Table of Contents

Section 11
Inspection and Evaluation of Waterways

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Section 11

Inspection and Evaluation of Waterways

Topic 11.1 Waterway Elements

11.1.1 Introduction

Rivers are the most dynamic geomorphic system that engineers must 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, bridges do not usually move, other than in keeping with planned structural deflections resulting from anticipated static and dynamic loading of the structure.

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. 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 11.1.1). See Topic 11.2 for 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 stream flow so that an accurate assessment and record of the present condition of the bridge and waterway can be determined.

Figure 11.1.1 Pier Foundation Failure

11.1.2 Properties Affecting Waterways

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

- The physical characteristics of the bridge and waterway, including streambed material.
- 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 waterway.
- Changes in the river channel or flow due to development projects (such as dams, diversions, and channel stabilization) or natural phenomena.
- The physical interaction between the abutments, piers, and footings supporting the bridge and the impact of hydraulic conditions.
- 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 stream gravel mining or landslides.

11.1.3 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. 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 should be 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 11.2 for the inspection and evaluation of waterways.

11.1.4 Channel Characteristics

The channel is the well-defined depression that contains and guides stream flow during normal flow conditions (see Figure 11.1.2).

Elements of a Channel

- Streambed - the bottom or floor of the channel. The lowest elevation of the streambed is the "thalweg" elevation.
- Embankments - the sloped sides of the channel, which extend from the streambed to the surrounding ground elevation (floodplain).
- Streamflow - the water, suspended particles, chemicals, and any debris moving through the channel.

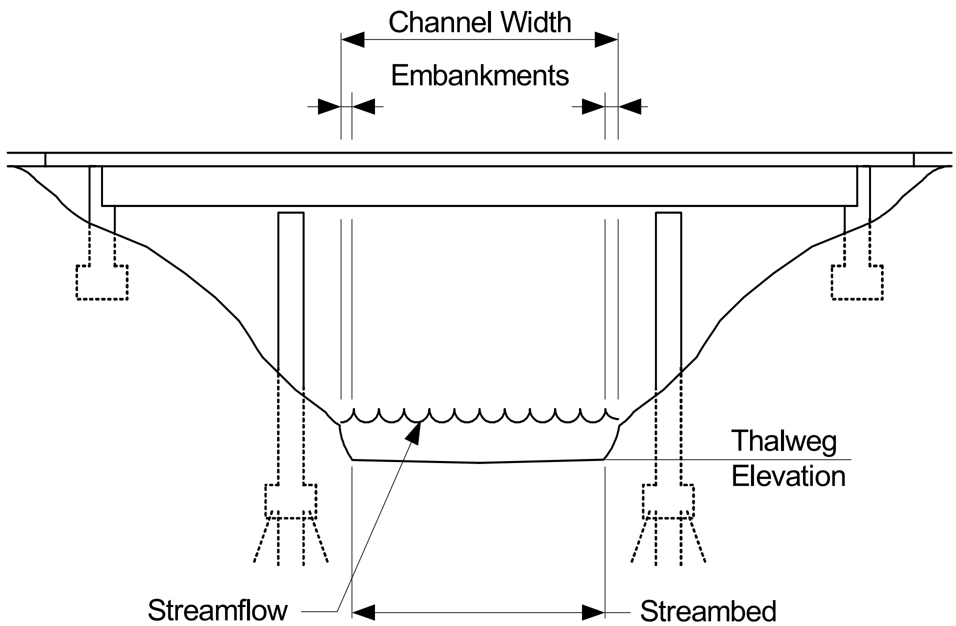


Figure 11.1.2 Typical Waterway Cross Section Showing Well Defined Channel Depression

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. They change at a relatively slow rate and in a predictable manner, except during catastrophic flood events. Figure 11.1.3 illustrates the major characteristics of a meandering river.

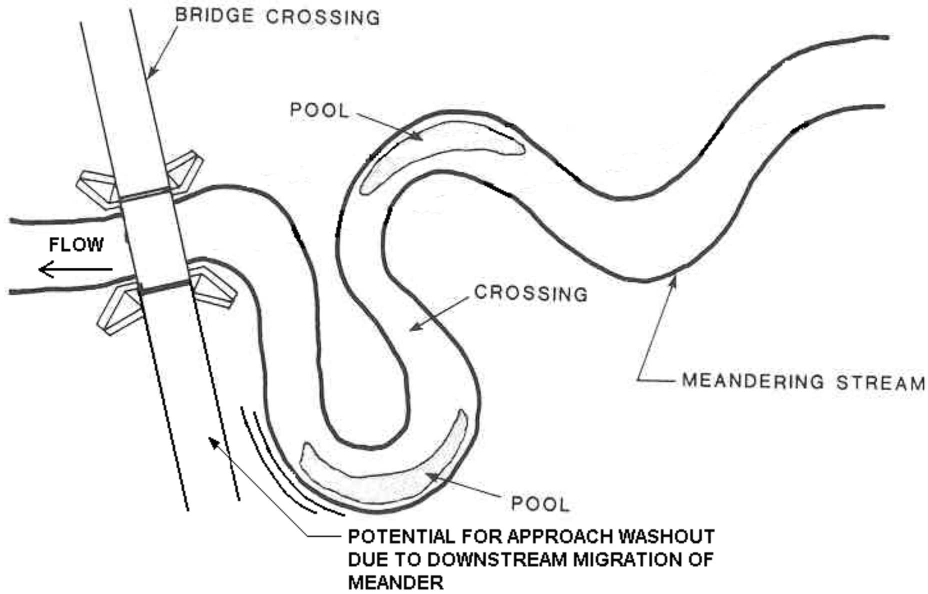


Figure 11.1.3 Meandering River

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 stream flow 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 11.1.4 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 measures. The characteristics of straight rivers are identified in Figure 11.1.4.

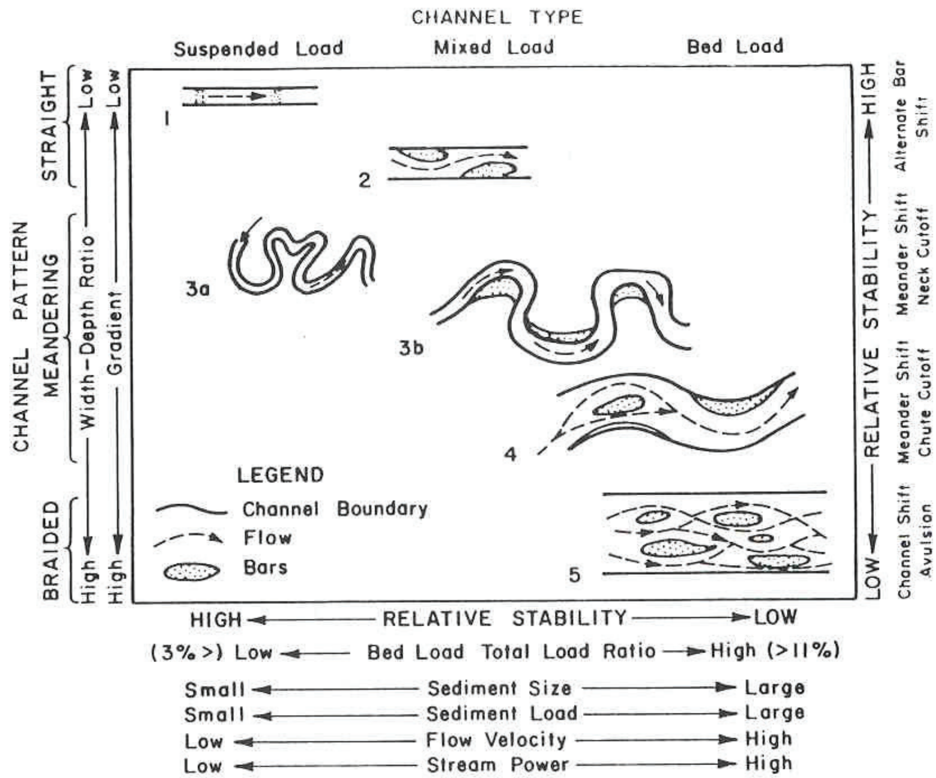


Figure 11.1.4 Plan View of Rivers

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.

11.1.5 Floodplain Characteristics

The floodplain is the overbank area outside the channel that carries flood flows in excess of channel capacity (see Figure 11.1.5). 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.

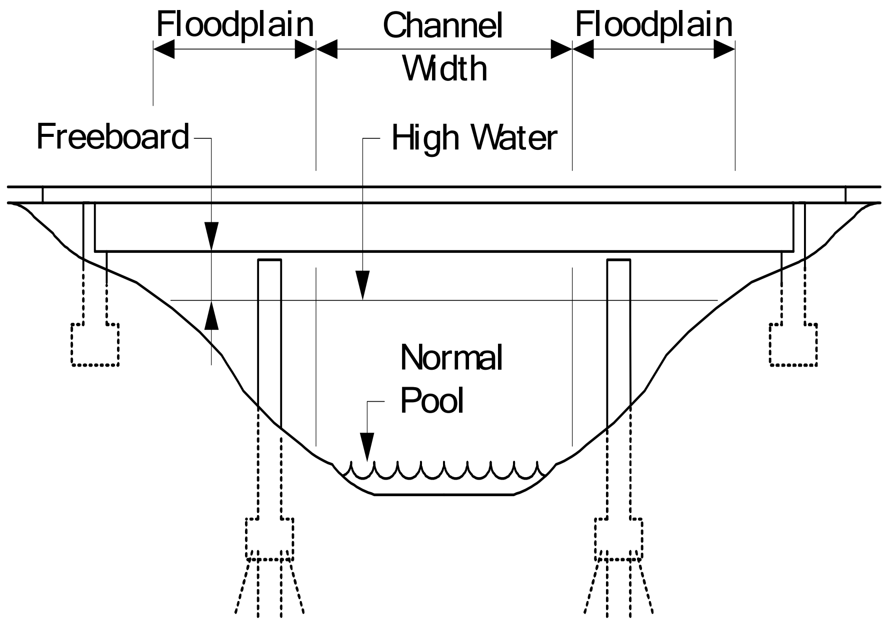


Figure 11.1.5 Typical Floodplain

11.1.6 Hydraulic Opening Characteristics

The hydraulic opening is the entire area beneath the bridge which is available to pass flood flows (see Figure 11.1.6). The bottom of the superstructure, the two bridge abutments, and the streambed or ground elevation binds the hydraulic, or waterway, opening. For multiple spans, intermediate supports such as piers or bents restrict the hydraulic or bridge waterway opening.

A common term, freeboard, is used to describe the distance from the bottom of the superstructure to the top of the water surface at a specific reference point (see Figure 11.1.5). Measurements of freeboard can fluctuate due to the flow rate in the waterway and the elevation of the streambed and floodplain. This measurement, in conjunction with average water depth, enables bridge inspectors to detect sudden or drastic changes in the water elevation from inspection to inspection by comparing freeboard measurements from past inspections. The term design freeboard is the expected freeboard at design flood flow.

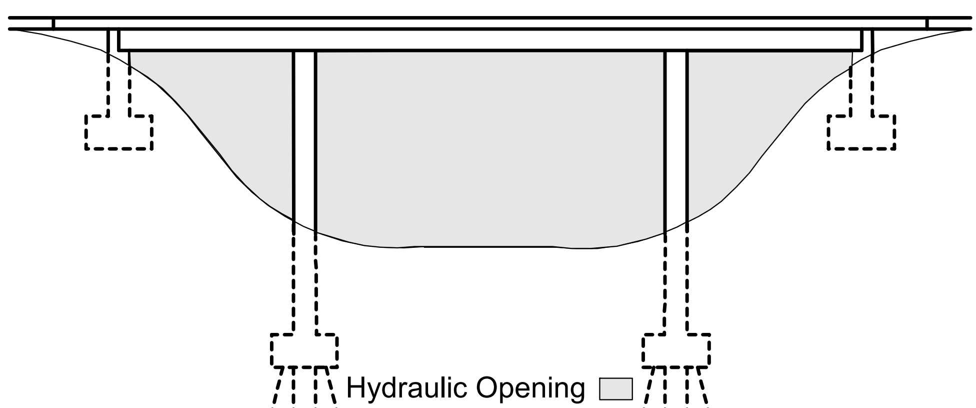


Figure 11.1.6 Hydraulic Waterway Opening

11.1.7 Hydraulic Control Structures Characteristics

Hydraulic control structures are often utilized to provide protection for bridges against lateral migration of the channel and against high velocity flows and scour. A hydraulic control structure is a man-made or man-placed device designed to direct stream flow and protect against lateral migration or undermining. These flow control structures may be utilized either at the bridge, upstream from the bridge, or downstream from the bridge. Control structures are designed by hydraulic and geotechnical engineers and are installed to redirect stream flow and flood flows within the watercourse and through the bridge waterway opening. Some of the more common hydraulic control structures include:

- Riprap
- Spurs
- Guidebanks
- Gabions
- Slope stabilization methods
- Channel lining
- Footing aprons

Riprap consists of properly sized and graded rock that is either natural or manmade, placed adjacent to abutments, piers, or along embankments (see Figure 11.1.7). 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 forces of the flowing water. This generally requires placement of the riprap on side-slopes that range between 1.5 or 3.0 horizontal to 1 vertical (1.5H:1V to 3H:1V), depending upon the design criteria. Flatter side-slopes of such as 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.

Spurs are devices designed to protect as well as redirect stream flow (see Figure 11.1.8). Common applications occur on meandering rivers. The spurs are placed at the outside of the meandering bends to redirect the flow and minimize lateral stream migration.

Guidebanks are constructed to redirect flood flows smoothly through the bridge waterway opening without endangering end substructure units from scour (see Figure 11.1.9). Scour hole formation occurs at the ends of the guidebanks rather than at the structure.

Gabions consist of rectangular rock-filled wire mesh baskets anchored together and generally anchored to the surface which they are designed to protect, such as embankments and substructure footings (see Figure 11.1.10). 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 consist of the placement of geotextiles, wire mesh, or plantings on the existing channel embankments (see Figure 11.1.11). It is anticipated the various stabilization methods will fill with sediment and help sustain plant growth. The roots from the plants contribute to stabilize the embankment or flood plane.

Channel lining is normally a concrete or bituminous pavement on the channel embankment and sometimes extends across the streambed. Channel linings also may be revetment mats or some other form of bed armoring (see Figure 11.1.12). A typical revetment mat is formed by interlocking precast concrete blocks placed on a geotextile fabric. The interlocking matrix allows for use over varying land contours and grades.

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 11.1.13). Footing aprons protect footings from undermining. The aprons are not a structural element of the abutment or pier footings.

Figure 11.1.7 Crushed Stone Riprap

Figure 11.1.8 Spurs Constructed on Mackinaw River (Illinois Route 121)

Figure 11.1.9 Guidebanks Constructed on Kickapoo Creek Near Peoria, Illinois

Figure 11.1.10 Gabion Basket Serving as Slope Protection

Figure 11.1.11 Wire Mesh and Grass Slope Stabilization

Figure 11.1.12 Concrete Revetment Mat (Photo Courtesy of CSI Geosynthetics)

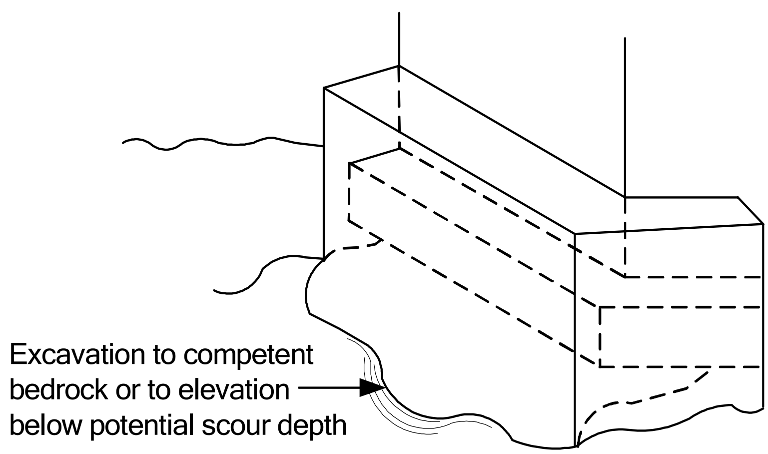


Figure 11.1.13 Concrete Footing Apron to Protect a Spread Footing from Undermining

Table of Contents

Section 11

Inspection and Evaluation of Waterways

Topic 11.2 Inspection of Waterways

11.2.1 Introduction

The bridge inspector must 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, the bridge inspector should have a thorough understanding of the different types of waterway elements and deficiencies, as well as the various inspection techniques. See Topic 11.1 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 affected.

11.2.2 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. 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 should be carefully noted. Observations of local change in flow directions and surveys of changes in bed and bank elevations must also be made. 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 11.2.1).

Figure 11.2.1 Flood Flow Around a Pier Showing 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. The lateral location of these surveyed points should be noted 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. 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 should be 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. The inspector should 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.

11.2.3 Waterway Deficiencies

Scour

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

Degradation and aggradation are long-term streambed elevation changes. Degradation is the gradual and even lowering of the streambed elevation due to a deficiency in sediment load available for transport via the stream (see Figure 11.2.2). Aggradation is the gradual and even rise in streambed elevation from deposition or buildup of streambed material, due to an overabundance of sediment load available for transport via the stream. (see Figure 11.2.3).

Figure 11.2.2 Streambed Degradation

Figure 11.2.3 Streambed Aggradation

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 four forms of scour that must be considered in evaluating the safety of bridges:

- General scour
- Contraction scour
- Local scour
- Lateral stream migration

General Scour

General scour can occur in a short time with the right conditions. General scour or degradation scour would occur whether or not there was a bridge crossing or constriction in the stream. General scour degrades the bed along some considerable length of the river (see Figure 11.2.4).

Figure 11.2.4 General Scour

General scour 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. General scour 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

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. Since general scour involves degradation of the channel bed 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 general scour 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)
- Other land use changes

These changing conditions may cause aggradation, loss of waterway cross section, or general scour. This may reduce the degree of safety experienced by the abutments and the piers, 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 should be 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 11.2.5 and 11.2.6). 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 11.2.7).

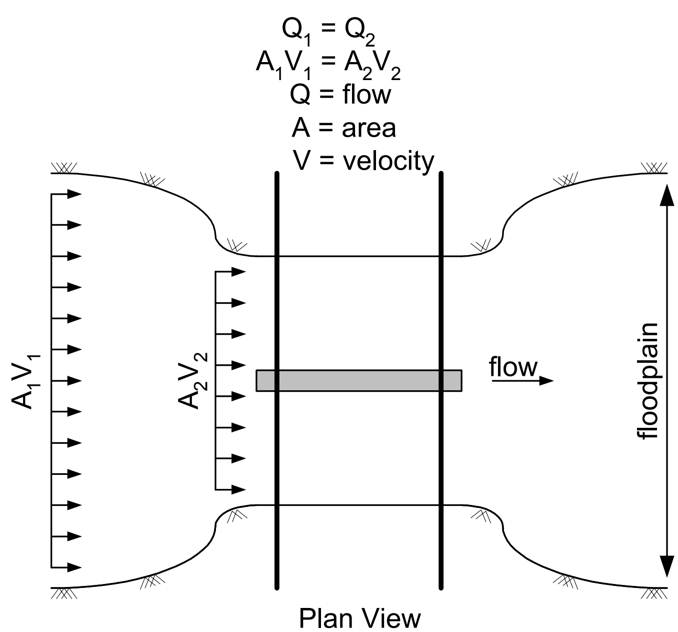


Figure 11.2.5 Severe Contraction Scour

Figure 11.2.6 Severe Contraction Scour at a Multiple-Span Bridge Site

Figure 11.2.7 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 11.2.7)
- Heavy vegetation in the waterway or floodplain (see Figure 11.2.8).
- 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 (see Figure 11.2.5).

- 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 11.2.9).
- Ice formation or ice jams that temporarily reduce the waterway opening and produce contraction (see Figure 11.2.10).
- Debris buildup, which often reduces the waterway opening (see Figure 11.2.11).

The effects of contraction scour can be very severe.

Figure 11.2.8 Vegetation Constricting the Waterway

Figure 11.2.9 Sediment Deposits Within the Waterway Opening

Figure 11.2.10 Ice in Stream Resulting in Possible Contraction Scour

Figure 11.2.11 Debris Build-up in the Waterway

Local Scour

Local scour occurs around an obstruction that has been placed within a stream, such as a pier or an abutment and 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 11.2.12). Some common obstructions are:

- Abutments – floodplain overbank flow is collected along and forced around abutments at high velocities (see Figure 11.2.13).
- Wide Piers - scour depth is proportional to width (see Figure 11.2.14).
- Long Piers - can produce multiple vortices and greater scour depth if the pier is at an angle to the flow direction (see Figure 11.2.15).
- 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 11.2.16).
- 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 cakes piled up against piers can produce the same effect as a wider pier, increasing both contraction and local scour effects. Debris should be removed as a safety precaution to prevent pier failure

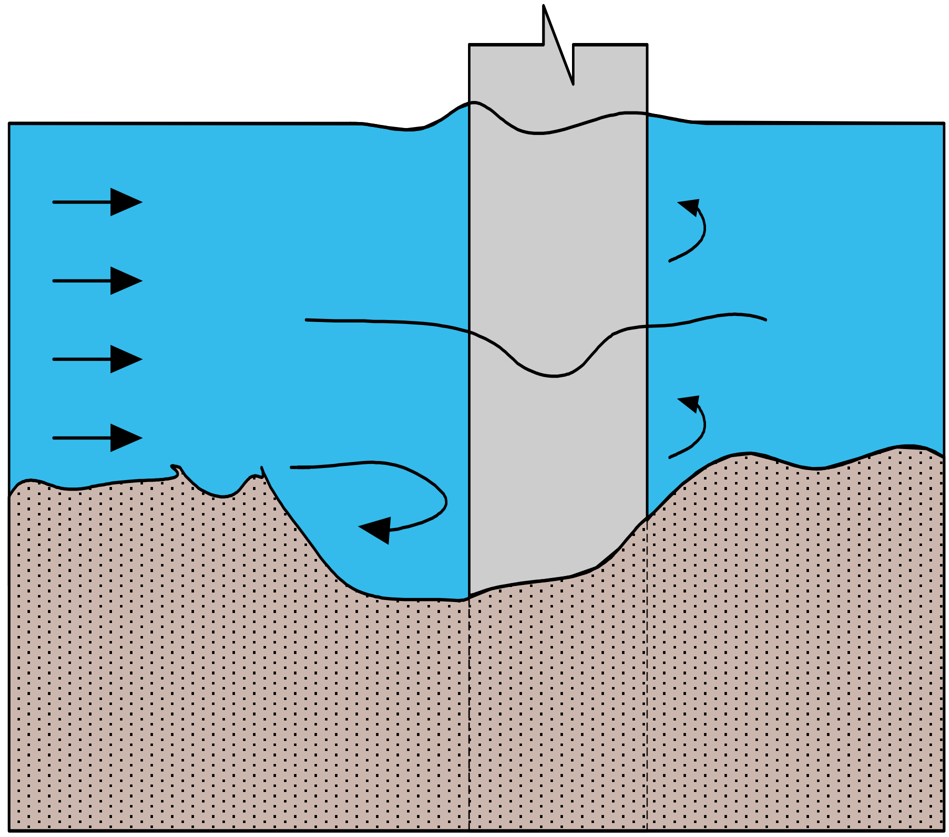


Figure 11.2.12 Local Scour at a Pier

Figure 11.2.13 Local Scour at an Abutment

Figure 11.2.14 Wide Pier

Figure 11.2.15 Long Pier

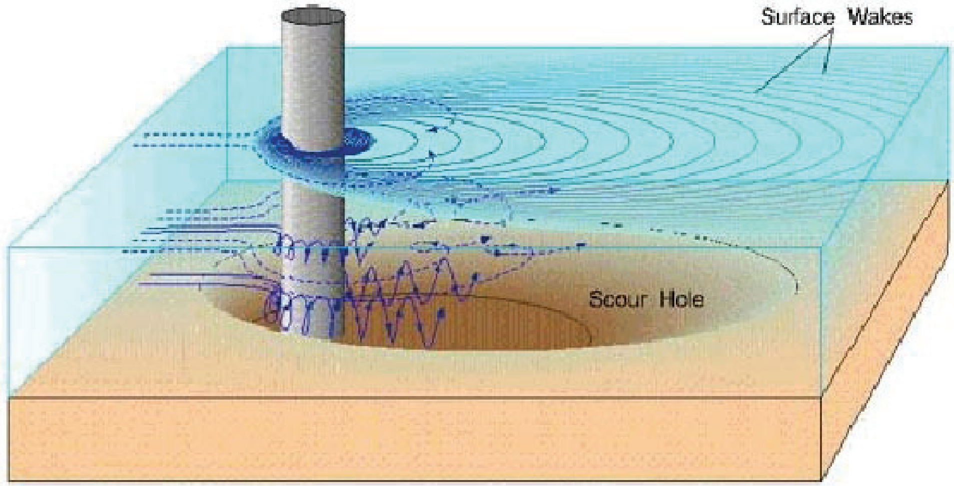


Figure 11.2.16 Local Scour Due to Streamflow Behavior in Deep Water

Scour depths resulting from local scour are larger 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, critical supporting elements of the bridge should be subjected 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, remedial measures must be taken 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 should 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, a bridge rating should be based 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.

The inspector should 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 scour 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 are often threatened by this type of scour (see Figure 11.2.17).

Figure 11.2.17 Lateral Stream Migration Endangering a Full Height Abutment

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 (see Figure 11.2.18)
- Channel widening or degradation (see Figure 11.2.19)
- Manmade channel changes

Figure 11.2.18 Stream Meander Changes

Figure 11.2.19 Channel Widening

11.2.4 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, careful consideration should be given 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. A careful record of changes in characteristics of materials should be recorded 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 11.2.20). 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.

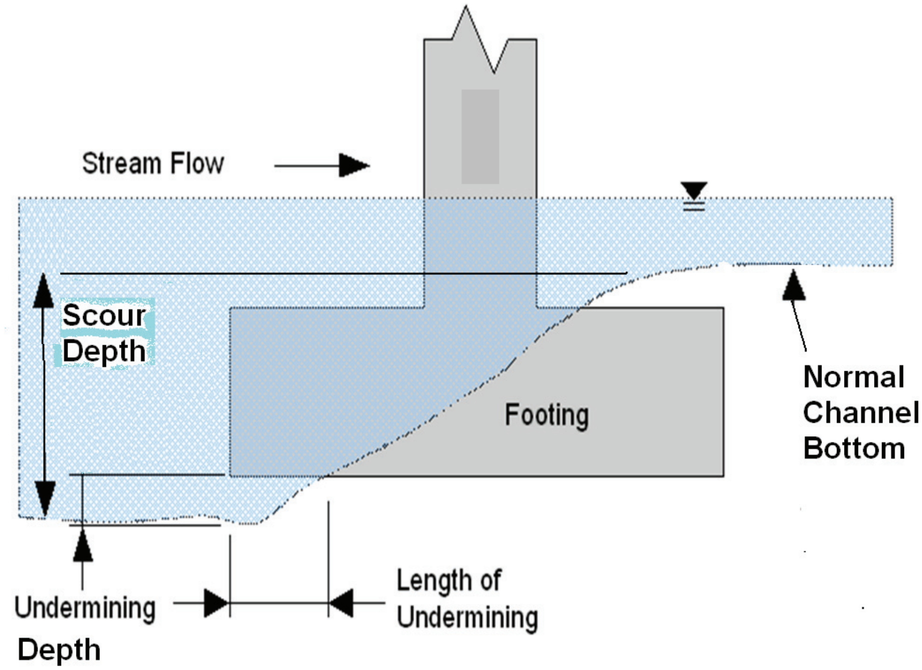


Figure 11.2.20 Scour and Undermining

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. Undermining can pose an immediate threat to safety and must be addressed immediately.

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, the inspector should take detailed measurements, showing the height, width, and penetration depth of the undermined cavities. Refer to Topic 11.3 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 11.2.21).

Figure 11.2.21 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.

11.2.5 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, the inspector should develop a detailed plan of investigation, as well as forms for recording observations. A systematic procedure should be used 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 Requirements

Prior to beginning the inspection, the bridge inspector should 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 11.2.22). 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 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 3.4. 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 11.2.22)
- Sounding line (lead line to measure depths of scour)
- Fathometer to determine water depth
- Diving equipment (see Figure 11.2.23 and Topic 11.3)
- 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

Figure 11.2.22 Probing Rod and Waders

Figure 11.2.23 Surface Supplied Air Diving Equipment

Special Considerations

Special considerations should be given 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 11.2.24).

Navigational control is necessary when inspecting large waterways. The Coast Guard should be notified 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 11.2.25).

Figure 11.2.24 Rapid Flow Velocity

Figure 11.2.25 Navigable Waterway

11.2.6 Inspection Procedures and Locations

Inspection procedures include:

- Visual
- Probing
- Measure/Document

Visual

The primary method used to inspect waterways is visual. The inspector must look at the site in the vicinity of the bridge. The inspector also needs to look at the flood plain. This observation may have to be done during periods of high water flow.

Probing

After the inspector gets the general condition by visually inspecting the bridge site, the next step is to probe for any scour or undermining. Care should be taken 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.

Measure/Document

Measurements to obtain the cross section and profile must be taken. 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 11.2.26 and 11.2.27). The streambed profile and hydraulic opening should be compared to previous inspections.

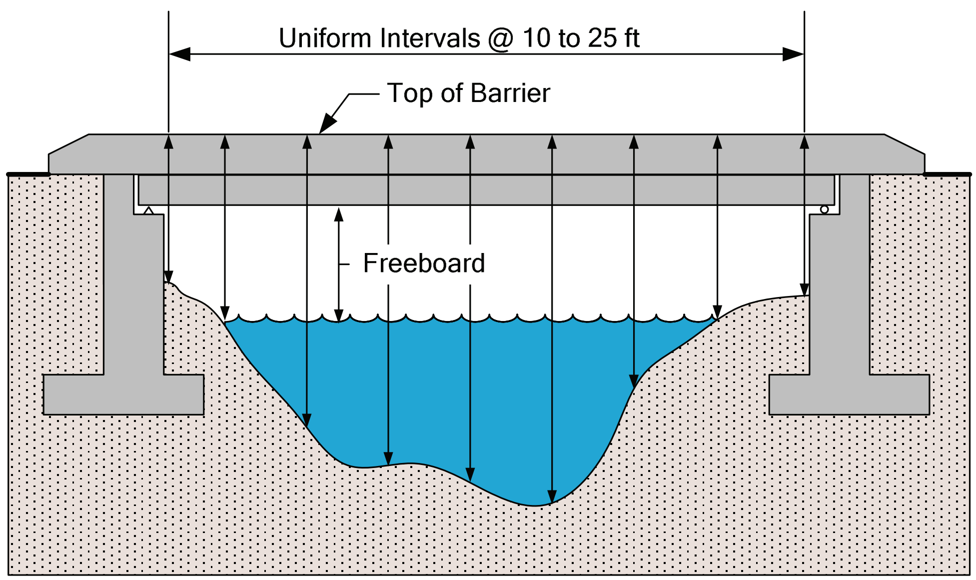


Figure 11.2.26 Streambed Cross-Section

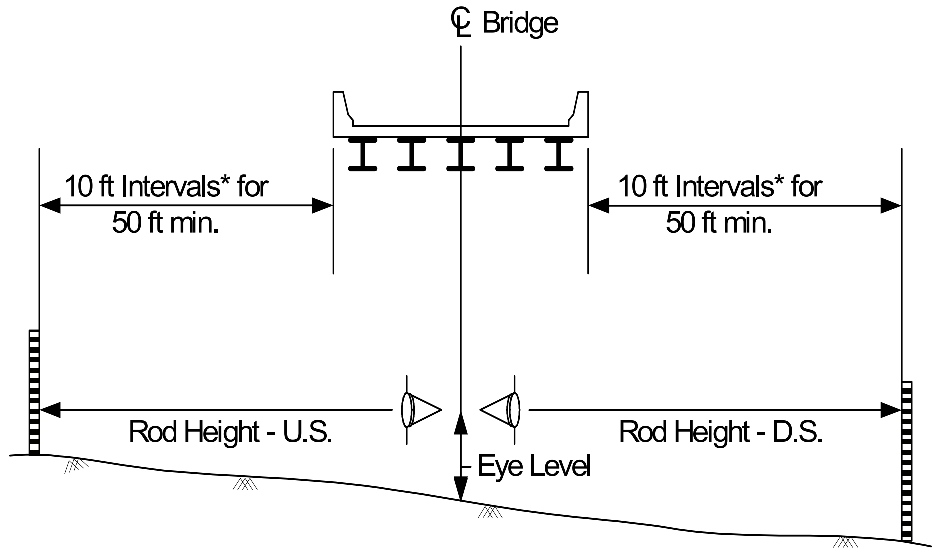


Figure 11.2.27 Streambed Profile

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 11.2.28).
- 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 11.2.29).
- 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 11.2.28 Pile Bent Deterioration Normally Hidden Underwater

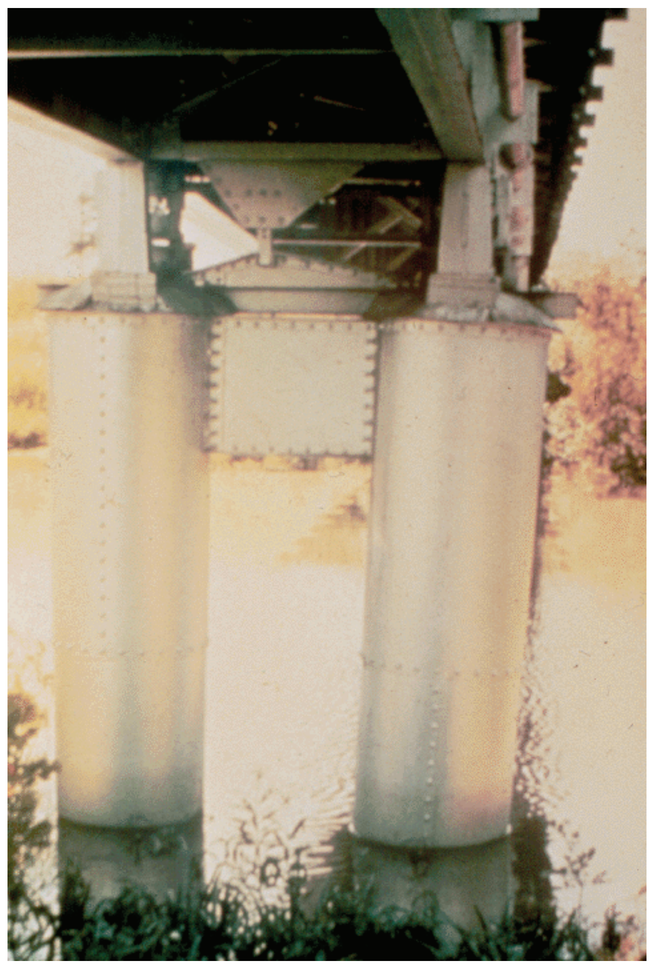


Figure 11.2.29 Out of Plumb Pier Column

Superstructure

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

The following items should 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 11.2.30).
- Check to see if debris is lodged in superstructure elements or tree limbs above the superstructure (see Figure 11.2.31).
- 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 in the floodplain.
- 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 11.2.32).

Figure 11.2.30 Superstructure Misalignment

Figure 11.2.31 Drift Lodged in a Superstructure

Figure 11.2.32 Typical Simple Multi-Span 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 11.2.33).
- 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 11.2.33 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. The inspector should also look for irregularities in the embankment slope.

It is even more 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 will be necessary for the inspector 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.
- Determine the streambed material.
- Check for degradation (see Figure 11.2.34).
- 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 in the floodplain (see Figure 11.2.35).
- Examine approaches for signs of overtopping.
- Determine if the hydraulic opening is causing or has the potential to cause scour under the bridge.

Figure 11.2.34 Severe Streambed Degradation Evident at Low Water

Figure 11.2.35 Approach Roadway Built in the Floodplain

Upstream and Downstream Channel

Banks

- Stable - gradually sloped, grass covered with small trees. Banks are still basically in their original locations. Slope stabilization measures are in place and intact (see Figure 11.2.36).
- Unstable **-** bank is sloughing due to scour, evidence of lateral movement or erosion, damage to slope stabilization measures (see Figure 11.2.37).

Figure 11.2.36 Stable Banks

Figure 11.2.37 Unstable, Sloughing Banks

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 11.2.38 and 11.2.42).
- 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 11.2.39).
- 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 11.2.40).
- 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 11.2.38 Sediment Accumulation Redirecting Streamflow

Figure 11.2.39 Fence in Stream at Bridge

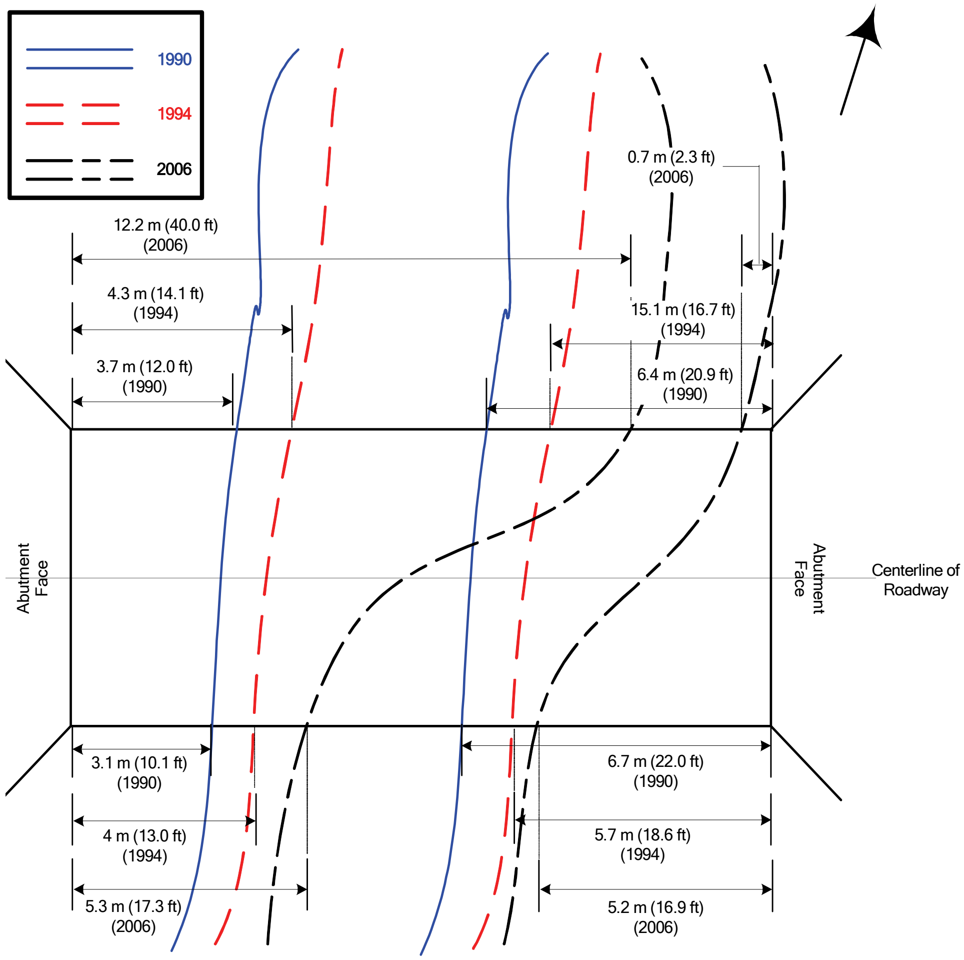


Figure 11.2.40 Waterway Alignment 1990 - 2006

Floodplain

- Check for evidence of embankment sloughing, undermining, and lateral embankment movement resulting from significant stream flow.
- 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 (see Figure 11.2.41).
- 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 11.2.42).

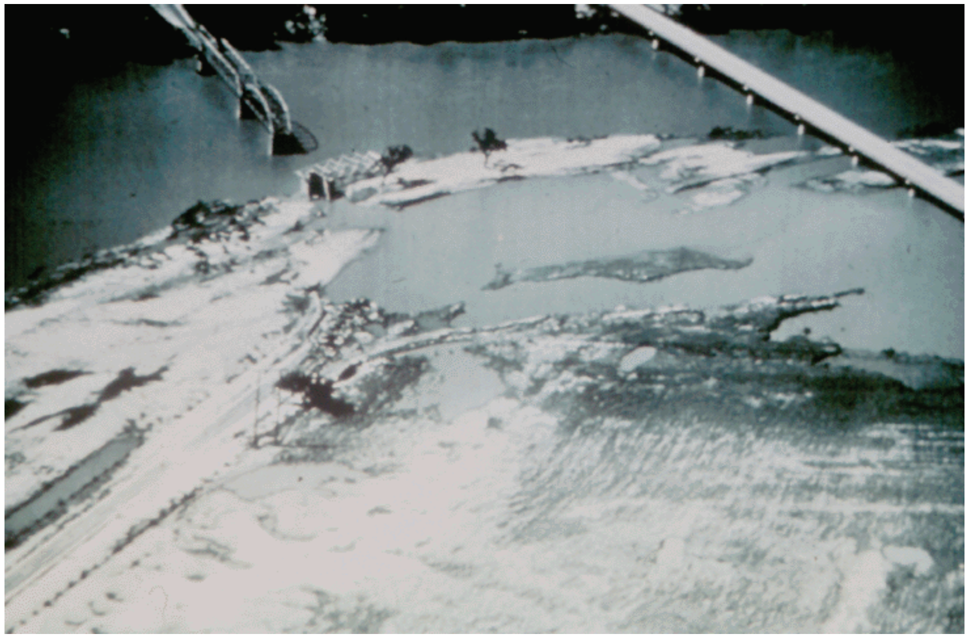


Figure 11.2.41 Approach Spans in the Floodplain

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 11.2.43). 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 11.2.42 Debris and Sediment in the Downstream Channel

Figure 11.2.43 Upstream Dam

11.2.7 Evaluation

Scour Potential Assessment

Bridges over streams and rivers are subject to scour and should be 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.
- A plan of action should be developed 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 for a scour potential assessment that:

- Accurately records the present condition of the bridge and the stream (see Figure 11.2.44).
- 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, the bridge should be further evaluated by an interdisciplinary team made up of structural, geotechnical, and hydraulic engineers.

Figure 11.2.44 Scour at a Pile Abutment

Recognition of Scour Potential

The inspector must 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 11.2.45 and 11.2.46).
- Streambed materials such as loose cohesive soils, sand or gravel material, are highly susceptible to accelerated scour rates (see Figure 11.2.46).
- 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 11.2.47).
- 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 11.2.48).

- Banks that are sloughing, undermined, or moving laterally are signs of potential scour at a bridge (see Figure 11.2.49).

Figure 11.2.45 Fast Flowing Stream

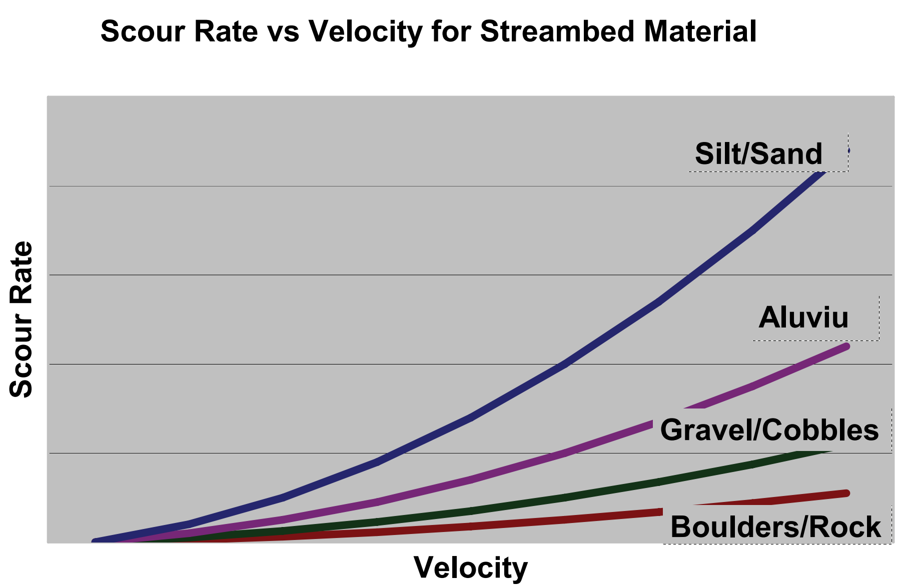


Figure 11.2.46 Scour Rates vs. Velocity for Common Streambed Materials

Figure 11.2.47 Typical Misaligned Waterway

Figure 11.2.48 Typical Large Floodplain

Figure 11.2.49 Lateral Stream Migration

Substructure

The following condition of bridge foundations and substructure units should be considered in the inspector's 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 11.2.50).
- Rotational, horizontal, or vertical movement of piers and abutments are evidence of undermining (see Figure 11.2.51).
- 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 11.2.52).
- Restriction 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 11.2.53).

Figure 11.2.50 Stream Alignment Not Parallel with Abutments

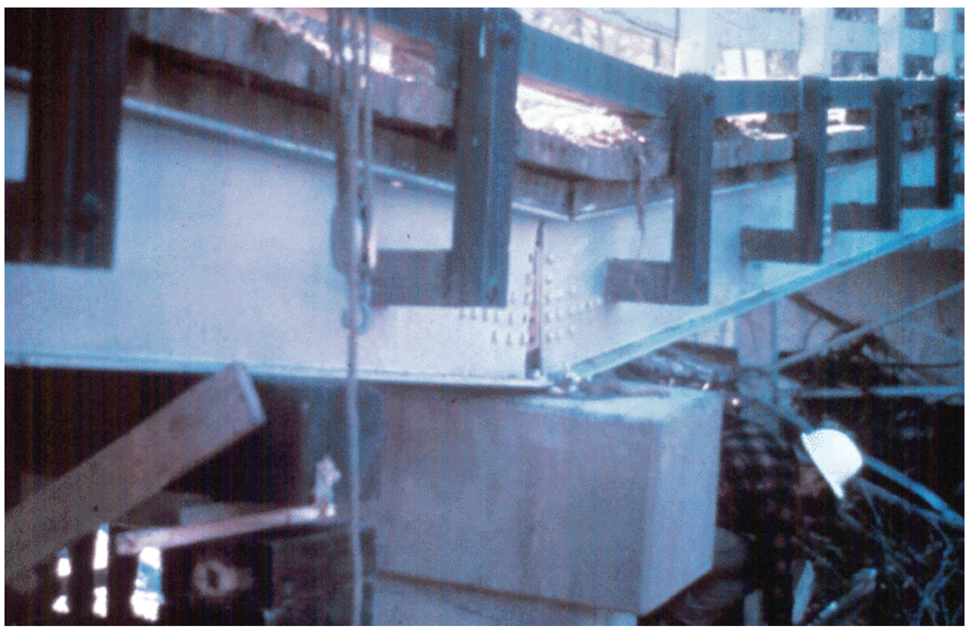


Figure 11.2.51 Rotational Movement and Failure Due to Undermining

Figure 11.2.52 Exposed Piling Due to Scour

Figure 11.2.53 Accelerated Flow Due to Restricted Waterway

Superstructure

The following conditions associated with the superstructure should be considered 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 Rating Guidelines

Scour Evaluation

The factors to be considered in a scour evaluation require a broader scope of study and effort than those considered in a bridge inspection. 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 Rating Guidelines.

Substructure (Item 60)

Substructure rating is a key item for rating the bridge foundations for vulnerability to scour damage. When a bridge inspector finds that a scour problem has already occurred, it should be considered in the condition rating of the substructure. If the bridge is determined to be scour critical, the condition rating for Item 60 should be further evaluated to ensure that any existing problems have been properly considered. The rating factor given to Item 60 should be consistent 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. The condition of the channel, adjacent rip-rap, bank protection, guidebanks, and evidence of erosion, channel movement or scour should all be considered 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 by a bridge inspector, the bridge should 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 11.2.54).
- 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 11.2.55).
- 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 11.2.56).

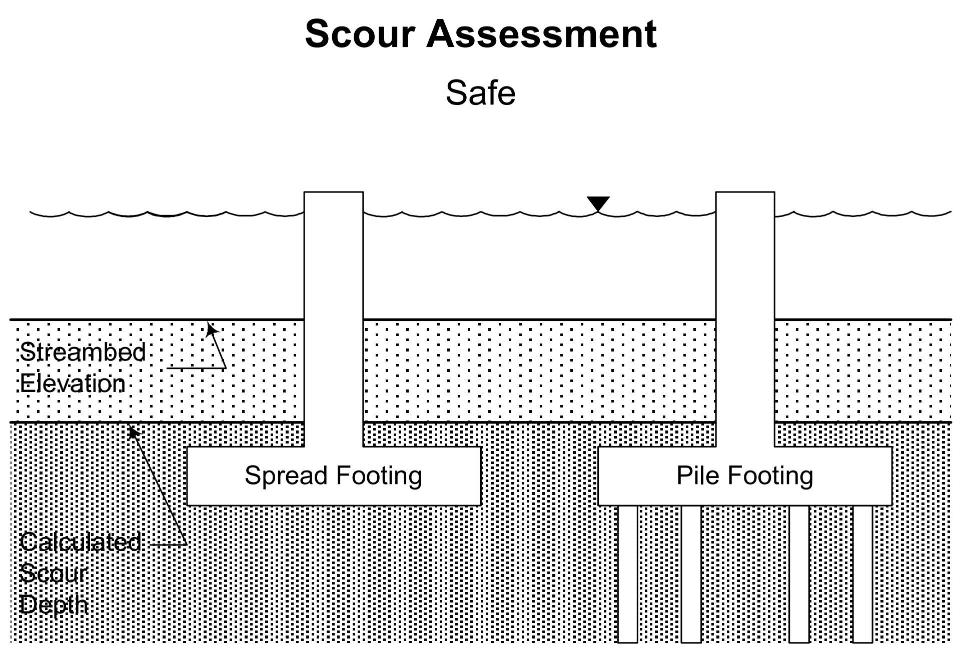


Figure 11.2.54 Scour Assessment - Safe

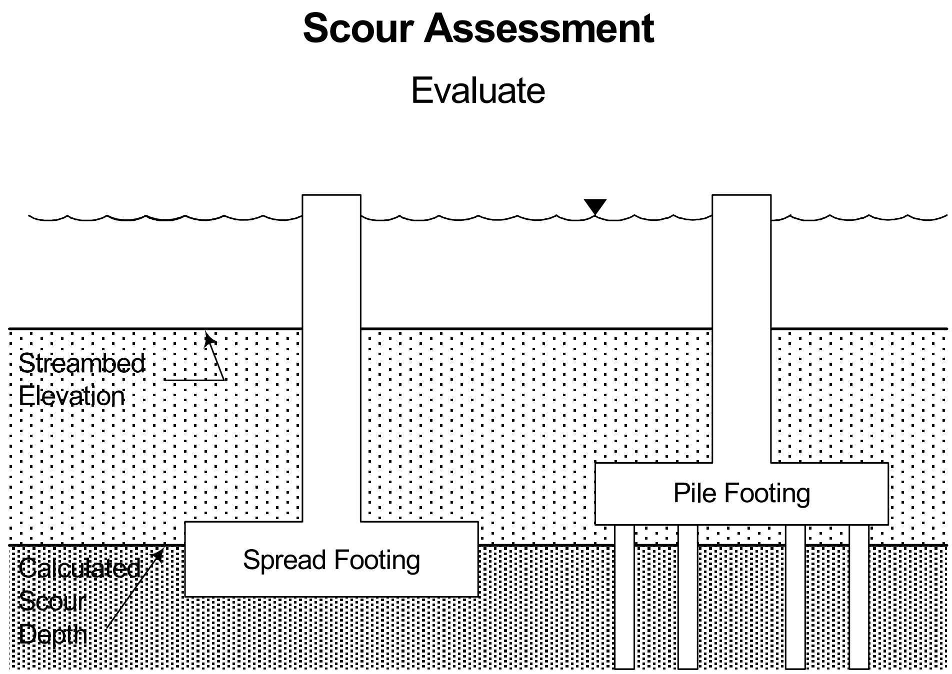


Figure 11.2.55 Scour Assessment - Evaluate

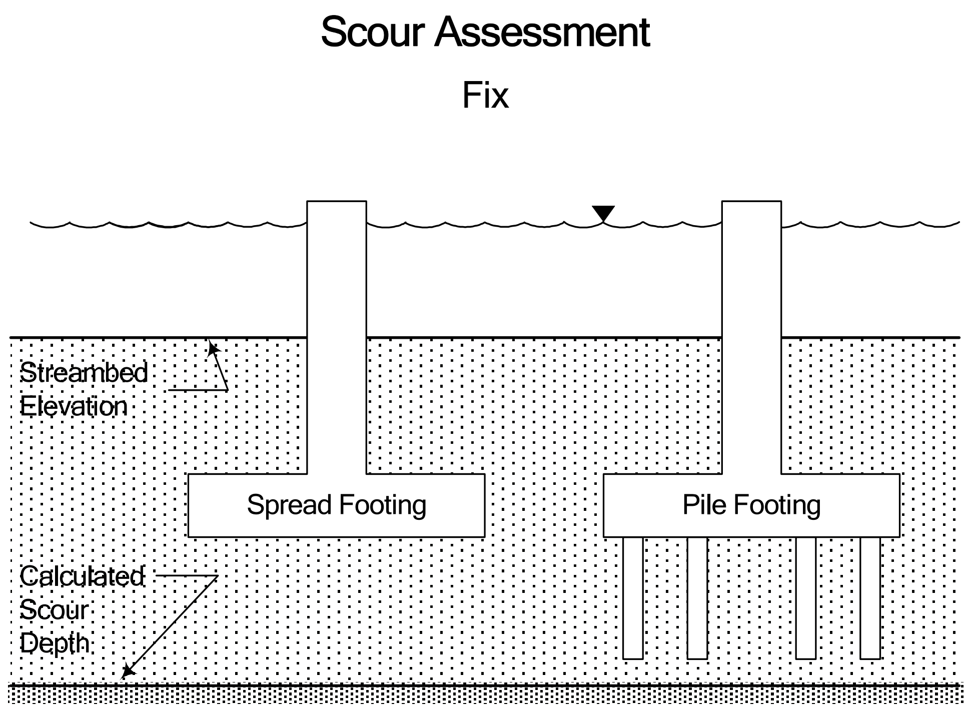


Figure 11.2.56 Scour Assessment - Fix

For scour critical bridges, the NBIS requires that a Plan of Action must be developed for monitoring and correcting the scour problem. Bridges which are scour critical must then be monitored in accordance with the plan. 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, however, and probably will occur again in the future.

11.2.8 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 11.2.57 (Exhibit 63) Culvert Failure Due to Overtopping

Figure 11.2.58 (Exhibit 64) Culvert Almost Completely Blocked by Sediment Accumulation

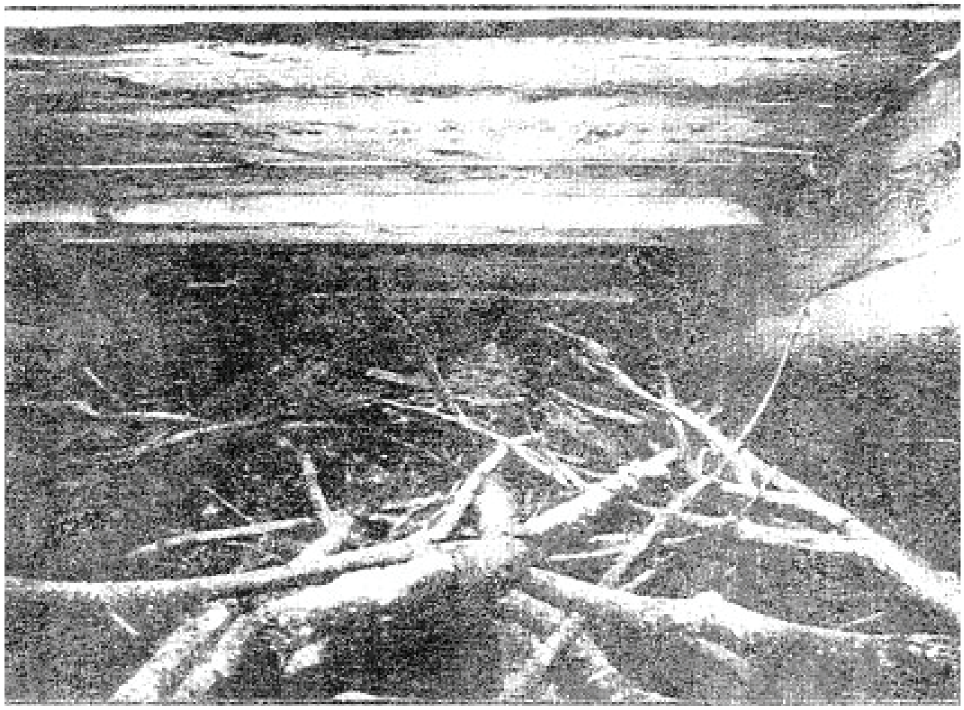


Figure 11.2.59 (Exhibit 65) Drift and Debris Inside Timber Box Culvert

Table of Contents

Section 11
Inspection and Evaluation of Waterways

Topic 11.3 Underwater Inspection

11.3.1 Introduction

The need for underwater inspections is great. Approximately 86 percent of the bridges in the National Bridge Inventory (NBI) are built over waterways, and most bridge failures occur because of underwater problems. Underwater members must be inspected 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 11.3.1). As a result, bridge owners have been mandated to develop a master list of bridges requiring underwater inspections.

Figure 11.3.1 Schoharie Creek Bridge Failure

In general, the term "underwater inspection" is taken to mean a hands-on inspection requiring underwater breathing apparatus and related diving equipment. The expense of such inspections necessitates careful consideration of candidate bridges.

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 11.3.2), underwater inspection and management techniques must be used to establish their condition so that failures can be avoided.

Figure 11.3.2 Liberty Bridge over Monongahela River

In many cases, a multi-disciplinary team including structural, hydraulic and geotechnical engineers must evaluate a bridge located over water. 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 *AASHTO Manual for Condition Evaluation of Bridges*, all structures must receive routine underwater inspections at intervals not to exceed sixty months or 72 months with FHWA approval. This is the maximum interval permitted between underwater inspections for bridges which are both 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 must determine the inspection interval that is appropriate for each individual bridge. Factors to consider in establishing the inspection frequency and levels of inspection include:

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

Selected Bridges

Those bridges that require underwater inspection must be noted on individual inspection and inventory records as well as be compiled in a master list. For each bridge requiring underwater inspection, the following information should be included 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

11.3.2 Methods of Underwater Inspection

The location of underwater elements must be identified and a description of the underwater elements must be included in the inspection records. The inspection frequency and procedures for each bridge requiring underwater inspection must be included in the inspection record. The elements requiring underwater inspections must be inspected according to these procedures.

There are three general methods used to perform underwater inspections:

- Wading inspection
- Self-contained diving (SCUBA)
- Surface-supplied diving

Wading Inspection

Wading inspection is the basic method of underwater inspection used on structures over wadable 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 with waders and a life preserver or a boat (see Figure 11.3.3).

Figure 11.3.3 Wading Inspection

Self-contained Diving

In this mode, the diver operates independently from the surface, carrying his/her own supply of compressed breathing gas (typically air). SCUBA, an acronym for Self-Contained Underwater Breathing Apparatus, is the most common type of self-contained diving equipment used (see Figure 11.3.4). Self-contained diving is often employed during underwater bridge inspections. 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. Extreme care should be exercised when using self-contained 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.

Figure 11.3.4 Self-Contained Inspection Diver

Surface-Supplied Diving

As its name implies, surface-supplied diving uses a breathing gas supply that originates above the water surface. 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 11.3.5).

Figure 11.3.5 Surface-Supplied Diving Inspection

Method Selection Criteria

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

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

11.3.3 Diving Inspection Intensity Levels

Originating in the United States Navy and offshore diving industry, the designation of standard levels of inspection has gained 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 nondestructive testing

Level I

Level I inspection consists of a "swim-by" overview at arm's length with minimal cleaning to remove marine growth. Although the Level I inspection is referred to as a "swim-by" inspection, it must 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. 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 selecting 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 growth. 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. In some cases, cleaning is time consuming and should be restricted to critical areas of the structure. The thoroughness of cleaning should be governed by what is necessary to determine the condition of the underlying material. Removal of all growth is generally not needed. 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 150 to 300 mm (6 to 12 inches) in height, should be cleaned at designated locations:

- Rectangular piles - the cleaning should include 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

On large elements, such as piers and abutments, areas at least 0.09 m^2 (1 square foot) in size should be cleaned at three or more levels on each face of the element (see Figure 11.3.6). Deficient areas should be measured, and the extent and severity of the damage documented.

Figure 11.3.6 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.

11.3.4 Types of Inspection

A comprehensive review must be made of all bridges contained in an agency's inventory to determine 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:

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

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

Initial Inspections

An inventory inspection is the first inspection of a bridge as it becomes a part of the bridge inventory. An inventory inspection may also apply when there has been a change in the configuration of the structure such as widening, lengthening, bridge replacement, or change in ownership (see Figure 11.3.7). The inventory inspection is a fully documented investigation, and it must be accompanied by an analytical determination of load capacity, which includes scour analyses if appropriate.

Figure 11.3.7 Bascule Bridge on the Saint Croix River

There are two primary purposes for an inventory inspection:

- Collection of Structure Inventory and Appraisal (SI&A) data
- Establish as-built conditions

The second important aspect of the inventory inspection is the determination of baseline structural conditions and the identification and listing 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.

Routine Inspections

A routine 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 "inventory" or previously recorded conditions, and to ensure that the structure continues to satisfy present service requirements.

The routine inspection must fully satisfy the requirements of the NBIS with respect to maximum inspection frequency, updating of SI&A data, and the qualifications of the inspection personnel.

Routine inspections of substructures in water must be conducted at least once every sixty months. Structures having underwater members which are partially deteriorated or which are in unstable channels may require shorter inspection intervals. Criteria must be established for determining the level and frequency to which these underwater elements will be inspected base on such factors as construction material, environment, age, scour characteristics, condition rating from past inspections and known deficiencies. Certain underwater structural elements may be inspected at greater than sixty month intervals, not to exceed seventy-two months, with written FHWA approval. This may be appropriate when past inspection findings and analysis justifies the increased inspection interval.

The scope of work for a routine inspection should include:

- A Level I inspection should be made on 100% of the underwater portion of the structure to determine obvious problems.
- A Level II inspection should be made on at least 10% of underwater units selected as determined by the Level I inspection.
- A Level III inspection may need to be performed to gain additional data so that the structural conditions can be evaluated with certainty.

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

- Inspect the channel bottom and sides for scour.
- Cross sections of the channel bottom should be taken and compared with as-built plans or previously taken cross sections to detect lateral channel movement or deepening (see Figure 11.3.8).
- Soundings should be made in a grid pattern (see Figure 11.3.9) about each pier and upstream and downstream of the bridge, developing contour

elevations of channel bottom, to detect areas of scour. Permanent reference point markers should be placed on each abutment/pier (see Figure 11.3.10). Data obtained from the soundings should 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 should be determined with probes in the vicinity of piers and abutments (see Figure 11.3.11). In streams carrying large amounts of sediment, reliable scour depth measurements may be difficult at low flow due to scour hole backfilling.

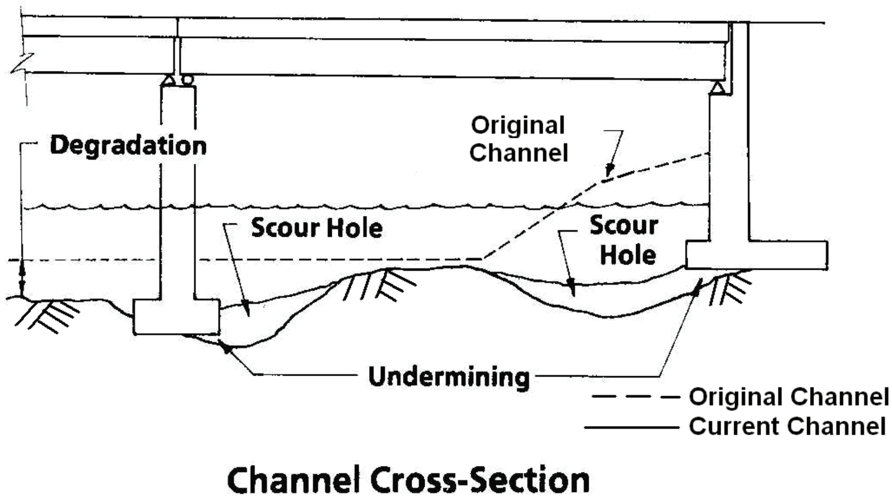


Figure 11.3.8 Channel Cross Section (Current Inspection versus Original Channel)

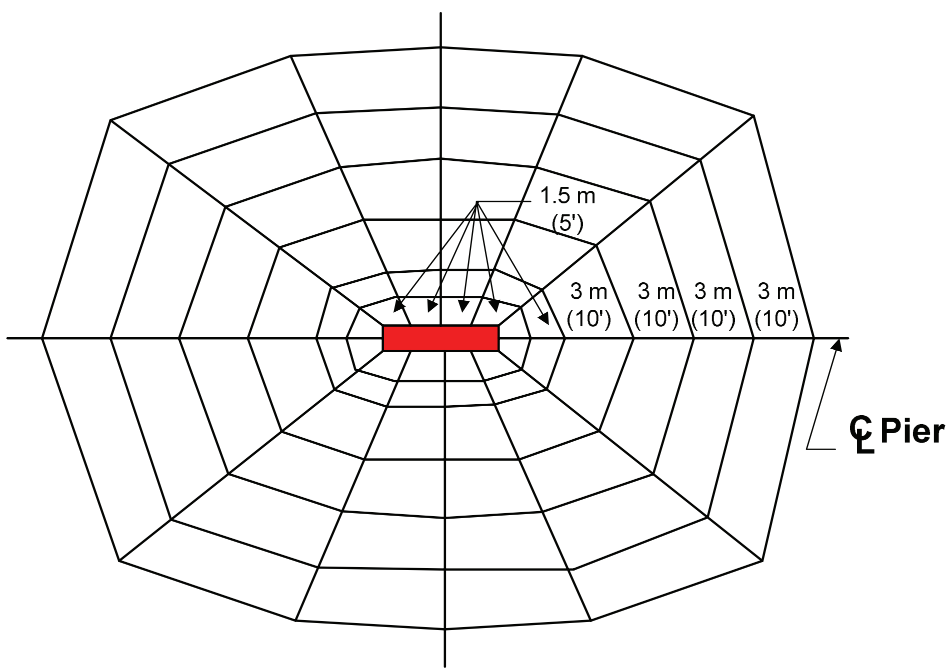


Figure 11.3.9 Pier Sounding Grid

Figure 11.3.10 Permanent Reference Point (Bolt Anchored in Nose of the Pier, Painted Orange)

Figure 11.3.11 Local Scour; Causing Undermining of a Pier

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 inspection must 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, inspectors must evaluate section loss, make measurements for misalignment of members, and check for any loss of foundation support.

Situations that may warrant a damage inspection include:

- Bridge elements should be inspected after floods. Bridge elements located in streams, rivers, and other waterways with known or suspected scour potential should be inspected after every major runoff event to the extent necessary to ensure bridge foundation integrity (see Figure 11.3.12).
- Bridges should be inspected underwater if there is visible damage above water from vessel impact. This should be done in order to determine the extent of damage and to establish the extent of liability of the vessel owner for damages.
- 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 (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.
- Buildup of debris at piers or abutments effectively widens the unit and may cause scouring currents or increase the depth of scour (see Figure 11.3.13).
- 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. Bridges should also by inspected underwater following significant earthquakes (see Figure 11.3.14).

Figure 11.3.12 Flood Conditions: Note Pier Settlement.

Figure 11.3.13 Buildup of Debris At Pier

Figure 11.3.14 Movement of a Substructure Unit

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, nondestructive tests may need to be performed.

The inspection may include a load rating to assess the residual capacity of the member or members, depending on the extent of the deterioration or damage.

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

- Inconclusive results from a routine inspection
- Suspect hidden or internal damage
- 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
- Adverse environmental conditions such as brackish and polluted water

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.

All findings should be recorded using notes and sketches. Underwater photographs and video recordings should also be used where visibility permits.

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 Inspections

A special 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).

11.3.5 Qualifications of Diver-Inspectors

An underwater bridge inspection diver must complete FHWA approved comprehensive bridge inspection training course or other FHWA approved underwater bridge inspection training course.

The underwater inspector must have knowledge and experience in bridge inspection. All underwater inspections should be conducted under the direct supervision of a qualified bridge inspection team leader. A diver not fully qualified as a bridge inspection team leader must be used under close supervision.

As the ability of the underwater inspector to safely access and remain at the underwater work site is paramount to a quality inspection, the individual must possess a combination of commercial diving training and experience, which demonstrates his/her competence as a working diver.

Federal Commercial Diving Regulations

Underwater bridge inspection, using either self-contained or surface-supplied equipment, is a form of commercial diving. In the United Sates, commercial diving operations are federally regulated by both the Occupational Safety and Health Administration (OSHA), and the U.S. Coast Guard. OSHA regulates all commercial diving operations performed inland and on the coast (through 29 CFR Part 1910, Subpart T-Commercial Diving Operations). This reference should be consulted for details on commercial diving procedures and safety.

Diver Training and Certification

OSHA Safety Requirements

The OSHA standard 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.

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 two, separate 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 must contain 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.

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. On the world-wide web, go to *www.adc-usa.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. Regarding staffing levels, OSHA requires a minimum of three (3) dive team members, whether conducting self-contained or surface supplied diving operations.

11.3.6 Planning an Underwater 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 (inventory) underwater inspections that set a benchmark for future inspections. It is, therefore, 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 all 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.

11.3.7 Substructure Units and Elements

The underwater portions of bridge structures can be classified into five broad categories: bents, piers, abutments, culverts, and protection systems. 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 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 11.3.15 through 11.3.17 for photographs of pile bents of different material types.

Figure 11.3.15 Timber Pile Bent

Figure 11.3.16 Steel Pile Bent

Figure 11.3.17 Concrete Pile Bent

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

Piers

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 three common types of piers the inspector is likely to encounter:

- Column pier
- Column pier with solid web wall (see Figure 11.3.18)
- Cantilever or hammerhead pier (see Figure 11.3.19)
- Solid shaft pier (see Figure 11.3.20)

Figure 11.3.18 Column Pier with Solid Web Wall

Figure 11.3.19 Cantilever or Hammerhead Pier

Figure 11.3.20 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 must be inspected underwater. Abutments can be constructed from concrete, masonry, or timber and may be supported by spread footings, piles, caissons, or pedestals.

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 pile foundations (see Figure 11.3.21).

Figure 11.3.21 Severe Flood-Induced Abutment Scour

Culverts

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 11.3.22). Diving operations in physically confined space must be conducted in compliance with Federal commercial diving regulations, as well as the individual agency's Safe Practices Manual. The ADC "Consensus Standards For Commercial Diving Operations" also offers guidance for the safe conduct of confined space diving operations.

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. Surface-supplied air diving equipment should be used 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. Those structures exhibiting debris accumulations, which partially or fully constrict one end of a culvert, should be approached with caution, as excited animals may try to leave the culvert in haste, while the inspector is entering.

Figure 11.3.22 Inspection of Culvert With Limited Freeboard and Ice Cover

Protection Systems

Dolphins and fenders are often placed around substructure units to protect them from impact damage. Since these systems are usually at least partially underwater, a diving inspection should be conducted in concert with the substructure unit inspection. Additional protection systems and scour countermeasures include spur dikes, streambed armoring, rip rap, wing dams, and check dams (see Figure

11.3.23).

Figure 11.3.23 Damaged Protective System

11.3.8 Scour Investigations

Divers may be able to note scour degradation 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 should routinely check for such scour holes. A typical approach is to take depth measurements around the substructure, both directly adjacent and at concentric intervals. It should also be noted 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.

Depth measurements will not directly reveal the more general scour of significant sections of the streambed. However, the diver may find evidence of such scour from examination of the structure if parts of the substructure are exposed, or by comparing successive cross sections.

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 two methods:

- Sounding devices
- Diver investigations

Sounding Devices

Although sounding-sensing devices can be used independently of diving, they are commonly part of an underwater inspection. With the exception of poles and lead lines, sounding-sensing devices depend on some type of signaling system. While these systems are quite effective, they can be misinterpreted. An on-site diver can investigate questionable readings and more fully determine the channel bottom conditions.

Black and White Fathometer

The most commonly used device is the black and white fathometer. A transducer floats just below the waterline and bounces sound waves off the bottom. Depths are continuously recorded on a strip chart.

Advantages of the black and white 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 also fail to detect refilled scour holes during calm water
- 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

Fathometer/Theodolite

The horizontal scale problem can be solved by using equipment, which combines a fathometer with a total station theodolite. The theodolite is set up on shore, it tracks and records the coordinates of the transducer, and it automatically records depths at specified increments using a microprocessor. The data can be processed and plotted as a topographic map.

Dual Frequency and Color Fathometer

Dual frequency and color fathometers can be used to detect refilling, since more than one frequency is utilized. With color fathometers, materials of different densities are displayed as different colors. The primary drawback is that a hard copy cannot be obtained except with videotape recordings.

Ground-Penetrating Radar

Ground-penetrating radar and tuned transducer (low frequency sonar) equipment are also used in scour surveys. These are good in shallow water but not very effective in salty, brackish water.

Fixed Instrumentation

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 11.3.24).

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.

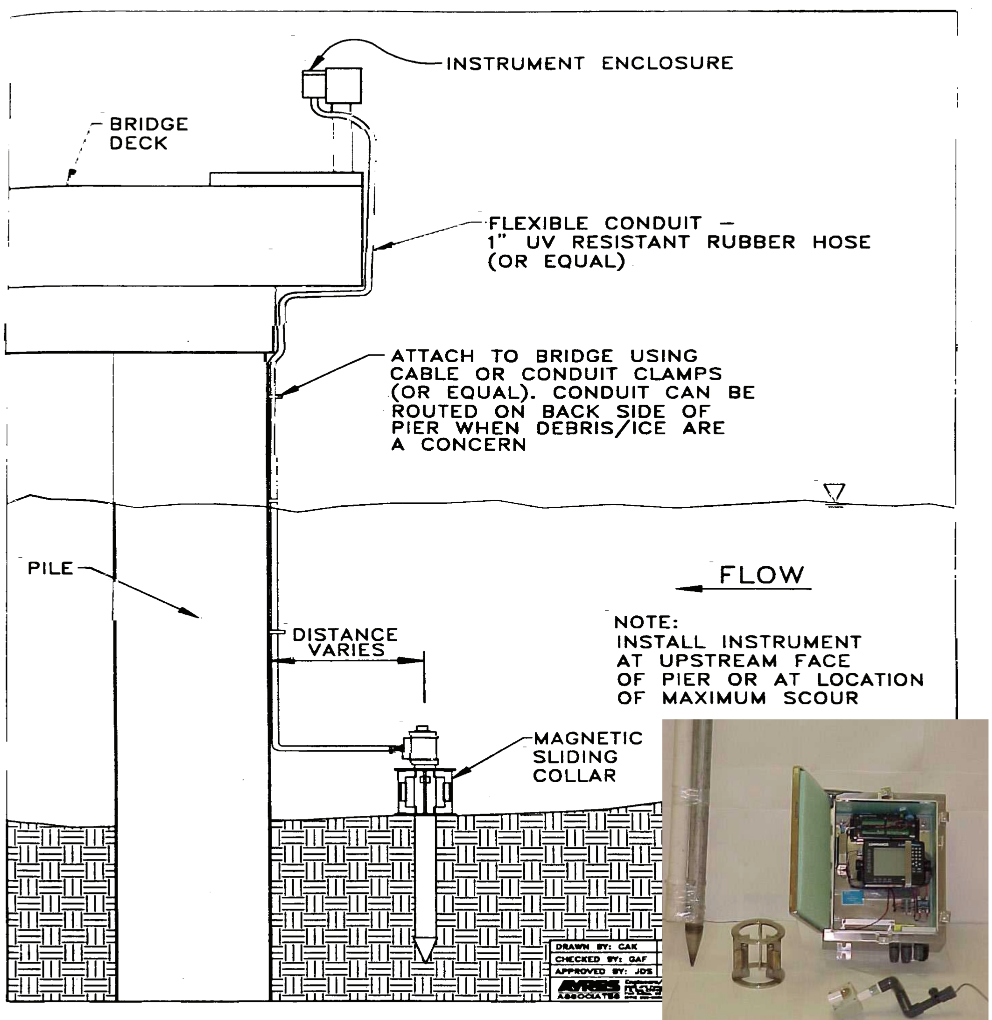


Figure 11.3.24 Scour Monitoring Collar

Diver Investigations

Diver investigations include:

- Laying out a grid pattern and taking depth measurements
- Sampling soils to determine backfilling of scour holes
- Probing to check for refilling
- Detecting undermining and scour holes (see Figure 11.3.25)
- Detecting small diameter but deep scour holes around piles
- Protective system evaluation (e.g., rip rap)

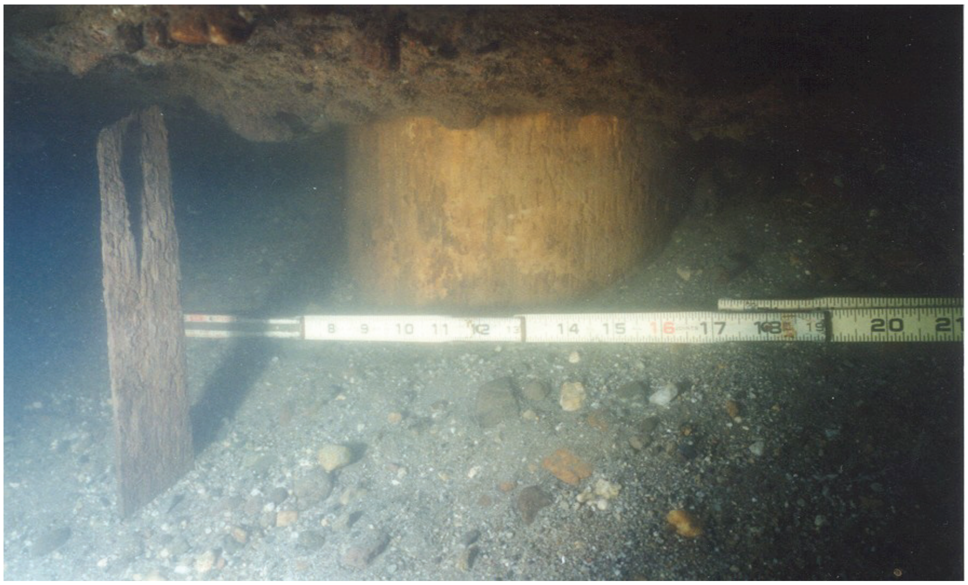


Figure 11.3.25 Pier Undermining, Exposing Timber Foundation Pile

11.3.9 Underwater Inspection for Material Defects

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 and Masonry

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 can be very serious (see Figure 11.3.26).

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

Masonry substructures can experience cracking of the stones and mortar joints.

See Topics 2.2 and 2.4 for detailed descriptions of concrete and masonry defects.

Figure 11.3.26 Concrete Deterioration

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 biological organisms, such as fungi, insects, bacteria, and marine borers. The ingredients for an 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. It is, therefore, important to carefully inspect in the vicinity of connectors, holes, or other surface blemishes (see Figure 11.3.27).

Figure 11.3.27 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. Special care should be taken in differentiating between treated and untreated piles to ensure a thorough inspection of any exposed, untreated piles. With each inspection, the diameter or circumference should be noted for each timber pile. As a minimum, these measurements should be made at the waterline and mud line. Comparisons should be made 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. All bore holes should be plugged. Ultrasonic techniques for timber piling are also available.

See Topic 2.1 for detailed descriptions of timber material defects.

Steel

Underwater steel structures are highly sensitive to corrosion, particularly in the low to high water zone (see Figure 11.3.28). Whenever possible, steel should be measured to determine if section loss has occurred. Ultrasonic devices are particularly useful to determine steel thicknesses.

Figure 11.3.28 Deteriorated Steel Piles at Splash Zone

If submerged steel elements are partially encased in concrete, the exposed steel adjacent to the encasement is particularly susceptible to aggressive corrosion.

See Topic 2.3 for detailed descriptions of steel material defects.

Previous Repairs

The inspector must also be alert to note deterioration of previous member repairs or rehabilitation. The first step in the inspection of previous repairs is to review all existing bridge substructure plans prior to the actual inspection. Repair areas should be noted as important areas of inspection.

Typical previous repairs may include:

- Steel cover plates
- Concrete fill repairs
- Epoxy crack repairs
- Concrete encasement or jacketing
- Limited replacement of members
- Masonry stone replacement
- Underpinning and rip rap to repair scour

Hands-on Inspection of Material Underwater

When visibility permits, the diver should visually observe 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 should "feel" for damage. Because orientation and location are often difficult to maintain, the diver should be systematic in the inspection. Regular patterns should be established 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

Any damage encountered should be measured 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 - thickness of remaining sound material should be accurately measured 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 rot, 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, written notes or logs should be kept, 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.

The results should also be included in an inspection form or report. Drawings and text should describe all aspects of the inspection and any damage found. The report should also include recommendations on condition assessment, repairs, and time interval for the next inspection. See Figure 11.3.29 for a sample underwater inspection form.

See Topic 4.3 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 11.3.29 Sample Underwater Inspection Form

NUMERICAL CONDITION RATING DEFINITIONS FOR STRUCTURAL ITEMS

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

NUMERICAL CONDITION RATING DEFINITIONS FOR DEGRADATION/AGGRADATION

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

Figure 11.3.29 Sample Underwater Inspection Form (Continued)

11.3.10 Underwater Inspection Equipment

Diving Equipment

Personal diving equipment includes:

- Wetsuit or drysuit (drysuit should be used when diving in water either known or suspected to be contaminated) (see Figure 11.3.30)
- Face mask or helmet (see Figure 11.3.31)
- Breathing apparatus
- Weight belt
- Swim fins
- Knife
- Wristwatch
- Buoyancy compensator (a flotation device capable of maintaining a diver face up at the surface)
- Depth gauge
- Pressure gauge

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 11.3.32 and 11.3.33). The umbilical is typically made up of several members, including, at a minimum, an air hose, strength member (or safety line), communication line, and pneumofathometer hose. The pneumofathometer provides diver depth measurements to the surface (see Figure 11.3.34). A reserve air tank, or bail-out bottle, should also be worn by the diver for emergency use.

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

Figure 11.3.30 Vulcanized Rubber Dry Suit

Figure 11.3.31 Full Face Lightweight Diving Mask with Communication System

Figure 11.3.32 Surface-Supplied Air Equipment, Including Air Compressor, Volume Tank With Air Filters, and Umbilical Hoses

Figure 11.3.33 Surface-Supplied Diving Equipment Including Helmet, or Hard Hat

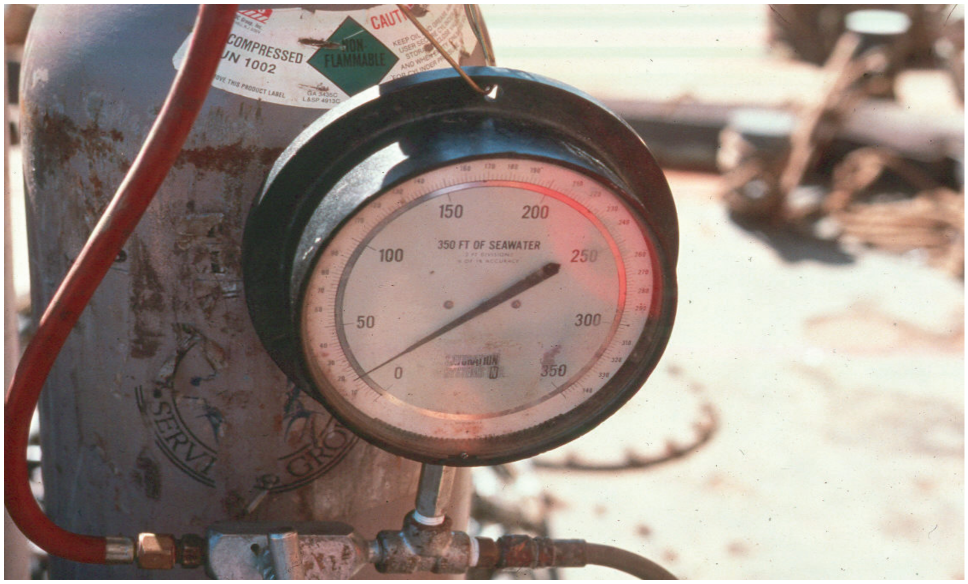


Figure 11.3.34 Pneumofathometer Gauge

Equipment malfunction leading to loss of air supply must 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 should always be worn by the diver (see Figure 11.3.35). Carbon monoxide poisoning can occur if the air intake of the surface supplied air compressor is located near the exhaust of other motorized equipment.

Figure 11.3.35 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 enhance the underwater inspection. Conventional hardwire (telephone) and wireless systems exist, which can even 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 (see Figure 11.3.36):

- The greatest benefit to the dive team is increased safety in the event of diver entanglement or equipment malfunction.
- Allows the diver to immediately describe observations and location of deficiencies for simultaneous recording by a note taker on the surface.
- The diver can verbally interact with topside inspection personnel to clarify what is being observed, without leaving the suspect area.
- The note taker 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 11.3.37).

Figure 11.3.36 Communication Box System

Figure 11.3.37 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. Typically, a 5.5 m (18-foot) or larger vessel can safely handle the equipment and crew (see Figures 11.3.38 and 11.3.39). Occasionally, access is made from the bridge itself.

Figure 11.3.38 Access Barge and Exit Ladder

Figure 11.3.39 Access From Dive Boat

Tools

A number of inspection tools are available. The dive team should have access to the appropriate tools and equipment as warranted by the type of inspection being conducted.

Hand Tools

While most hand tools can be used underwater, the most useful include rulers, calipers, scrapers, probes (ice picks, dive knifes, and screwdrivers), flashlight, hammers (especially masonry and geologist's hammers), wire brushes, incremental borers, and pry bars (see Figure 11.3.40). These tools are usually tethered to the diver to prevent their loss underwater.

Figure 11.3.40 Diver-Inspector with a Pry Bar

Power Tools

Power tools include grinders, chippers, drills, hammers and saws. While pneumatic tools are sometimes used, hydraulic tools tend to be favored for heavy or extensive work.

Cleaning Tools

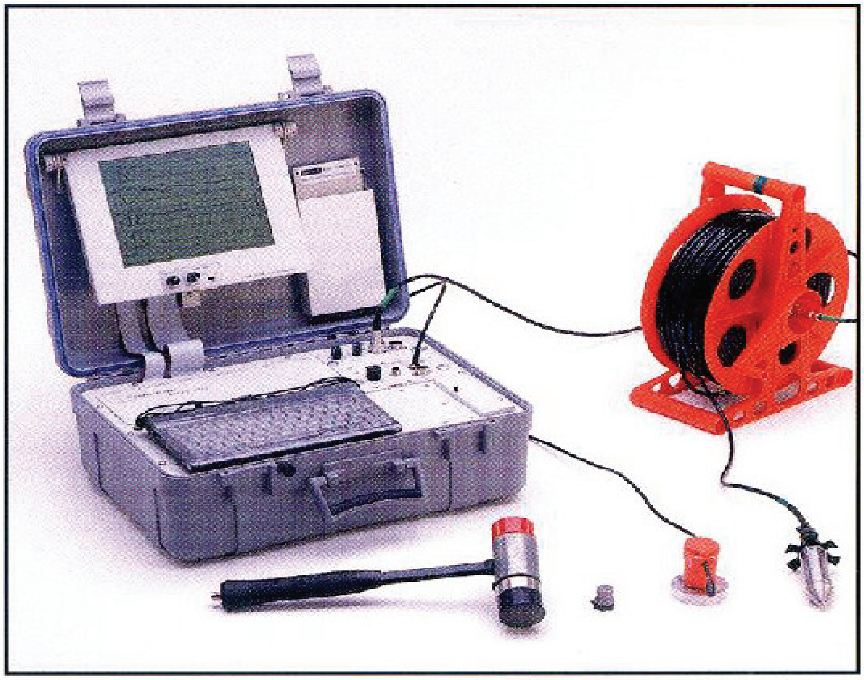
Light cleaning can be accomplished with scrapers and wire brushes. Heavier cleaning requires automated equipment such as grinders and chippers. One of the most effective means of cleaning is with the use of water blasters (see Figure 11.3.41). Particular care must be taken with such equipment to ensure that structural damage does not result from overzealous blasting.

Figure 11.3.41 Cleaning with a Water Blaster

Nondestructive Evaluation Equipment

- 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.
- A V-meter is an ultrasonic device that requires two transducers and measures the distance required for the sound wave to pass through the concrete. Similar devices have also been developed for timber.
- A waterproof Schmidt hammer can be used underwater to measure concrete compression strength in-place.
- An 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.
- 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. The articulating yoke is positioned on the member in question, and energized. The powdered metal particles are then sprayed over the specimen, in 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. As such, the inspector can readily locate deficiencies that may otherwise remain undetected.
- Parallel Seismic testing can be used to determine pile embedment lengths when as-built plans are not available. The test involves boring a hole in the vicinity of the existing pile or footing and lowering a hydrophone receiver to the bottom. While raising the receiver in small increments, a part of the foundation is struck with an instrumented hammer causing compression or shear waves to travel from the foundation into the surrounding soil. The hydrophone tracks the time it takes for the compression and shear waves to reach the receiver. By plotting the arrival times and measuring the corresponding depth of the receiver, the pile tip location can be determined.

This information is very valuable in determining a bridge's susceptibility to scour. The Parallel Seismic test can be used for steel, concrete, timber and masonry foundations (see Figure 11.3.42).



SE/IR/PS-I System

Figure 11.3.42 Parallel Seismic Testing Equipment

Coring Equipment

Coring is a partially destructive evaluation method whose use is usually limited to critical areas. Cores can be taken in either concrete or timber (see Figure 11.3.43).

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 11.3.44). Two-inch diameter cores are common, but coring tools are available in other sizes (see Figure 11.3.45). Cores not only provide knowledge about interior concrete consistency but also can be tested to determine compression strength.

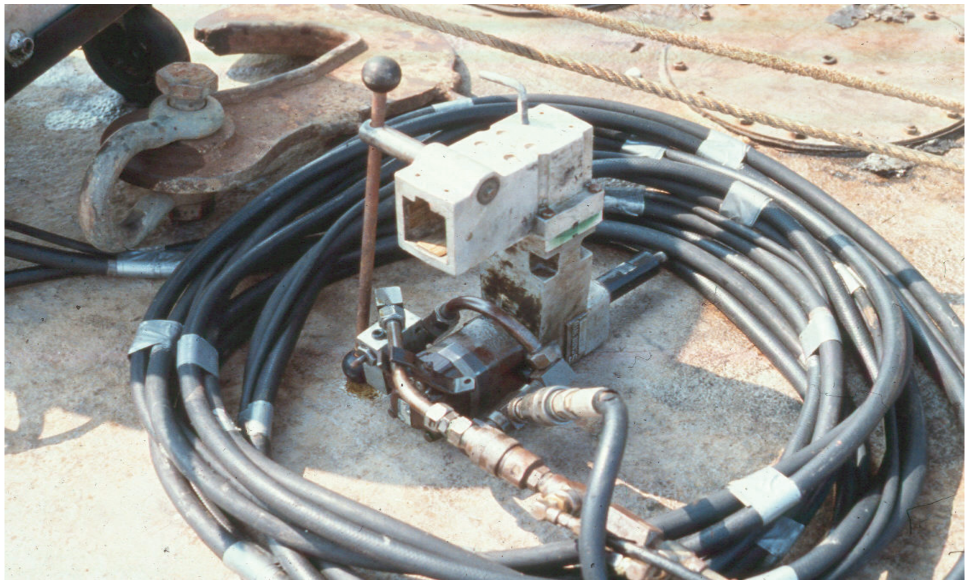


Figure 11.3.43 Coring Equipment

Figure 11.3.44 Concrete Coring Taking Place

Figure 11.3.45 Concrete Core

Timber coring is much simpler and less costly to perform than concrete coring (see Figure 11.3.46). 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. Examination of the core should include its compressibility, evidence of borers or other infestation, and indications of void areas. The hole should always be plugged with a treated hardwood dowel to prevent infestation.

Figure 11.3.46 Timber Core

Underwater Photography and Video Equipment

Cameras come with a variety of lens and flash units. In some cases, visibility is limited and the camera must be placed close to the subject. Wide-angle lenses are therefore most often used (see Figure 11.3.47). Suspended particles often dilute the light reaching the subject and can reflect light back into the lens. When visibility is very low, clear water boxes can be used. The boxes are constructed of clear plastic and can be filled with clean water. By placing the box against the subject area, the dirty water is displaced and the camera shot can be taken through the clear water (see Figure 11.3.48).

Figure 11.3.47 Underwater Photographer

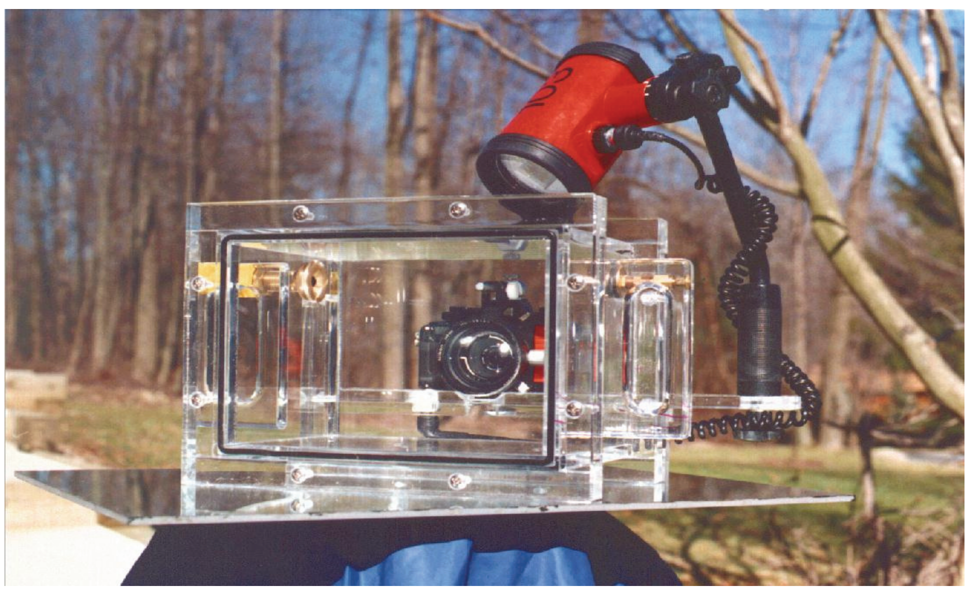


Figure 11.3.48 Camera with a Clear Box

Video equipment is available either as self-contained, submersible units or as submersible cameras having cable connection to the surface monitor and controls (see Figure 11.3.49). 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.

Figure 11.3.49 Underwater Video Inspection

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. Its effectiveness diminishes substantially in stream velocities greater than 0.8 m/s (1.5 knots) and is limited by cloudy water, inability to determine the exact orientation and position of the camera, and control sensitivity. Also important to note is that an ROV cannot typically perform cleaning operations prior to photos being taken.

11.3.11 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.

Dealing with Current

Most waterways have low flow periods when current will not hinder an inspection. Diving inspections should be planned with this consideration in mind. Divers can work in current below 0.8 m/s (1.5 knots) with relatively little hindrance. As current increases, special precautions are required. Bottom anchors, shielding devices, and special anchoring/tethering systems may be required, depending upon the site-specific conditions encountered at the bridge (see Figure 11.3.50).

Figure 11.3.50 Diving Inside a Cofferdam

Obviously, waterway conditions may sometimes be too swift to allow safe diving operations (see Figure 11.3.51).

Figure 11.3.51 Excessive Current

Dealing with Drift and Debris

The drift and debris that often collects at bridge substructures can be quite extensive (see Figure 11.3.52). 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.

Removal, past history, and safety are concerns that must be addressed in dealing with the presence of drift and debris.

Figure 11.3.52 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 must be provided for if an inspection of the underwater elements is to proceed. While in some cases it 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. A separate drift removal team, working ahead of the dive inspection team, could possibly be utilized.

Divers must also have a safety concern about the buildup of debris near a bridge. 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 11.3.52).

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 11.3.53). The cost of cleaning heavily infested substructures may be completely impractical. In such cases, spot cleaning and inspection may be the only practical alternative.

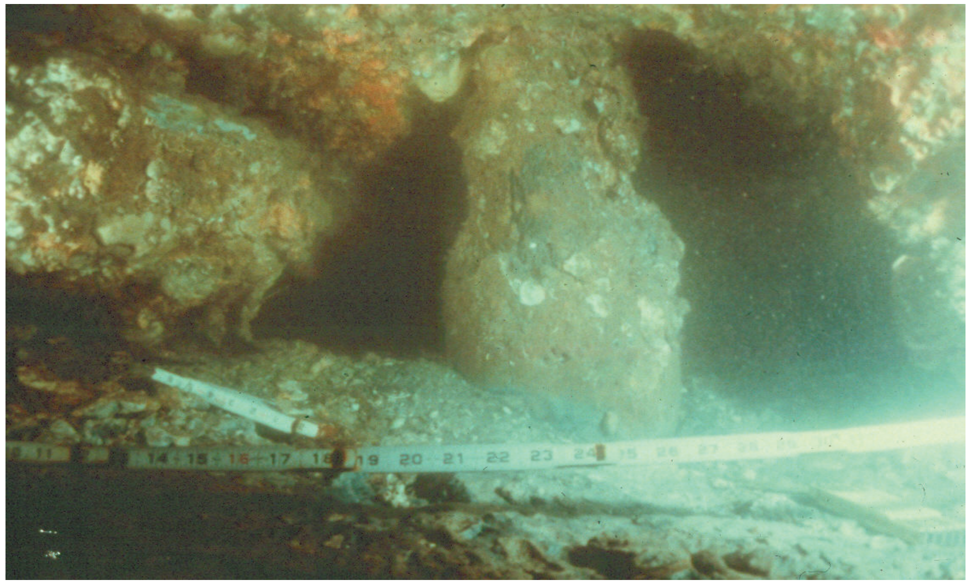


Figure 11.3.53 Cleaning a Timber Pile

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 must be conscientiously planned and executed step-by-step underwater. For example, maintaining orientation and location during an underwater inspection requires continual attention. Distractions are plentiful and range from living organisms, such as fish, snakes, and crustaceans, to environmental conditions, such as cold, high current, and 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 should 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 hazard is vessel traffic near the dive area. There should always be someone topside with the responsibility of watching boat traffic (see Figure 11.3.54). In addition, flags should be displayed 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 11.3.55).

Figure 11.3.54 Commercial Marine Traffic

Figure 11.3.55 Alpha (left) and Sport Diver (right) Flags