.

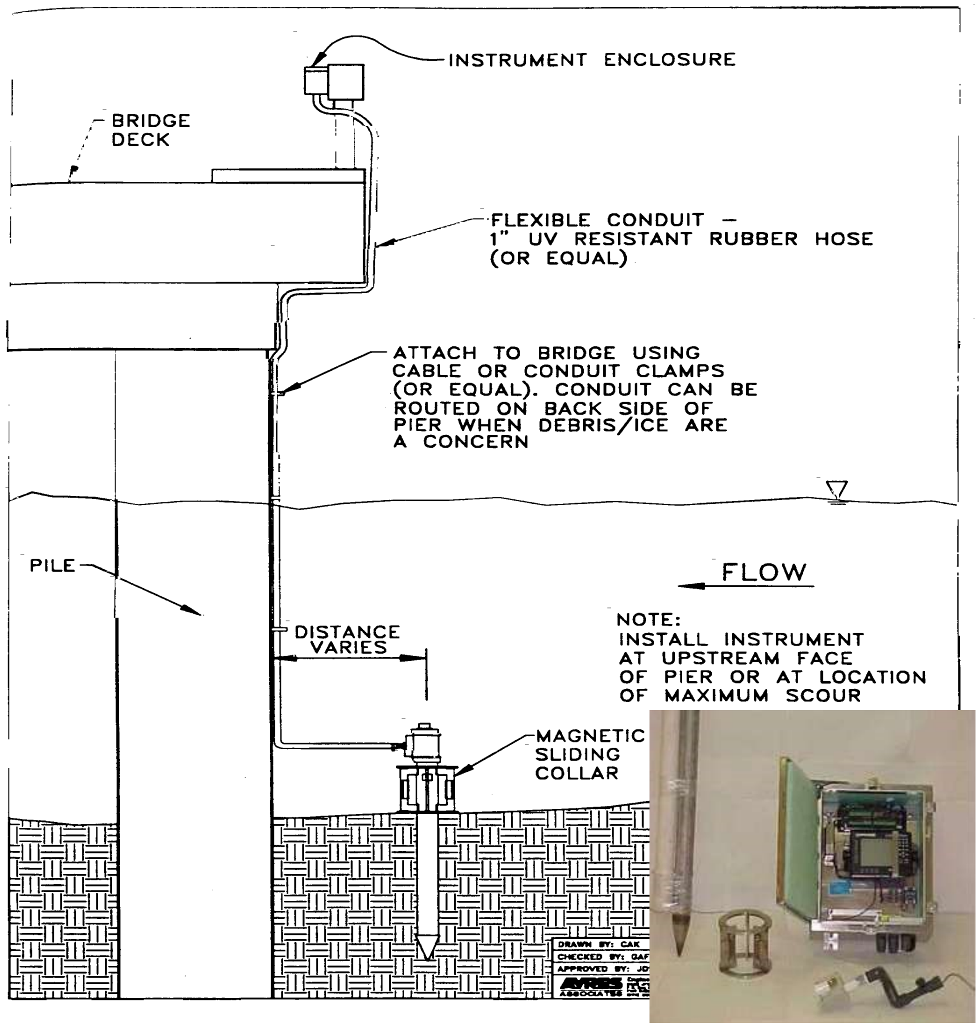

Figure 13.2.34 Scour Monitoring Collar

Locations

When inspecting the bridge waterway, three main areas are of concern. These areas include the channel under the bridge, the upstream channel, and the downstream channel.

Channel Under the Bridge

Substructure

- Inspect substructure units below water level for defects, damage and foundation condition (see Figure 13.2.35).
- Measure heights and lengths of foundation element exposures, and dimensions of foundation undermining (opening height, width, and penetration depth), as applicable. Document with sketches and photos.
- Note location of high water mark on abutments and piers.
- Plumb face of abutments and piers for local settlement (see Figure 13.2.36).
- Check abutments and piers for accumulations of debris (drift).

- In case of damage to scour countermeasures, check condition and function of channel protection devices adjacent to substructure units.
- In case of changes in streambed elevations generate streambed profile.
- In case of changes in streambed cross section generate streambed cross-sections for typical upstream, downstream, and under structure waterway configurations.
- Locate and contour large scour holes at the substructure.
- Establish a grid system for depth soundings at substructure elements, which can be repeated in subsequent inspections.
- Take photographs to document conditions of abutments, piers, and channel features.
- Check bridge seats and bearings for transverse movement.

Figure 13.2.35 Pile Bent Deterioration Normally Hidden Underwater

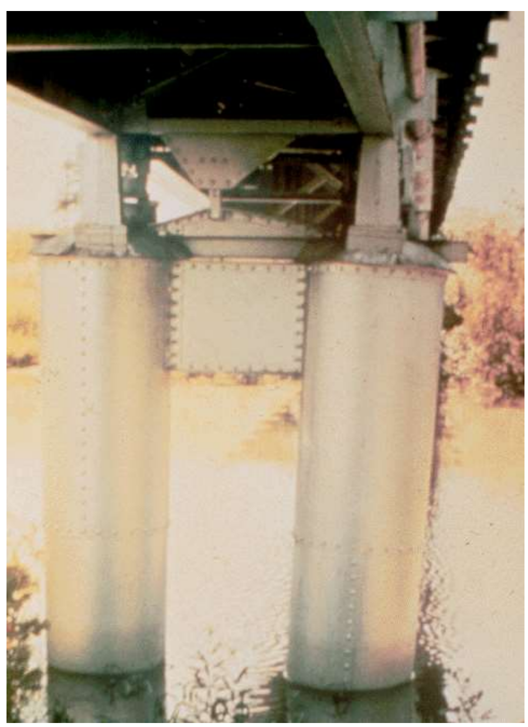

Figure 13.2.36 Out of Plumb Pier Column

Superstructure

During a waterway inspection, the superstructure can be a good indicator of existing waterway deficiencies.

The following items need to be reviewed:

- Check to see if the superstructure is tied to the substructure to prevent washout.
- Sight along the superstructure to reveal irregularity in grade or horizontal alignment caused by settlement (see Figure 13.2.37).
- Check to see if debris is lodged in superstructure elements or tree limbs above the superstructure (see Figure 13.2.38).
- Check for high watermarks or ice scars on trees.
- Talk to local residents about high water during previous flood events.
- Check any hydraulic engineering scour evaluation studies for overtopping flow elevation and frequency.
- Check to see if the superstructure is below the design flood level elevations.
- Check to see if the superstructure presents a large surface of resistance during floods.
- Note if the superstructure is vulnerable to collapse in the event of excessive foundation movement (i.e., simple span and non-redundant vs. continuous) (see Figure 13.2.39).

Figure 13.2.37 Superstructure Misalignment

Figure 13.2.38 Drift Lodged in a Superstructure

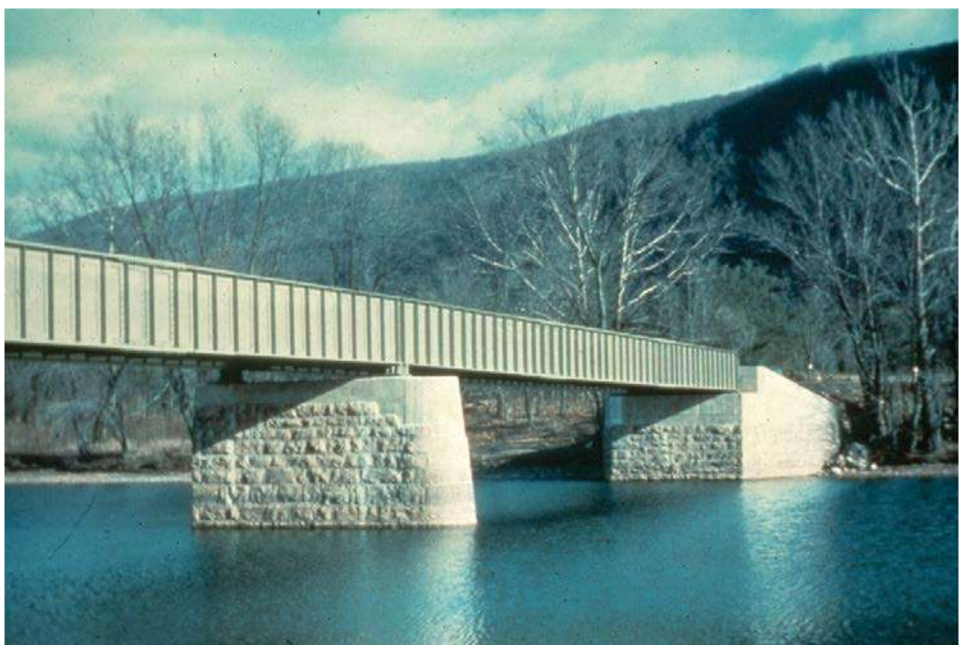

Figure 13.2.39 Multi-Span Simply Supported Bridge

Channel Protection and Scour Countermeasures

- Examine any river training and bank protection devices to determine their stability and condition.
- Check for any gaps or spreading that have occurred in the protective devices.
- Check for separation of slope pavement joints.
- Check for exposure of underlying erodible material.
- Inspect for steepening of the protective material and the surface upon

which these materials are placed.

- Check for evidence of slippage of protective works.
- Check the condition and function of riprap as well as changes in size of riprap.
- Check for evidence of failed riprap in the stream (see Figure 13.2.40).
- Check for the proper placement, condition, and function of guidebanks, or spurs.
- Check the streambed in the vicinity of the channel protection for evidence of scour under the device.
- Check to see if the streamflow is impinging behind the protective devices.

Figure 13.2.40 Failed Riprap

It is essential to identify any change that is observable, including changes in the gradation of riprap. It is also essential to carefully inspect the integrity of the wire basket where gabions have been used.

Disturbance or loss of embankment and embankment protection material is usually obvious from close scrutiny of the embankment. Unevenness of the surface protection is often an indicator of the loss of embankment material from beneath the protective works. However, loss of embankment material may not be obvious in the early stages of failure. Also look for irregularities in the embankment slope.

It is difficult to determine conditions of the protective works beneath the water surface. In shallow water, evidence of failure or partial failure of protective works can usually be observed. However, with deeper flows and sediment-laden flows, it is necessary to probe or sound for physical evidence to identify whether failure or partial failure exists.

Waterway Area

- Check the hydraulic opening with respect to the floodplain. If the width is small compared to the floodplain and return flow is expected to be large, there could be high potential for contraction scour and abutment scour
- Determine the type of streambed material.
- Check for degradation (see Figure 13.2.41).
- Check for local scour around piers and abutments and record data.
- Inspect during drought conditions when applicable.
- Check for contraction scour due to abutment placement, sediment build-up, and vegetation.
- Check for debris underwater, which may constrict flow or create local scour conditions.
- Check to see if the approach roadways are located in the floodplain (see Figure 13.2.42).
- Examine approaches for signs of overtopping.
- Determine if the hydraulic opening is causing or has the potential to cause scour under the bridge.

Figure 13.2.41 Severe Streambed Degradation Evident at Low Water

Figure 13.2.42 Approach Roadway Built in the Floodplain

Upstream and Downstream of the Bridge

Streambanks

- Stable **-** gradually sloped, grass covered with small trees. Streambanks are still basically in their original locations. Slope stabilization measures are in place and intact (see Figure 13.2.43).
- Unstable **-** streambank is sloughing due to scour, evidence of lateral movement or erosion, damage to slope stabilization measures (see Figure 13.2.19).

Figure 13.2.43 Stable Streambanks

Main Channel

- Record the flow conditions (e.g. low or high).
- Estimate velocities using floats.
- Check for sediment buildup and debris, which may alter the direction of stream flow (see Figure 13.2.44).
- Check for cattle guards and fences, which may collect debris. The results may be sediment buildup, channel redirection, or an increase in velocity and contraction scour (see Figure 13.2.45).
- Determine the streambed material type.
- Check for aggradation or degradation. Check several hundred feet upstream and downstream of the bridge.
- Check the basic alignment of the waterway with respect to the structure and compare it to its original alignment (lateral stream migration) (see Figure 13.2.46).
- Record the direction and distribution of flow between piers and abutments.
- Make sketches and take pictures as necessary to document stream alignment, conditions of bank protection works, and anything that appears unusual at each inspection.

Figure 13.2.44 Sediment Accumulation Redirecting Streamflow

Figure 13.2.45 Fence in Stream at Bridge

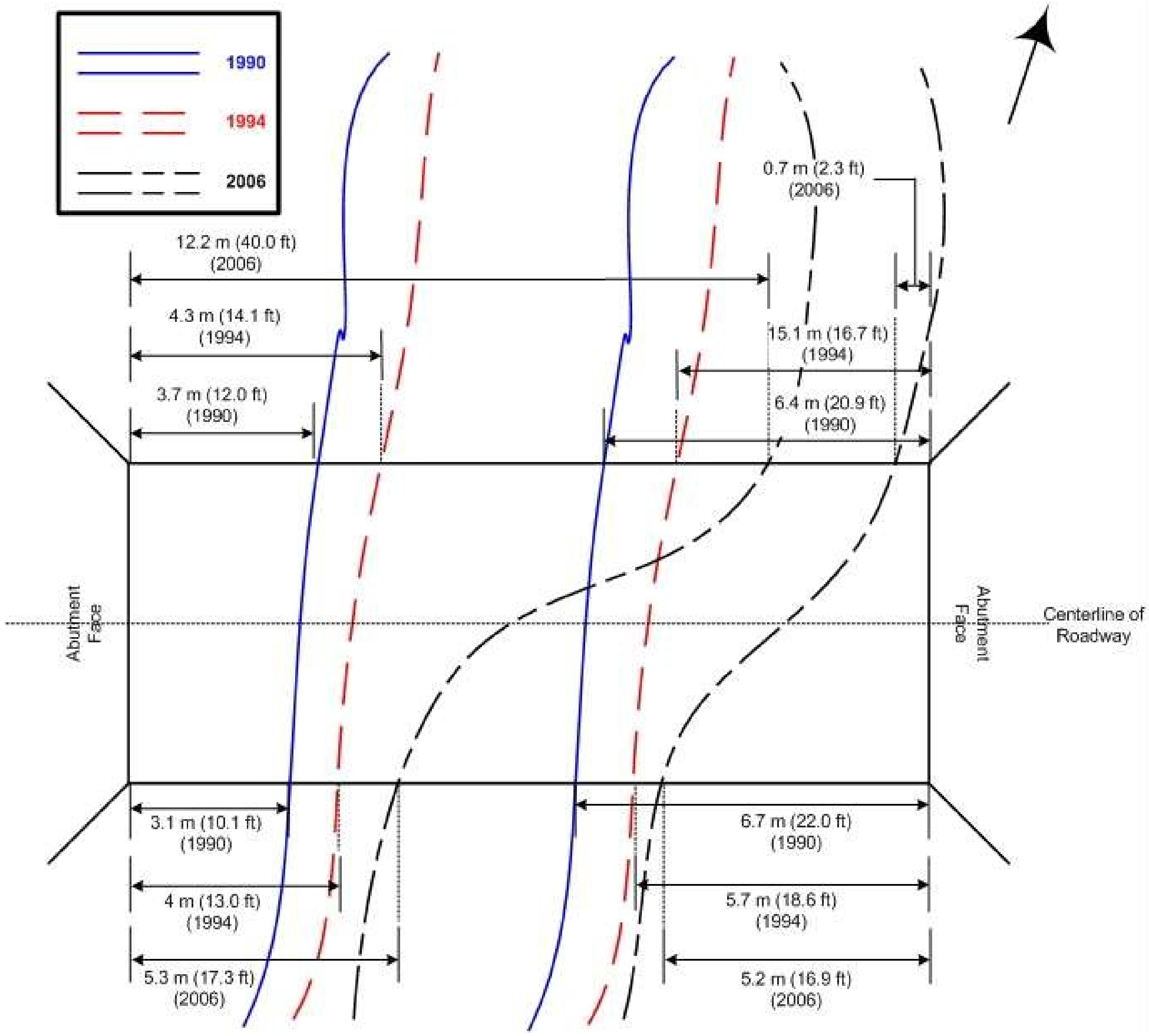

Figure 13.2.46 Waterway Alignment 1990 - 2006

Floodplain

- Check for evidence of embankment sloughing, undermining, and lateral stream migration resulting from significant stream flow (see Figure 13.2.47).
- Check for amounts and locations of debris, sediment accumulations, tree scaring, and amounts of vegetation growth, all of which may indicate the frequency of stream flow on the floodplain.
- Check for accumulations of sediments, debris, or significant vegetation growth in the waterway that may impact sufficient waterway adequacy and adversely affect streamflow under the main channel span.
- Check for damage to the approach pavement, shoulders, and embankments to determine if the stream flow overtops the approach roadway during flood flows or returns to the main channel to flow under the structure.
- Check the extent of structures, trees, and other obstructions that could impact stream flow and adversely affect the bridge site (see Figure 13.2.48).

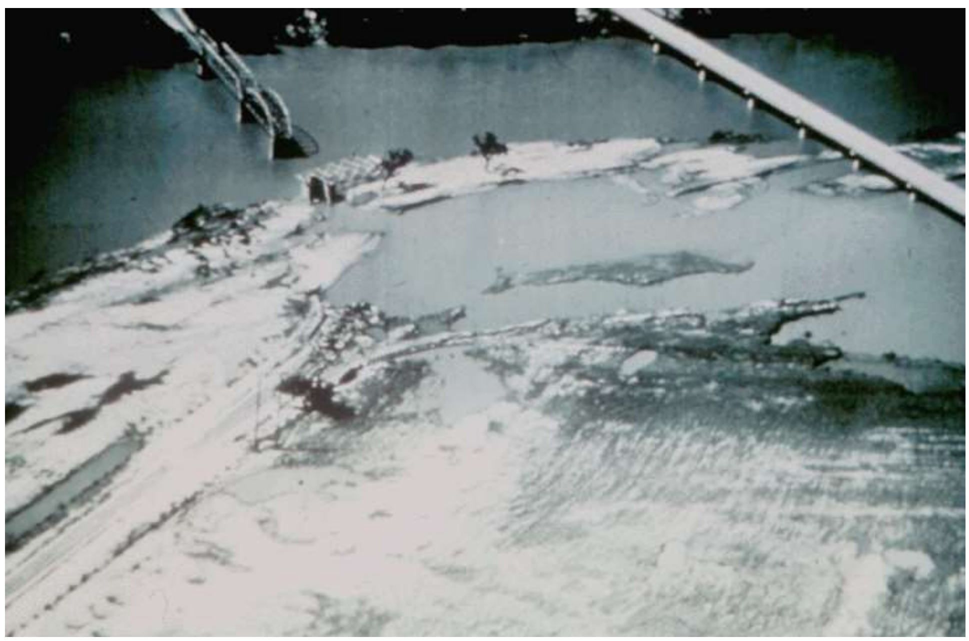

Figure 13.2.47 Approach Spans in the Floodplain

Figure 13.2.48 Debris and Sediment in the Channel

Other Features

- Check for streamflow impact of any other features such as tributaries, confluence of another waterway, dams, and substructure units from other bridges (see Figure 13.2.49). This may create conditions for high stream flow velocity through the bridge.
- Report any recent construction activity (e.g. causeways, fishing piers, and stranded vessels) which may affect stream flow under the bridge.

Figure 13.2.49 Upstream Dam

13.2.7 Evaluation

Scour Plan of Action

A plan of action is prepared to monitor any known and potential deficiencies and address any critical findings for bridges that are determined to be scour critical. Instructions regarding the type and frequency of inspections in regards to monitoring the performance and the closing of the bridge during or after flood events are included in the scour plan of action. A schedule for the design and construction of scour countermeasures if it is determined they are needed for the bridge are also included.

Scour Potential Assessment

Bridges over streams and rivers are subject to scour and are evaluated to determine their vulnerability to floods and to determine whether they are scour critical.

Purpose and Objective

In a scour evaluation, structural, hydraulic and geotechnical engineers have to make decisions on:

- Priorities for making bridge scour evaluations.
- The scope of the scour evaluations to be performed in the office and in the field.
- Whether a bridge is a scour critical bridge.
- Develop a plan of action for each scour critical bridge.
- Which scour countermeasures may reduce the bridge's vulnerability to scour.
- Which scour countermeasures are most suitable and cost-effective for a given bridge site.
- Priorities for installing scour countermeasures.

- Monitoring and inspecting scour critical bridges.

A responsibility of the bridge inspector is to gather on-site data for an assessment of scour potential, that:

- Accurately records the present condition of the bridge and the stream (see Figure 13.2.50).
- Identifies conditions that are indicative of potential problems with scour and stream stability.

To accomplish these objectives, the inspector needs to recognize and understand the potential for scour and its relationship with the bridge and stream. When an actual or potential scour problem is identified by a bridge inspector, further evaluation the bridge is completed by an interdisciplinary team made up of structural, geotechnical, and hydraulic engineers.

Figure 13.2.50 Scour at a Pile Abutment

Recognition of Scour Potential

Identify and record waterway conditions at the bridge, upstream of the bridge, and downstream of the bridge. Indications that could establish a scour potential include waterway, substructure and superstructure.

Waterway

- Stream flow velocity is a major factor in the rate of scour. High velocities produce accelerated scour rates (see Figures 13.2.51 and 13.2.52).
- Streambed materials such as loose cohesive soils, sand or gravel material, are highly susceptible to accelerated scour rates (see Figure 13.2.53).

- Orientation of waterway opening such as misaligned or skewed structure foundation elements, which can frequently generate adverse streamflow conditions, can lead to scouring of the streambed especially during flood flows (see Figure 13.2.53).
- Large floodplains constricted to a narrow hydraulic opening under a structure can result in accelerated scour during flood flow, due to high velocities and changes in local flow direction (see Figure 13.2.54).
- Banks that are sloughing, undermined, or moving laterally are signs of potential scour at a bridge (see Figure 13.2.55).

Figure 13.2.51 Fast Flowing Stream

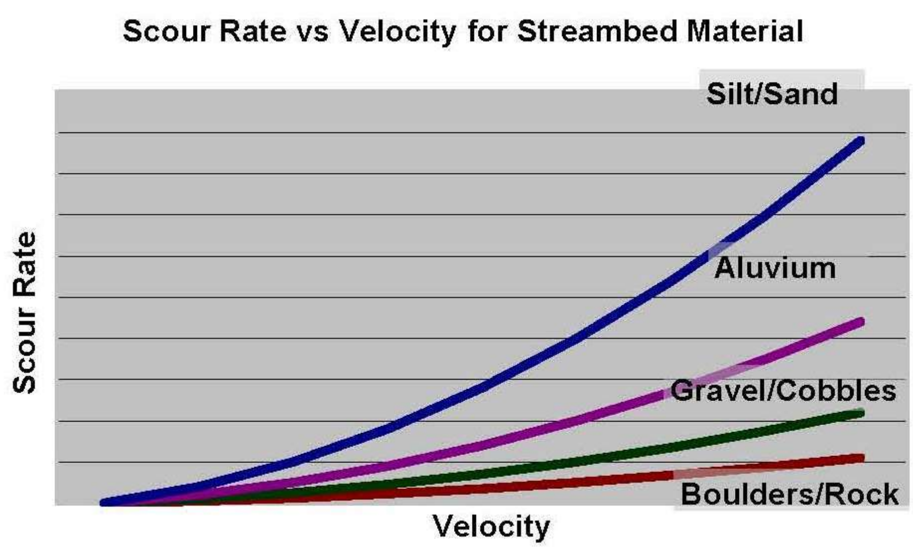

Figure 13.2.52 Scour Rates vs. Velocity for Common Streambed Materials

Figure 13.2.53 Typical Misaligned Waterway

Figure 13.2.54 Typical Large Floodplain

Figure 13.2.55 Lateral Stream Migration

Substructure

Consider the following condition of bridge foundations and substructure units in the scour potential assessment:

- Piers and abutments that are not parallel with the stream flow especially during flood flow conditions, can lead to local scour of foundations (see Figure 13.2.56).
- Rotational, horizontal, or vertical movement of piers and abutments are evidence of undermining (see Figure 13.2.57).
- Spread footing foundation levels above maximum calculated scour depth determined for a particular streambed material are subject to undermining and failure. Exposed piling can be damaged or deteriorated and can lead to failure. Loss of supporting surrounding soil can also diminish pile capacity (see Figure 13.2.58).
- Constriction of the general waterway opening beneath the structure due to numerous large piers or simply an inadequate span length between abutments can increase streamflow velocities and lead to contraction scour (see Figure 13.2.59).

Figure 13.2.56 Stream Alignment Not Parallel with Abutments

Figure 13.2.57 Rotational Movement and Failure Due to Undermining

Figure 13.2.58 Exposed Piling Due to Scour

Figure 13.2.59 Accelerated Flow Due to Constricted Waterway

Superstructure

Consider the following conditions associated with the superstructure in recognizing scour potential:

- Evidence of overtopping indicates insufficient hydraulic opening and excessive flow velocities.
- Insufficient freeboard can trap debris, increasing the potential for a washout.
- Simple span designs are most susceptible to collapse in the event of foundation movement or increased flows during a flood event.

NBI Condition Rating Guidelines

Scour Evaluation

The scour evaluation is an engineering assessment of existing and potential problems and making a sound judgement on what steps can be taken to eliminate or minimize future damage.

In assessing the adequacy of the bridge to resist scour, the inspector and engineer need to understand and recognize the interrelationships between several items. The inspector can expedite the engineers' evaluation by considering the following:

- Substructure Condition Rating (Item 60)
- Channel and Channel Protection Condition Rating (Item 61)
- Waterway Adequacy Appraisal Rating (Item 71)
- Scour Critical Bridges (Item 113)

See Topic 4.2 for a detailed description of NBI Condition Rating Guidelines.

Substructure (Item 60)

Substructure rating is a key item for rating the bridge foundations for vulnerability to scour damage. When a scour problem is found that has already occurred, considered it in the condition rating of the substructure. If the bridge is determined to be scour critical, further evaluate the condition rating for Item 60 to ensure that any existing problems have been properly considered. Be consistent with the rating factor given to Item 60 with the one given to Item 113 whenever a rating factor of 2 or below is determined for Item 113.

Channel and Channel Protection (Item 61)

This item permits rating the physical channel condition affecting streamflow through the bridge waterway. Consider the condition of the channel, adjacent rip-rap, bank protection, guidebanks, and evidence of erosion, channel movement or scour in establishing the rating for Item 61.

Waterway Adequacy (Item 71)

This is an appraisal item, rather than a condition item, and permits assessment of the adequacy of the bridge waterway opening to pass flood flows.

Scour Critical Bridges (Item 113)

This item permits a rating of current bridge conditions regarding its vulnerability to flood damage. A scour-critical bridge is one with abutment or pier foundations that are considered unstable due to:

- Observed scour at the bridge site, or
- Having scour potential as determined by a scour evaluation

When an actual or potential scour problem is identified, the bridge is to be further evaluated by an interdisciplinary team comprised of structural, hydraulic and geotechnical engineers.

In this process, the effects of a 100-year flood (a flood which has a one percent chance of occurring in any year) would be considered, but the effects of a "superflood" or 500-year flood would also be assessed and assigned to one of three conditions.

- Safe condition - if calculations indicate that the likely scour depth of the superflood would be above the top of the footing, the bridge would be considered safe or stable (see Figure 13.2.60).
- Evaluate condition - if calculations indicate a scour depth within the limits of a spread footing or piles, further structural or foundation evaluation may be needed to establish the likely stability of the foundation (see Figure 13.2.61).
- Fix condition - where there are indications that scour depth will lie below the bottom of the spread footing or piles, then the bridge would be considered clearly scour critical and would be at risk to damage or collapse (see Figure 13.2.62).

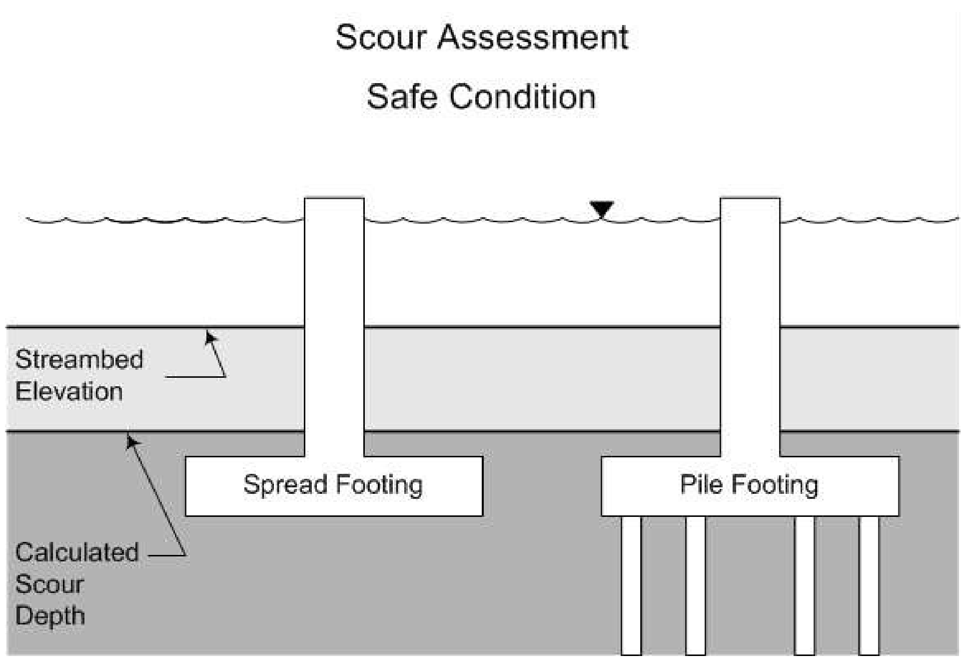

Figure 13.2.60 Scour Assessment - Safe

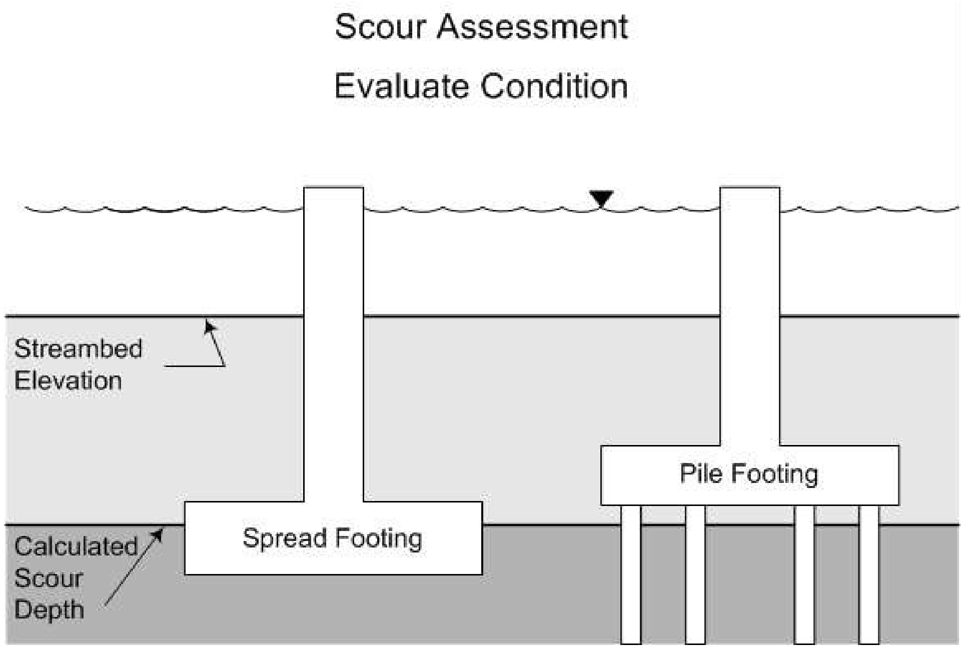

Figure 13.2.61 Scour Assessment - Evaluate

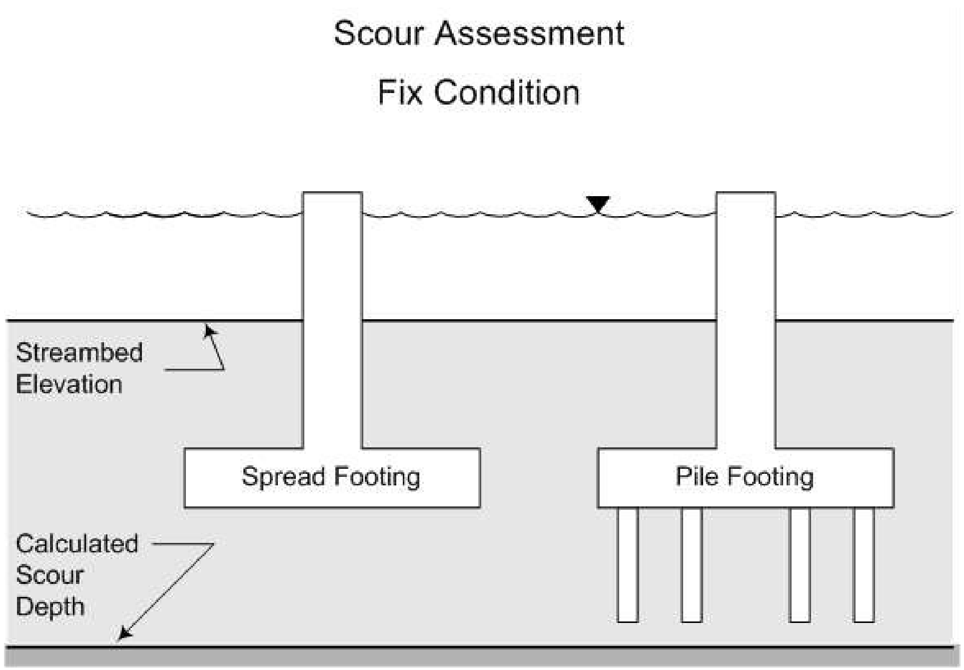

Figure 13.2.62 Scour Assessment - Fix

For scour critical bridges, the NBIS requires that a Plan of Action is developed for monitoring and correcting the scour problem. Monitor, in accordance with the plan, bridges which are scour critical. Such a plan would address the type and frequency of future inspections to be made and would include a schedule of timely design and construction actions for appropriate countermeasures to protect the bridge. The countermeasures might include the possibility of riprap, bed armoring, or flow-control structures or embankments.

Washouts of scour critical bridges, which appeared to be stable in the past, have still occurred. Recognizing potential problems and developing a Plan of Action for scour critical bridges will help reduce the likelihood of washouts.

13.2.8 Culvert Waterway

The following excerpt is from a reproduction of the out-of-print Culvert Inspection Manual (Supplement to Manual 70), July 1986 – Chapter 5, Section 3:

Section 3. WATERWAYS

5-3.0 General.

The primary function of most culverts is to carry surface water or traffic from one side of a roadway embankment to the other side. The hydraulic design of culverts usually involves the determination of the most economical size and shape of culvert necessary to carry the design discharge without exceeding the headwater depth allowable. It is essential that the culvert be able to handle the design discharge. If the culvert is blocked with debris or the stream changes course near the ends of the culvert, the culvert may be inadequate to handle design flows. This may result in excessive ponding, flooding of nearby properties, and washouts of the roadway and embankment. In addition changes in upstream land use such as clearing, deforestation, and real estate development may change the peak flow rates and stream stability. It is therefore important to inspect the condition of the stream channel, SI&A item 61, and evaluate the ability of the culvert to handle peak flows, SI&A item 71.

5-3.1 Stream Channel--What to Look for During Inspection.

The stream channel should be inspected to determine whether conditions exist that would cause damage to the culvert or surrounding properties. Factors to be checked include culvert location (horizontal and vertical alignment), scour, and accumulation of sediment and debris. These factors are closely related to each other. Poor culvert location can result in reduced hydraulic efficiency, increased erosion and sedimentation of the stream channel, and increased damage to the embankment and surrounding properties. A brief discussion of each of these factors is provided.

a. Horizontal Alignment - The inspector should check the condition of the stream banks and any bank protection at both ends of the culvert. He should also check for erosion and indications of changes in the direction of the stream channel. Sketches and photographs should be used to document the condition and alignment at the time of inspection. Abrupt stream alignment changes retard flow and may require a larger culvert; they cause increased erosion along the outside of the curve, damage to the culvert, and increased sedimentation along the inside of the curve. Where sharp channel curves exist at either the entrance or exit of a culvert, the inspector should check for sedimentation and erosion.

b. Vertical Alignment - Vertical alignment problems are usually indicated by scour or accumulation of sediment. Culverts on grades that differ significantly from the natural gradient may present problems. Culverts on flat grades may have problems with sediment build up at the entrance or within the barrel. Culverts on moderate and steep grades generally have higher flow velocities than the natural stream and may have problems with outlet scour. Scour and sediment problems may also occur if the culvert barrel is higher or lower than the streambed.

c. Scour - Erosion generally refers to loss of bank material and a lateral movement of the channel. Scour is more related to a lowering of the streambed due to the removal and transporting of stream bed material by flowing water. Scour may be classified into two types: local scour and general scour.

(1) Local scour is located at and usually caused by a specific flow obstruction or object, which causes a constriction of the flow. Local scour occurs primarily at the culvert outlet.

(2) General scour extends farther along the stream and is not localized around a particular obstruction. General scour can involve a gradual, fairly uniform degradation or lowering of the stream channel. It can also result in abrupt drops in the channel that move upstream during peak flows. This type of scour is referred to as head cutting. Head cutting may be a serious problem if it is occurring in the channel downstream from the culvert, since it may threaten the culvert as it moves upstream. Head cutting may also occur in the stream channel immediately upstream from depressed inlets. Where upstream head cutting is usually not as serious a problem for the culvert, it can affect upstream structures and properties.

The upstream channel should be checked for scour that may undermine the culvert or erode the embankment. Scour that is undermining trees or producing sediment that could block or reduce the culvert opening should also be noted. The stream channel below the culvert should be checked for local scour caused by the culvert's discharge and for general scour that could eventually threaten the culvert.

d. Accumulation of Sediment and Debris - Deposits of debris or sediment that could block the culvert or cause local scour in the stream channel should be noted. Accumulations of debris or sediment in the stream may cause scour of the streambanks and roadway embankment, or could cause changes in the channel alignment. Debris and sediment accumulations at the culvert inlets or within the culvert barrel reduce the culvert's capacity and may result in excessive ponding. It also increases the chances for damage due to buoyant forces. Downstream obstructions, which cause water to pond at the culvert’s outlet, may also reduce the culvert's capacity. Debris collectors are used in some culverts so that the opening is not blocked by floating materials.

5-3.2 Waterway Adequacy - What to Look for During Inspection.

The preceding paragraphs dealt with evaluating the condition of the stream channel and identifying conditions that could cause damage to the culvert or reduce the hydraulic efficiency of the culvert. A closely related condition that must be evaluated is the waterway adequacy or ability of the culvert to handle peak flows, changes in the watershed, and changes in the stream channel which might affect the hydraulic performance. Guidelines for rating SI&A item 71, Waterway Adequacy, are presented in the Coding Guide.

a. High Water Marks - The high water elevation will vary with each flood but should still be checked to evaluate waterway adequacy. Ideally, culverts should be checked during or immediately after peak flows to determine whether water is being ponded to excessive depths, flooding adjoining properties, or overflowing the roadway, as shown in Exhibit 63. High water marks are needed to define the upstream pond elevation and the downstream tailwater elevation. Several high water marks should be obtained, if possible, to insure consistency. High water marks in the culvert barrel, in the drain down area near the inlet, or near turbulent areas at the outlet are generally misleading. An inspection can also determine high water levels for peak flows by looking for debris caught on fences, lodged in trees, or deposited on the embankment. Information may also be obtained by interviewing area residents. Indications of excessive ponding, flooding, or overtopping of the roadway should be investigated to determine the cause. If the cause is apparent, such as a blocked inlet, it should be reported for scheduling of appropriate maintenance. If the cause is not apparent, the culvert should be reported for evaluation by a hydraulic specialist.

b. Drainage Area - The inspector should be aware that changes in the drainage might have an effect on the discharge that culverts must handle. Replacement of an upstream culvert with a larger structure may eliminate upstream ponding, causing more water to reach the culvert sooner. Land clearing, construction, channel improvements, or removal of upstream dams or sediment basins may also affect discharge rates. Similarly, changes in land use may increase or decrease the amount of rainfall that infiltrates the ground and the amount that runs off. The inspector should note in the inspection report any apparent changes that are observed and be aware that changes a considerable distance upstream may affect the performance of downstream structures. Obstructions downstream from a culvert that back water up to the culvert may also affect the performance of the culvert.

c. Scour - As previously discussed, scour that changes the stream alignment at the ends of the culvert can reduce the hydraulic efficiency.

d. Sedimentation and Debris - Accumulation of debris and sediment at the inlet or within the culvert barrel reduces both the size of the opening and the culvert's capability to handle peak flows. Severe drift and sediment accumulations are illustrated in Exhibits 64 and 65. However, culverts are occasionally designed with fill in the bottom to create a more natural streambed for fish.

Figure 13.2.63 (Exhibit 63) Culvert Failure Due to Overtopping

Figure 13.2.64 (Exhibit 64) Culvert Almost Completely Blocked by Sediment Accumulation

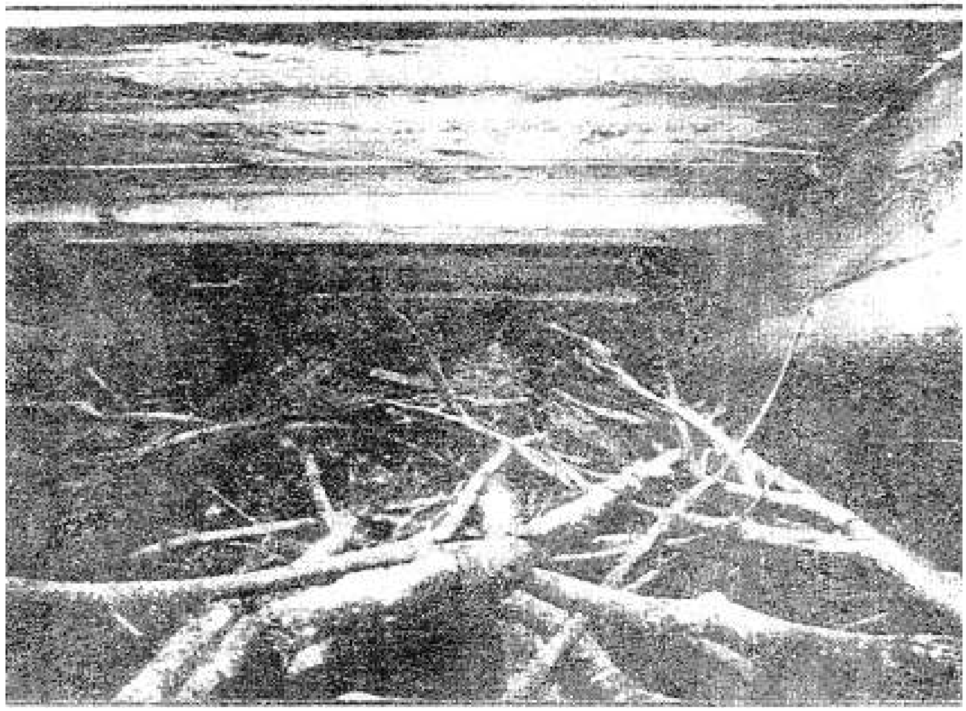

Figure 13.2.65 (Exhibit 65) Drift and Debris Inside Timber Box Culvert

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Table of Contents

Chapter 13

Inspection and Evaluation of Waterways

Topic 13.3 Underwater Inspection

13.3.1 Introduction

The need for underwater inspections is great. Approximately 83 percent of the bridges in the National Bridge Inventory (NBI) are built over waterways. While many of these bridges do not have foundation elements actually located in water, a great many do and most bridge failures occur because of underwater issues. Inspect underwater members to the extent necessary to determine with certainty that their condition has not compromised the structural safety of the bridge.

Several bridge collapses during the 1980's, traceable to underwater deficiencies, have led to revisions in the National Bridge Inspection Standards (NBIS) (see Figure 13.3.1). As a result, bridge owners are required to develop a master list of bridges requiring underwater inspections.

Figure 13.3.1 Schoharie Creek Bridge Failure

According to the NBIS, underwater inspection is the inspection of the underwater portion of a bridge substructure and the surrounding channel, which cannot be inspected visually at low water by wading or probing, generally requiring diving or other appropriate techniques.

The expense of such inspections necessitates careful consideration of candidate bridge, since underwater inspection is a hands-on inspection requiring underwater breathing apparatus and related diving equipment.

Bridge Selection Criteria

Bridges that cross waterways often have foundation elements located in water to provide the most economical total design. Where these elements are continuously submerged (see Figure 13.3.2), use underwater inspection and management techniques to establish their condition so that failures can be avoided.

Figure 13.3.2 Liberty Bridge over Monongahela River

In many cases, a multi-disciplinary team including structural, hydraulic and geotechnical engineers evaluate a bridge located over water that is a candidate for underwater inspection. Underwater inspection is therefore only one step in the total investigation of a bridge.

Selection Criteria

Various factors influence the underwater bridge inspection selection criteria. In accordance with the *Code of Federal Regulations* (23 CFR Part 650) and the *AASHTO Manual for Bridge Evaluation (MBE)*, all structures receive routine underwater inspections at intervals not to exceed 60 months, or 72 months with FHWA approval. This is the maximum interval permitted between underwater inspections for bridges which are in excellent condition underwater and which are located in passive, nonthreatening environments. More frequent routine and in-depth inspections may be desirable for many structures and necessary for critical structures. The bridge owner determines the inspection interval that is appropriate for each individual bridge. Factors to consider in establishing the inspection frequency and levels of inspection include:

- Age (*CFR* and *MBE*)
- Traffic volume (*MBE*)
- Size (*MBE*)
- Susceptibility to collision (*MBE*)
- Extent of deterioration (*MBE*)
- Performance history of bridge type (*MBE*)
- Load rating (*MBE*)
- Location (*MBE*)
- National defense designation (*MBE*)

- Detour length (*MBE*)
- Social and economical impacts due to bridge being out of service (*MBE*)
- Type of construction materials (*CFR*)
- Environment (*CFR*)
- Scour characteristics (*CFR*)
- Condition ratings from past inspections (*CFR*)
- Known deficiencies (*CFR*)

Selected Bridges

Note those bridges that require underwater inspection on the bridges' individual inspection and inventory records. For each bridge requiring underwater inspection, include the following information as a minimum:

- Type and location of the bridge
- Type and frequency of required inspection
- Location of members to be inspected
- Inspection procedures to be used
- Dates of previous inspections
- Maximum water depth and velocity (if known)
- Special equipment requirements
- Findings of the last inspection
- Follow-up actions taken on findings of the last inspection
- Type of foundation
- Bottom of foundation elevation or pile tip elevation
- Include each bridge on a master list for the Agency

13.3.2 Diving Inspection Intensity Levels

Originating in the offshore diving industry and adopted by the United States Navy, the designation of standard levels of inspection has gained widespread acceptance. Three diving inspection intensity levels have evolved as follows:

- Level I: Visual, tactile inspection
- Level II: Detailed inspection with partial cleaning
- Level III: Highly detailed inspection with non-destructive testing (NDT) or partially destructive testing (PDT)

Routine underwater inspections normally include a 100 percent Level I inspection and a 10 percent Level II inspection, but it may include a Level II and Level III inspection to determine the structural condition of any submerged portion of the substructure with certainty.

Level I

Level I inspection consists of a close visual inspection at arm's length with minimal cleaning to remove marine growth of the submerged portions of the bridge. This level of inspection is used to confirm the continuity of the members and to detect any undermining or elements that may be exposed that would normally be buried. Although the Level I inspection is referred to as a "swim-by" inspection, it needs to be detailed enough to detect obvious major damage or deterioration. A Level I inspection is normally conducted over the total (100%) exterior surface of each underwater element, involving a visual and tactile inspection with limited probing of the substructure and adjacent streambed. In areas where light is minimal, handheld lights may be needed. If the water clarity is poor enough that the inspector cannot inspect the member visually, a tactile inspection may be performed by making a sweeping motion of the hands and arms to cover the entire substructure.

The results of the Level I inspection provide a general overview of the substructure condition and verification of the as-built drawings. The Level I inspection can also indicate the need for Level II or Level III inspections and aid in determining the extent and the location of more detailed inspections.

Level II

Level II inspection is a detailed inspection that requires that portions of the structure be cleaned of marine or aquatic growth. In some cases, cleaning is time consuming, particularly in salt water, and needs to be restricted to critical areas of the structure. However, in fresh water, aquatic coatings can be removed by just wiping the structural element with a glove.

Generally, the critical areas are near the low waterline, near the mud line, and midway between the low waterline and the mud line. On pile structures, horizontal bands, approximately 6 to 12 inches in height, preferably 10 to 12 inches, need to be cleaned at designated locations:

- Rectangular piles - the cleaning includes at least three sides
- Octagonal piles - at least six sides
- Round piles - at least three-fourths of the perimeter
- H-piles - at least the outside faces of the flanges and one side of the web

Figure 13.3.3 Level II Cleaning of a Steel Pile

On large elements, such as piers and abutments, clean areas at least 1 square foot in size at three or more levels on each face of the element (see Figure 13.3.4). For a structure that is greater than 50 feet in length, clean an additional three levels on each exposed face. It is important to select the locations to clean to help minimize any potential damage to the structure and to target more critical locations. Measure and document deficient areas, including both the extent and severity of the damage.

It is intended to detect and identify high stress, damaged and deteriorated areas that may be hidden by surface growth. A Level II inspection is typically performed on at least 10% of all underwater elements. Govern the thoroughness of cleaning by what is necessary to determine the condition of the underlying material. Complete removal of all growth is generally not required.

Figure 13.3.4 Diver Cleaning Pier Face For Inspection

Level III

A Level III inspection is a highly detailed inspection of a critical structure or structural element, or a member where extensive repair or possible replacement is contemplated. The purpose of this type of inspection is to detect hidden or interior damage and loss in cross-sectional area. This level of inspection includes extensive cleaning, detailed measurements, and selected nondestructive and other testing techniques such as ultrasonics, sample coring or boring, physical material sampling, and in-situ hardness testing. The use of testing techniques is generally limited to key structural areas; areas that are suspect; or areas that may be representative of the entire bridge element in question.

13.3.3 Types of Inspection

A comprehensive review of all bridges contained in an agency's inventory will indicate which bridges require underwater inspection. Many combinations of waterway conditions and bridge substructures exist. For any given bridge, the combination of environmental conditions and structure configuration can significantly affect the requirements of the inspection. It is generally accepted that there are five different types of inspections used for underwater inspections:

- Routine underwater (periodic)
- Initial (inventory)
- Damage
- In-depth
- Special (interim)

Underwater inspections are typically either routine or in-depth inspections.

Routine Underwater (Periodic) Inspections

A routine underwater (or periodic) inspection is a regularly scheduled, intermediate level inspection consisting of sufficient observations and measurements to determine the physical and functional condition of the bridge, to identify any change from initial or previously recorded conditions, and to ensure that the structure continues to satisfy present service requirements. A routine underwater inspection will incorporate Level I, Level II and a scour evaluation.

The summary guidelines for a routine underwater inspection include:

- A Level I inspection will be conducted on 100% of the underwater portion of the structure to determine obvious problems.
- A Level II inspection will be conducted on at least 10% of underwater units selected as determined by the Level I inspection.
- Scour evaluations which help give the cross-section of the channel by sounding and probing near the elements underwater

The dive team may also conduct a scour evaluation at the bridge site, including:

- Inspect the channel bottom and sides for scour.
- Cross sections of the channel bottom will be taken and compared with as-built plans or previously taken cross sections to detect lateral channel movement or deepening (see Figure 13.3.5).
- Soundings are to be made in a grid pattern (see Figure 13.3.6) about each pier and upstream and downstream of the bridge, developing contour

elevations of the channel bottom, to detect areas of scour. Permanent reference point markers can be placed on each abutment/pier (see Figure 13.3.7). Data obtained from the soundings will be correlated with the original plans (if available) of the bridge foundations and tied to these markers for reference during future underwater inspections.

- Local scour and undermining can be determined with probes in the vicinity of piers and abutments (see Figure 13.3.8). In streams carrying large amounts of sediment, reliable scour depth measurements may be difficult at low flow due to scour hole backfilling.

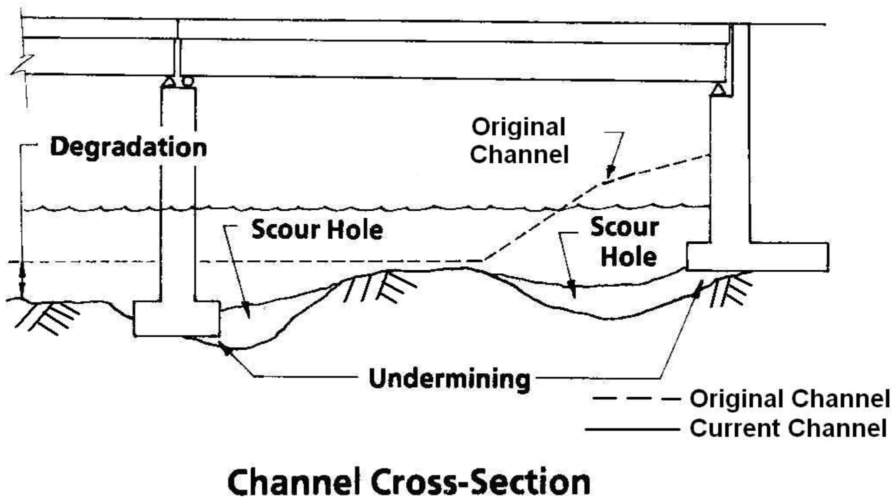

Figure 13.3.5 Channel Cross-Section (Current Inspection Versus Original Channel)

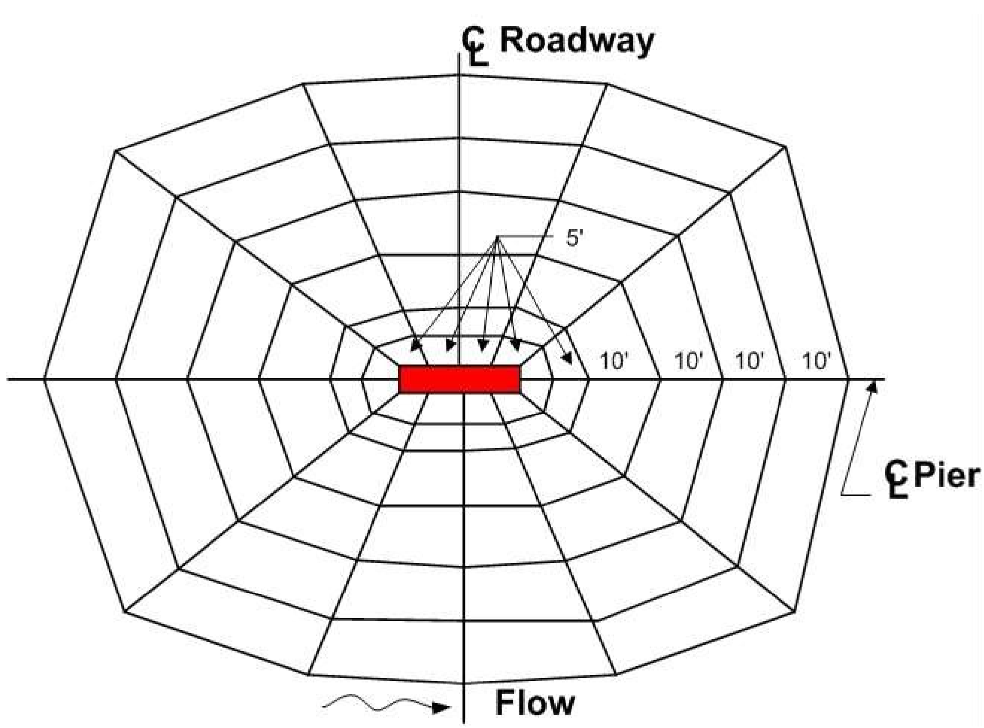

Figure 13.3.6 Pier Sounding Grid

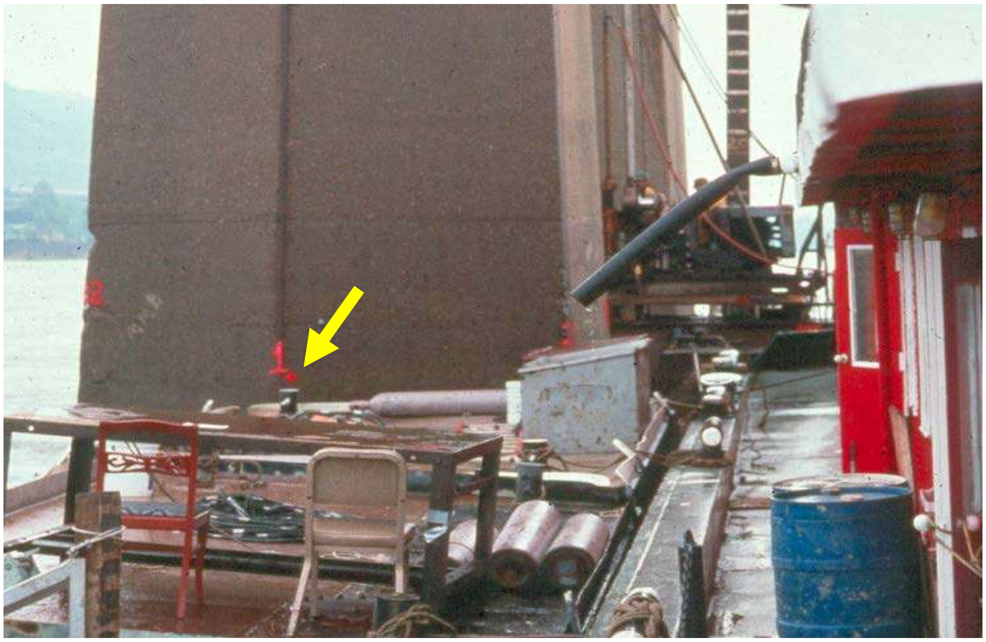

Figure 13.3.7 Permanent Reference Point (Bolt Anchored in Nose of the Pier, Painted Orange)

Figure 13.3.8 Local Scour; Causing Undermining of a Pier

Initial (Inventory) Inspections

An initial (or inventory) inspection is the first inspection of a bridge as it becomes a part of the bridge inventory. An initial inspection is a fully documented investigation that will typically incorporate Level I and Level II inspections and a scour evaluation as required for a routine inspection. In addition, this type of inspection will provide all of the Structure Inventory and Appraisal (SI&A) and other relevant data to determine the baseline structural conditions. It also identifies and lists the existing problems and locations of existing problems or locations in the structure that may have potential problems. Aided by a prior detailed review of plans, it is during this inspection that any underwater members (or details) are noted for subsequent focus and special attention (see Figure 13.3.9).

An initial inspection may also be required when there has been a change in the configuration of the structure such as widening, lengthening, bridge replacement, or change in ownership.

Figure 13.3.9 Bascule Bridge on the Saint Croix River

Damage Inspections

Certain conditions and events affecting a bridge may require more frequent or unscheduled inspections to assess structural damage resulting from environmental or accident related causes.

The scope of the inspection is to be sufficient to determine the need for emergency load restrictions or closure of the bridge to traffic and to assess the level of effort necessary to repair the damage. The amount of effort expended on this type of inspection will vary significantly depending upon the extent of the damage. If major damage has occurred, evaluate section loss, make measurements for misalignment of members, and check for any loss of foundation support.

In-Depth Inspections

An in-depth inspection is a close-up, hands-on inspection of one or more members below the water level to detect any deficiencies not readily apparent using routine inspection procedures. When appropriate or necessary to fully ascertain the existence of or the extent of any deficiencies, Level III, nondestructive tests may need to be performed.

The in-depth inspection typically includes Level II inspection over extensive areas and Level III inspection of limited areas. Nondestructive testing is normally performed, and the inspection may include other testing methods, such as extracting samples for laboratory analysis and testing, boring, and probing.

One or more of the following conditions may dictate the need for an in-depth inspection:

- Inconclusive results from a routine inspection
- Critical structures, whose loss would have significant impact on life or property

- Unique structures, whose structural performance is uncertain
- Prior evidence of distress
- Consideration of reuse of an existing substructure to support a new superstructure or planned major rehabilitation of the superstructure

The distinction between routine and in-depth inspections is not always clearly defined. For some bridges, such as steel pile supported structures in an actively corrosive environment, it may be necessary to include Level III, nondestructive testing inspection techniques as part of routine inspections.

Special (Interim) Inspections

A special (or interim) inspection is scheduled at the discretion of the individual in charge of bridge inspection activities. A special inspection is used to monitor a particular known or suspected deficiency (e.g., foundation settlement or scour).

Conditions for Inspections

Situations that may warrant a damage, in-depth or a special underwater inspection include:

- Unusual floods - inspect bridge elements after floods. Inspect bridge elements located in streams, rivers, and other waterways with known or suspected scour potential after every major runoff event to the extent necessary to ensure bridge foundation integrity (see Figure 13.3.10).
- Vessel impact - inspect bridges underwater if there is visible damage above water from vessel impact. This is to be done in order to determine the extent of damage and to establish the extent of liability of the vessel owner for damages.
- Unusual ice floes - ice floes can damage substructure elements, and accumulations of ice on the elements can cause scouring currents or increase the depth of scour.
- Prop wash from vessels - prop wash from vessels (i.e., turbulence caused by the propellers of marine vessels) can cause scouring currents and may propel coarse-grained bottom materials against substructure elements in a manner similar to that of blast cleaning operations.
- Adverse environmental conditions - rapid and severe deterioration of substructure materials may be caused by brackish water, polluted water, and water with high concentrations of chemicals. Some waterways may promote microbial induced corrosion (MIC) on steel submerged substructure elements.
- Floating and build-up of debris - buildup of debris at piers or abutments effectively widens the unit and may cause scouring currents or increase the depth of scour (see Figure 13.3.11).
- Above water evidence of deterioration or movement - evidence of deterioration or movement will require underwater inspection. Many underwater deficiencies only become apparent above water when the distress extends above the waterline or is manifested by lateral movement or settlement. Inspect bridges underwater following significant earthquakes (see Figure 13.3.12).

Figure 13.3.10 Flood Conditions: Pier Settlement.

Figure 13.3.11 Buildup of Debris At Pier

Figure 13.3.12 Movement of a Substructure Unit

Frequency of Inspection

Conduct routine inspections of substructures in water at least once every 60 months. This is only applicable to substructures that are in excellent condition and for substructures that have current conditions that are considered acceptable for that timeframe and without any concerns that may require more frequent monitoring.

Structures having underwater members which are partially deteriorated or are in unstable channels may require shorter inspection intervals. Establish criteria for determining the level and frequency to which these underwater elements will be inspected base on such factors as:

- Structure age
- Type of construction materials
- Configuration of the substructure
- Adjacent waterway features such as dams, dikes or marinas
- Susceptibility of streambed materials to scour
- Maintenance history
- Saltwater pollution
- Damage due to waterborne traffic, debris or ice

Certain underwater structural elements may be inspected at greater than 60-month intervals, not to exceed 72 months, with written FHWA approval. This may be appropriate when past inspection findings and analysis justifies the increased inspection interval.

Some bridge owners, however, may shorten the underwater inspection interval to 24 or 48 months to coincide with a regular routine bridge inspection (24 to 48 months) or a fracture critical member inspection (24 months).

13.3.4 Qualifications of Diver-Inspectors

An underwater bridge inspection diver needs to complete an FHWA-approved comprehensive bridge inspection training course or other FHWA-approved underwater bridge inspection training course.

The underwater inspector needs to have knowledge and experience in bridge inspection. Conduct all underwater inspections under the direct supervision of a qualified bridge inspection team leader. A diver not fully qualified as a bridge inspection team leader is to be used under close supervision.

The ability of the underwater inspector to safely access and remain at the underwater work site is paramount to a quality inspection. The individual is to possess a combination of commercial diving training and experience as a working diver. This allows the inspector to meet the particular challenges of the underwater working conditions for that inspection.

Team leader requirements for those in charge of underwater inspection are the same as their top-side counterparts. See Topic 1.2 Responsibilities of the Bridge Inspector and *Title 23 of the Code of Federal Regulations, Part 650, Subpart C*.

Federal Commercial Diving Regulations

Underwater bridge inspection, using either self-contained or surface-supplied equipment, is a form of commercial diving. In the United Sates, commercial diving operations are federally regulated by the Occupational Safety and Health Administration (OSHA). OSHA regulates all commercial diving operations performed inland and on the coast (through *Title 29 of the Code of Federal Regulations, Part 1910, Subpart T, Commercial Diving Operations*). Consult this reference for details on commercial diving procedures and safety.

Diver Training and Certification

OSHA Safety Requirements

The OSHA Commercial Diving Operations standard applies to all diving and related support operations that are conducted in connection to diving. The OSHA delineates diving personnel requirements, including general qualifications of dive team members. The standard also provides general and specific procedures for diving operations, and provides requirements and procedures for diving equipment and recordkeeping:

- Personnel requirements - all divers are to be trained, which includes dive physiology, first aid, and cardiopulmonary resuscitation (CPR)
- General and specific operating procedures - employers are to develop a safe diving practices manual for diving operations which includes the following:
    - Designate a person to be in charge of the operation who is qualified by training and experience
    - SCUBA gear is not to be used for depths greater than 130 feet sea water
    - SCUBA gear is not to be used in currents that are exceeding 1 knot unless diver is line tended
    - Surface-supplied air is not allowed for depths greater than 220 feet sea water
    - A recompression chamber needs to be on-site and ready for use for dives that exceed 100 feet sea water and for dives that are outside the no-decompression limits,
    - Minimum size dive team for both SCUBA and surface-supplied diving operations is to be three, but more personnel may be required
- Equipment procedures - minimum equipment requirements are specified for diver and diving equipment, equipment testing and requirements
- Record keeping requirements - requirements are set for the recording and retaining of documents related to diving related illness, injuries, or fatalities, diving exposure, decompression evaluations, medical treatment, equipment inspection and testing, and depth-time profiles

U.S Army Corp Army of Engineers Safety and Health Requirements is another safety standard that may be used and is similar to OSHA standards, except it provides more specific guidance as to the minimum dive team personnel required for various diving conditions. It also provides a more definitive requirement for diving qualifications and requires that divers be certified in the emergency administration of oxygen.

Visit www.osha.gov for more information.

ANSI Standards for Commercial Diver Training

American National Standards Institute (ANSI) Standards exist, which define minimum training standards for both recreational SCUBA and commercial divers. These standards provide clear-cut distinctions between recreational and commercial diver training. While not federal law, these standards constitute the consensus of both the recreational and commercial diving communities, following ANSI's requirements for due process, consensus, and approval.

The American National Standard for Divers- Commercial Diver Training-Minimum Standard (ANSI/ACDE-01-1998) requires a formal course of study, which contains at least 625 hours of instruction. This training may come from an accredited commercial diving school, military school, or may be an equivalent degree of training achieved prior to the effective date of the Standard, which includes a documented combination of field experience and/or formal classroom instruction. Visit www.ansi.org/ for more information.

ADC International Requirements

The Association of Diving Contractors International (ADC) is a non-profit organization representing the commercial diving industry. The ADC publishes "Consensus Standards For Commercial Diving Operations", which have been developed to present the minimum standards for basic commercial diving operations conducted either offshore or inland. The Consensus Standards, in part, duplicate the ANSI standard for commercial diver training, but subdivide the minimum 625 hours of training into both a formal course of study (317 hours, minimum), and on the job training (308 hours, minimum). The ADC also formally issues OSHA-recognized Commercial Diver Certification Cards to individuals meeting minimum training standards. Visit www.adc-int.org/ for more information.

Dive Team Requirements

The Federal Highway Administration's main concern is whether the diver has knowledge and experience in underwater bridge inspection. The individual employers are in the best position to determine the specific requirements of their dive teams.

13.3.5 Planning an Underwater Inspection

The primary goal for an underwater inspection is for the dive team to complete the work safely and to perform a complete and accurate inspection. Planning for underwater bridge inspections is particularly important because of:

- The complexity and potential hazards involved in conducting the inspection
- Unknown factors which may be discovered during the diving
- The difficulty for the bridge owner to verify the thoroughness of the inspection
- The cost of conducting underwater inspections

These factors are most influential for first-time (initial) underwater inspections that set a benchmark for future inspections. Therefore, it is important to distinguish between the first-time and follow up inspections.

The effectiveness of an underwater inspection depends on the agency's ability to properly consider the following factors:

- Method of underwater inspection (i.e., Dive mode)
- Diving inspection intensity level
- Type of inspection
- Qualifications of diver-inspectors
- Specific bridge site conditions, including access requirements, and waterway and climate conditions

With these factors considered, an agency may opt for a lower level of inspection. Depending on conditions and the type of damage found, a higher level may then be necessary to determine the actual bridge condition. It is also possible that different levels may be required at various locations on the same bridge.

The steps in planning an underwater inspection include:

- Preliminary planning - This determines the goal of the inspection and decides what information is to be gathered and the amount of detail.
- Data collection and research - The next step is to obtain design and as-built drawings of the bridge to determine the configuration of the structure, construction materials and foundation type. It is also important to include any past records of repairs as well as past inspection reports. This may help indicate the progression of any deficiencies, deterioration of repairs, waterway conditions and access points. Also, any scour data or plan of action is to be reviewed.
- Hazard analysis - When planning an inspection, it is recommended that the site be examined to identify all potential hazards and ways to work around these hazards. Planning may include the avoidance or removal of the hazard, the selection of appropriate operational methods, the choice of the appropriate inspection and diving equipment and the use of special protective equipment. Common hazards may include swift current, deep water, high altitudes, extreme water temperatures, limited or no visibility, marine wildlife, contaminated water, ice floes or fixed ice, floating or accumulated debris, watercraft operations or construction operations.
- Dive inspection operations plan - This will include team member assignments and responsibilities, inspection procedures and objectives, equipment requirements, emergency information and procedures, and a review of potential hazards and mitigation techniques that will be used.
- Risk assessment - This is a qualitative process that evaluates the hazardousness of the proposed underwater inspection based on the parameters that relate the inspection team characteristics and the demands the diving operation will take.

Quality Control and Quality Assurance

To aid with quality control (QC) and Quality Assurance (QA) and to ensure procedures are in place and followed, check lists have been developed to aid the bridge owner and the dive team. See Figure 13.3.3.

Underwater Bridge Inspection—NHI Course 130091 | Reference Manual

Bridge Owner's Underwater Inspection Plan Checklist

Bridge Identification

- ☐ Bridge Name
- ☐ Structure ID
- ☐ Owner
- ☐ Route
- ☐ Milepoint
- ☐ Latitude
- ☐ Longitude
- ☐ Underwater inspection interval
- ☐ Points of Contact (name and phone number) for immediate action such as closing the bridge based on findings:______________________________
  ____

Marine Information

- ☐ Waterway Name
- ☐ Navigable? (Y/N)___________
  If so:
  - ☐ Waterway river point
  - ☐ Inspection coordination contacts (names, agencies, phone #s, required lead time for notification)
- ☐ Type of water - salt/fresh/brackish
- ☐ Anticipated dive depths: ________
- ☐ Anticipated current: ________
- ☐ Anticipated water visibility: _________
- ☐ Other waterway concerns or items to note, i.e., presence near military facility, tribal fishing, water quality concerns, historic presence of logjams, etc.

Scour Information

- ☐ Is bridge Scour Critical? ________
- ☐ Current Bridge Scour Code (Item 113): _____
- ☐ Is Plan of Action (POA) in place?
- ☐ Are scour mitigation/countermeasures present? (Locations, types and significance)
- ☐ Are scour monitoring devices present? (Locations and types)

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Figure 13.3.13 Bridge Owner's Underwater Inspection Plan Checklist

Underwater Bridge Inspection—NHI Course 130091 | Reference Manual

Structure Information

- ☐ Type of Superstructure
  - Main Spans
  - Approach Spans
- ☐ Type of Substructure
  - Abutments
  - Piers
  - Foundations

Inspection Information

- ☐ Date of last inspection
- ☐ Findings and necessary follow-up from previous inspection
- ☐ Routine Inspection codes for:
  - Substructure Condition ______
  - Superstructure Condition ______
  - Channel and Channel Protection ______
  - Waterway Adequacy ______
- ☐ Special equipment necessary

Dive Team Certification Requirements

- ☐ Team Leader
  - ☐ NBIS requirements
  - ☐ Professional Engineer
  - ☐ Successful completion of underwater bridge inspection course
  - ☐ OSHA qualified diver
- ☐ Team Members
  - ☐ Engineer-diver
  - ☐ Successful completion of comprehensive bridge inspection course
  - ☐ Successful completion of underwater bridge inspection course
  - ☐ OSHA qualified diver

Inspection Requirements (Directions to dive team)

- ☐ Specify level of inspection (I, II or III) and amount of coverage of in-water elements

  Ex: Level I, 100%

  Level II, at three elevations on 10% of piles, and four locations at three elevations per substructure unit

  Level III,__________________

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Figure 13.3.13 Bridge Owner's Underwater Inspection Plan Checklist (cont'd.)

Underwater Bridge Inspection—NHI Course 130091 Reference Manual

- ☐ Specify Scour Inspection
  - Soundings around substructure units
  - Cross sections at upstream and downstream fascias
  - Cross sections at ___ ft and ____ft upstream and downstream of fascias
  - Profile along thalweg of waterway for ___ ft upstream and downstream of fascias
  - Fathometric survey with plotted contour lines extending ___ft upstream and downstream of fascias
- ☐ Substructure elements to be inspected by divers____________________
  ____
  ____
- ☐ If an element is identified to be inspected underwater is not in water,
  ____
- ☐ Required Dive Mode
  - ☐ Scuba
  - ☐ Scuba with communication
  - ☐ Surface supplied air with communication
- ☐ Reference Datum ______________________________
- ☐ Criteria for Underwater Photographs
  - Minimum number per substructure unit
    - Typical conditions
    - Conditions rated less than ____
- ☐ Check and document condition of structural members looking for cracks, spalling, abrasion, corrosion, exposed reinforcing steel, and undermining
- ☐ Document depth, length, height, and location of exposed or undermined portions of the foundations. Record number of exposed piles for footings supported by piles.
- ☐ Photography requirement
- ☐ Video requirement
- ☐ Check for and document presence and effectiveness of scour mitigation/countermeasures
- ☐ Sounding requirement
- ☐ Acoustic imaging
- ☐ Check for and document presence, condition, and operability of scour monitoring devices

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Figure 13.3.13 Bridge Owner's Underwater Inspection Plan Checklist (cont'd.)

☐ Examine streambed and channel for stability, especially around substructure units

☐ Note presence of debris build-up

Criteria for Communications from Dive Team

☐ In event of critical/emergency condition

☐ Frequency otherwise: start, finish, daily?

____

____

Report Requirements

☐ Document findings from inspection in report

☐ Record pertinent inspection environment—current, depths, visibility, equipment used, etc.

☐ Comment on any recommendations and justification for changes that need to be made to Superstructure, Substructure, Channel & Channel Protection, Scour and/or Waterway Adequacy codes based on this inspection.

☐ Document recommendations for needed repairs and their urgency

☐ Include plan and elevation of the structure with important features highlighted

☐ Include definitions referred to in this document for Levels of Inspection, degree of corrosion, urgency of repairs, etc.

☐ Other ____

Figure 13.3.13 Bridge Owner's Underwater Inspection Plan Checklist (cont'd.)

13.3.6 Substructure Units and Elements

The underwater portions of bridge structures can be classified into the following categories: bents, piers, abutments, caissons, cofferdams, protection devices and culverts. Proper identification is important since various elements may require different inspection procedures, levels of inspection, or inspection tools.

Bents

Bents can be divided into two groups:

- Column bents
- Pile bents

Column bents have two or more columns supporting the superstructure and may in turn be supported by piling below the mud line. The column bents are typically constructed of concrete, but the piling may be timber, concrete, or steel.

Pile bents carry the superstructure loads through a pile cap, into the piles and directly to the underlying soil or rock. The piles (and pile cap) can be constructed of timber, steel, or concrete. Pile bents are generally distinguished from piers by the presence of some battered piles and also bracing which provides stability for the individual piles. See Figures 13.3.14 through 13.3.16 for photographs of pile bents of different material types.

See Topic 12.2. for detailed description of the two bent types.

Figure 13.3.14 Timber Pile Bent

Figure 13.3.15 Steel Pile Bent

Figure 13.3.16 Concrete Pile Bent

Important items to be noted by the inspector are collision damage, and material deficiencies. Scour of the river bottom material at the bottom of the piles can result in instability of the piles. The underwater inspector compares present scour and resultant pile length with that observed in previous inspections.

Piers

Piers consist of three basic elements, which are the pier cap, shaft, and footing. Piers carry superstructure loads from the pier cap to the footing, which may be a spread footing or may be supported on a deep foundation. Piers can be constructed of steel, timber, concrete, or masonry and are usually distinguished by two to four large columns or a single large shaft. As with pile bents, collision damage, material deterioration, and scour are important items to look for in an underwater inspection. It is also important for the inspector to note if the pier shaft or columns are vertical. There are four common types of piers the inspector is likely to encounter:

- Column pier
- Column pier with solid web wall (see Figure 13.3.17)
- Cantilever or hammerhead pier (see Figure 13.3.18)
- Solid shaft pier (see Figure 13.3.19)

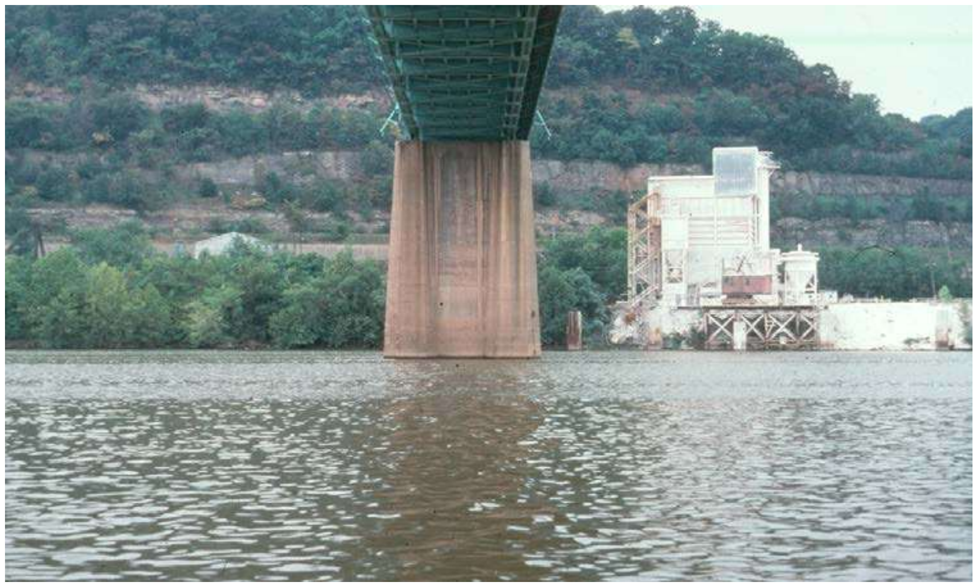

Figure 13.3.17 Column Pier with Solid Web Wall

Figure 13.3.18 Cantilever or Hammerhead Pier

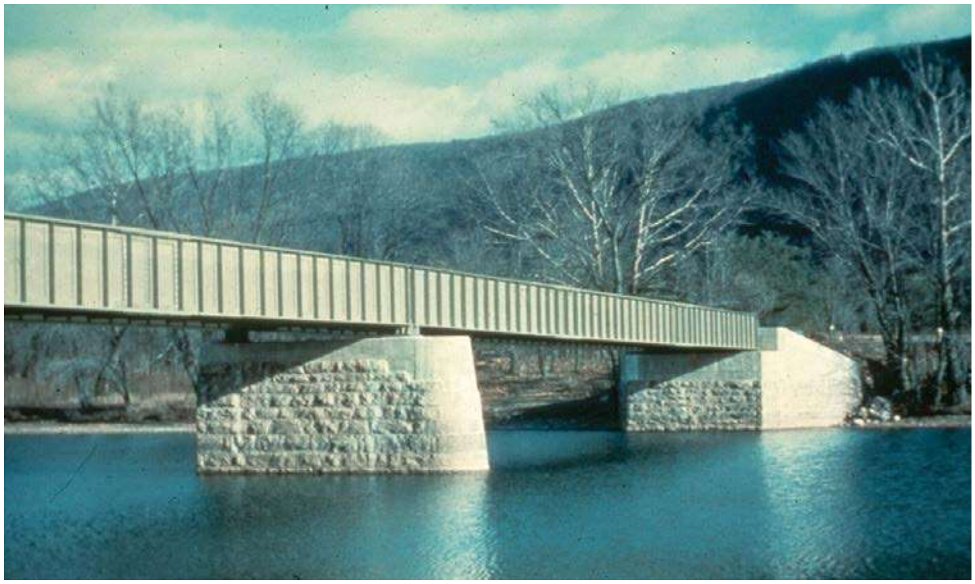

Figure 13.3.19 Solid Shaft Pier

Abutments

Abutments carry the superstructure loads to the underlying soil or rock and also retain the earth at the end of the structure. In most cases, the abutments are dry during low water periods and do not require a diving inspection. However, occasionally the abutments remain continually submerged and will require an underwater inspection (see Figure 13.3.19). Abutments can be constructed from concrete, masonry, or timber and may be supported by spread footings, piles, caissons, or pedestals. The most common abutment types include:

- Full height or closed
- Stub, semi-stub or shelf type
- Open or spill-through type
- Integral

Scour is probably the most critical item to be aware of when performing an underwater abutment inspection. Extreme local scour (undermining) could result in a forward tilting or rotation of the abutment, especially on those abutments without deep foundations (see Figure 13.3.20).

Figure 13.3.20 Severe Flood-Induced Abutment Scour

Caissons

Caissons, or drilled shafts, are enclosures which are used to build a substructure's foundation and carry loads from the bridge through the unsound soil and water to sound soil or rock. When it is in place, a caisson can act as a pier's footing. Caissons are made from timber, reinforced concrete, steel plates, or a combination of the above materials.

Cofferdams and Foundation Seals

Cofferdams and foundation seals are used to maintain a dry work area when constructing piers and abutments in water. Cofferdams are constructed from steel sheet piling. Once the foundation is complete, the sheeting may be removed or cut-off at the bottom of the channel.

Before a cofferdam is dewatered, a concrete seal needs to be placed below the water on top of the soil and to prevent any uplift and flooding of the dewatered cofferdam.

Protection Devices

Dolphins, fenders, and shear fences are often placed around substructure units to protect them from impact damage (see Figure 13.3.21). They are designed to absorb some of the energy from a direct hit from a vessel. Since these systems are usually at least partially underwater, conduct a diving inspection in concert with the substructure unit inspection.

Dolphins are a group of timber piles, but may also be a group of steel or composite piles. Fenders usually consist of timber or steel members attached directly to a substructure unit or piles adjacent to the substructure unit. Shear fences are generally an extension of a fender system which consists of a series of timber piles supporting timber wales and sheeting.

Figure 13.3.21 Damaged Protective System

Culverts

A culvert is a hydraulic structure normally constructed entirely below the ground and may be constructed of concrete, steel, timber, or stone masonry. Culverts that may not be inspected while dry will be inspected by diving. The underwater inspection of culvert structures present unique challenges to the inspection team, as culverts exist in a wide range of sizes, shapes, lengths, materials, and environments. Areas of special concern to the dive team when conducting culvert inspections include confined space, submerged drift and debris, and animal occupation.

Physically confined space issues arise when inspecting culverts containing individual pipes, barrels, or cells with small interior dimension, or non-linear layout. Additionally, many culverts are continually either completely submerged, or exhibit limited freeboard. In northern environments, winter inspections may also include ice as a contributing factor (see Figure 13.3.22). Conduct diving operations in physically confined space in compliance with Federal commercial diving regulations, as well as the individual agency's Safe Practices Manual. The Occupational Safety and Health Administration (OSHA) also offers guidance for work requiring confined space entry.

Submerged drift and debris is a persistent threat to the underwater inspection team, combining with the physically confining nature of most culvert structures to greatly increase the threat of diver entanglement. The diver may be completely unaware of the presence of drift until fouled. Use surface-supplied air diving equipment when conducting diving operations in physically confined and/or debris-laden culverts.

Another threat to the diver involves animals living or seeking shelter inside the culvert. Snakes are often found in and around accumulations of sediment and drift, while, in the southeast United States, alligators often reside inside culvert structures. When inspecting a structure exhibiting debris accumulations, which partially or fully constrict one end of a culvert, approach with caution, as excited animals may try to leave the culvert in haste, while the inspector is entering.

Figure 13.3.22 Inspection of Culvert With Limited Freeboard and Ice Cover

13.3.7 Underwater Inspection for Material Deficiencies

The materials typically used in bridge substructures are concrete, timber, steel, and masonry. An estimated 75% of all underwater elements are concrete. The balance consists of timber, steel, and masonry, in descending order of use.

Concrete

Plain, reinforced, and prestressed concrete are used in underwater elements. Since the majority of substructures are basically compression units, concrete is a nearly ideal material choice. Some concrete damage tends to be surface damage that does not jeopardize the integrity of the system. However, concrete deterioration that involves corrosion of the reinforcement may lead to a reduction in load carrying capacity (see Figure 13.3.23).

Cracking, delamination, spalling and chemical attack are typical for concrete substructures exposed to water. Reinforcement exposed to water and air is subjected to section loss. Scaling occurs above the water surface while abrasion occurs in the area near the water surface.

See Topic 6.2 for detailed descriptions of concrete deficiencies.

Figure 13.3.23 Concrete Deterioration

Masonry

Masonry can be used in substructure units, but is seldom used as a material in newer bridges. Masonry substructures can experience cracking and delamination of the stones. Cracking of mortar joints at the normal waterline is a result of freeze-thaw damage.

See Topic 6.5 for detailed descriptions of masonry deficiencies.

Timber

Timber pile bents are typical for short span bridges in many parts of the country, particularly for older bridges. The primary cause of timber deterioration is decay, abrasion, collision, and biological organisms, such as fungi, insects, bacteria, and marine borers. The ingredients for a biological attack include suitable food, water, air, and a favorable temperature. The waterline of pile structures offers all of these ingredients during at least part of the year. Since water, oxygen, and temperature generally cannot be controlled in a marine environment, the primary means to prevent a biological attack is to deny the food source through treatment to poison the wood as a food source. Timber piles are particularly vulnerable if the treatment leaches out (which happens with age) or if the core is penetrated. Therefore, it is important to carefully inspect in the vicinity of connectors, holes, or other surface blemishes (see Figure 13.3.24).

Figure 13.3.24 Deteriorated Timber Piling

Piles used in older bridges quite often were not treated if the piles were to be buried below the mud line (eliminating the source of food and oxygen). However, in some cases, streambed scour may have exposed these piles. Take special care in differentiating between treated and untreated piles to ensure a thorough inspection of any exposed, untreated piles. With each inspection, note the diameter or circumference for each timber pile. As a minimum, make these measurements at the waterline and mud line. Make comparisons with the original pile size.

Another primary caution for inspecting underwater timber piles is that the damage is frequently internal. Whether from fungal decay or borers, timber piles may appear sound on the outside shell but be completely hollow inside. While some sources recommend hammer soundings to detect internal damage, this method is unreliable in the underwater environment. One way to inspect for such damage is to take core samples. Plug all bore holes. Ultrasonic techniques for timber piling are also available.

See Topic 6.1 for detailed descriptions of timber material deficiencies.

Steel

Underwater steel structures are highly sensitive to corrosion, particularly in the low to high water zone (see Figure 13.3.25). Whenever possible, measure steel to determine if section loss has occurred. Ultrasonic devices are particularly useful to determine remaining steel thicknesses.

Figure 13.3.25 Deteriorated Steel Piles at Splash Zone

Connections such as bolts, rivets and welds are examined for corrosion. If the steel members have a coating, check the condition of the coating and its ability to protect the steel. In addition to protecting a concrete deck, cathodic protection has been used to protect steel piles in harbor settings. These cathodic protection systems may become more popular in the future. Check to see if the system appears to be working and check the connections and power source.

See Topic 6.3 for detailed descriptions of steel material deficiencies.

Composite Materials

One composite material, known as fiber reinforced polymer (FRP) is a mixture of fibers and resin. FRP is becoming more popular throughout the transportation community and can be used for substructure units. This material is more resistant to marine borers than timber members.

Composite materials have mechanical deficiencies similar to traditional materials, which are due to impact, abrasion or construction related events. Environmental deficiencies in composite materials include fires and ultra-violet ray degradation.

See Topic 6.6 for detailed descriptions of fiber reinforced polymer material deficiencies.

Vessel Damage

Bridges that are located in water are susceptible to damage from any vessel on the water. Damage that happens from a vessel collision may be visible on top of the water, but the extent of the underwater damage cannot be properly assessed without a detailed underwater inspection.

Damage below normal water level caused by prop wash may not be visible above the water. Examples of vessels that rotate their propellers at high speeds and may cause prop wash are ferry's leaving terminals or tugboats moving barges from their moorings. The movement may pick up bottom material and discharge it against the foundations, essentially sandblasting the material which, in time, can cause the erosion of steel and concrete surfaces.

Hands-on Inspection of Material Underwater

When visibility permits, the diver visually observes all exposed surfaces of the substructure. Scraping over the surface with a sharp-tipped probe, such as a knife or ice pick, is particularly useful for detecting small cracks. With limited visibility, the diver "feels" for damage. Because orientation and location are often difficult to maintain, the diver will be systematic in the inspection. Establish regular patterns from well-defined reference points.

Typical inspection patterns include:

- Circular or semicircular horizontal sweeps around piers or abutments beginning at the base, moving upward a specified increment, and repeating until complete
- Probing zones of undermining of piers by moving uniform increments from start to finish and recording the undermined penetration
- Down one side and up the other for piles (or inspecting in a spiral pattern)
- For scour surveys, record depths at regular increments adjacent to substructure (e.g., at each pile or 10 foot increments around piers), and then at each measured point extend radially from the substructure a uniform distance and repeat depth measurements

Major advantages of surface-to-diver communications are that the diver can be guided from the surface with available drawings, and that immediate recording of observations can be made topside along with the clarification of any discrepancies with plans.

Measuring Damage

Measure any damage encountered in detail. As a minimum for a Level II or III inspection include:

- Location of the damage zone both horizontally and vertically from a fixed reference point
- A good vertical reference point is the waterline, provided that the waterline is measured with respect to a fixed reference point on the bridge prior to the dive
- For undermining of foundations, take enough measurements to define the zone no longer providing soil bearing
- If plans are not available, measure the basic dimensions of damaged members (it is also usually prudent to spot check dimensions of damaged members even if plans are available)
- Check for displacements of major elements and whether they are plumb
- Locate the beginning and ends of cracks and intermediate points as needed to define the pattern
- Measure the maximum crack width and penetration depth
- Measure the length, width, and penetration of spalls or voids, making note of exposure and condition of any reinforcing steel
- Note the degree of scaling on concrete
- Measure the thicknesses of all four flange tips on steel H-piles at distressed areas, and specify the vertical location
- Locate buckles, bulges, and significant loss of section in steel members -

accurately measure the thickness of remaining sound material when significant section loss is found

- Note damage at connections
- Measure the diameter of timber piles – note extent and width of checks, and extent of any decay, if found.

Recordkeeping and Documentation

Because of the effort spent in conducting underwater inspections, combined with the time between inspections, it is particularly important to carefully document the findings. On-site recording of all conditions is essential:

- It is recommended that sketches be used as much as possible; providing enough detail is critical since it is difficult to go back to check items once the diving is completed. Contour and plan view sketches of the area surrounding the substructure elements allow the inspector to track any scour or streambed movement. A profile of the streambed can also provide information for tracking the development of scour.
- In addition to sketches, keep written notes or logs, documenting the inspection.
- When significant damage is encountered, a tape recording of the diver's observations can also prove helpful.
- Underwater photographs and/or underwater videotapes can be used to support the inspection report.
- If repairs were recommended in previous inspection reports, verify the repairs were made and that they have addressed the deficiencies

Include the results in an inspection form or report. Drawings and text need to describe all aspects of the inspection and any damage found. Include recommendations on condition assessment, repairs, and time interval for the next inspection in the report. See Figure 13.3.26 for a sample underwater inspection form.

See Topic 4.4 for detailed descriptions of record keeping and documentation.

CONDENSED UNDERWATER BRIDGE INSPECTION REPORT

BRIDGE NUMBER	COUNTY NAME	ROAD NUMBER	ROAD NAME	DATE INSPECTED

BODY OF WATER: ____________________ **DIVE MODE:**

DIVING CONDITIONS

MAXIMUM CURRENT: AIR TEMPERATURE:

AVERAGE VISIBILITY: WATER TEMPERATURE:

BOTTOM MATERIAL: MAXIMUM DEPTH: ____________________

ITEMS INSPECTED: ____________________

ITEM OF INSPECTION	NCR**	REMARKS
1. PILING/SHAFTS		
2. FOOTINGS/CAISSONS/PEDESTALS		
3. COLUMNS/WALL PIERS		
4. BRACING/STRUTS/WEB WALLS		
5. ABUTMENTS/END BENTS		
6. RETAINING WALLS/WING WALLS		
7. FENDER SYSTEM/PIER PROTECTION		
8. EMBANKMENTS/SLOPES/BULKHEADS		
9. DEGRADATION/AGGRADATION		
10. OBSTRUCTION/FLOW		
11. MOVABLE BRIDGE PIERS (PIVOT, BASCULE, REST)		
12. CULVERT BARRELS		
13. CULVERT HEADWALLS		
14. SUBMARINE CABLE (S) ***		

* Deficiencies exist in this element that warrant written and/or sketched description which are provided in the "Comprehensive Report of Deficiencies" section of this report.

** NCR is an acronym for numerical condition rating, the definitions of which can be found on the back of this page.

*** Submarine Cables(s) rated using Non-Structural Features rating system [1 (Poor) to 4 (Good) or N]

INSPECTION PARTY

Name: Name:
Name: Name:

Figure 13.3.26 Sample Underwater Inspection Form

NUMERICAL CONDITION RATING DEFINITIONS FOR STRUCTURAL ITEMS

CODE	DESCRIPTION
N	NOT APPLICABLE
9	EXCELLENT CONDITION
8	VERY GOOD CONDITION-No problems noted.
7	GOOD CONDITION-Some minor problems. Minor maintenance may be needed.
6	SATISFACTORY CONDITION-Structural elements show some minor deterioration. Major maintenance is needed.
5	FAIR CONDITION-All primary structural elements are sound but may have minor section loss, cracking, spalling. Minor rehabilitation may be needed.
4	POOR CONDITION-Advanced section loss, deterioration, spalling. Major rehabilitation may be needed.
3	SERIOUS CONDITION-Loss of section, deterioration, spalling have seriously affected primary structural elements. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present. Repair or rehabilitation required immediately.
2	CRITICAL CONDITION-Advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present. Unless closely monitored it may be necessary to close the bridge until corrective action is taken.
1	AIMMINENT@ FAILURE CONDITION-Major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put back in light service.
0	FAILED CONDITION-Out of Service-beyond corrective action

NUMERICAL CONDITION RATING DEFINITIONS FOR DEGRADATION/AGGRADATION

CODE	DESCRIPTION
N	NOT APPLICABLE-Use when bridge is not over a waterway.
9	EXCELLENT CONDITION-No noticeable or noteworthy deficiencies, which affect the condition of the channel.
8	VERY GOOD CONDITION-Banks are protected or well vegetated. River control devices, such as spur dikes and embankment protection, are not required or are in stable condition. Some minor scour has occurred near bridge.
7	GOOD CONDITION-Bank protection is in need of minor repairs. River control devices and embankment protection have minor damage. There is minor streambed movement evident. Minor local scour developing near substructure.
6	SATISFACTORY CONDITION-Bank is beginning to slump. River control devices and embankment protection have considerable minor damage. There is minor streambed movement evident. Debris is restricting the waterway slightly. Scour holes deepening.
5	FAIR CONDITION-Bank protection is being eroded. River control devices and/or embankment have major damage. Trees and brush restrict the channel. Scour holes are becoming more prominent, affecting the stability of the substructure.
4	POOR CONDITION-Bank and embankment protection undermined with corrective action required. River control devices have severe damage. Large deposits of debris in the waterway. The streambed has changed its location but is causing no problem.
3	SERIOUS CONDITION-Bank protection has failed completely. Scour holes forming in embankment. River control devices have been destroyed. Streambed aggradation or degradation has changed the waterway to now threaten the bridge and/or approach roadway.
2	CRITICAL CONDITION-Abutment has failed (portion has settled) due to undermining of footing. The waterway has changed and now threatens the bridge and/or embankment. Scour is of sufficient depth beneath footing that substructure is in near state of collapse.
1	AIMMINENT@ FAILURE CONDITION-Bridge closed. Corrective action may put the structure back into light service.
0	FAILED CONDITION-Bridge closed. Replacement necessary.

Figure 13.3.26 Sample Underwater Inspection Form (Continued)

13.3.8 Special Considerations for Underwater Inspections

Once a diver enters the water, their environment changes completely. Visibility decreases and is often reduced to near zero, due to muddy water and depth. In many cases, artificial lighting is required. There are times when tactile (by feel) inspections are all that can be accomplished, significantly compromising the condition evaluation of the element(s) being inspected.

The diver not only has reduced perceptual capabilities but is less mobile as well. Maneuverability is essential for underwater bridge inspections. With either self-contained or surface-supplied equipment, the diver may find it useful to adjust his/her underwater weight to near buoyancy and use swim fins for propulsion.

It is important for the diver to be able to adapt to the environment and be familiar with the diving equipment. They are to feel safe and comfortable while working underwater to be able to do an effective job on the inspection and to remain safe while performing the inspection.

Dealing with Current

Most waterways have low flow periods when current will not hinder an inspection. Plan diving inspections with this consideration in mind. Divers can work in current below 1.0 knots with relatively little hindrance. Currents may vary in direction or velocity when inspecting around submerged obstacles such as cofferdams (see Figure 13.3.27).

Figure 13.3.27 Diving Inside a Cofferdam

Waterway conditions may sometimes be too swift to allow safe diving operations (see Figure 13.3.28). For these conditions, other appropriate procedures must be used to evaluate the condition of underwater elements.

Figure 13.3.28 Excessive Current

Dealing with Drift and Debris

The drift and debris that often collects at bridge substructures can be extensive (see Figure 13.3.29). This type of buildup typically consists of logs and limbs from trees that are usually matted or woven either against or within the substructure elements. Often this debris is located on the lower parts of the substructure and cannot be detected from the surface. The buildup can be so thick as to prevent access to major portions of the underwater substructure.

Address concerns such as removal, past history, and safety when dealing with the presence of drift and debris.

Figure 13.3.29 Debris

Since drift and debris are often under the water surface, it is difficult to estimate the time and cost required to remove and gain access. The removal of the drift and debris is required if a hands-on inspection of the underwater elements is to proceed. While in some cases debris can be removed by the inspection divers, heavy equipment, such as a hoist or underwater cutting devices, are often required.

Generally, such buildup occurs in repetitive patterns. If previous underwater inspections have been conducted, the presence of drift can be estimated based on past history. Also, certain rivers and regions tend to have a history of drift problems, while others do not. Knowledge of this record can help predict the likelihood of drift and debris accumulation. A separate drift removal team, working ahead of the dive inspection team, could possibly be utilized.

Debris build-up near a bridge creates unique safety concerns for the dive team. Occasionally, debris can be quite extensive and can lead to entanglements or sudden shifts which might entrap the diver. Divers normally approach debris from the downstream side to avoid entanglements (see Figure 13.3.29).

Cleaning

Bridges on many inland waterways are relatively clean and free of marine growth. In such cases, the inspection can be conducted with little extra effort from the diver other than perhaps light scraping.

In coastal waterways, the marine growth can completely obscure the substructure element and may reach several inches or more in thickness (see Figure 13.3.30). The cost of cleaning heavily infested substructures may be completely impractical. In such cases, spot cleaning and inspection may be the only practical alternative.

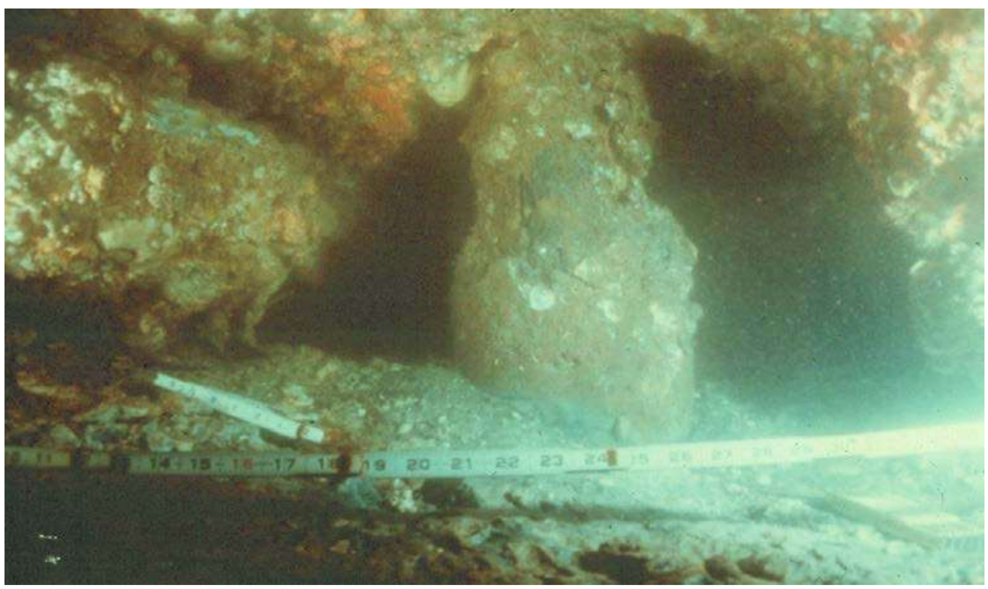

Figure 13.3.30 Cleaning a Timber Pile

Physical Limitations

This sometimes cold, dark, hostile underwater environment can result in a reduced physical working capacity. The diver is also totally dependent on external life support systems, which adds psychological stress. Things that can be done intuitively above water include a conscientiously planned effort and executed step-by-step procedures for underwater. For example, maintaining orientation and location during an underwater inspection requires continual attention. Typical distractions include living organisms, such as fish, snakes, and crustaceans and also environmental conditions, such as low temperatures, high current and heavy debris.

Decompression Sickness

Since the majority of bridge inspections are in relatively shallow water and of relatively short duration, decompression problems rarely occur. However, multiple dives have a cumulative effect and the no-decompression time limit decreases rapidly at depths greater than 50 feet. Therefore, divers routinely track their time and depth as a safety precaution. OSHA requires that a decompression chamber be on-site and ready for use for any dive made outside the no-decompression limits or deeper than 100 feet of seawater.

Marine Traffic

Another concern for divers is vessel traffic near the area to be inspected. Someone will always be topside with the responsibility of watching boat traffic (see Figure 13.3.31). In addition, display flags indicating that a diver is down. The international code flag "A", or “Alpha” flag (white and blue), signifies that a diver is down and to stay clear of the area. OSHA requires this flag. However, it is also prudent to display the sport diver flag (white stripe on red), since it is more likely that recreational boaters will recognize this flag (see Figure 13.3.32).

Figure 13.3.31 Commercial Marine Traffic

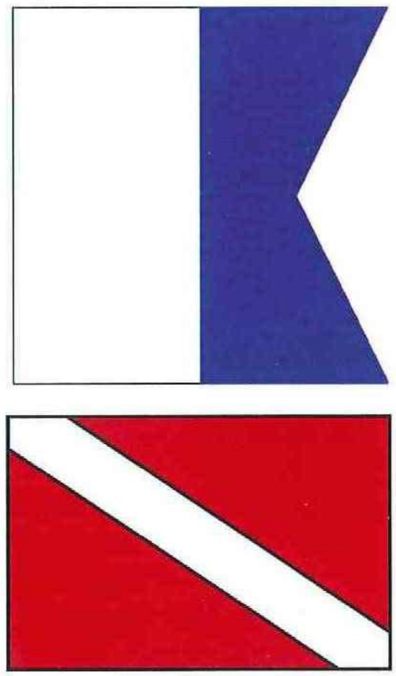

Figure 13.3.32 Alpha (top) and Sport Diver (bottom) Flags

13.3.9 Types of Underwater Inspection

Diving inspectors are responsible for identifying the location of underwater elements including a description of the underwater elements. They also verify if the inspection frequency and procedures are adequate in accordance with the inspection record. Inspectors can make recommendations to improve the underwater inspection procedures listed in the inspection record if conditions have changed.

According to the AASHTO *Manual for Bridge Evaluation*, underwater inspections can include wading or diving inspections. The National Bridge Inspection Standards (NBIS), however, define an underwater inspection as the inspection of the underwater portion of a bridge substructure and the surrounding channel that cannot be visually inspected at low water by wading or probing, which will require diving or appropriate techniques. For this topic three general methods used to perform underwater inspections are presented:

- Wading inspection
- Commercial SCUBA
- Surface-supplied diving

Wading Inspection

Wading inspection is the basic method of underwater inspection used on structures over wadeable streams. The substructure units and the waterway are evaluated using a probing rod, sounding rod or line, waders, and possibly a boat. Regular bridge inspection teams can often perform wading inspections during periods of low water (see Figure 13.3.33).

Figure 13.3.33 Inspector Performing a Wading Inspection

Commercial SCUBA

SCUBA, an acronym for Self-Contained Underwater Breathing Apparatus, is used for many underwater inspections in this country (see Figure 13.3.34). In this mode, the diver operates independently from the surface personnel, carrying their own supply of compressed breathing gas (typically air) with the diver inhaling the air from the supplied tank and the exhaust being vented directly to the surrounding water. SCUBA diving is employed during underwater bridge inspections due to its ease of portability and maneuverability in the water. It is used where the dives have a short duration at different locations rather than a long sustained dive. This dive mode is best used at sites where environmental and waterway conditions are favorable, and where the duration of the dive is relatively short. Exercise extreme care when using SCUBA equipment at bridge sites where the waterway exhibits low visibility and/or high current, and where drift and debris may be present at any height in the water column. The use of SCUBA gear is limited to water depths of 130 feet and the time on the bottom will be limited by the amount of air the diver can carry and the amount of time based upon the no-decompression limits.

Figure 13.3.34 SCUBA Inspection Diver

Surface-Supplied Diving

As its name implies, surface-supplied diving uses a breathing gas supply that originates above the water surface and is commonly referred to as lightweight diving equipment. This breathing gas (again, typically compressed air) is transported underwater to the diver via a flexible umbilical hose. Surface-supplied equipment provides the diver with a nearly unlimited supply of breathing gas, and also provides a safety tether line and hard-wire communications system connecting the diver and above water personnel. Using surface-supplied equipment, work may be safely completed under adverse conditions that often accompany underwater bridge inspections, such as: fast current, cold and/or contaminated water, physically confined space, submerged drift and debris, and dives requiring heavy physical exertion or of relatively long duration (see Figure 13.3.35). Depths of surface-supplied dives can be conducted down to 190 feet or if the bottom times are less than 30 minutes, to a depth of 220 feet. This form of diving provides advantages such as an "unlimited" air supply and communications plus bottom times that can exceed the decompression time limits used for SCUBA. The disadvantages of this form of diving is that it requires more topside support than SCUBA and it is limited in mobility due to the connection to the surface.

Figure 13.3.35 Surface-Supplied Diving Inspection

Inspection Type Selection Criteria

In determining whether a bridge can be inspected by wading or whether it requires the use of diving equipment, water depth is not be the sole criteria. Many factors combine to influence the proper underwater inspection type:

- Water depth
- Water visibility
- Current velocity
- Streambed conditions (softness, mud, "quick" conditions, and slippery rocks)
- Debris
- Substructure configuration

13.3.10 Underwater Inspection Equipment

Diving Equipment

Essential personal diving equipment includes:

- Wet suit or dry suit (also known as a exposure suits) (see Figure 13.3.36)
  - Wet suits allow a thin layer of water between the diver's skin and the suit. The water layer is warmed by the diver's body heat and acts as insulation to keep the diver warm.
  - Dry suits utilize air instead of water to insulate the body and are very effective in cold or polluted water.
- Face mask or helmet (see Figure 13.3.37)
- Buoyancy compensator (a flotation device capable of maintaining a diver face up at the surface)
- Breathing apparatus and/or reserve breathing air supply
- Weight belt
- Swim fins
- Knife
- Wristwatch
- Depth gauge
- Submersible pressure gauge
- Flashlight or dive light

Surface-supplied air diving equipment typically includes a compressor, which supplies air into a volume tank for storage. This compressed air is then filtered and regulated to the diver’s helmet or mask through an umbilical hose (see Figures 13.3.38 and 13.3.39). The umbilical is typically made up of several members, including, at a minimum, a breathing air hose, strength member (or safety line), communication line, and pneumofathometer hose. The pneumofathometer provides diver depth measurements to the surface (see Figure 13.3.40).

For self-contained diving, the breathing gas supply is contained within a pressurized tank, which is carried by the diver.

Figure 13.3.36 Vulcanized Rubber Dry Suit

Figure 13.3.37 Full Face Lightweight Diving Mask with Communication System

Figure 13.3.38 Surface-Supplied Air Equipment, Including Air Compressor, Volume Tank With Air Filters, and Umbilical Hoses

Figure 13.3.39 Surface-Supplied Diving Equipment Including Helmet or Hard Hat

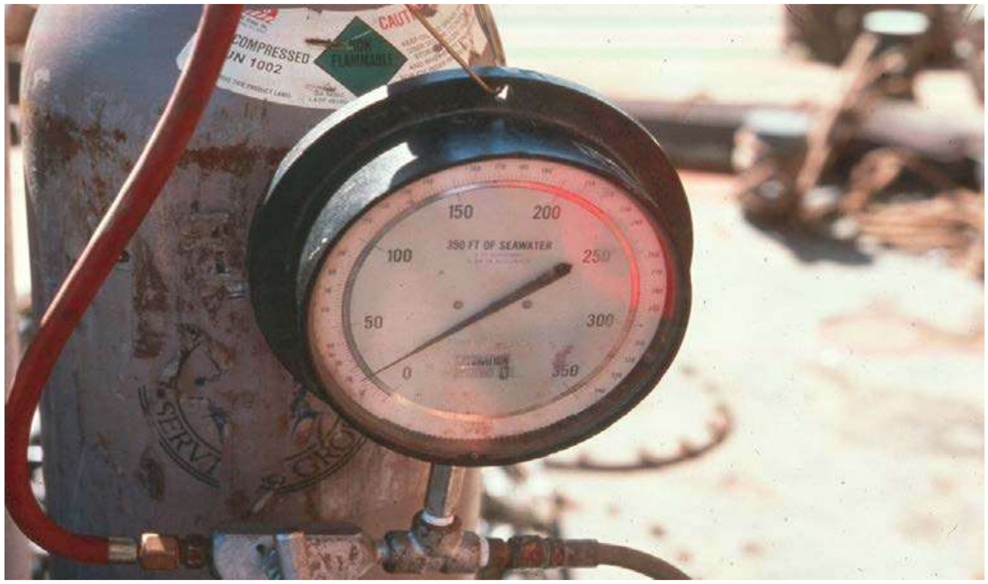

Figure 13.3.40 Pneumofathometer Gauge

Equipment malfunction leading to loss of air supply needs to be a constant concern to the dive team. Even in shallow water, submerged drift and debris adjacent to a bridge can make an emergency ascent an arduous affair, for both the diver and the support team. As such, a reserve air supply will always be worn by the diver using surface supplied air (see Figure 13.3.39). Carbon monoxide poisoning can occur if the air intake of the surface supplied air compressor is located near the exhaust of other motorized equipment (see Figure 13.3.38).

Figure 13.3.41 Surface-Supplied Diver with a Reserve Air Tank

Surface Communications

While not required in all situations, a two-way communication system linking the diver(s) and topside personnel greatly enhances the underwater inspection. There are two types of diver-to-surface communications: a conventional hardwire and a wireless system. In the hardwire system, the diver has a microphone and speaker connected to a surface transmitter-receiver through a cable. This is regularly used in surface-supplied diving. It can also be used when a SCUBA diver is using a full face mask with the mask tended to the surface with a strength or communication line. The wireless systems are available for use in SCUBA diving equipment. The advantage of a wireless system is that it allows the diver to have more mobility (see Figure 13.3.42), and can be used during self-contained diving operations.

There are several advantages provided to the underwater inspection team, through the use of direct two-way communication

- Dive team safety is increased in the event of diver entanglement or equipment malfunction
- Divers can immediately describe observations and location of deficiencies for simultaneous recording by a note taker on the surface
- Divers can verbally interact with topside inspection personnel to clarify what is being observed, without leaving the suspect area
- Note takers can follow drawings, verify their validity, note damage on the drawings at the proper location, and track the progress of the diver
- Surface communication also allows an inspection team leader/engineer at the surface to discuss observations with a diver who is not yet an inspection team leader, to direct attention to specific zones, and to ensure that a satisfactory inspection is completed, according to the type and severity of damage found (see Figure 13.3.43)

Figure 13.3.42 Wireless Communication Box System

Figure 13.3.43 Surface Communication With Inspection Team Leader

Access Equipment

While inspection of short-span bridges can often be accessed from shore, many bridges require a boat or barge for access. Boats may be in different sizes and types, but large enough so it can safely handle the diving equipment and personnel as well as a suitable size for the waterway conditions (see Figures 13.3.44 and 13.3.45). The boat needs to be equipped with an engine which will be dictated by the waterway conditions and the boat size.

Figure 13.3.44 Access Barge and Exit Ladder

Figure 13.3.45 Access From Dive Boat

Tools

A number of inspection tools are available. The dive team needs to have access to the appropriate tools and equipment (including both hand and power tools) as warranted by the type of inspection being conducted.

Hand Tools

While most hand tools can be used underwater, the most useful include rulers, calipers, scrapers, probes (ice picks, dive knifes, and screwdrivers), flashlight, hammers (especially masonry and geologist's hammers), axes, hand drills, wire brushes, incremental borers, hand saws, and pry bars (see Figure 13.3.46). These tools are usually tethered to the diver to prevent their loss underwater. Working with hand tools could be slow and may be impractical for larger jobs.

Figure 13.3.46 Diver with a Pry Bar and Diver with Hand Scraper

Power Tools

Power tools include both pneumatic and hydraulic tools. Pneumatic tools are not usually designed for underwater use, but can be adapted to perform the necessary tasks. Examples of pneumatic tools that can be used include pneumatic drills, chippers, hammers, scalers, and saws. Pneumatic tools are also limited to practical depths of 100 to 150 feet and can obscure the diver's vision by the bubbles produced by the tools.

Hydraulic tools are modified versions of tools used on dry land. Examples include grinders, chippers, drills, hammers and saws. The advantage of using hydraulic tools is that they do not create the bubbles that a pneumatic tool creates.

While pneumatic tools are sometimes used, hydraulic tools tend to be favored for heavy or extensive work often required during underwater inspections.

Cleaning Tools

Light cleaning can be accomplished with scrapers and wire brushes. Heavier cleaning requires automated equipment such as grinders and chippers. One of the most effective means of cleaning is with the use of water blasters (see Figure 13.3.47). Take particular care with such equipment to ensure that structural damage does not result from overzealous blasting.

Figure 13.3.47 Cleaning with a Water Blaster

Advanced Inspection Methods

When inspecting underwater elements, nondestructive evaluations (NDE) may be required to determine the structural condition and may be used in Level III inspection.

Steel

For steel substructures, the inspector is often concerned with measuring the remaining thickness of any corroded members. Nondestructive evaluations for underwater steel members include:

- Ultrasonic measuring devices measure the thickness of steel by passing a sound wave through the member. The transducer is placed on one side only, and the thickness is displayed on an LED readout. Totally submersible or surface display units are available. They are very effective for measuring thickness. There are two types of ultrasonic devices to be used underwater. One utilizes a waterproof transducer and cable that is carried below the water surface while the electronics and display remain on the surface. The second type can be placed in a waterproof container and taken underwater with the diver.
- Underwater magnetic particle testing equipment, typically consisting of an electromagnetic yoke and powdered metallic particles, are used to detect flaws at or near the surface of ferrous metal members and welds. The articulating yoke is positioned on the member in question, and energized. A liquid suspension containing a fluorescent dye and magnetic particles is applied to the area between the legs of the yoke. Discontinuities in the specimen, such as cracks, will cause a magnetic flux leakage field, which will attract the particles. The inspector photographs the particle pattern to document the test results. This is commonly used during inspections on offshore structures and not commonly used on bridges due to lack of underwater weld. It is also difficult to implement due to the high currents and the poor clarity of inland water.

Concrete

For concrete substructures, there are several nondestructive tests for in-depth inspections that can be performed.. Nondestructive evaluations for underwater concrete members include:

- An ultrasonic pulse velocity meter (or V-meter) is an ultrasonic device that requires two transducers and measures the distance required for the sound wave to pass through the concrete. This device is used to estimate the strength of concrete. It is also used to locate the discontinuity and low strength areas such as cracks and voids. Direct transmission methods require the transducers to be on opposite sides of the member and will provide the most accurate data. Indirect transmission methods place the transducers on the same side of the member and will require correction factors to properly interpret the data. Similar devices have also been developed for timber.
- A waterproof rebound hammer (also known as a Schmidt hammer) can be used underwater to estimate the compressive strength of in-place concrete based on its surface hardness. To use the hammer, the diver places and then presses it to the concrete surface until a mass in the hammer is released causing impact. The inspector estimates the concrete's strength with the use of the data.
- A rebar locator (or R-meter) is used to locate and measure the depth of cover and the size of reinforcing bars in concrete by inducing a magnetic field. This device will use a low frequency magnetic field to locate the steel.

Coring is a partially destructive evaluation method whose use is limited to critical areas. Cores can be taken in either concrete or timber (see Figure 13.3.48).

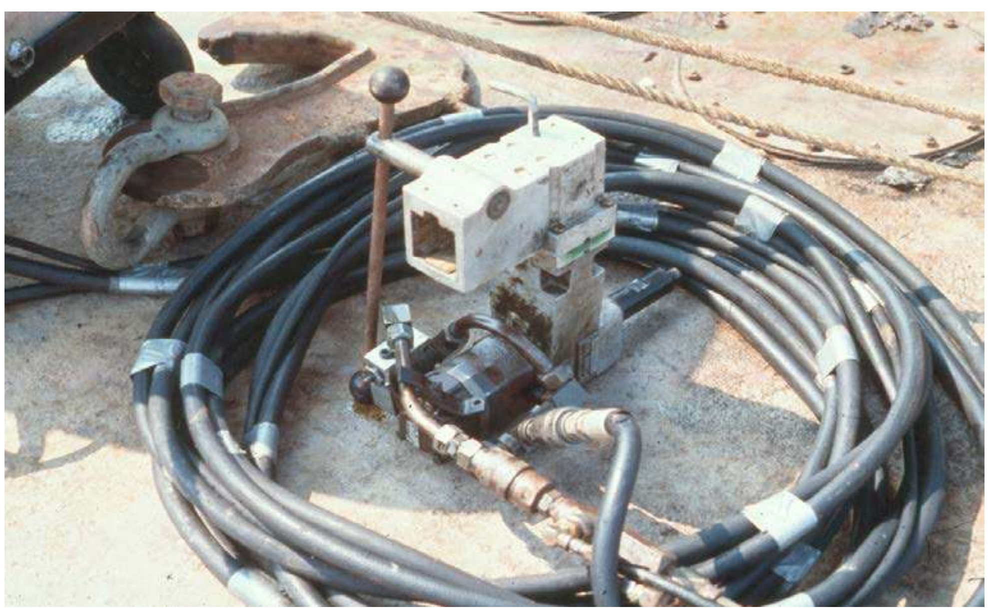

Figure 13.3.48 Coring Equipment

Concrete coring requires pneumatic or hydraulic equipment. Deep cores (3 feet or more) can be taken to provide an interior assessment of massive substructures (see Figure 13.3.49). Two-inch diameter cores are common, but coring tools are available in other sizes (see Figure 13.3.50). Cores not only provide knowledge about interior concrete consistency but also can be tested to determine compression strength. Be sure to select coring locations so the reinforcement is not damaged, unless a sampling of the reinforcement is desired. Patch the core holes upon completion.

Figure 13.3.49 Concrete Coring Taking Place

Figure 13.3.50 Concrete Core

Timber

Ultrasonic devices (V-meters) such as those used for concrete evaluations can be used to test timber members for internal voids or material breakdown caused by marine borers or decay.

Timber coring is much simpler and less costly to perform than concrete coring (see Figure 13.3.51). While power tools are sometimes used, the most effective procedure is still to hand core with an increment borer. This approach preserves the core for laboratory as well as field evaluation. The core indicates evidence of borers or other infestation, and of void areas. Always plug the hole with a treated hardwood dowel to prevent infestation.

Figure 13.3.51 Timber Core

Underwater Imaging

Photography

Color digital cameras come with a variety of lens and flash units. Popular cameras that can be used above water can be used underwater by placing them in a clear waterproof case, also known as a "housing". The boxes are constructed of clear plastic and can be used underwater (see Figure 13.3.52 and 13.3.53). There are also waterproof digital cameras that are designed specifically for underwater photography.

Figure 13.3.52 Various Waterproof Camera Housings

Figure 13.3.53 Diver Using a Camera in a Waterproof Housing

In some cases, visibility is limited and the camera needs to be placed close to the subject. Suspended particles often dilute the light reaching the subject and can reflect light back into the lens. When visibility is very low and the water is extremely turbid, clearwater boxes can be used (see Figure 13.3.54). A clearwater box is a clear plastic box that can be filled with clean water. The box can be placed up against the subject, which will displace the dirty water and allowing the camera to focus on the member being photographed.

Figure 13.3.54 Diver Using a Clearwater Box

Video

Video equipment is available either as self-contained, submersible units or as submersible cameras (or surface video cameras in a waterproof housing) having cable connection to the surface to view on the monitor or to record (see Figure 13.3.55). The latter type allows a surface operator to direct shooting while the diver concentrates on aligning the camera only. The operator can view the monitor, control the lighting and focusing, and communicate with the diver to obtain an optimum image. Since a sound track is linked to the communication equipment, a running commentary can also be obtained.

Smaller video cameras are in plastic cases and can be used with or without the umbilical to the surface where they are monitored. Video cameras may also be attached to a staff or a truck mounted arm so it can be deployed from a bridge deck and can relay images to the monitors and recording devices.

Figure 13.3.55 Underwater Video Inspection

Remotely Operated Vehicle (ROV)

An extension of the video camera is a remotely operated vehicle (ROV), where the diver is eliminated and the camera is mounted on a surface controlled propulsion system (see Figure 13.3.56). Its effectiveness diminishes substantially in stream velocities greater than 1.5 knots and is limited by cloudy water, inability to determine the exact orientation and position of the camera, and difficulties the operator may have controlling the vehicle due to the current or the umbilical being tangled. The ROV cannot perform cleaning operations prior to photos being taken.

Figure 13.3.56 Remotely Operated Vehicle (ROV)

Underwater Acoustic Imaging

Underwater acoustic imaging can provide greatly improved images of the channel bottom conditions, undermining and submerged foundations (see Figure 13.3.57). This can aid in the planning of diving operations by detecting areas of possible damage and will allow the divers to concentrate in these areas. It can also enhance diver safety by identifying potential dive hazards before anyone would enter the water. Acoustic imaging can also provide images of an underwater element that a underwater camera may not be able to take due to the turbidity of the water. Imaging also can operate at distances of 200 feet, while cameras, even in fairly clear water, has an effective range of only a few feet.

This is also useful when an emergency evaluation of a bridge may be necessary after a bridge is damaged by a collision, especially if the water conditions (e.g., high current, low visibility, debris) preclude the use of divers.

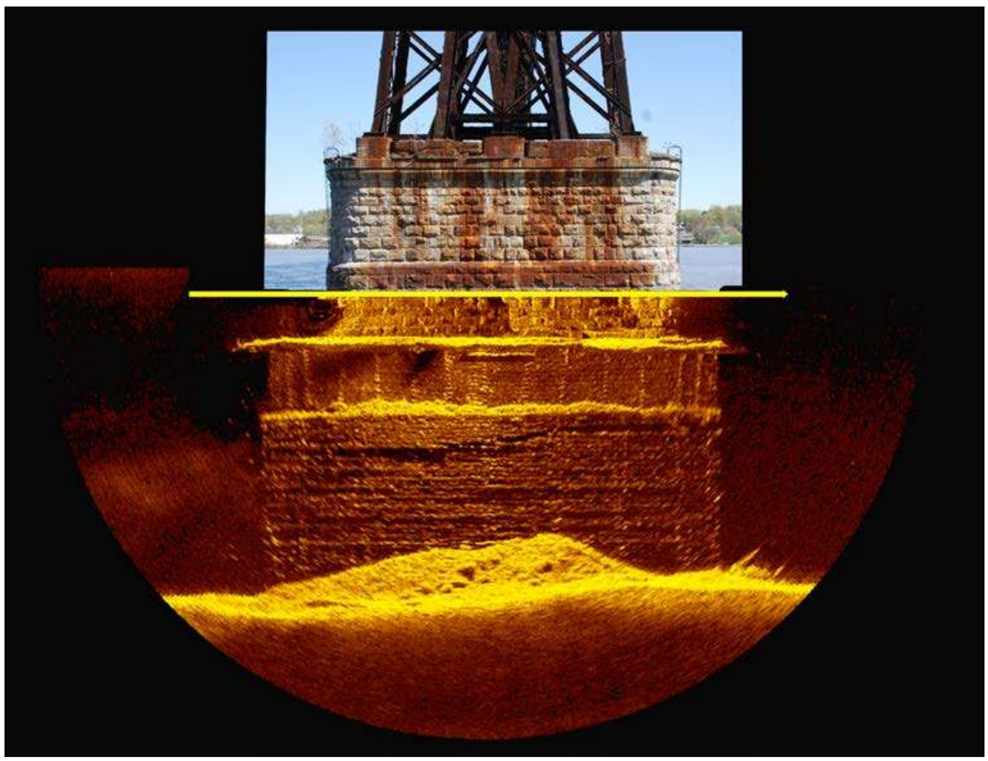

Figure 13.3.57 Acoustic Imaging of a Pier

13.3.11 Scour Inspections

Divers may be able to note scour under certain conditions. The most important assessment is how much of the bent or pier is exposed when compared to plans and typical designs.

Local scour is often detectable by divers since this type of scour is characterized by holes near bents, piers, or abutments. Divers routinely check for such scour holes. A typical approach is to take depth measurements around the substructure, both directly adjacent and at concentric intervals. Note that divers typically operate in low current situations. Sediment often refills scour holes during these periods, making detection of even local scour difficult. However, since this refilled sediment is usually soft, a diver using a probing rod can often detect the soft areas indicating scour refilling.

The diver's role is primarily to point out a potential scour problem. Almost invariably, an additional interdisciplinary engineering investigation will be needed. The diver's primary role in scour investigation is to measure scour by one of these methods:

- Sounding devices
- Geophysical inspections
- Diver inspections

Sounding Devices

Although sounding-sensing devices can be used independently of diving, they are commonly part of an underwater inspection. See Advanced Inspection Methods in Topic 13.2.6 on the procedures to record the stream cross section and profile. An on-site diver can investigate questionable readings and more fully determine the channel bottom conditions.

Fathometer

A fathometer consists of a transducer that is suspended in the water, a sending/receiving device, and a recording device that will display the depth on paper or a display. It can be either in color or black and white. A transducer floats just below the waterline and bounces sound waves off the bottom. Depths are continuously recorded on a strip chart.

Advantages of fathometer include the following:

- Inexpensive
- Effective
- "User-Friendly" output

Disadvantages include the following:

- False readings can occasionally occur due to heavy drift or heavy turbulence
- Fathometers may fail to detect refilled scour holes during calm water
- Fathometers do not provide what type of material makes up the channel bottom
- The strip chart moves at a constant rate and does not record a horizontal

scale; unless the boat can be kept at a constant speed, the scale becomes distorted; GPS has been added in recent years to provide a more exact location where readings are taken

Geophysical Inspection

Scour most commonly occurs during a flood. After a flood, the sediment settles, possibly refilling any scour hole that the flood may have caused. Geophysical tools can be used to measure scour after a scour hole has been refilled.

Ground-Penetrating Radar

Ground-penetrating radar (GPR) equipment are also used in scour surveys (see Figure 13.3.58). They can be used to obtain high resolution, continuous subsurface profiles on land or in shallow water which is less than 25 feet deep. GPR transmits short electromagnetic pulses into the subsurface and will measure the travel time to and from the subsurface for the signal to return. Once the signal encounters an interface between two different materials, a portion of the energy will be sent back to the surface and the rest will be sent into deeper layers. These are not as effective when encountering material that is highly conductive (e.g., clay), in salt water, or water with heavy amounts of sediment.

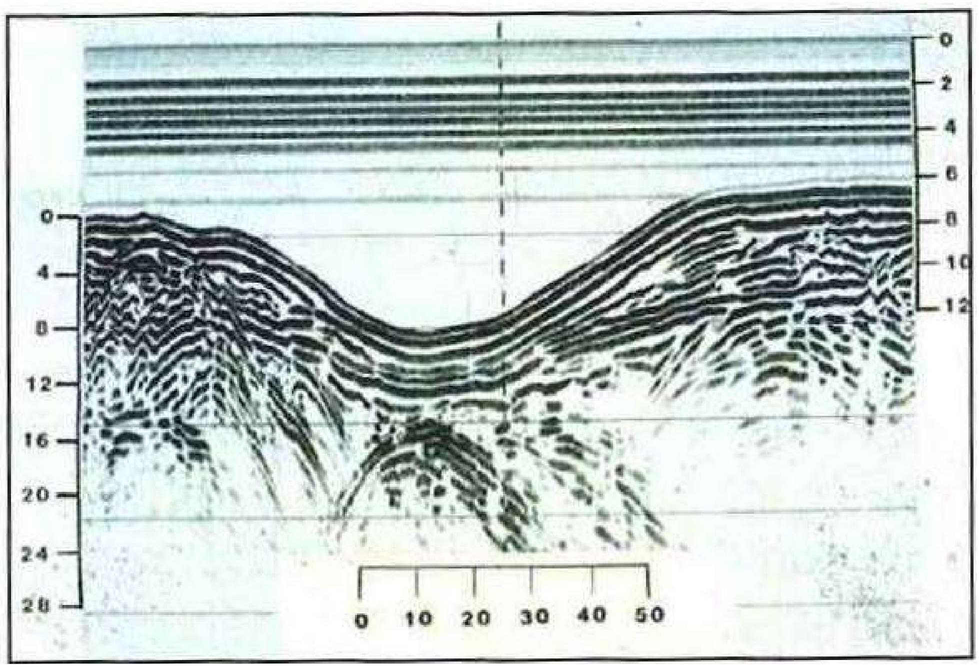

Figure 13.3.58 Ground Penetrating Radar Record

Tuned Transducers

Tuned transducers, or low-frequency sonar, is a seismic system that operates through the transmission and reception of acoustic waves. This system consists of a transmitter, a transducer towed alongside the boat, a receiver and a graphic recorder. The transmitter will produce a sound wave that is directed toward the bottom of the channel by the transducer. A portion of the sound wave will be reflected back to the surface and a portion will penetrate into the bottom of the channel. Other portions of the wave will bounce off the material once there is acoustical impedance between the layers (see Figure 13.3.59).

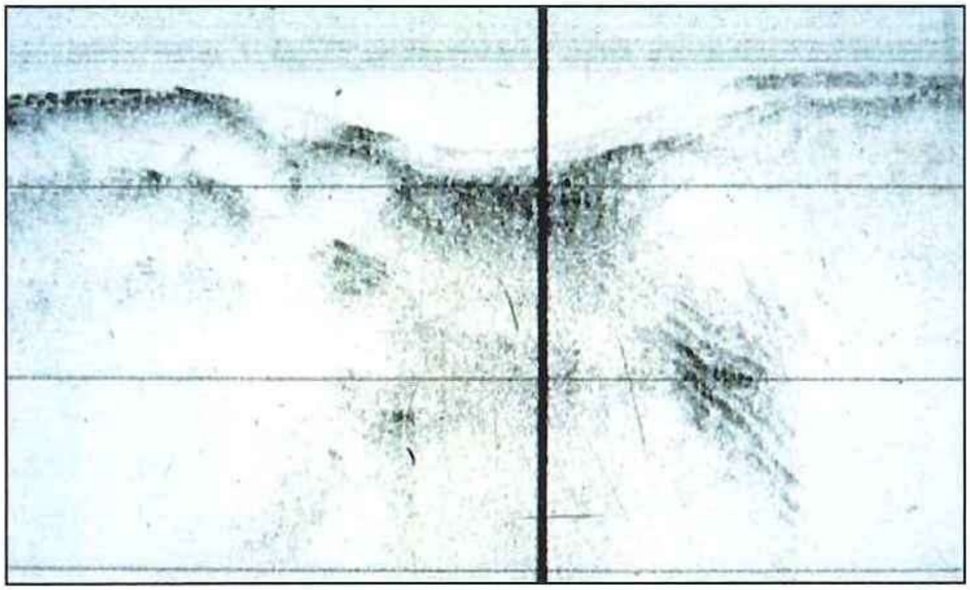

Figure 13.3.59 Tuned Transducer Record

Diver Inspections

When identifying a scour critical bridge, the diver has a limited role. Although divers may be able to identify the conditions during an underwater inspection, the greatest scour occurs at periods of high flow. Diver inspections include:

- Record bottom conditions adjacent to submerged foundations
- Detect undermining and scour holes near the upstream end of the foundation (see Figure 13.3.60)
- Detect soil build-up soil at downstream end
- Note any debris which may cause local scour
- Note type of bottom material
- Note the presence, location and size of rip rap
- Detect small diameter but deep scour holes that may expose the footing or cause undermining
- Record dimensions of undermining, if it exists
- Note any piles to be examined if they are exposed

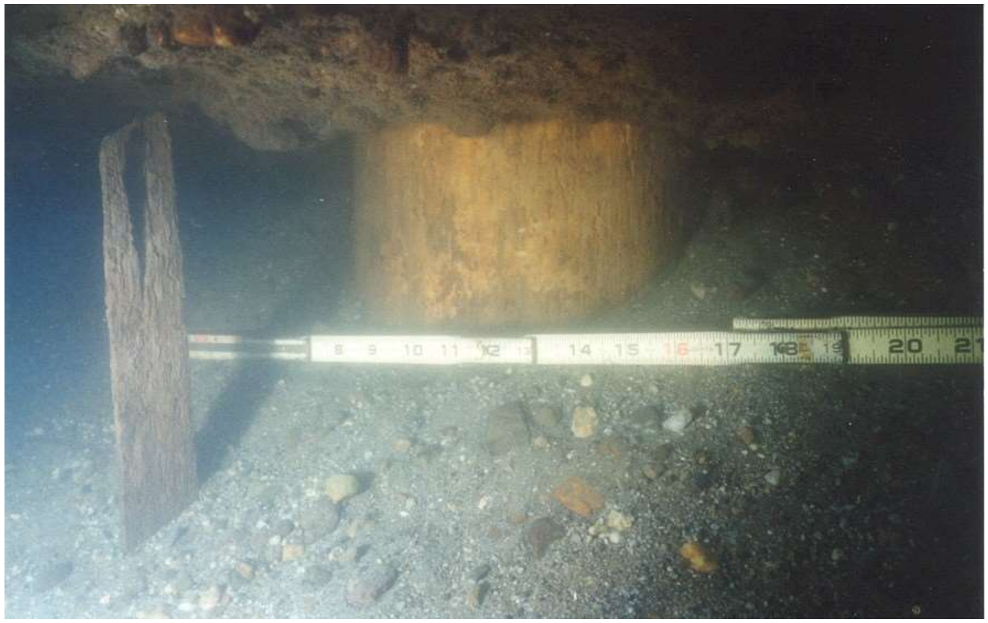

Figure 13.3.60 Pier Undermining, Exposing Timber Foundation Pile

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Characteristics, Inspection and Evaluation of Culverts

Topic 14.1 Culvert Characteristics

14.1.1 Introduction

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

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

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

Figure 14.1.1 Culvert Structure

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

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

Purpose of Culvert Inspection

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

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

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

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

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

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

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

Safety

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

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

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

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

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

Maintenance Needs

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

Outcomes

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

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

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

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

14.1.2 Differentiation Between Culverts and Bridges

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

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

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

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

Hydraulic

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

Structural

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

Figure 14.1.2 Box Culvert with Shallow Cover

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

Maintenance

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

Traffic Safety

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

Construction

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

Durability

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

Inspection

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

14.1.3 Structural Characteristics of Culverts

Loads on Culverts

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

Permanent Loads

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

Transient Loads

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

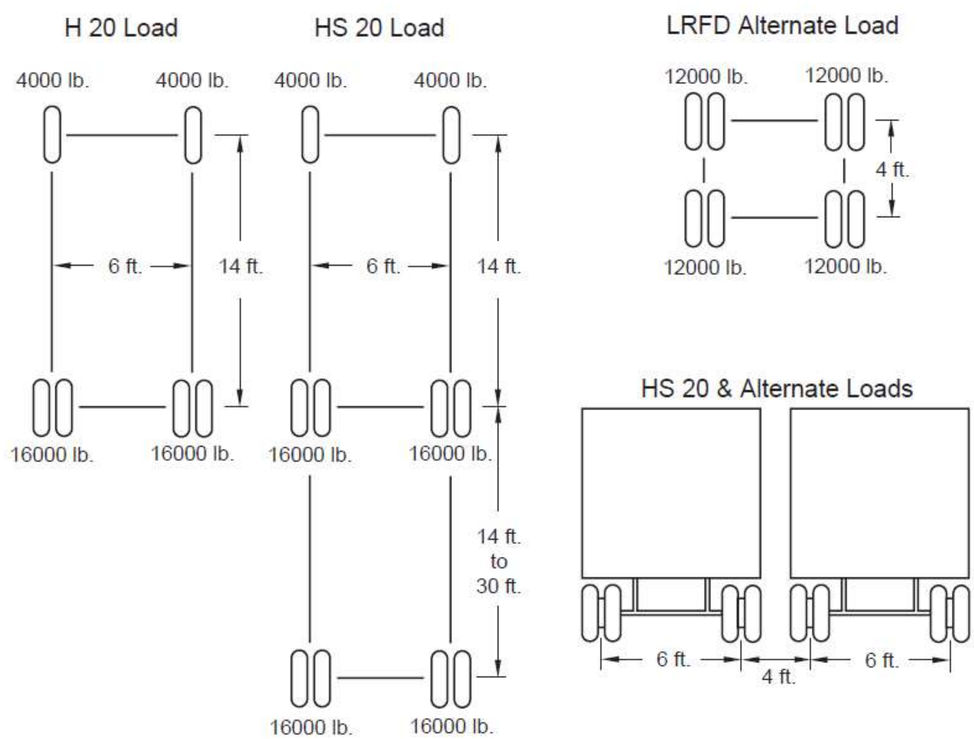


Figure 14.1.3 AASHTO Wheel Loads and Wheel Spacings

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

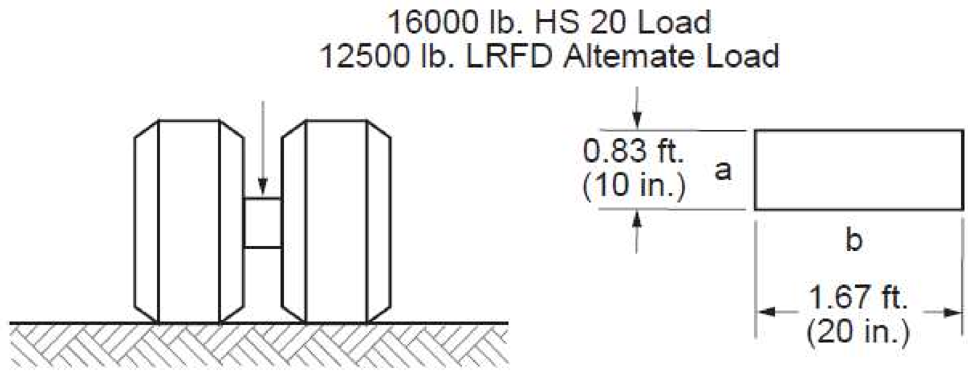
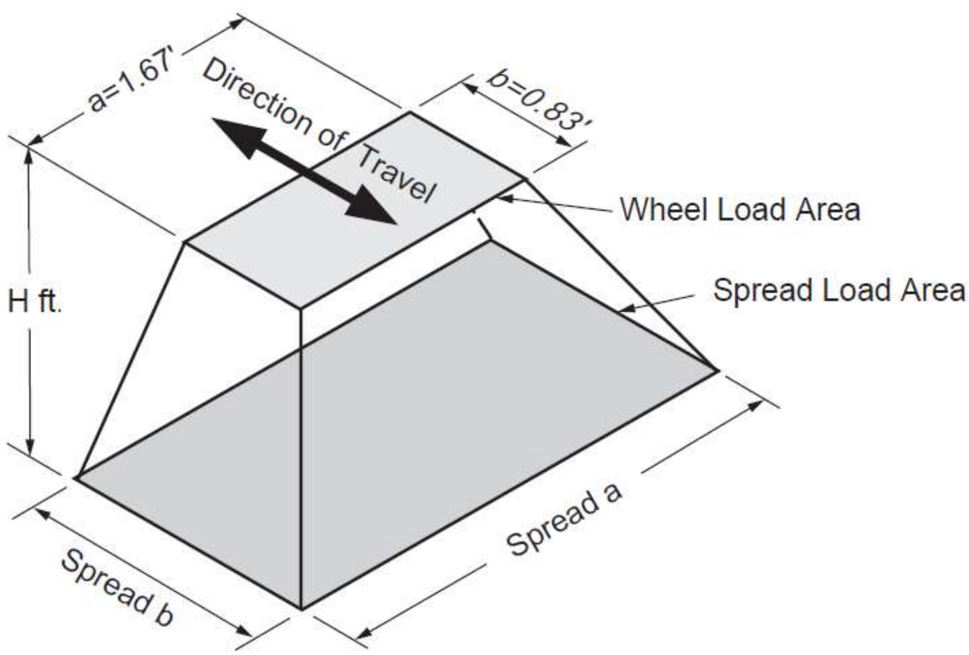


Figure 14.1.4 AASHTO Wheel Load Surface Contact Area (Foot Print)

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



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

Figure 14.1.5 Spread Load Area (Single Dual Wheel)

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

Categories of Structural Materials

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

Rigid Culverts

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

Rigid Culverts are presented in detail in Topic 14.2.

Flexible Culverts

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

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

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

Flexible culverts are presented in detail in Topic 14.3.

Construction and Installation Requirements

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

- Compaction and Side Support - Good backfill material and adequate compaction are of critical importance to flexible culverts. A well-compacted soil envelope is needed to develop the lateral pressures required to maintain the shape of flexible culverts. Well-compacted backfill is also important to the performance of rigid culverts. Poorly compacted soils do not provide the intended lateral support.

- Trench Width - Trench width can significantly affect the earth loads on rigid culverts. It is therefore important that trench widths be specified on the plans and that the specified width not be exceeded without authorization from the design engineer.

- Foundations and Bedding - A foundation capable of providing uniform and stable support is important for both flexible and rigid culverts. The foundation must be able to support the structure at the proposed grade and elevation without concentration of foundation pressures. Foundations are relatively yielding when compared to side fill. Establishing a suitable foundation requires removal and replacement of any hard spots or soft spots. Bedding is needed to level out any irregularities in the foundation and to insure uniform support. When using flexible culverts, bedding is shaped to a sufficient width to permit compaction of the remainder of the backfill, and enough loose material is placed on top of the bedding to fill the corrugations. When using rigid culverts, the bedding conforms to the conditions specified in the plans and is shaped to allow compaction and to provide clearance for the bell ends on bell and spigot type rigid pipes. Adequate support is critical in rigid pipe installations, or shear stress may become a problem.

- Construction Loads - Culverts are generally designed for the loads they carry after construction is completed. Construction loads may exceed design loads. These heavy loads can cause damage if construction equipment crosses over the culvert installation before adequate fill has been placed or moves too close to the walls, creating unbalanced loading. Additional protective fill may be needed for equipment crossing points.
- Camber - In high fills the center of the embankment tends to settle more than the areas under the embankment side slopes. In such cases it may be necessary to camber the foundation slightly. This is accomplished by using a flat grade on the upstream half of the culvert and a steeper grade on the downstream half of the culvert. The initial grades are set to prevent waterponding or pocketing.

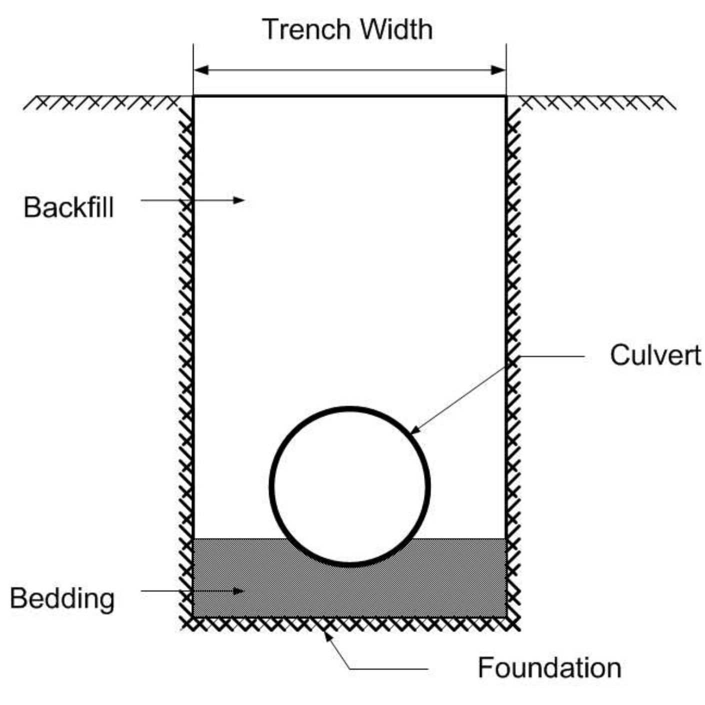


Figure 14.1.6 Culvert Construction and Installation Requirements

14.1.4 Culvert Shapes

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

Circular

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

Figure 14.1.7 Circular Culvert Structure

Pipe Arch and Elliptical Shapes

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

Figure 14.1.8 Pipe Arch Culvert

Arches

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

Figure 14.1.9 Arch Culvert

Box Sections

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

Figure 14.1.10 Concrete Box Culvert

Multiple Barrels

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

Figure 14.1.11 Multiple Cell Concrete Culvert

Frame Culverts

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

Figure 14.1.12 Frame Culvert

14.1.5 Culvert Materials

Precast Concrete

Precast concrete culverts are manufactured in six standard shapes:

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

With the exception of box culverts, concrete culvert pipe is manufactured in up to five standard strength classifications. The higher the classification number, the higher the strength. Box culverts are designed for various depths of cover and live loads. All of the standard shapes are manufactured in a wide range of sizes. Circular and elliptical pipes are available with standard sizes as large as 180 inches in diameter, with larger sizes available as special designs. Standard box sections are also available with spans as large as 144 inches. Precast concrete arches on cast-in-place footings are available with spans up to 41 feet. A listing of standard sizes is provided in Topic 14.2. Refer to Topic 14.2 for a detailed discussion of precast concrete culverts.

Cast-in-Place Concrete

Culverts that are reinforced cast-in-place concrete are typically either rectangular or arch-shaped. The rectangular shape is more common and is usually constructed with multiple cells (barrels) to accommodate longer spans. One advantage of cast-in-place construction is that the culvert can be designed to meet the specific requirements of a site. Due to the long construction time of cast-in-place culverts, precast concrete or corrugated metal culverts are sometimes selected. However, in many areas, cast-in-place culverts are more practical and represent a significant number of installations. Refer to Topic 14.2 for a detailed discussion of cast-in-place concrete culverts.

Metal Culverts

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

Figure 14.1.13 Large Structural Plate Pipe Arch Culvert

Figure 14.1.14 Large Structural Plate Box Culvert

Masonry

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

Figure 14.1.15 Stone Masonry Arch Culvert

Timber

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

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

Figure 14.1.16 Timber Box Culvert

Plastic

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

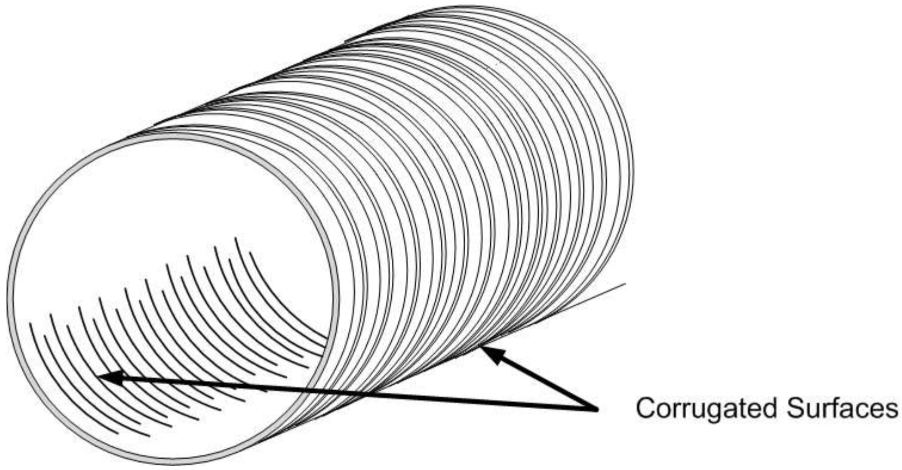


Figure 14.1.17 Schematic of a Single Walled Plastic Culvert

Other Materials

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

14.1.6 Culvert End Treatments

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

The most common types of end treatments are:

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

Figure 14.1.18 Culvert End Projection

Figure 14.1.19 Culvert Mitered End

Figure 14.1.20 Culvert Skewed End

Figure 14.1.21 Culvert Headwall and Wingwalls

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

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

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

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

Figure 14.1.22 Apron

Figure 14.1.23 Riprap Basin

14.1.7 Hydraulics of Culverts

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

- Hydrologic Analysis
- Hydraulic Analysis

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

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

Hydrologic Analysis

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

Climatic Factors

Climatic factors that may influence the amount of runoff include:

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

Topographic Factors

Topographic factors that may influence runoff include:

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

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

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

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

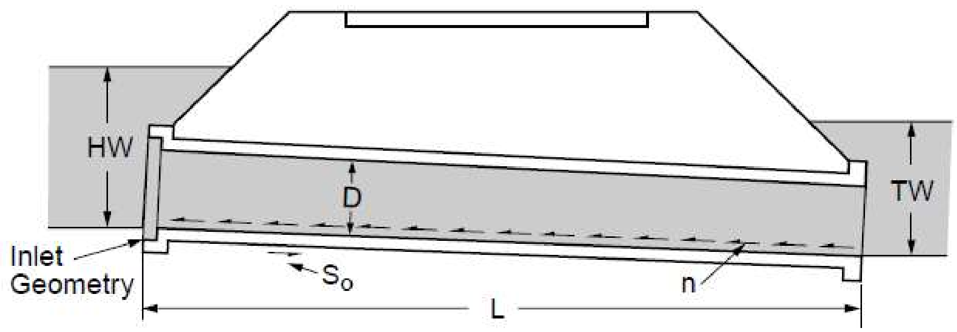
Hydraulic Analysis

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

- Inlet control
- Outlet control

Inlet Control

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



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

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

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

Outlet Control

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

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

Special Hydraulic Considerations

Inlet and Outlet Protection

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

Protection Against Piping

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

14.1.8 Factors Affecting Culvert Performance

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

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

14.1.9 Types and Locations of Culvert Distress

Types of Distress

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

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

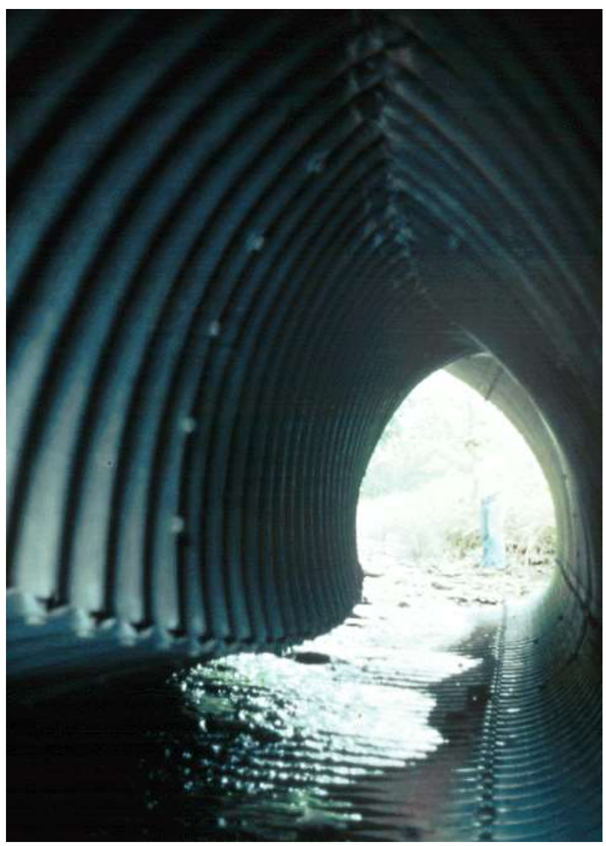


Figure 14.1.25 Bending or Shear Failure

Figure 14.1.26 Cracking of Culvert End Treatment Due to Foundation Settlement

Figure 14.1.27 Scour and Undermining at Culvert Inlet

Figure 14.1.28 Debris and Sediment Buildup

Inspection Locations

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

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

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

Overall Condition

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

Approach Roadway and Embankment

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

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

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

Figure 14.1.29 Approach Roadway at a Culvert Site

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

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

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

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

Figure 14.1.30 Repaired Roadway Over a Culvert

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

Embankment

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

Figure 14.1.31 Slide Failure

End Treatments

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

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

Figure 14.1.32 Headwall and Wingwall End Treatment on Box Culvert

The most common types of box culvert end treatments are:

- Skewed Ends
- Headwalls

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

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

Figure 14.1.33 Potential for Tilted Wingwalls

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

Figure 14.1.34 Skewed End

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

Figure 14.1.35 Culvert Headwall and Wingwall End Treatment

Appurtenance Structures Typical appurtenance structures are:

- Aprons
- Energy Dissipators

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

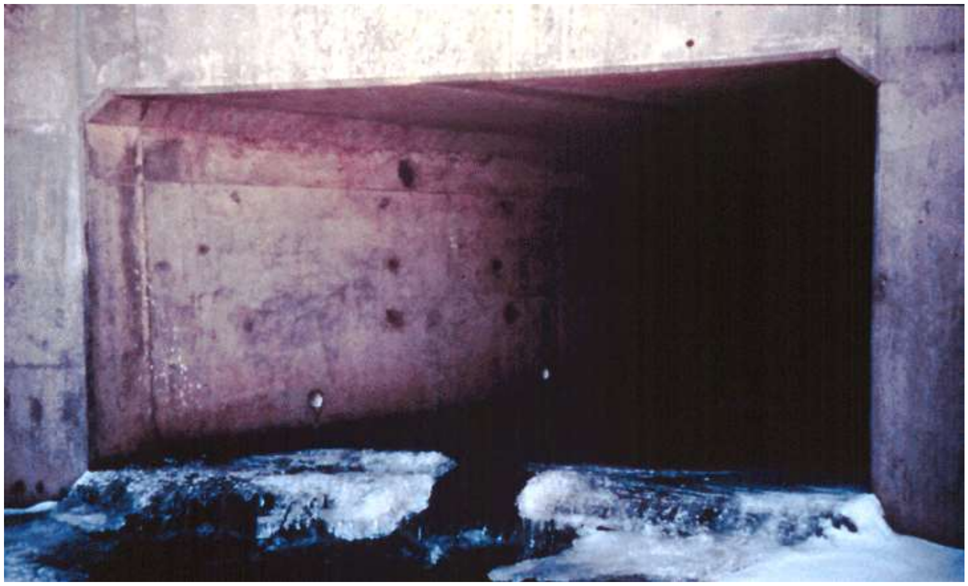


Figure 14.1.36 Apron

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

Figure 14.1.37 Energy Dissipater

Culvert Barrel

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

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

14.1.10 Durability

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

14.1.11 Soil and Water Conditions that Affect Culverts

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

- pH Extremes
- Electrical Resistivity
- Soil Characteristics

pH Extremes

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

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

Electrical Resistivity

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

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

Soil Characteristics

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

14.1.12 Culvert Protective Systems

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

Extra Thickness

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

Bituminous Coating

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

Bituminous Paved Inverts

Paving the inverts of corrugated metal culverts to provide a smooth flow and to protect the metal has sometimes been an effective protection from particularly abrasive and corrosive environments. Bituminous paving is usually at least 1/8 inch thick over the inner crest of the corrugations. Generally only the lower quadrant of the pipe interior is paved. Fiber binding is sometimes used to improve the adherence of bituminous material to the metallic-coated pipe.

Other Coatings

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

Table of Contents

Chapter 14
Characteristics, Inspection and Evaluation of Culverts

Topic 14.2 Rigid Culverts

14.2.1 Introduction

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

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

Figure 14.2.1 Rigid Culvert

14.2.2 Design Characteristics

Concrete Culverts

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

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

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

Concrete Box Culverts

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

Figure 14.2.2 Concrete Box Culvert

Figure 14.2.3 Multi-Cell Concrete Box Culvert

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

Cast-in-Place

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

Precast

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

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

Figure 14.2.4 Precast Concrete Box Culvert

Concrete Pipe Culverts

Precast concrete pipe culverts are manufactured in three standard shapes:

- Circular
- Horizontal elliptical
- Vertical elliptical

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

Figure 14.2.5 Concrete Pipe Culvert

Figure 14.2.6 Twin Concrete Pipe Culvert

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

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

Concrete Arch Culverts

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

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

Figure 14.2.7 Concrete Arch Culvert

Concrete Frame Culverts

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

Figure 14.2.8 Concrete Frame Culvert

Masonry Culverts

Stone Masonry Arch Culverts

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

Figure 14.2.9 Stone Masonry Arch Culvert

Timber Culverts

Timber Box Culverts

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

Figure 14.2.10 Timber Box Culvert

Loads on Culverts

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

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

Box Culverts

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

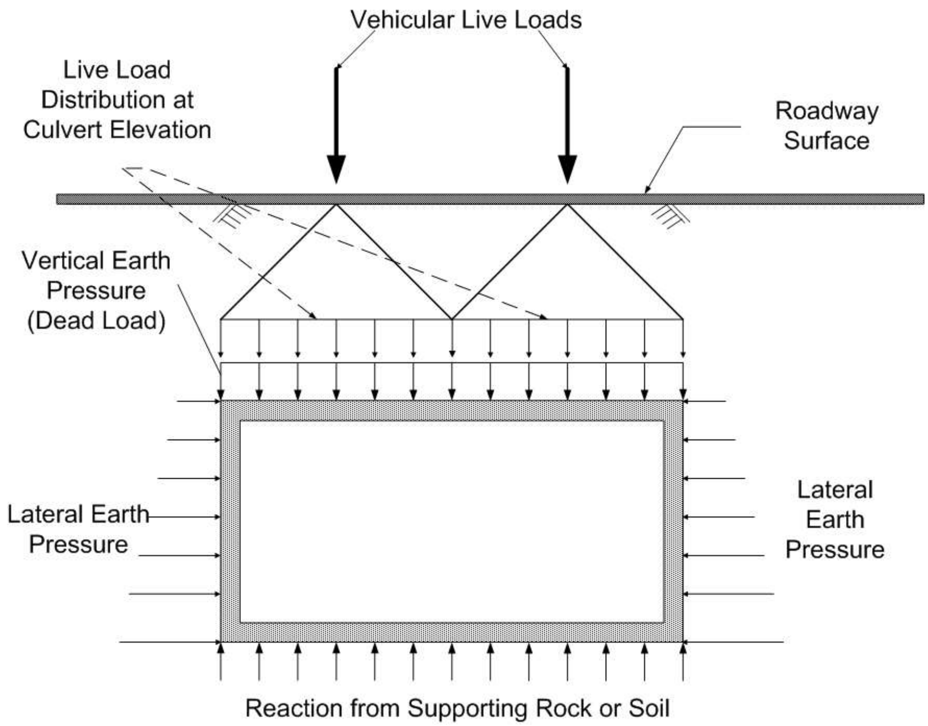


Figure 14.2.11 Loads on a Concrete and Timber Box Culvert

Pipe Culverts

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

Arch and Frame Culverts

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

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

Primary and Secondary Members

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

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

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

Steel Reinforcement for Concrete Culverts

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

Primary Reinforcement

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

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

Secondary Reinforcement

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

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

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

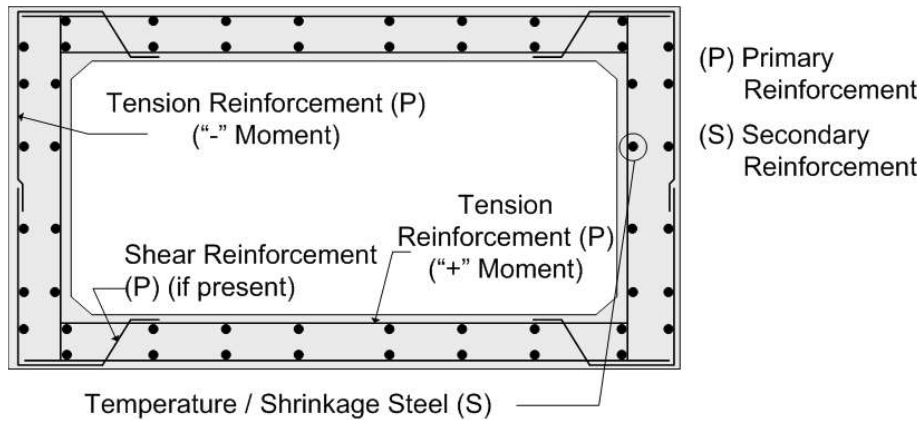


Figure 14.2.12 Steel Reinforcement in a Concrete Box Culvert

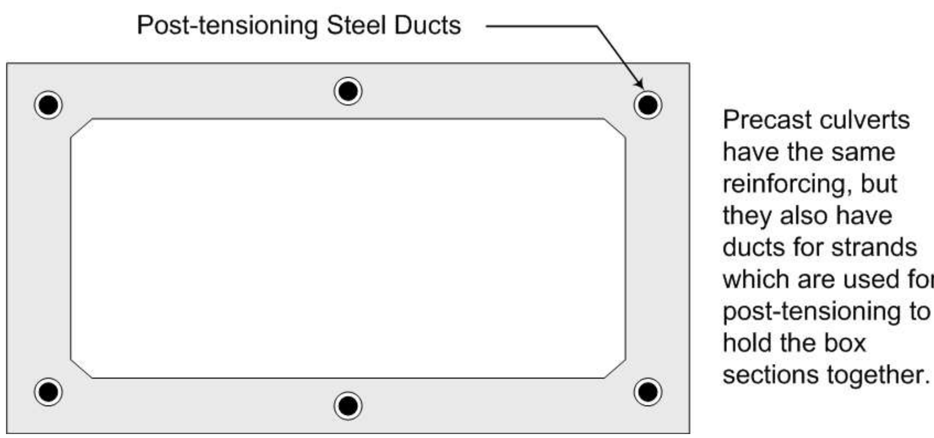


Figure 14.2.13 Precast Box Section with Post-tensioning Steel Ducts

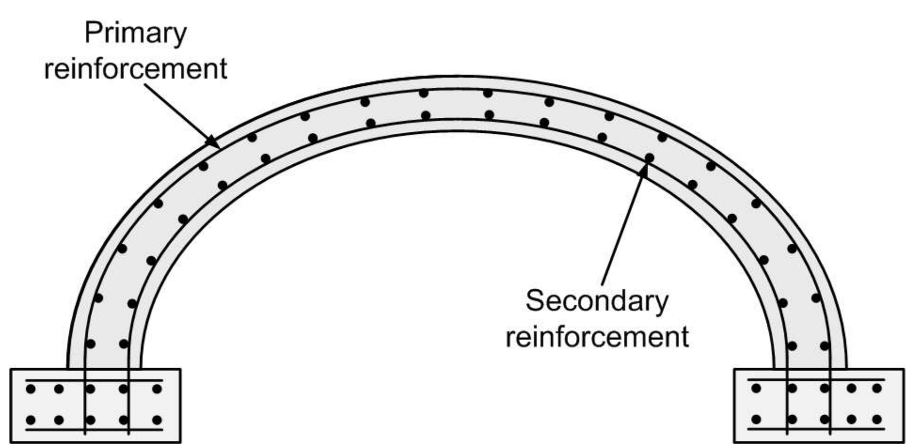


Figure 14.2.14 Steel Reinforcement in a Concrete Arch Culvert

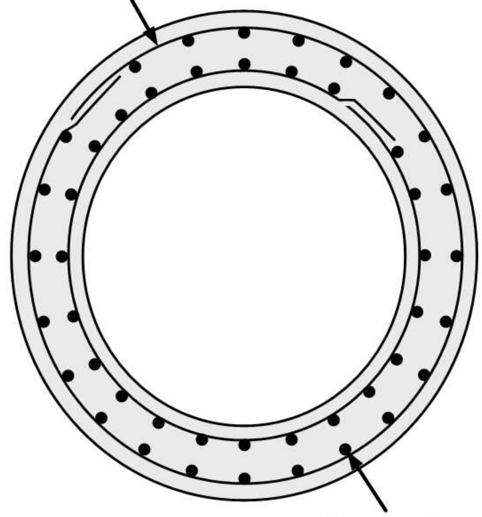


Figure 14.2.15 Steel Reinforcement in a Concrete Pipe Culvert

14.2.3 Overview of Common Deficiencies

Common deficiencies that occur in concrete rigid culverts include:

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

- Loss of prestress
- Carbonation

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

Common deficiencies that occur in masonry rigid culverts include:

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

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

Common deficiencies that occur in timber rigid culverts include:

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

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

14.2.4 Inspection Methods and Locations

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

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

Methods

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

Visual

Concrete

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

Masonry

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

Timber

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

Physical

Concrete

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

Masonry

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

Timber

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

Advanced Inspection Methods

Concrete/Masonry

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

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

Other methods, described in Topic 15.2.3, include:

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

Timber

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

- Sonic testing
- Spectral analysis
- Ultrasonic testing
- Vibration

Other methods, described in Topic 15.1.3, include:

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

Locations

Areas Subjected to Movement and Misalignment

Vertical Movement

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

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

Lateral Movement

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

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

Rotational Movement

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

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

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

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

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

Figure 14.2.16 Sighting Along Culvert Sidewall to Check Horizontal Alignment

Bearing Areas

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

Shear Zones

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

Flexural Zones

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

Areas Exposed to Drainage

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

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

Figure 14.2.18 Missing Stones in Masonry Culvert

Areas Exposed to Traffic

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

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

Scour and Undermining

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

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

Joints

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

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

Figure 14.2.19 Precast Concrete Box Culvert Joint

Cracks

Longitudinal Cracks

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

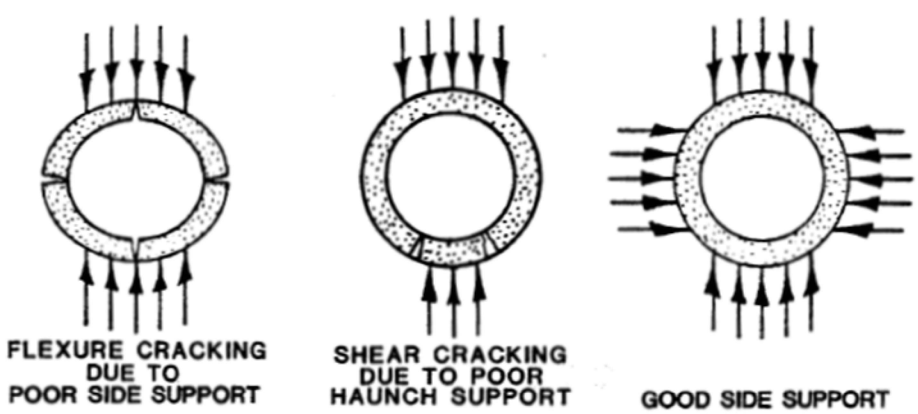


Figure 14.2.20 Longitudinal Cracks in Pipe Culvert

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

Transverse Cracks

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

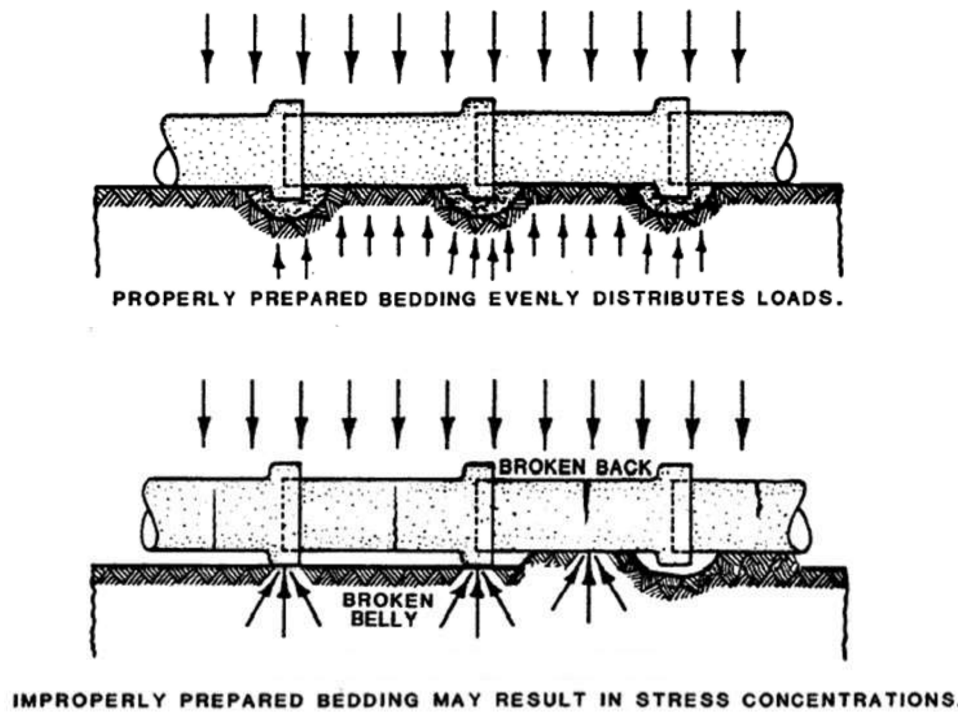


Figure 14.2.21 Transverse Cracks in Pipe Culvert

Spalls

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

Slabbing

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

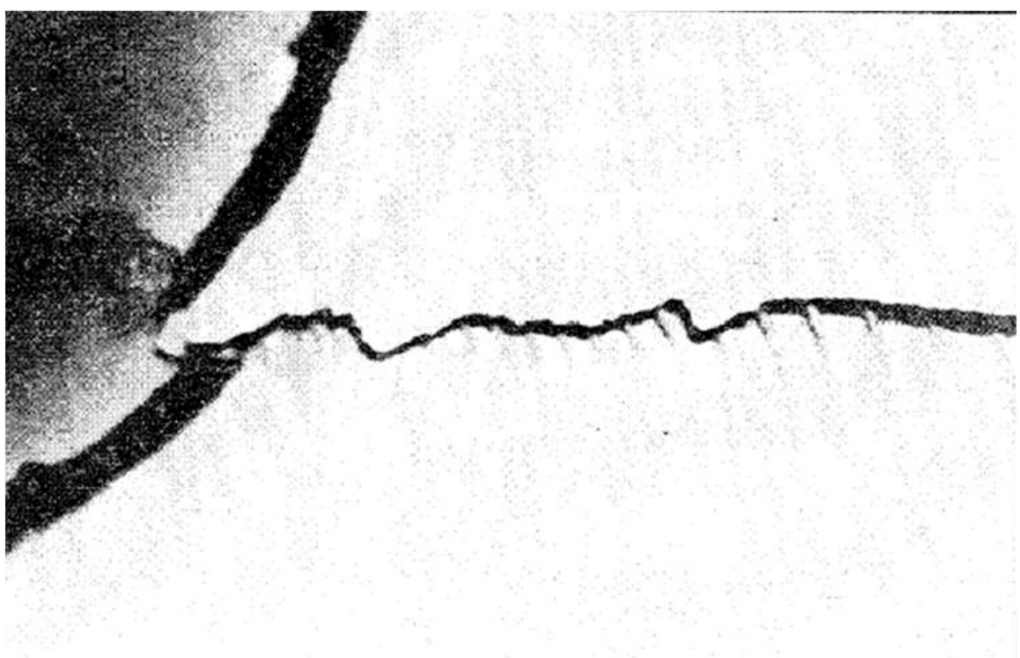


Figure 14.2.22 Shear Slabbing (Source: *FHWA Culvert Inspection Manual*)

Durability

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

End Section Drop-off

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

Wingwalls and Headwalls

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

Figure 14.2.23 Cast-in-Place Concrete Headwall and Wingwall

14.2.5 Evaluation

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

NBI Component Condition Rating Guidelines

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

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

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

Element Level Condition State Assessment

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

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

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

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

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

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

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

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

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

Figure 14.2.24 NBI Component Condition Rating Guidelines for Culverts

Dimensions and Approximate Weights of Concrete Pipe

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

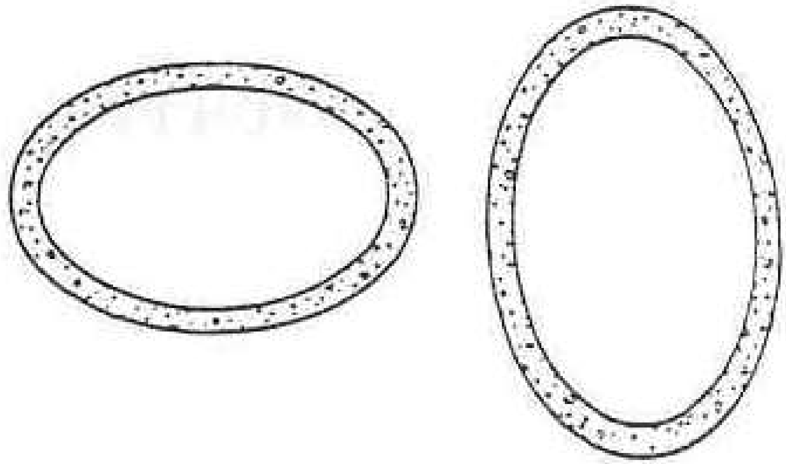
Large Sizes of Pipe Tongue and Groove Joint			
Internal Diameter Inches	**Internal Diameter Feet**	**Wall Thickness Inches**	**Approximate Weight, pounds per foot**
114	9 ½	9 ½	3840
120	10	10	4263
126	10 ½	10 ½	4690
132	11	11	5148
138	11 ½	11 ½	5627
144	12	12	6126
150	12 ½	12 ½	6647
156	13	13	7190
162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

* For description of ASTM C 76 see page 14.2.30

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

Typical Cross Section of Arch Pipe

Horizontal and Vertical Ellipse Pipe



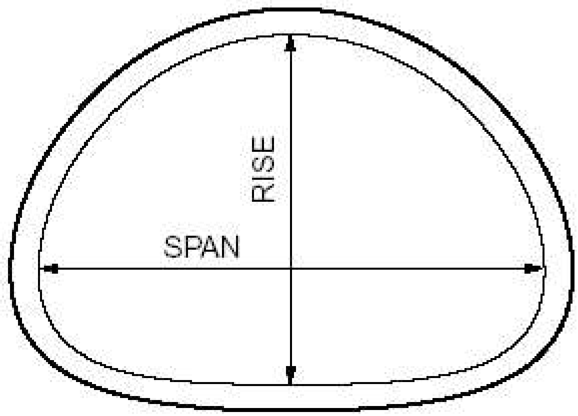
Dimensions and Approximate Weights of Elliptical Concrete Pipe

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

* For description of ASTM C 507 see page 14.2.30

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

Typical Cross Section of Arch Pipe



Dimensions and Approximate Weights of Concrete Arch Pipe

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

* For description of ASTM C 506 see page 14.2.30

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

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

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

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

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

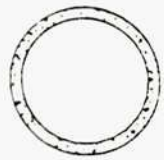
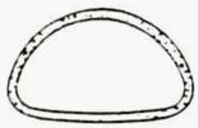
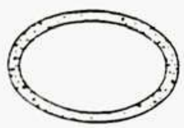
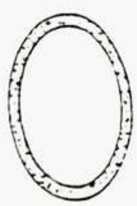
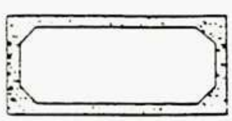
SHAPE	RANGE OF SIZES	COMMON USES
CIRCULAR 	12 to 180 inches reinforced 4 to 36 inches non-reinforced	Culverts, storm drains, and sewers.
PIPE ARCH 	15 to 132 inches equivalent diameter	Culverts, storm drains, and sewers. Used where head is limited.
HORIZONTAL ELLIPSE 	Span x Rise 18 to 144 inches equivalent diameter	Culverts, storm drains, and sewers. Used where head is limited.
VERTICAL ELLIPSE 	Span x Rise 36 to 144 inches equivalent diameter	Culverts, storm drains, and sewers. Used where lateral clearance is limited.
RECTANGULAR (box sections) 	Span 3ft to 12ft	Culverts, storm drains, and sewers. Used for wide openings with limited head.
ARCH 	Span 24 ft to 41 ft	Culvert and storm drains. For low, wide waterway enclosures.

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

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Table of Contents

Chapter 14
Characteristics, Inspection and Evaluation of Culverts

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Topic 14.3 Flexible Culverts

14.3.1 Introduction

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

Figure 14.3.1 Pipe Arch Flexible Culvert

Figure 14.3.2 Flexible Box Culvert