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Chapter 13

Inspection and Evaluation of Waterways

Topic 13.1 Waterway Elements

13.1.1

Introduction

Rivers are the most dynamic geomorphic system that engineers have to cope with in the design and maintenance of bridges. The geomorphic features of the river can change dramatically with time. During major floods, significant changes can occur in a short period of time. While rivers are dynamic or can move locations, bridges do not move locations.

There are several ways in which channels can change and thereby jeopardize the stability and safety of bridges. The channel bed can scour (degrade) so that bed elevations become lower, undermining the foundation of the piers and abutments. Deposition of sediment on the channel bed (aggradation) can reduce conveyance capacity through the bridge opening. Flood waters are then forced around the bridge, attacking roadway approaches, channel banks, and flood plains. Another consequence of aggradation is that the river stage may be increased to where it exerts lateral thrust and lift on the deck and girders of the bridge (see Figures 13.1.1 and 13.1.2). The other primary way in which bridges can be adversely affected by a waterway is through bank erosion or avulsion, causing the channel to shift laterally. These phenomena of aggradation, degradation or scour, bank erosion, and lateral migration can be a result of natural or induced causes and can adversely affect the bridge (see Figure 13.1.3). Topic 13.2 presents detailed descriptions of waterway deficiencies.

Of all the bridges in the National Bridge Inventory (NBI), approximately 86% are built over waterways. Bridge inspectors need to understand the relationship between the bridge and waterway elements. This understanding involves being able to recognize and identify the streambed, embankments, floodplain, and streamflow so that an accurate assessment and record of the present condition of the bridge and waterway can be determined.



Figure 13.1.1 Failure Due to High Water Levels During Hurricane: Aerial View



Figure 13.1.2 Failure Due to High Water Levels During Hurricane: Close-Up View



Figure 13.1.3 Pier Foundation Failure

13.1.2

Properties Affecting Waterways

Safety is a major concern in the inspection of bridges over active waterways. Various properties can affect waterways and structures.

- The size, shape and orientation of the bridge superstructure and foundation units.
- The physical characteristics such as channel sinuosity, slope, streambed and bank material classification and bank geometry and vegetative cover.
- The geomorphic history of the waterway (history of changes in the location, shape, and elevation of the channel).
- The hydraulic forces imposed on the bridge by the streamflow.
- Changes in the river channel or flow due to development projects (such as dams, diversions, urbanization and channel stabilization) or natural phenomena.
- The condition of hydraulic control structures that have been utilized to help protect the bridge and adjacent channel.
- Changes in the sediment balance in the stream due to nearby streambed gravel mining or landslides.

13.1.3

Purpose of Waterway Inspections

There are three major purposes for conducting waterway inspections.

- Identify critical damage
- Record existing channel conditions
- Monitor channel changes

Identify Critical Damage

Waterway inspections are needed to identify conditions that cause structural collapse of bridge structures. Deficient piling along with damage or deterioration to foundation members can only be detected during a waterway inspection. Entering the water and probing around the foundations is necessary to detect loss of foundation support.

Record Existing Channel Conditions

Waterway inspections are conducted to create a record of the existing channel conditions adjacent to the bridge. Conditions such as channel opening width, depth at substructure elements, channel cross-section elevations, water flow velocity, and channel constriction and skew are noted and compared to previously recorded conditions.

Accessing the waterway to measure and record channel conditions may be restricted by several factors including channel width and depth, flow velocity, or pollution. These factors may require the bridge inspector to return to the site during a period of low flow. Alternatively the inspector may need to consider using an alternate means of waterway access, such as a boat, or an alternative inspection technique, such as underwater diving inspection.

Monitor Channel Changes

Current waterway inspection data should be compared to previous inspection data in order to identify channel changes. This “tracking” of channel change over time is an important step in ensuring the safety of the bridge. Over time, vertical changes, due to either degradation or aggradation processes, or horizontal alignment changes, due to lateral migration of the channel, could result in foundation undermining, bridge overtopping, or even collapse of the structure. If major changes are found, a formal scour analysis of the site, involving a multi-disciplinary team of engineers, may be needed to estimate floodwater elevations, velocities, angle of attack, and potential scour depths. Potential threats to bridge members caused by channel changes can thus be dealt with before damage actually occurs. See Topic 13.2 for the inspection and evaluation of waterways.

13.1.4

Channel Characteristics

According to the Hydraulic Design Series Number 6 (HDS-6) Highways in the River Environment, channels are typically well-defined and confine the streamflow during normal flow conditions (see Figure 13.1.4).

Elements of a Channel

- Streambed - the bottom or floor of the channel.
- Streambank - the sloped sides of the channel, which extend from the streambed to the surrounding ground elevation (floodplain).
- Streamflow - the water, suspended sediment, and any debris moving through the channel.
- Thalweg elevation – lowest elevation of the stream.

Elements of floodplains are presented in Topic 13.1.5.

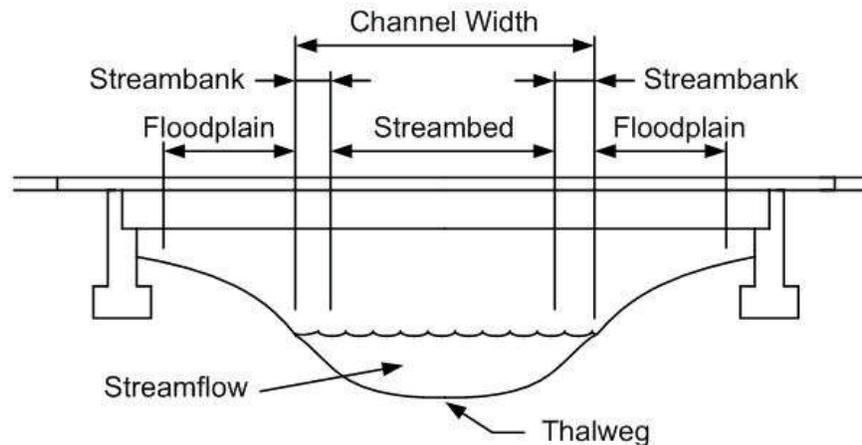


Figure 13.1.4 Typical Waterway Cross Section Showing Well Defined Channel Depression

Types of Channels

Knowledge of the type and profile of a waterway or river channel is essential to understand the hydraulics of the channel and its potential for change. The type of river may dictate certain tendencies or responses that may be more adverse than others. To aid in this understanding, various key river classes are briefly explained. Rivers can be broadly classified into four categories:

- Meandering rivers
- Braided rivers
- Straight rivers
- Steep mountain streams

Meandering Rivers

Meandering rivers consist of a series of bends connected by crossings. In general, pools exist in the bends. The dimensions of these pools vary with the size of the river, flow conditions, radius of the curvature of the bends, and type of bed and bank material. Such rivers are fairly predictable and experience relatively slow velocities. Figure 13.1.5 shows some differences between the various river categories. Figure 13.1.6 illustrates the major characteristics of a meandering river.

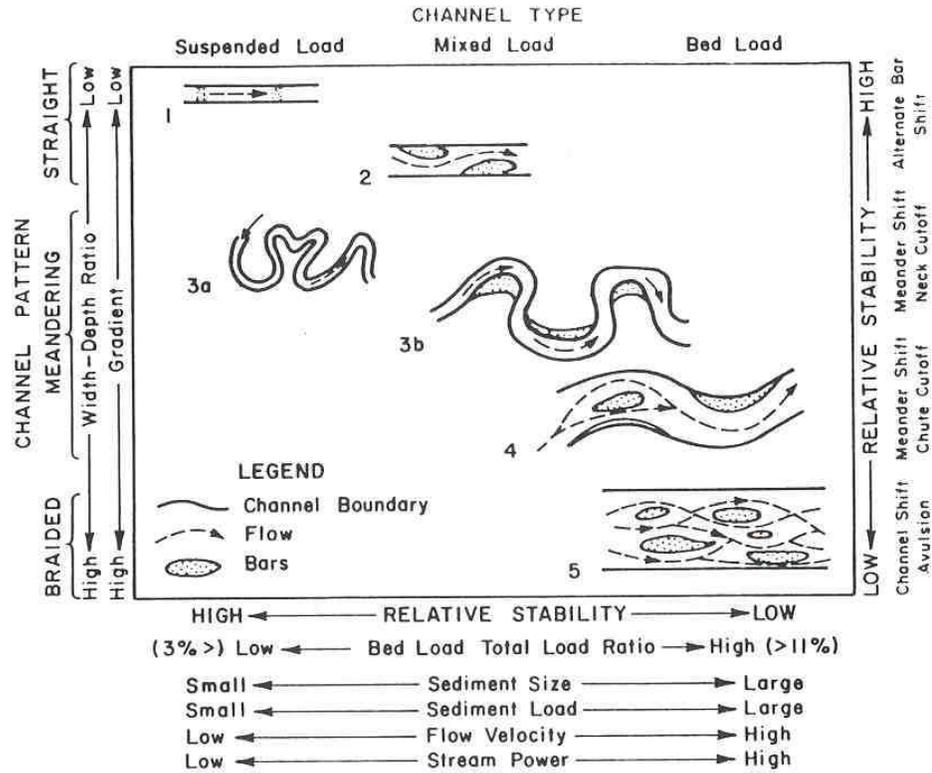


Figure 13.1.5 Plan View of Rivers

Braided Rivers

Braided rivers consist of multiple channels that are intertwined in braided form. At flood stages, the appearance of braiding is less noticeable. The bars dividing the multiple channels may become submerged, and the river will appear to be relatively straight. Braided rivers have steeper slopes and experience higher streamflow velocities which may cause larger scour or undermining problems.

Braided rivers can change rapidly, causing different velocity distributions, partial blockages of portions of the waterway beneath bridges, and larger quantities of debris that can be a hazard to bridges and cause accelerated scour. Figure 13.1.4 illustrates the plan view of typical rivers, including meandering, straight, and braided. This figure also relates form of river to channel type based on sediment load and relative stability of river type.

Straight Rivers

Straight rivers are something of an anomaly. Most straight rivers are in a transition between meandering and braided types. In straight rivers, any development that would flatten the gradient would accelerate change from a straight system to a meandering system. Conversely, if the gradient were increased, the channel may become braided. Therefore, in order to maintain the straight alignment over a normal range of hydrologic conditions, it may become necessary to utilize channel hydraulic control structures (Topic 13.1.7). The characteristics of straight rivers are identified in Figure 13.1.5.

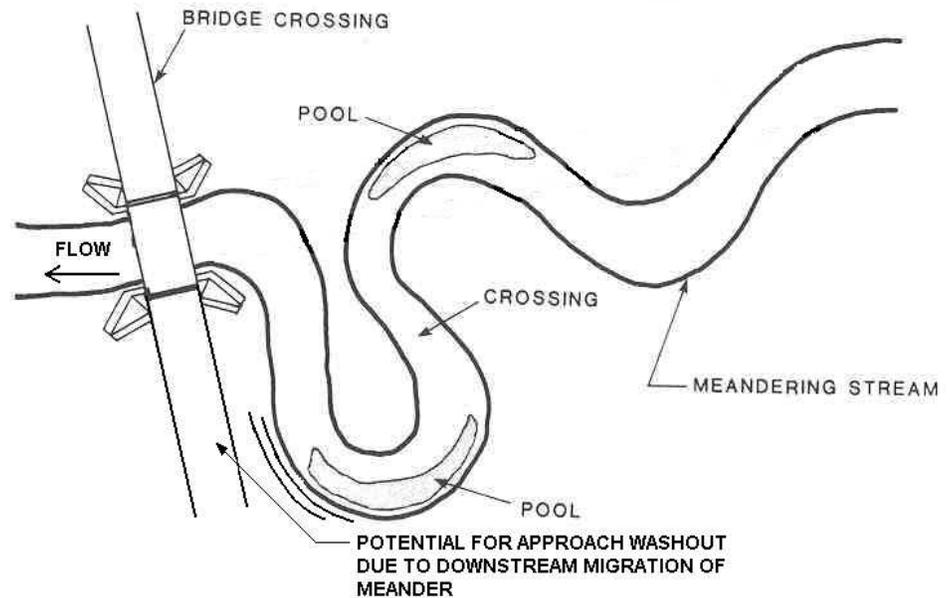


Figure 13.1.6 Meandering River

Steep Mountain Streams

Steep mountain streams are controlled by geologic formations, rock falls, and waterfalls. They experience very small changes in either plan form or profile when subjected to the normal range of discharges. The bed material of such river systems can consist of gravel, cobbles, boulders, or some mixture of these different sizes. Even though these rivers are relatively stable, they can experience significant velocity and flow changes during episodic flood events.

13.1.5

Floodplain Characteristics

The floodplain is the overbank area outside the channel that carries flood flows in excess of channel capacity (see Figure 13.1.7). It is common to find bridges built within the floodplain. For many structures, the floodplain is quite large, as compared to the channel. Observations made during periods of high water can help the inspector identify the floodplain.

Elements of a Floodplain

- Freeboard – the vertical distance between the design flood water surface and the lowest point of the superstructure to account for waves, surges, drift and other contingencies (see Figure 13.1.5)
- Normal stage – the streamflow stage prevailing during the greater part of the year (between low and high water levels)
- Waterway area – the entire area beneath the bridge which is available to pass flood flows.

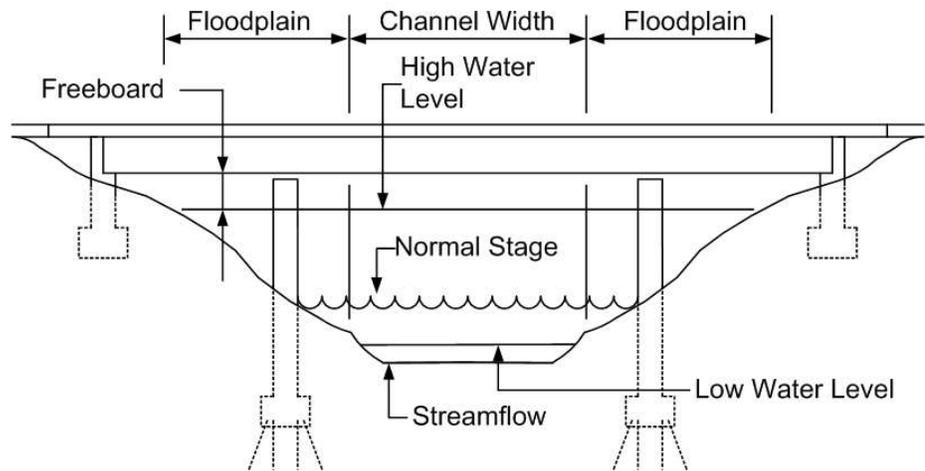


Figure 13.1.7 Typical Floodplain

Channel characteristics are presented in detail in Topic 13.1.4.

13.1.6

Hydraulic Opening

The hydraulic opening is the entire area beneath the bridge which is available to pass flood flows (see Figure 13.1.8). The bottom of the superstructure, the two bridge abutments, and the streambed or ground elevation bounds the hydraulic, or waterway, opening. For multiple spans, intermediate supports such as piers or bents restrict the hydraulic or bridge waterway opening.

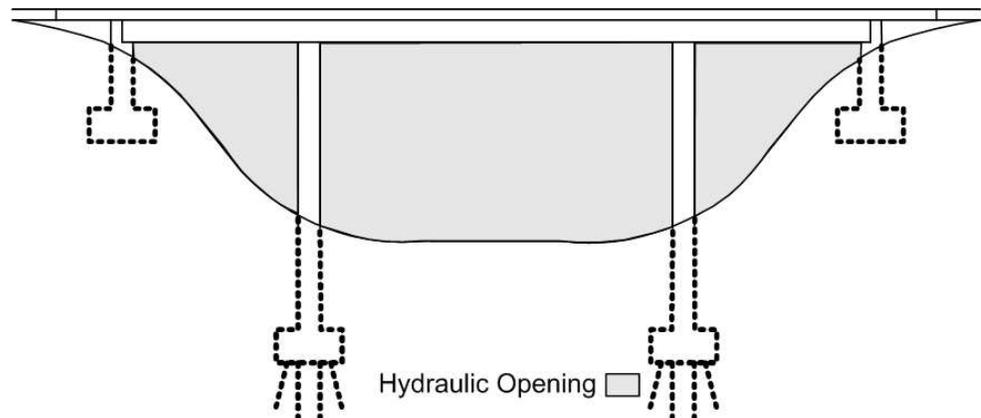


Figure 13.1.8 Hydraulic Waterway Opening

13.1.7

Hydraulic Countermeasures

Hydraulic countermeasures are often utilized to provide protection for bridges against lateral migration of the channel and against high velocity flows and scour. A hydraulic countermeasure is a man-made or man-placed device designed to direct streamflow and protect against lateral migration or scour. These flow hydraulic control countermeasures may be utilized either at the bridge, upstream from the bridge, or downstream from the bridge. Countermeasures are designed by hydraulic and geotechnical engineers and are installed to redirect streamflow and flood flows within the watercourse and through the bridge waterway opening. Hydraulic countermeasures are broken into two distinct categories which are river training structures and armoring countermeasures.

River Control Structures River control structures are countermeasures designed to modify the flow to help prevent. A couple examples of river training structures are spurs and guide banks. A complete list of the various types of river training structures is located in HEC-23 Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Design Guidance, 3rd edition.

Spurs

Spurs are linear structures, designed with properly sized and placed rocks, that projects into a channel and placed on the outside bends of the bank to protect the streambank by reducing flow velocity, inducing deposition of sediment or redirecting the flow (see Figure 13.1.10). Common applications occur on meandering streams where they are placed on the outside of the bends to redirect the flow and minimize lateral stream migration.

Guide banks

Guide banks are dikes which extend upstream from the approach embankment at either or both sides of the bridge opening to direct the flow through the opening (see Figure 13.1.11). Scour hole formation occurs at the upstream ends of the guide banks if left unprotected. Common scour prevention devices for guide banks include riprap.

Armoring Countermeasures

Armoring countermeasures tend not to alter the flow significantly, but are design to resist hydraulic stresses of the design flood events. Some examples of armor countermeasures include riprap, gabions, slope stabilization, channel linings and footing aprons. A complete list of the various types of armoring countermeasures is located in HEC-23.

Riprap

Layers or facings of properly sized and graded rock or broken concrete, placed or dumped to protect an abutment, pier or embankment from erosion (see Figure 13.1.9). Riprap has also been used to almost all kinds of armor which include wire-enclosed riprap partially grouted riprap, sacked concrete and concrete slabs. Riprap should be protected against subsurface erosion by filters formed either of properly graded sand/gravel or of synthetic fabrics developed and utilized to replace the natural sand/gravel filter system. It must be placed on an adequately flat slope to be able to resist the anticipated forces of the flowing flood waters. Proper design and placement of riprap is essential. This generally requires placement of the riprap on side-slopes no steeper than 1.5 to 1 vertical (1.5H:1V). Flatter side-slopes of such as 2H:1V to 3H:1V are preferable. Proper design and placement of riprap is essential. Inappropriate installations can aggravate or cause the conditions they were intended to correct or prevent.

Gabions

Rectangular rock- or cobble- filled wire mesh baskets or compartmented rectangular containers, anchored together and generally anchored to the surface they are protecting (see Figure 13.1.12). Gabions may be placed on steeper slopes than riprap or may even be stacked vertically, depending upon the design procedure and site conditions.

Slope Stabilization Methods

Slope stabilization methods consist of the placement of geotextiles, wire mesh, riprap, paving, revetment, plantings or other materials on channel embankments, intended to protect the slope from erosion, slipping or caving or to withstand external hydraulic pressure (see Figure 13.1.13). It is anticipated the various stabilization methods will fill-in with sediment and help sustain plant growth. The roots from the plants contribute to stabilize the embankment or flood plain.

Channel Lining

Channel lining is a concrete pavement that extends across the streambed. Channel linings also may be revetment mats or some other form of bed armoring. A typical revetment mat is formed by interlocking precast concrete blocks linked by cable (polyester or steel) placed on a geotextile fabric. The interlocking matrix allows for use over varying land contours and grades (see Figure 13.1.14). Channel linings may also consist of formed concrete. This type is less flexible and versatile than revetment mats and other bed armoring (see Figure 13.1.15).

Footing Aprons

Footing aprons are protective layers of material surrounding the footing of a substructure unit. Footing aprons usually consist of cast-in-place concrete (see Figure 13.1.16 and 13.1.17). Footing aprons protect footings from undermining. The aprons are not a structural element of the abutment or pier footings and are considered a structural countermeasure instead of a hydraulic countermeasure.



Figure 13.1.9 Crushed Stone Riprap



Figure 13.1.10 Spurs



Figure 13.1.11 Guide banks Constructed on Kickapoo Creek Near Peoria, Illinois



Figure 13.1.12 Gabion Basket Serving as Slope Protection

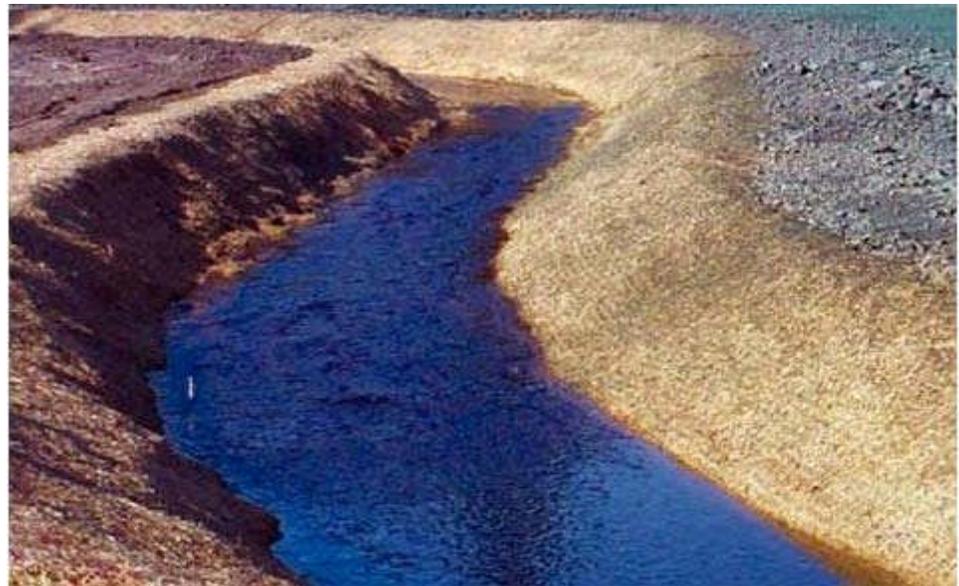


Figure 13.1.13 Slope Stabilization



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

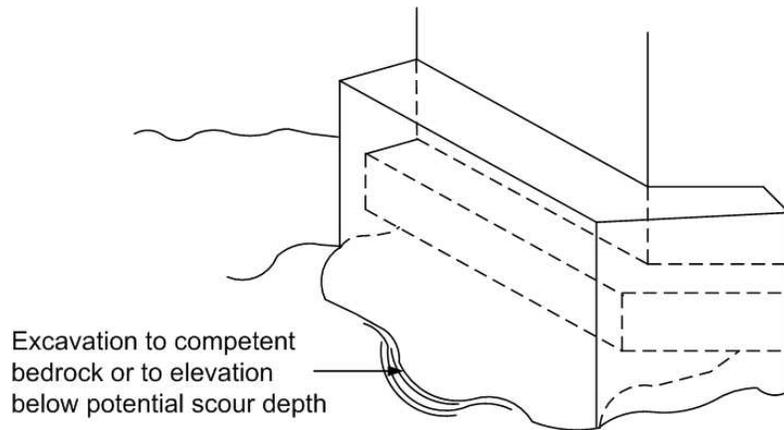


Figure 13.1.17 Concrete Footing Apron to Protect a Spread Footing from Undermining

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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).

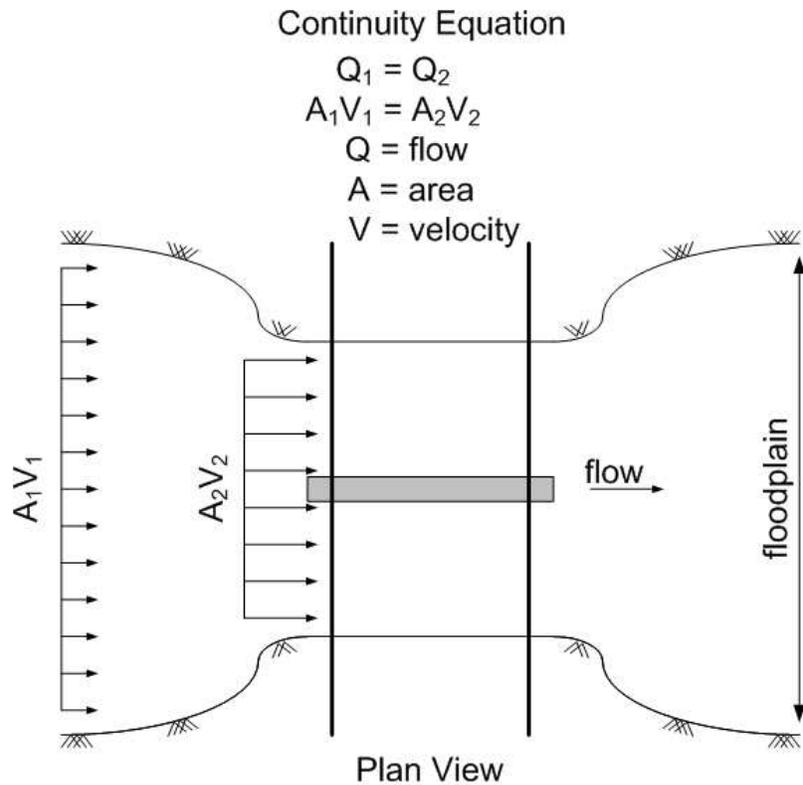


Figure 13.2.6 Stream Contraction Schematic



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

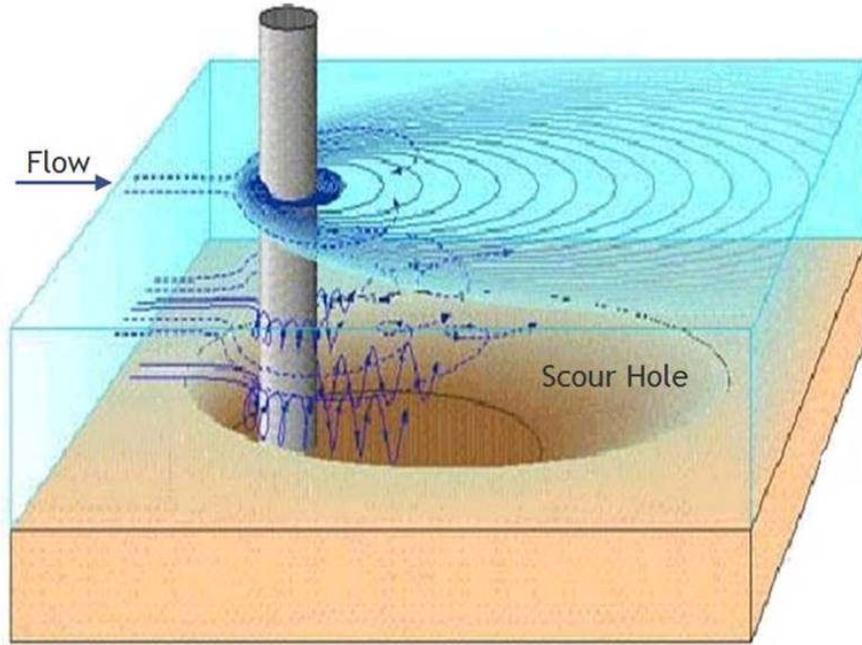


Figure 13.2.13 Local Scour at a Pier



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).

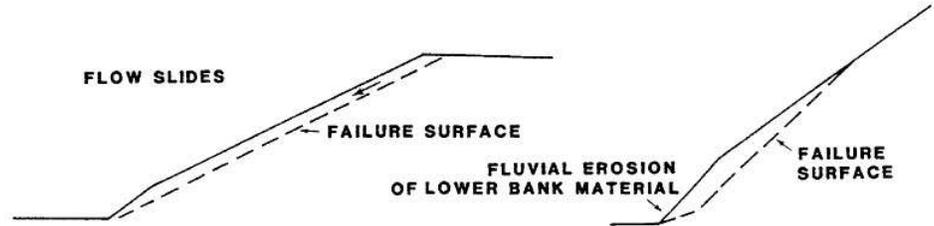


Figure 13.2.23 Schematic of Noncohesive Bank Material

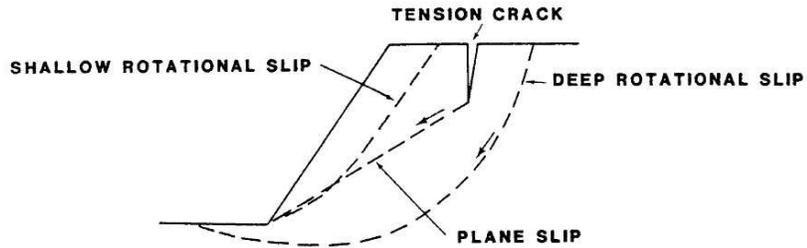


Figure 13.2.24 Schematic of Cohesive Bank Material

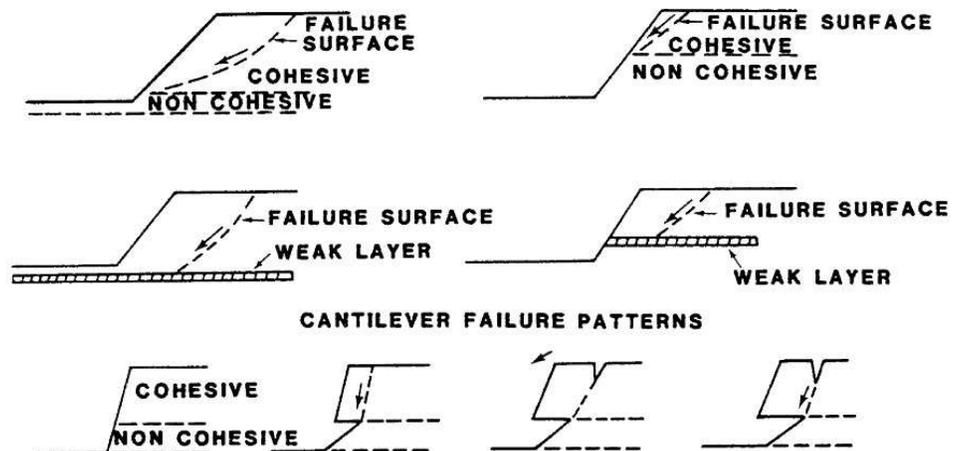


Figure 13.2.25 Schematic of Cohesive Bank Material

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.

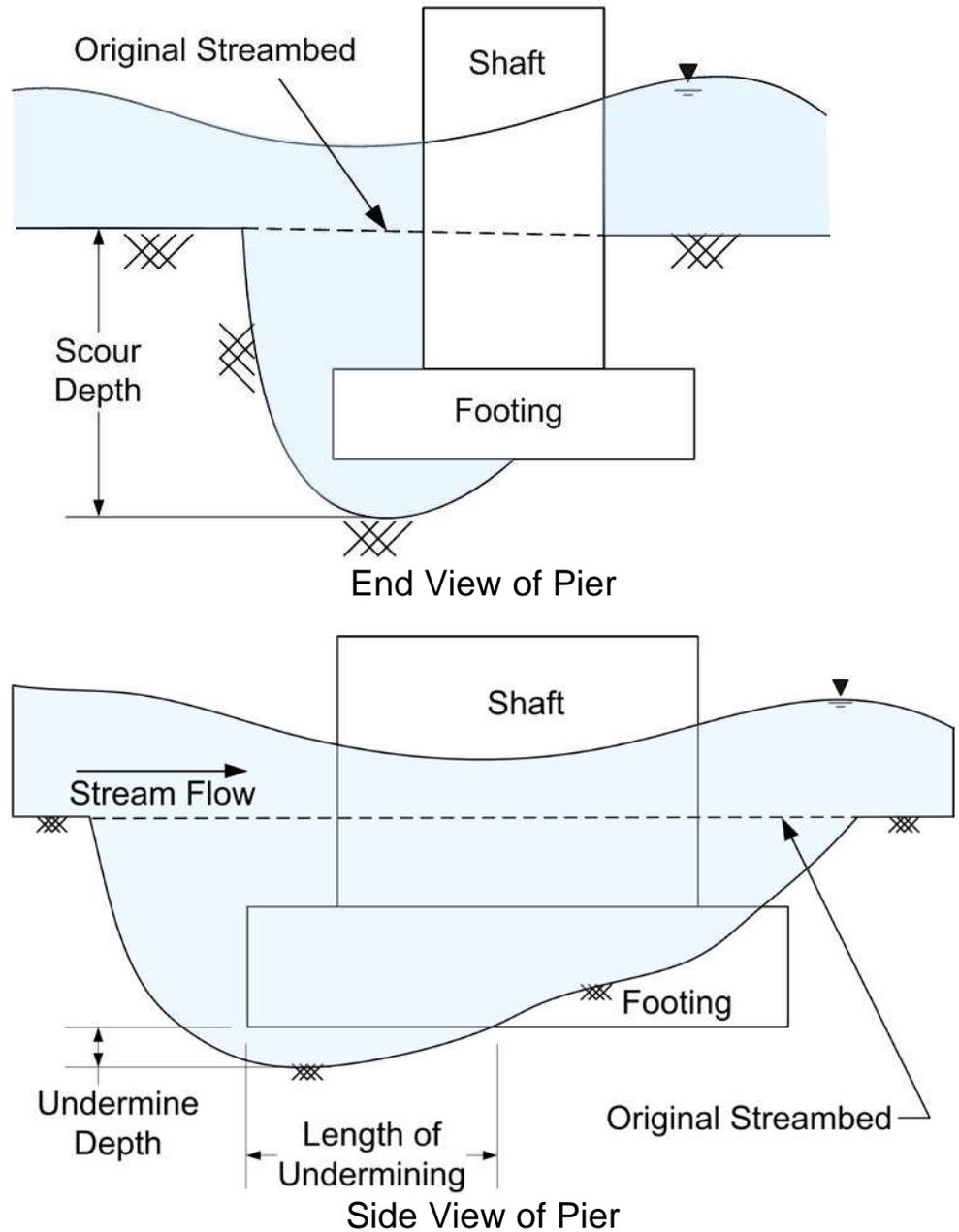


Figure 13.2.26 End and Side View of Scour and Undermining

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).

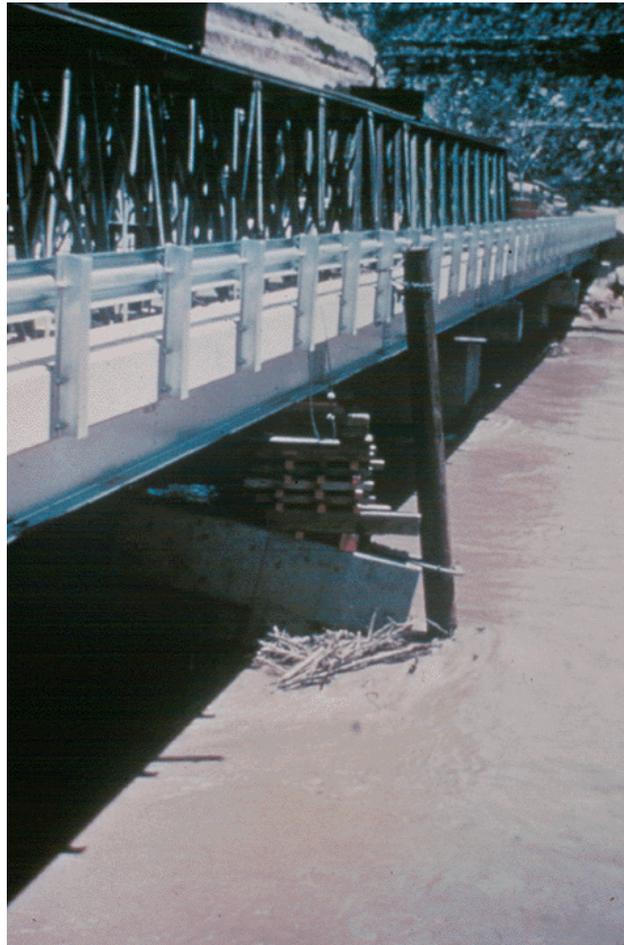


Figure 13.2.27 Pier Settlement due to Undermining

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.

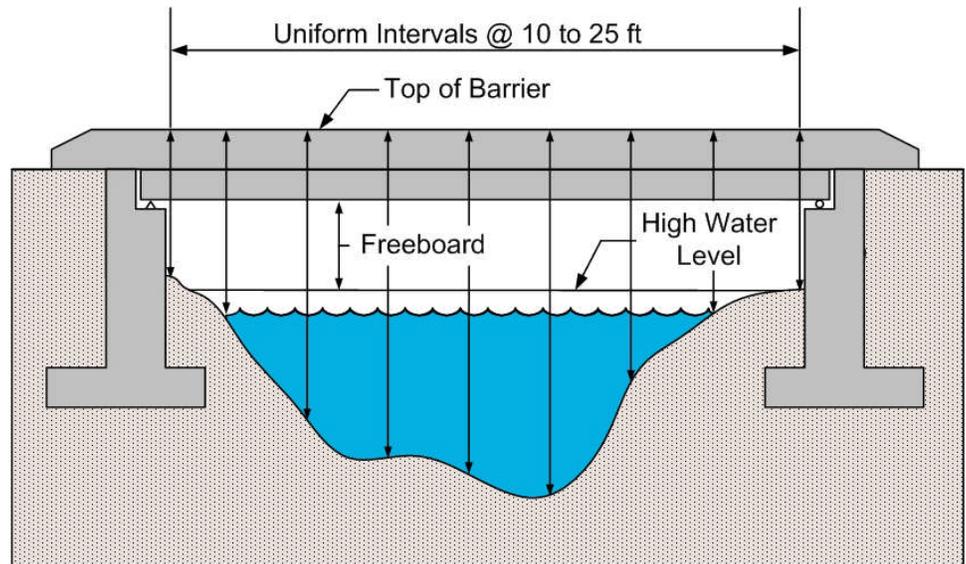


Figure 13.2.32 Streambed Cross-Section

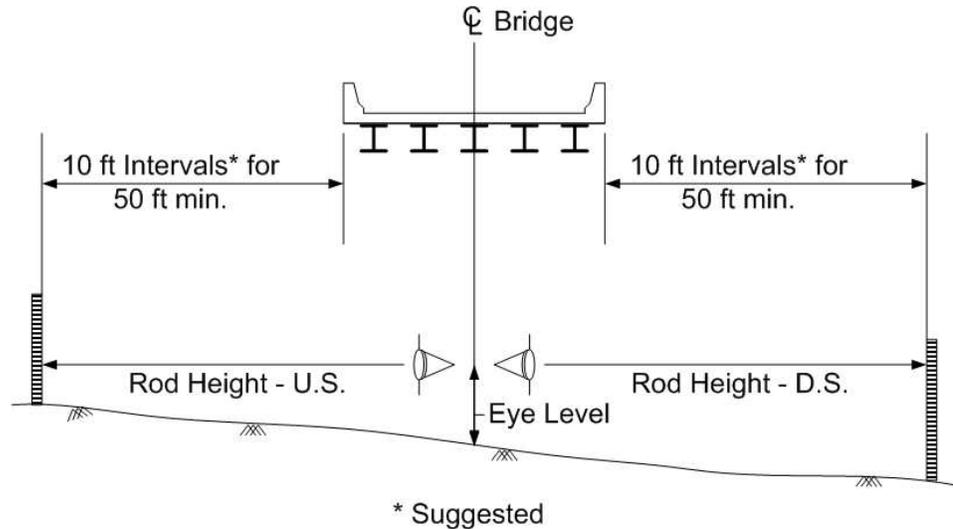


Figure 13.2.33 Streambed Profile

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.

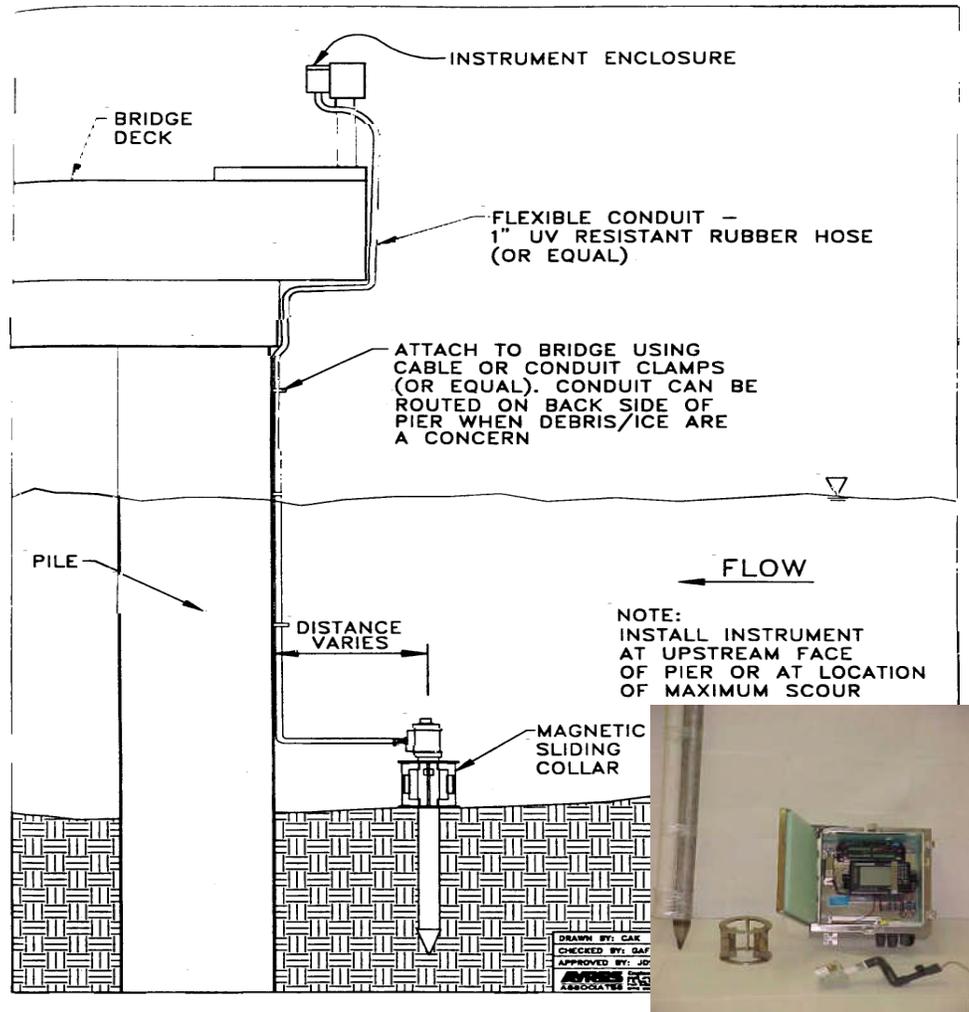


Figure 13.2.34 Scour Monitoring Collar

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

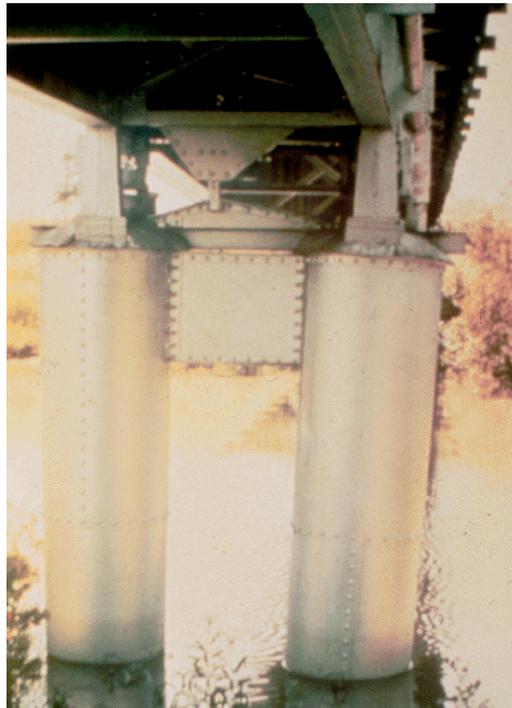


Figure 13.2.36 Out of Plumb Pier Column

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

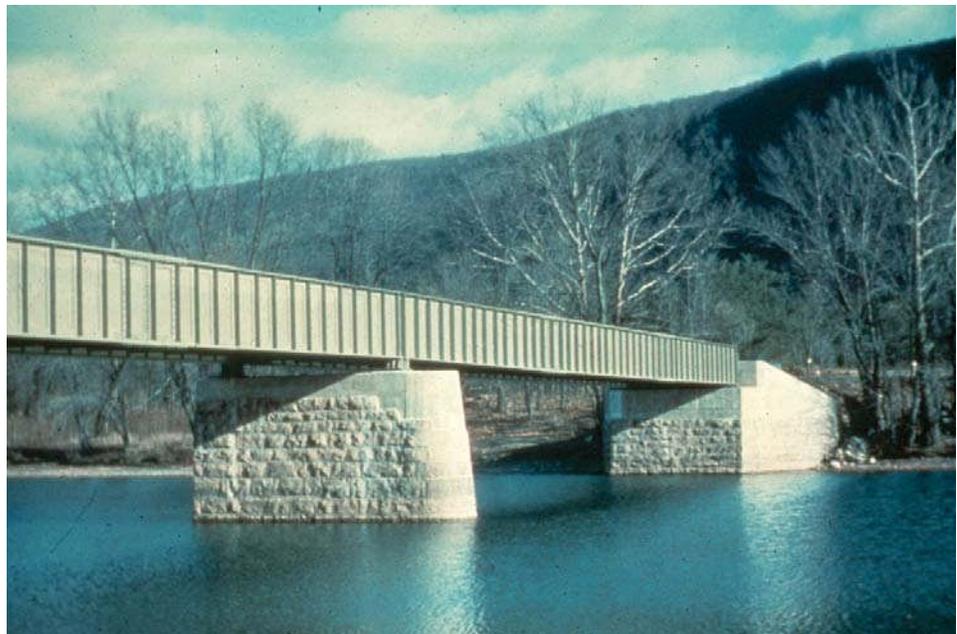


Figure 13.2.39 Multi-Span Simply Supported Bridge

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

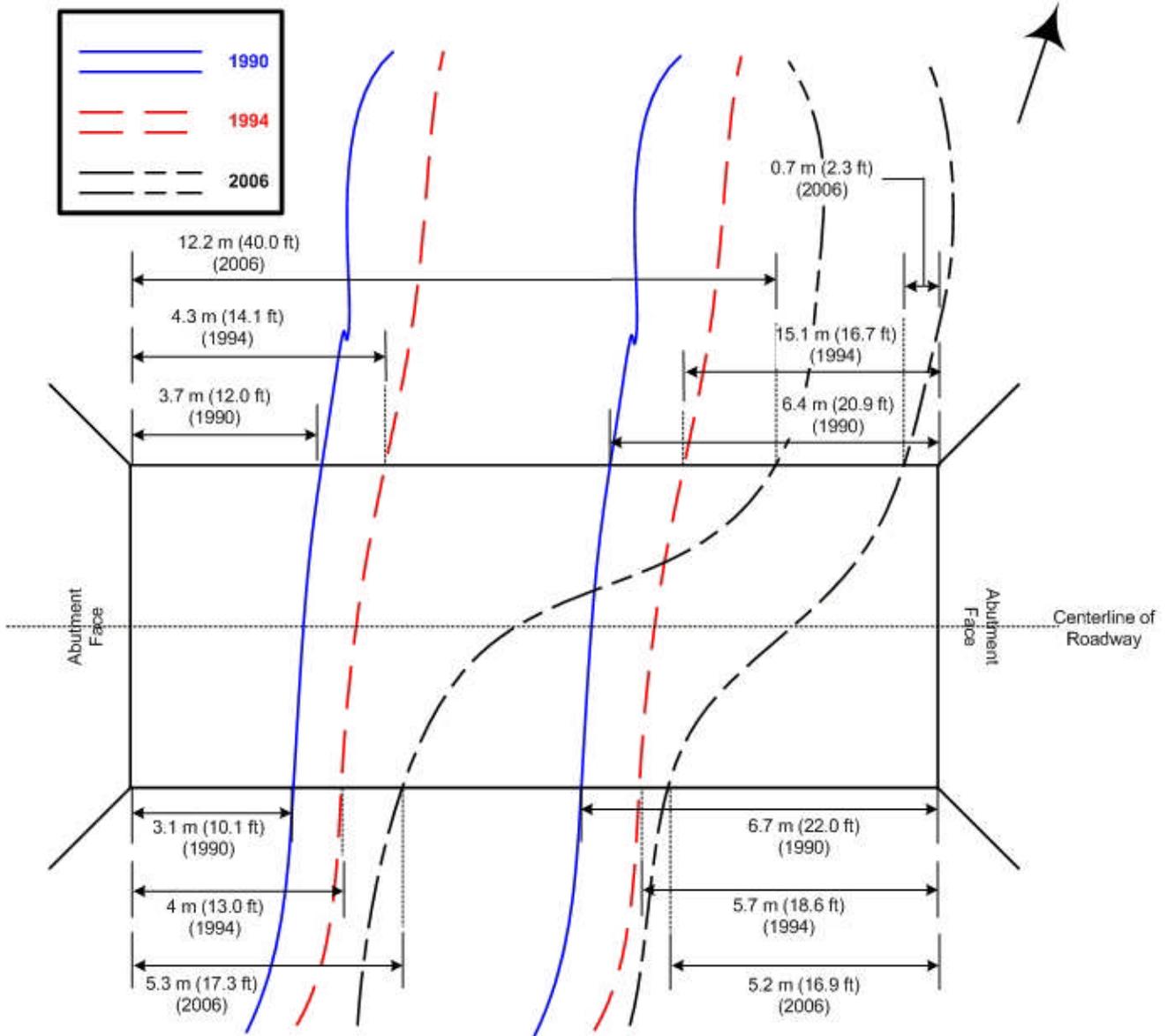


Figure 13.2.46 Waterway Alignment 1990 - 2006

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).

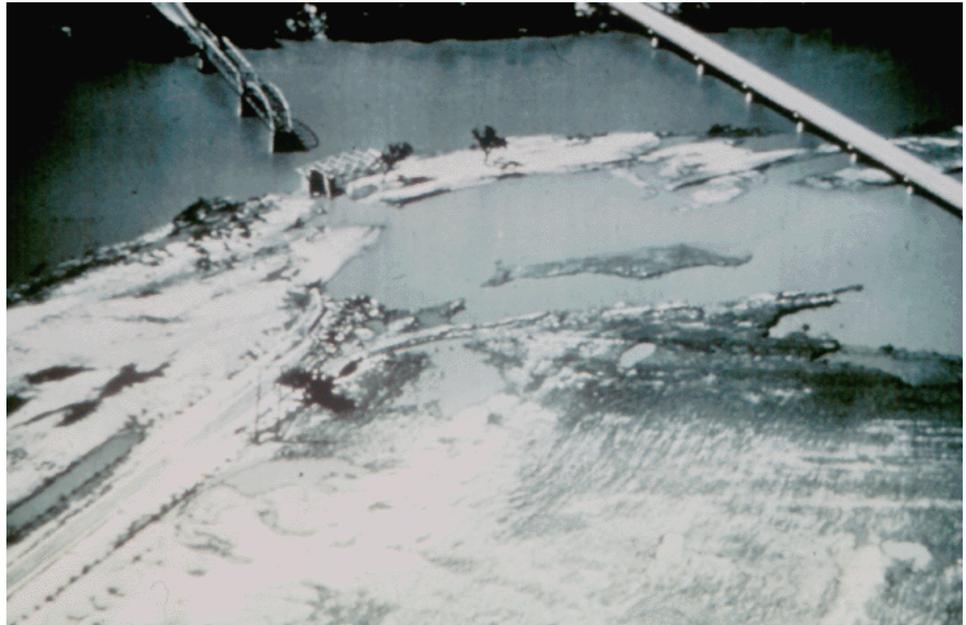


Figure 13.2.47 Approach Spans in the Floodplain



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

Scour Rate vs Velocity for Streambed Material

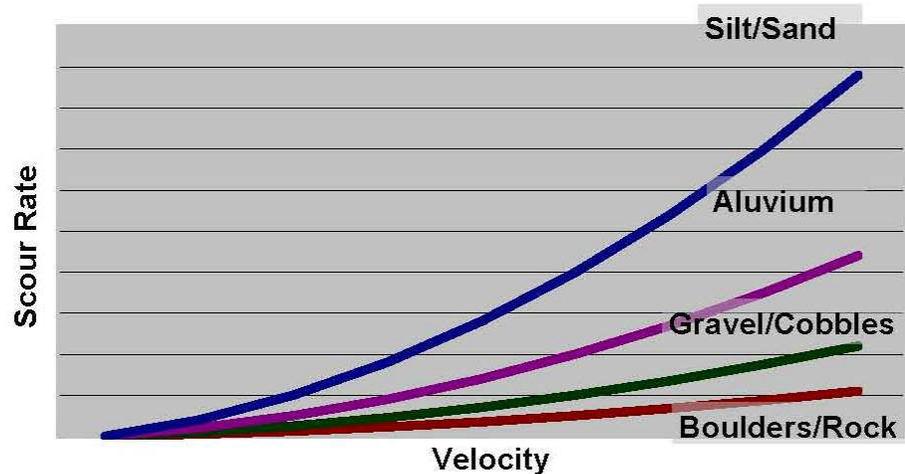


Figure 13.2.52 Scour Rates vs. Velocity for Common Streambed Materials



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).

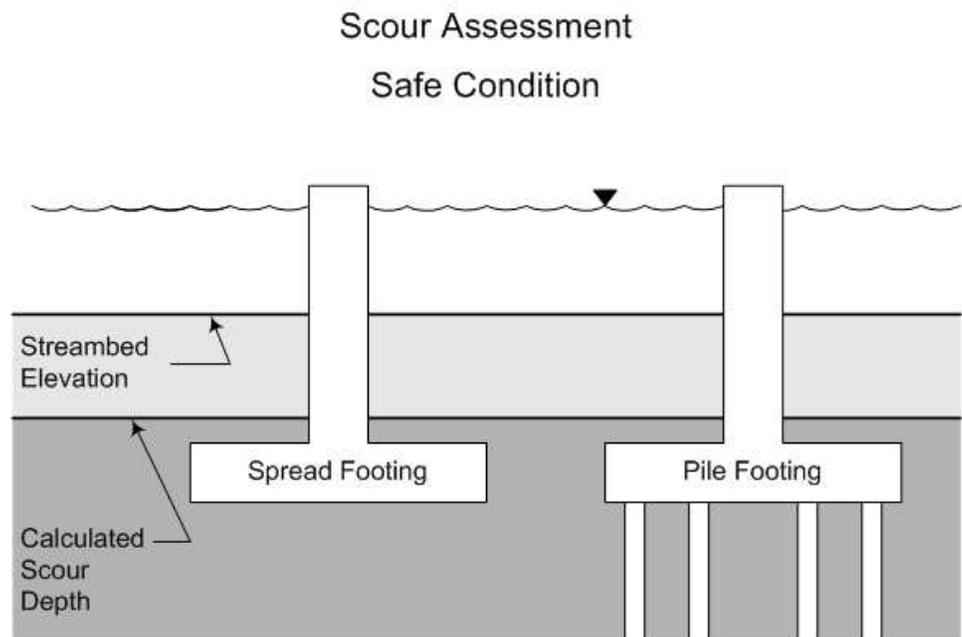


Figure 13.2.60 Scour Assessment - Safe

Scour Assessment
Evaluate Condition

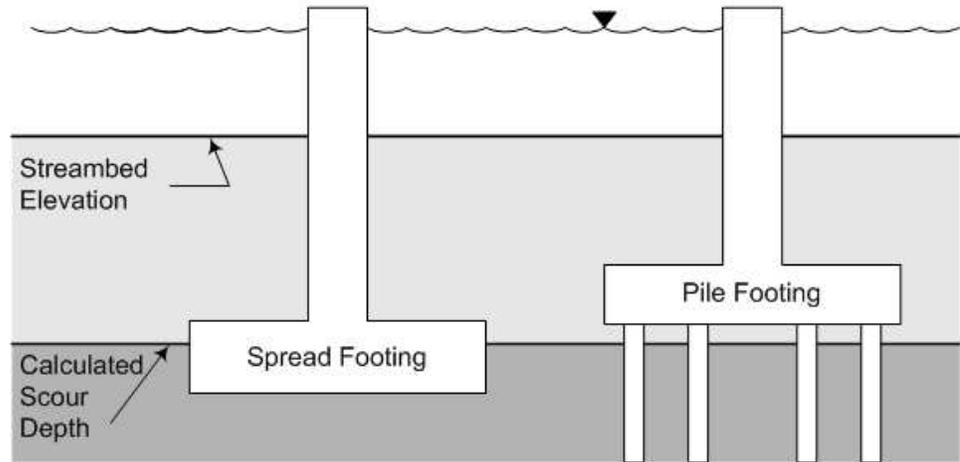


Figure 13.2.61 Scour Assessment - Evaluate

Scour Assessment
Fix Condition

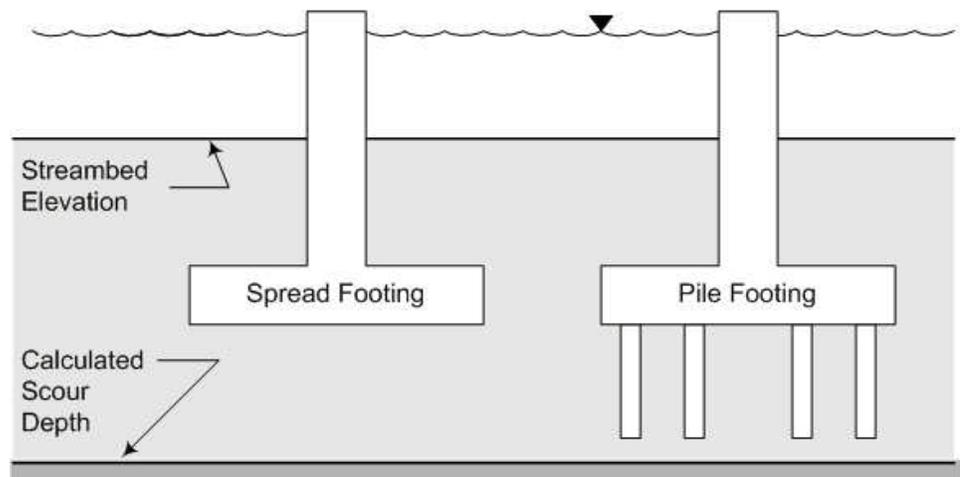


Figure 13.2.62 Scour Assessment - Fix

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

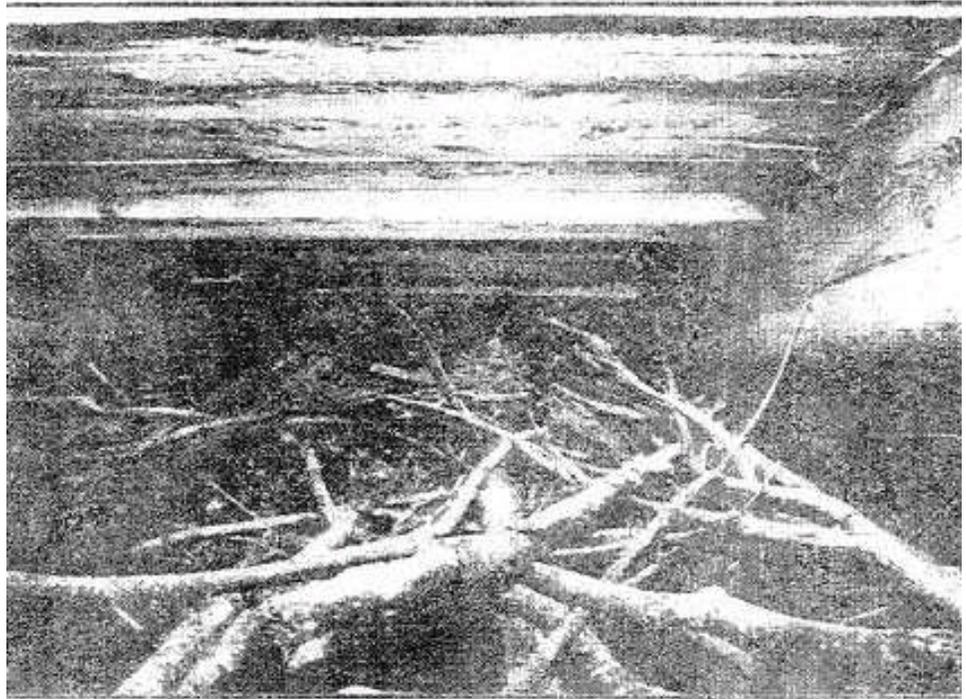


Figure 13.2.65 (Exhibit 65) Drift and Debris Inside Timber Box Culvert

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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:

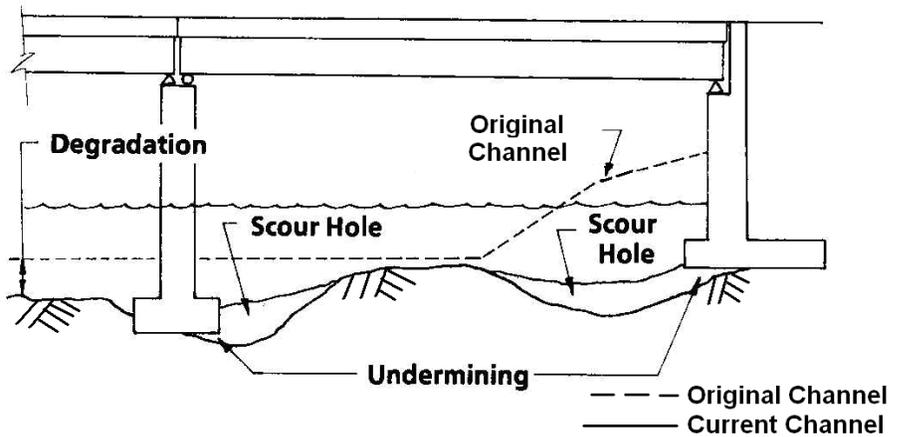
- A Level I inspection will be conducted on 100% of the underwater portion of the structure to determine obvious problems.
- A Level II inspection will be conducted on at least 10% of underwater units selected as determined by the Level I inspection.
- Scour evaluations which help give the cross-section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



Channel Cross-Section

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

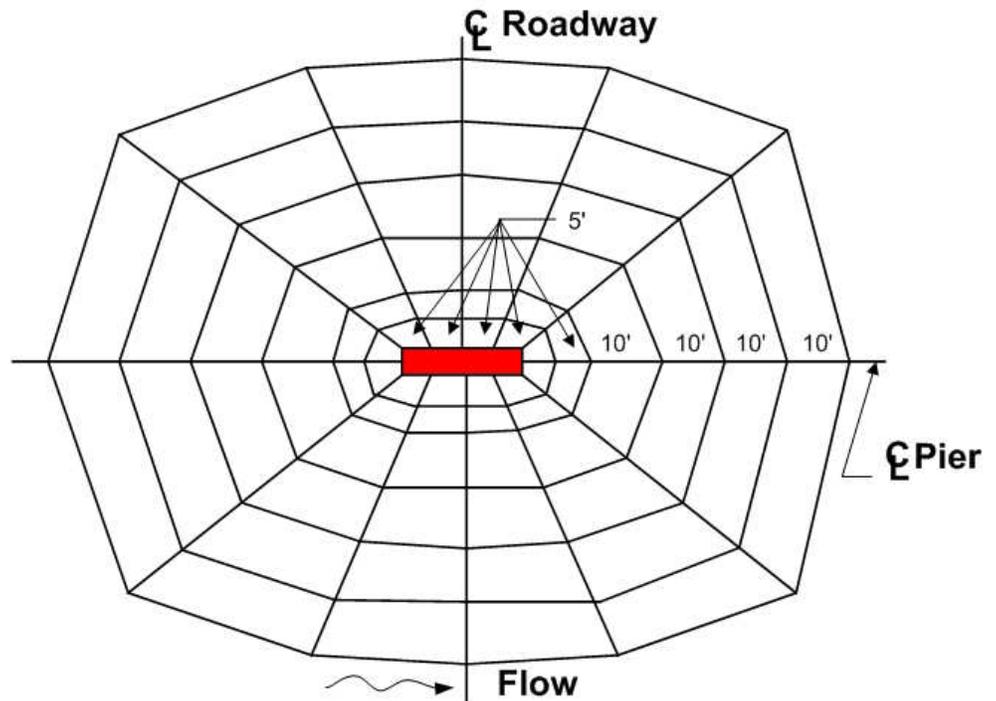


Figure 13.3.6 Pier Sounding Grid

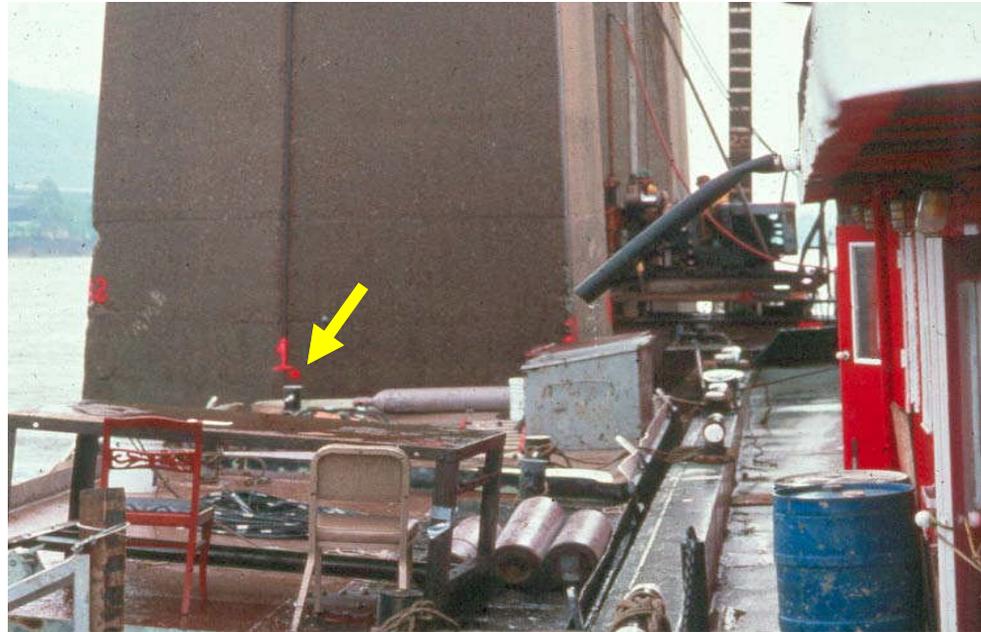


Figure 13.3.7 Permanent Reference Point (Bolt Anchored in Nose of the Pier, Painted Orange)



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 States, 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.

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)

Figure 13.3.13 Bridge Owner's Underwater Inspection Plan Checklist

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, _____

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

- 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

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

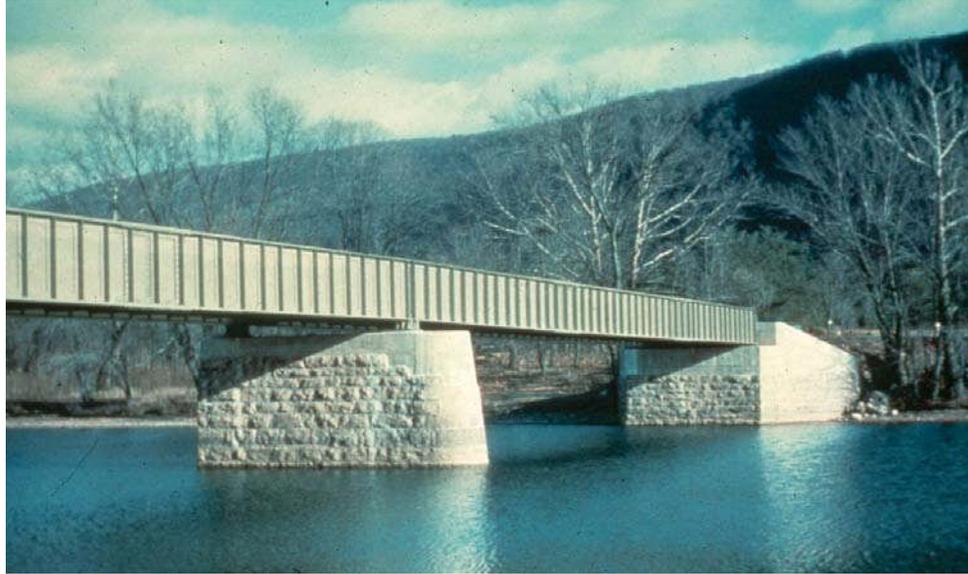


Figure 13.3.19 Solid Shaft Pier

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

<u>CODE</u>	<u>DESCRIPTION</u>
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	IMMINENT@ 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

<u>CODE</u>	<u>DESCRIPTION</u>
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	IMMINENT@ 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.

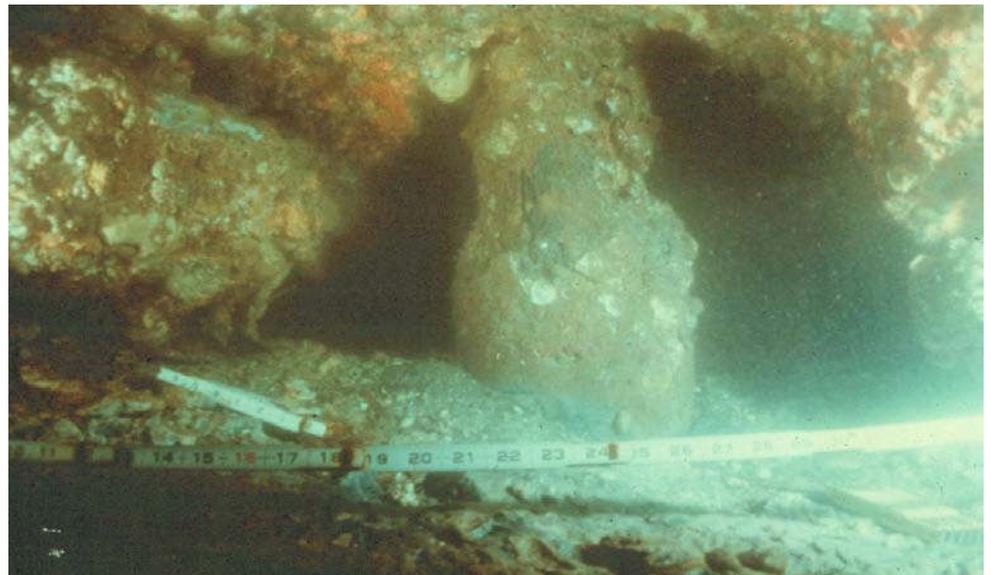


Figure 13.3.30 Cleaning a Timber Pile

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

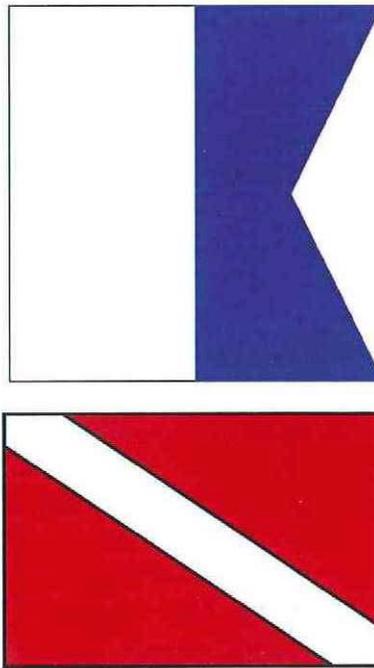


Figure 13.3.32 Alpha (top) and Sport Diver (bottom) Flags

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 knives, 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).

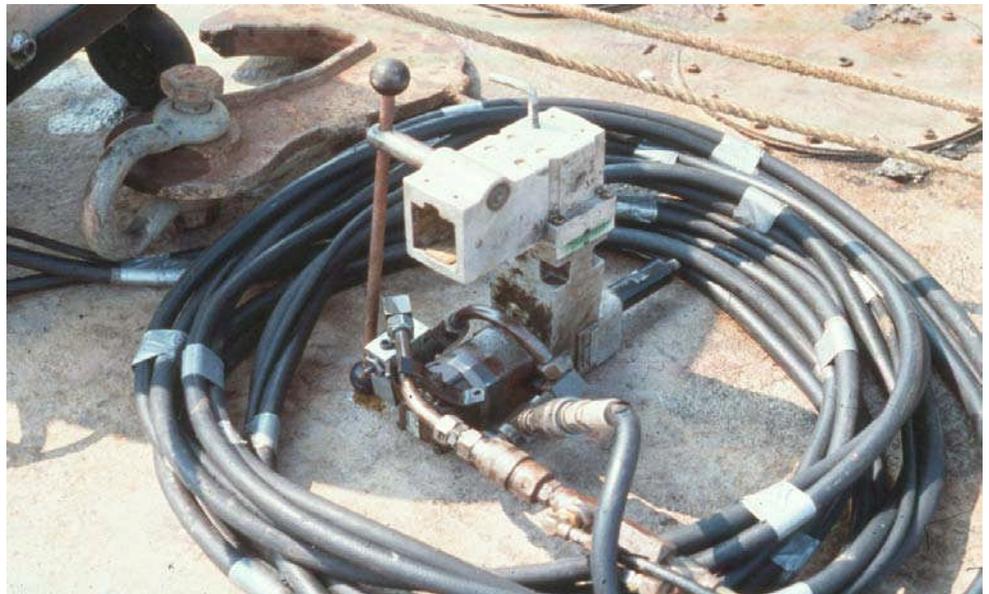


Figure 13.3.48 Coring Equipment

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.

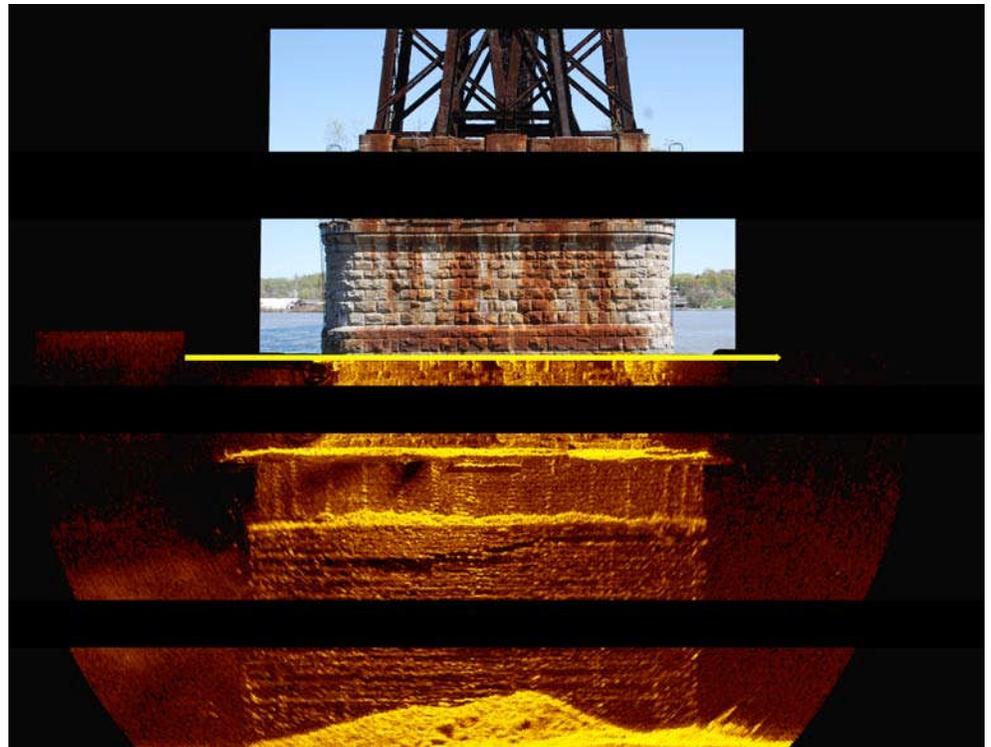


Figure 13.3.57 Acoustic Imaging of a Pier

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.

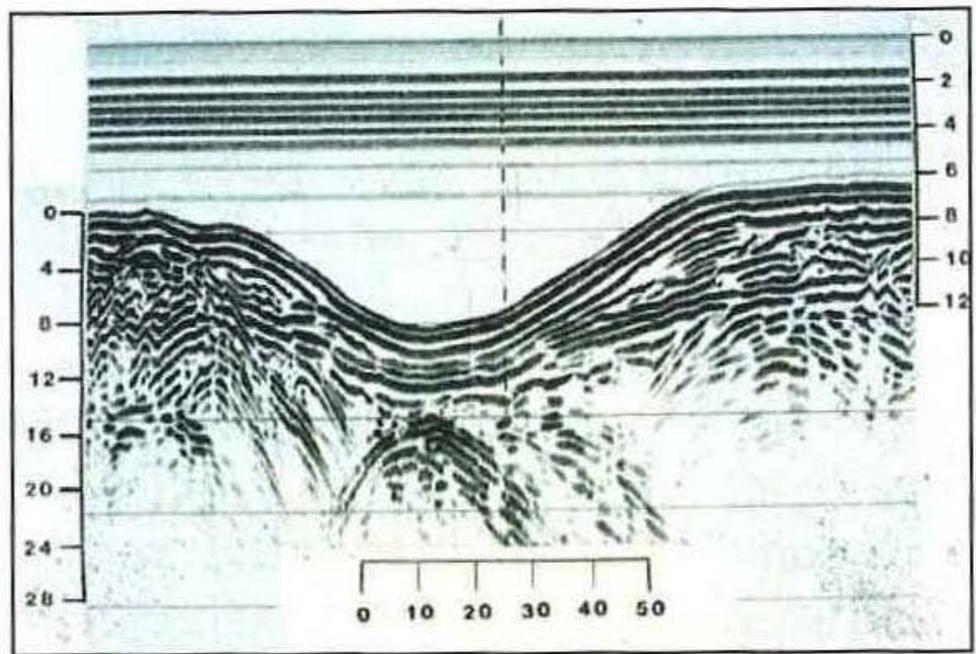


Figure 13.3.58 Ground Penetrating Radar Record

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).

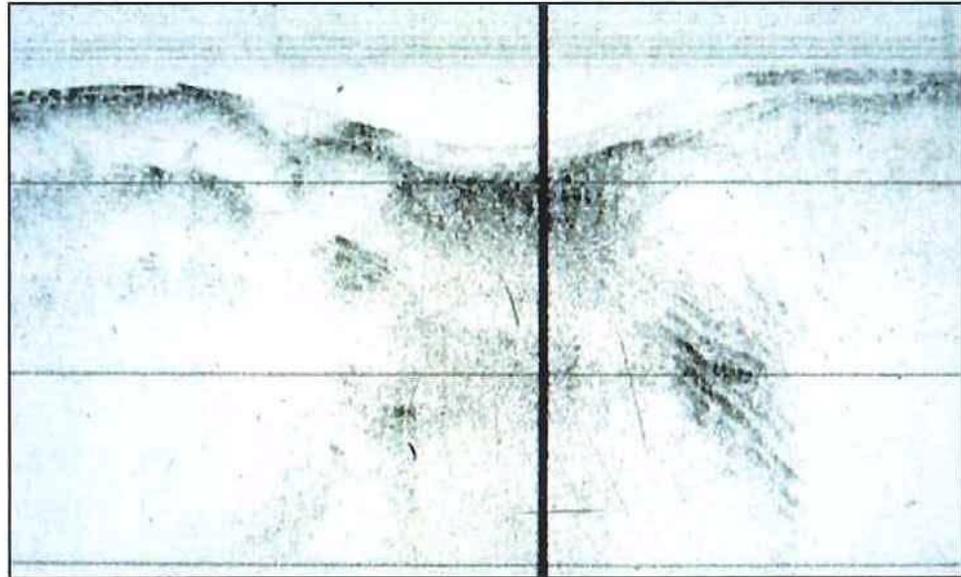


Figure 13.3.59 Tuned Transducer Record

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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