FIELD MANUAL

Scour Critical Bridges: High-Flow Monitoring and Emergency Procedures

Idaho Transportation Department

Prepared for

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1. INTRODUCTION

Approximately 198 of Idaho's highway bridges are rated scour-critical, meaning they are at risk of failure due to scour. Some of the scour-critical bridges require monitoring during periods of high flow in order to protect the traveling public. This manual provides guidance on the procedures for high-flow monitoring. It is intended as a field reference for use by monitoring crews.

The monitoring crew for a scour-critical bridge has a very important job with significant responsibilities. As the field personnel assigned to the bridge, you are the eyes and ears of the department. To properly perform your job, you must understand the general nature of scour, know what to look for in the field, understand how to make detailed scour measurements, and properly execute notification processes and bridge closure should a serious problem be discovered. The responsibility you carry is great and lives may depend on how you perform your job.

Section 2 explains basic scour concepts and definitions. This is necessary background information for anyone attempting to measure scour in the field. Section 3 describes the content of Plans of Action for scour-critical bridges. A Plan of Action has not yet been developed for every scour-critical bridge. Where available, however, a Plan of Action provides useful information for the field monitoring crew.

Section 4 describes commonly used scour monitoring equipment. The important concept of scour-critical elevations is discussed in Section 5. Monitoring procedures are explained in Section 6. Finally, Section 7 describes emergency action protocols.

2. BASIC SCOUR CONCEPTS AND DEFINITIONS

Crews responsible for monitoring scour-critical bridges should have a basic understanding of scour concepts. This section explains what scour is, different types and components of scour, and the factors that influence scour potential.

Scour is the result of the erosive action of flowing water, removing sediment from the streambed and banks of streams and from around the piers (intermediate supports) and abutments (end supports) of bridges. Different types of sediment scour at different rates. Loose granular soils such as coarse sands, gravels and larger materials, are rapidly eroded by flowing water, while cohesive or cemented soils, such as clays and silts, are more resistant to erosion. However, ultimate scour (maximum scour) in cohesive or cemented soils can be as deep as scour in sand-bed streams. Under constant flow conditions, scour will reach a maximum depth in sand-bed and gravel-bed material in hours; cohesive streambed material in days; glacial till, sandstones, and shale in months; limestone in years, and dense granite in centuries. Under flow conditions typical of actual bridge crossings, attainment of the ultimate scour depth may take several floods.

2.1 Types of Scour

Scour can be classified into two types, clear-water and live-bed, defined below:

- Clear-water scour: No transport of streambed sediment from upstream being carried into the crossing.

- Live-bed scour: Streambed sediment from upstream is transported into the crossing.

A scour hole formed by clear-water scour may be visible during a post-flood inspection. The scour hole at a pier formed by live-bed scour may not be visible during a post-flood inspection because the scour hole is deepest during the peak of the flood and then partially or fully refills as the flood recedes.

2.2 Components of Scour

Total scour at a highway crossing is comprised of three components:

1. Long-term aggradation or degradation
2. General scour at the bridge, across the bridge opening
3. Local scour at piers and abutments

Long-term aggradation raises the streambed and degradation lowers the streambed over a long distance along the stream. Aggradation and degradation are typically not caused by the bridge, but rather by other factors related to a longer segment of the stream.

General scour at the bridge can be clear-water or live-bed, and it usually occurs as contraction scour. Contraction scour is caused by the width constriction of the waterway or floodplain imposed by the road embankments and the bridge structure. It occurs when the waterway opening through the bridge is smaller than the natural flow area. Contraction scour typically extends across the entire width of the bridge opening. The contraction scour depth may or may not be uniform across the bridge opening. The scour that occurs at the outside of bends is another example of general scour.

Local scour is a result of the obstruction of flow caused by the piers and abutments. The obstruction caused by a pier creates a horseshoe-shaped vortex around the front and sides of the pier, as illustrated in **Figure 1**. A similar process causes scour at abutments that form an obstruction to the flow, as shown in **Figure 2**. The horizontal extent of local scour is relatively small compared to the other components of scour, but the depth of local scour is often greater than the other components. Local scour can be either clear-water or live-bed. Under live-bed conditions, the local scour is deepest near the peak of the flood, and refills at least partially as the flood recedes.

In scour prediction calculations, the computed values of the three scour components are added to obtain the total predicted scour at a pier or abutment (**Figure 3**).

2.3 Lateral Migration

In addition to the three components described above, potential lateral migration (side-to-side movement) of the stream must be assessed when evaluating total scour at bridge piers and abutments. Lateral migration of the main channel occurs naturally, but can also be induced or magnified by human activities. A channel moving laterally may affect the stability of piers along the channel bank, erode abutments, damage the approach roadway embankments, or increase the total scour by changing the flow direction at piers and abutments. **Figure 4** shows an abutment undermined by lateral migration. Factors that affect lateral stream movement are the geomorphology of the stream (the ongoing trends of change in the stream alignment), the location of the crossing on or near a channel bend, flood characteristics, and the characteristics of the streambed and bank sediments.

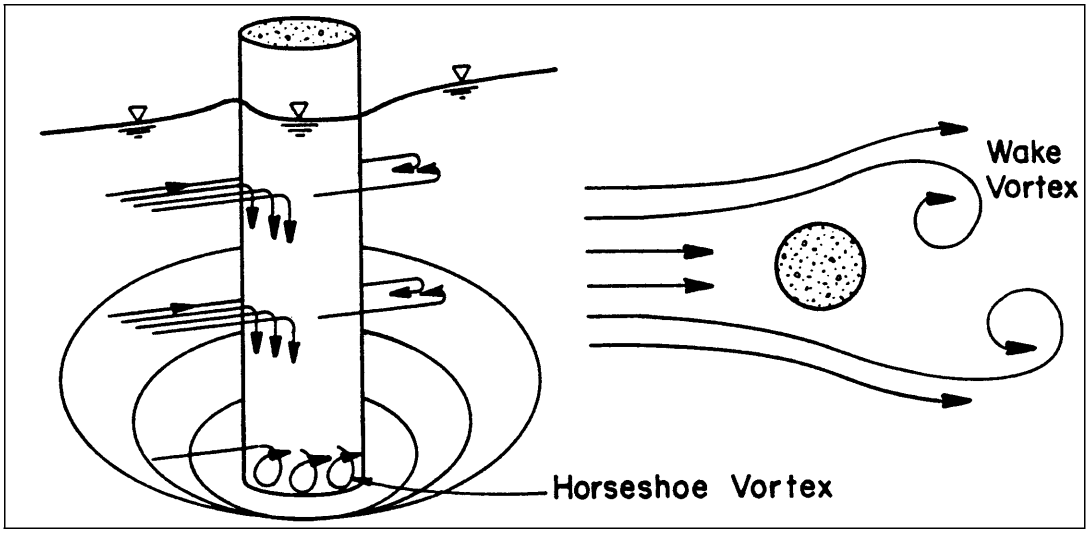

Figure 1. Schematic illustrating local scour processes at a cylindrical pier.

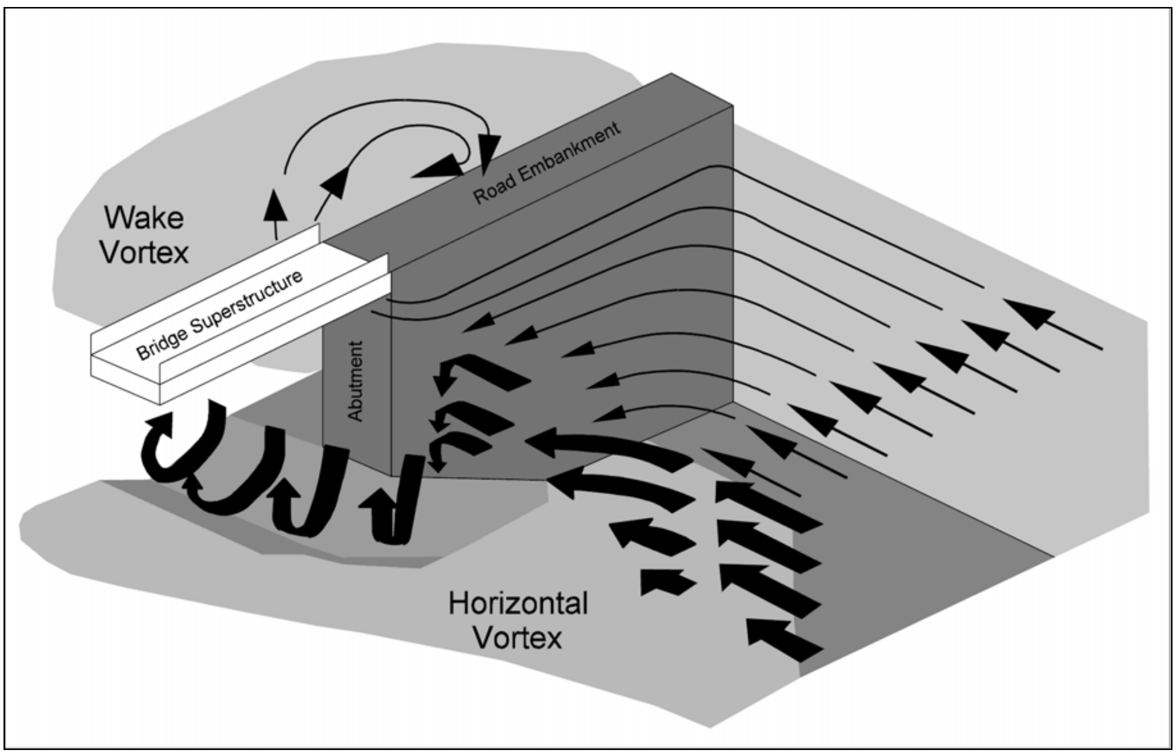

Figure 2. Schematic illustrating local scour processes at an abutment.

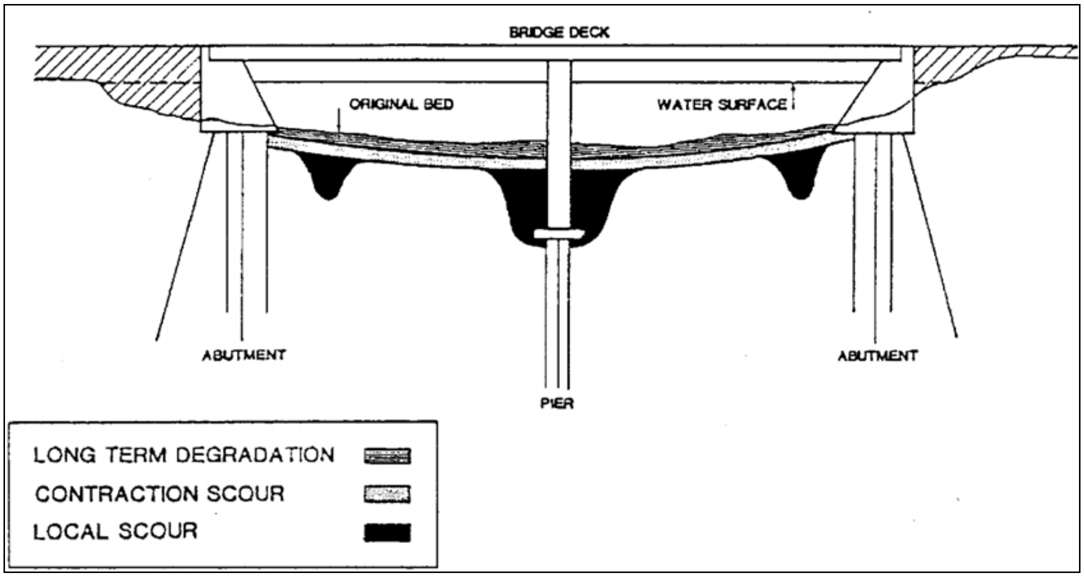

Figure 3. Total scour and its components.

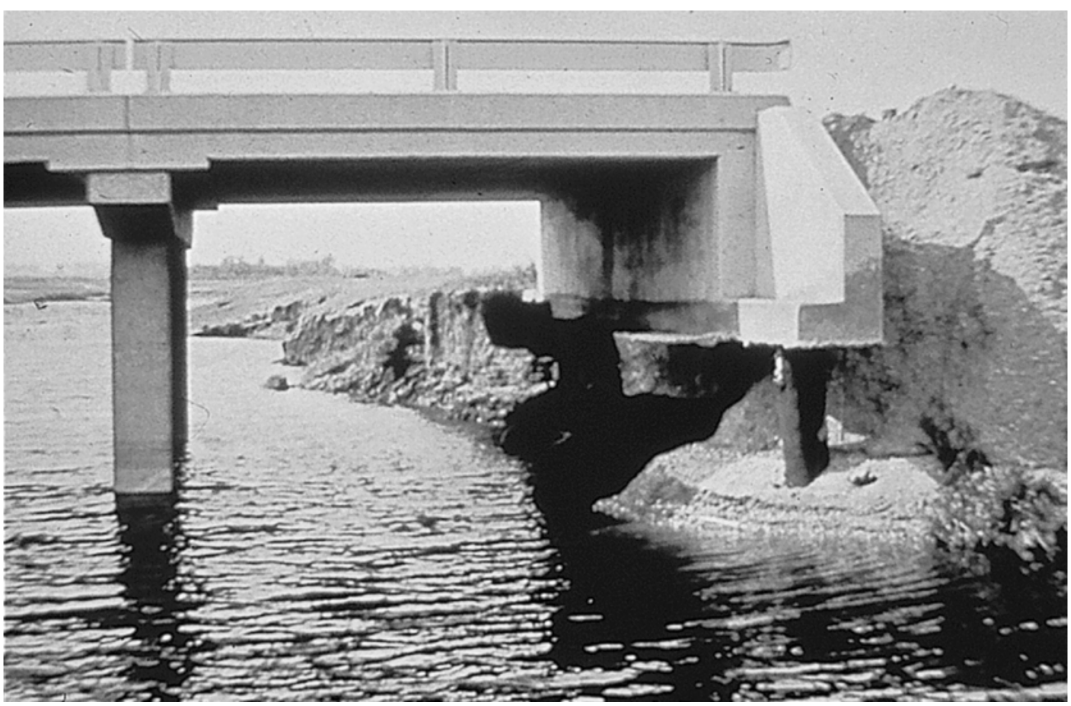

Figure 4. A bridge abutment that has been undermined by lateral migration.

2.4 Tips to Remember When Monitoring Contraction Scour

- Significant contraction scour can occur if overbank flows (the portion of the high-flow above and outside of the banks of the main channel) are captured by roadway approach embankments and forced through the bridge opening.

- Flow through relief bridges or over approaching roadway embankments can reduce the flow and contraction scour in the main channel bridge opening.

- Deep contraction scour is possible at relief bridges located in the overbank.

- If there is no overbank flow, only a change in the effective main channel width (including bridge piers in the flow) will influence live-bed contraction scour.

- Large substructure elements (piers, pile caps, pile groups) can increase contraction scour significantly.

- Submergence of the bridge superstructure causes pressure flow (vertical contraction scour), which can increase scour dramatically.

2.5 Tips to Remember When Monitoring Pier Scour

- Width of pier has a direct effect on the depth of scour. Wider piers produce deeper scour than narrow piers under the same conditions.

- Maximum expected pier scour depth ranges from 2.4 to 3 times the pier width for circular or round-nosed piers aligned with the flow.

- Length of the pier has no appreciable effect on scour depth if the pier is aligned with the flow; however, an angle of attack of the flow to the pier has a large effect on local scour.

- Velocity of the approaching flow increases the scour depth. Faster flow produces deeper scour.

- Fine streambed sediments (silt and clay) will have scour depths as deep as sand-bed streams, even if bonded by cohesion. The effect of cohesion is to increase the time it takes to reach the ultimate scour depth.

- In sand-bed channels, the maximum depth of scour is measured in hours. With cohesive streambed materials (silt, clay, sandstone, rock, etc.) it may take days, months, or even years to reach the maximum scour depth.

- Shape of the pier has an effect on scour. A streamlined upstream end reduces the strength of the horseshoe vortex reducing scour depth. A streamlined downstream end reduces the strength of the wake vortices.

- Square-nose pier will have a maximum scour depth about 20 percent larger than a sharp-nose pier and 10 percent larger than a cylinder or round-nose pier.

- Shape of the pier nose has no effect on the magnitude of the scour when the angle of the attack is greater than about 5 degrees.

- Ice and debris can increase the width of the piers, change the shape of piers, and cause the flow to plunge downward against the streambed and increase pier scour.

2.6 Tips to Remember When Monitoring Abutment Scour

- Potential for lateral channel migration, long-term degradation, and contraction scour should be considered when monitoring for abutment scour.

- Riprap and guide banks may protect an abutment from failure.

- Abutment scour will be most severe where the approach roadway embankment leading to the abutment obstructs a significant amount of overbank flow.

- Scour can occur along the upstream portion of the abutment due to the horizontal vortex and at the downstream end of the abutment as the flow expands through the bridge opening.

- Abutment scour will increase if the abutment (embankment) is skewed in an upstream direction (into the flow).

- Abutment scour will decrease if the abutment (embankment) is skewed in a downstream direction (away from the flow).

- Vertical wall abutment without wingwalls can have twice the scour depth as a spill-through (sloping) abutment. **Figure 5** is an illustration of abutment types.

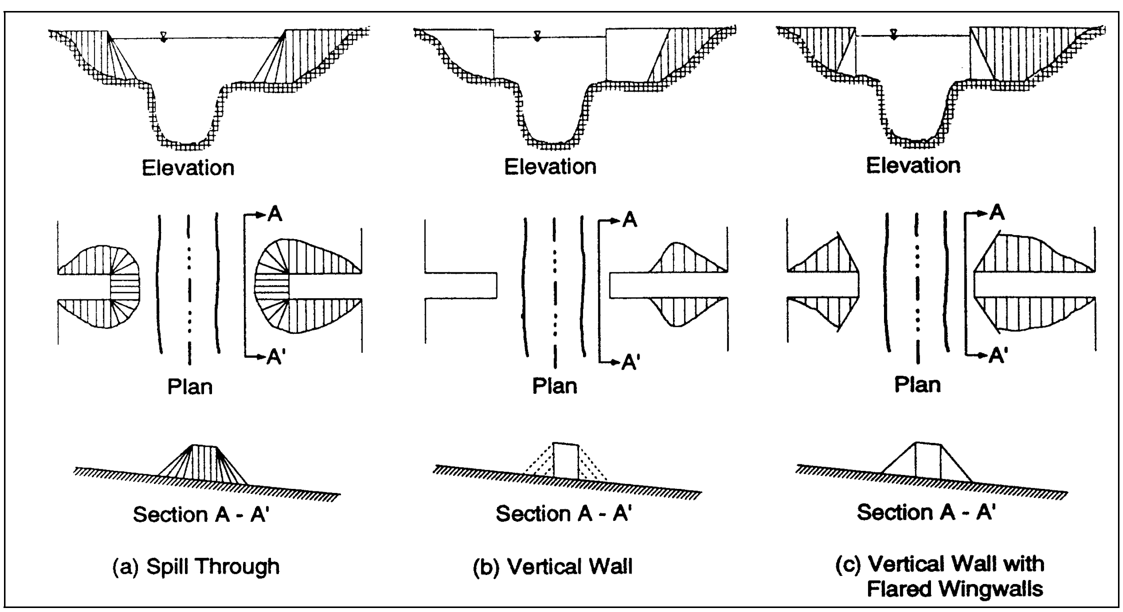

Figure 5. Illustration of abutment types.

3. PLANS OF ACTION FOR SCOUR-CRITICAL BRIDGES

3.1 What is a Plan of Action?

Each scour-critical bridge should ideally have an associated Plan of Action and an information packet developed for the monitoring crews. The full Plan of Action includes:

- General information about the bridge, including inspection cross-section plots and bridge structural elements plotted on a common vertical datum
- Inspection and monitoring requirements for the bridge, along with any necessary bridge-specific data to support the inspection and monitoring program
- Conceptual countermeasure designs and a schedule for countermeasure installation, if applicable
- Detour map, closure protocol, and signing layout plan in case bridge closure is required

The elements contained in a Plan of Action for a given bridge will vary depending on the economic risk of bridge failure and the annual probability of failure. Idaho's scour-critical bridges have been subdivided into four scour categories. These scour categories are described below.

Scour Category A - Vital Bridges. These bridges have an economic risk of failure in excess of $5,000,000. Consequently, these bridges should not be allowed to fail due to scour processes. The minimum response to scour-critical conditions for Category A scour-critical bridges focuses on the design and installation of effective scour countermeasures. However, prior to countermeasure installation, Category A bridges are treated as Category B, C, or D bridges, depending on the predicted annual probability of failure. Therefore, the Plan of Action for these bridges may include interim monitoring and closure plans. Once the scour countermeasures are installed, no high flow monitoring will typically be required. However, if the channel, abutments, or piers are armored to resist scour, then post-flood scour inspection will be required to ensure the long-term performance of the countermeasures.

Category B - Extreme Scour-critical Bridges. These bridges have an economic risk of failure of less than $5,000,000, but have a predicted annual probability of failure in excess of 10 percent. The minimum scour response for this category will provide instructions to close the bridge for any flood event. The Plan of Action will also describe inspection requirements for the bridge. It will not typically include any high-flow monitoring beyond the minimal monitoring necessary to determine that a flood is occurring.

Category C – Severe Scour-Critical Bridges. These bridges have an economic risk of failure of less than $5,000,000 and a predicted annual probability of scour failure between 1 and 10 percent. A bridge is also in this category if it has a predicted annual probability of failure less than 1 percent, but has shallow (spread footing) foundations subject to sudden, catastrophic failure. A bridge monitoring plan should be developed by the bridge owner, in consultation with ITD personnel, for each bridge in this category. Category C bridges should be treated as Category B bridges until a monitoring plan has been developed and implemented.

The typical response plan for a Category C bridge will focus on a monitoring and closure strategy. Once the monitoring plan is implemented, however, structural, monitoring and hydraulic countermeasures may be developed for each bridge as funding allows. Successful installation of structural or hydraulic countermeasures at these structures may allow their reclassification from scour critical status to low-risk status in the NBI (Code 7 under Item 113).

Category D - Moderate Scour-Critical Bridges. These bridges have an economic risk of failure less than $5,000,000, deep foundations, such as pile or drilled-shaft foundations and a predicted annual probability of failure of less than 1 percent. The scour response strategy for these bridges typically focuses on inspection, qualitative monitoring, and closure protocols.

3.2 What do You Need from the Plan of Action?

The scour monitoring crew members should familiarize themselves with the contents of the Plan of Action for a given bridge prior to commencing monitoring activities. At a minimum, the crew should review the cover page and executive summary and determine whether all the necessary data, monitoring equipment, and signage are available for the crew.

Certain items from the Plan of Action should be reproduced and prepared for field use (i.e., laminated) in advance of monitoring activities. These items include the cover page and executive summary, the Scour-Critical Elevations Table (or the Monitoring, Closure, and Scour-Critical Water Surface Elevations Table if a WSEL-based scour monitoring strategy has been implemented at the bridge), the detour map, closure protocol, and signing layout plan, the current bridge inspection cross section plotted with historical soundings and bridge foundation elements, contact information, and any special bridge-specific monitoring and closure instructions. An equipment list should be developed for monitoring activities at each bridge. Sufficient stocks of signage and other supplies should be kept to allow high-flow monitoring at several scour-critical bridges simultaneously within the jurisdiction.

The crew performing high-flow monitoring should be focused on looking for indicators that the bridge is at imminent risk of failure. When it is necessary to monitor a bridge during high flows, the monitoring crew should have the necessary guidance information readily at hand. If a Plan of Action has been prepared for the bridge to be monitored, it should provide the following useful information to the monitoring crew.

- Description of what high-flow monitoring is to be performed, if any
- Description of the type of instrument to use
- Instruction on when to start high-flow monitoring
- Where to focus measurement efforts during high-flow monitoring
- A table of scour critical elevations or water surface elevations
- Reminder to check the condition of any previously installed countermeasures
- What to do as a result of certain findings during the monitoring

The following sections describe the typical steps required within each scour category to meet the expected monitoring requirements.

4. MONITORING ACTIVITIES AT SCOUR-CRITICAL BRIDGES

4.1 Safety Precautions During Monitoring Activities

The monitoring crew should look for signs of bridge distress before getting on the bridge and throughout the high-flow monitoring effort. Such signs would include, but not necessarily be limited to:

- Overtopping of the bridge deck or approach roadway
- Pressure flow at the bridge (the low chord mostly or fully submerged)
- Vertical or lateral displacement of the superstructure
- Excessive horizontal or vertical separation at bridge deck joints
- Visible damage to the bridge deck, low chord, or substructure
- Sinkholes in the roadway behind the abutments
- Massive debris buildup, especially if near the low chord

If any of these or other signs of structural distress are apparent at any time, the crew should call for a bridge closure and should avoid getting on the bridge if at all possible. A bridge under extreme distress, near Henry's Fork, Idaho is shown in **Figure 6**. Note the abrupt sag in the profile (due to a failed pier), the debris buildup (which shows that the bridge deck was overtopped), and the water surface still very near the low chord.

Figure 6. Bridge near Henry's Fork, Idaho showing signs of pier failure.

4.2 Step-By-Step Procedure for Scour Category A Bridges

Category A bridges are of such importance that an individual Plan of Action should be developed for each bridge, with specific monitoring instructions, rather than a general plan of action applicable to all bridges in the category. The guidelines given below for other scour categories will assist in understanding the monitoring activities required by each Plan of Action for Category A bridges.

4.3 Step-By-Step Procedure for Scour Category B

The appropriate response for Category B bridges is bridge closure for any flood event. The Plan of Action will describe what flood event triggers bridge closure. The critical flood level may be described on the basis of water surface elevation, discharge, bankfull flow, official flood warnings (e.g., National Weather Service) or rainfall conditions. See Appendix A for a description of flood event triggers that could be used to close a Category B bridge.

Step-by-step instructions:

1. Make sure that the bridge you are monitoring is a Category B bridge.

2. From the Plan of Action determine the flood event trigger for closure.

3. **If the trigger is water surface elevation** and the bridge has signage posted at the critical water surface, compare the current water surface to the posted level. If there is no signage, measure the water surface elevation from the reference point described in the Plan of Action. See Appendix B for information on water surface elevation measurements. If the water surface is below the critical water surface elevation, continue monitoring as needed based on storm conditions. If the water surface is above the critical level, immediately close the bridge per the Plan of Action. Section 5.1 provides additional information on bridge closure.

4. **If the trigger is discharge**, it may not be immediately necessary to visit the bridge. Obtain the current discharge reading based on available sources (call USGS, check USGS website, etc.). If the discharge is below the critical discharge no action is required. Continue monitoring discharge as needed based on storm conditions, including a site visit if conditions warrant (rapidly increasing precipitation or runoff). If the discharge is above the critical value, immediately travel to the bridge site and conduct an inspection to verify conditions, then initiate bridge closure actions per the Plan of Action. Section 5.1 provides additional information on bridge closure.

5. **If the trigger is bankfull flow and rising rapidly**, evaluate flow conditions by visual inspection at the bridge site. If the flow is currently at bankfull and rising more than 1 foot/hour, close the bridge per the Plan of Action. Section 5.1 provides additional information on bridge closure.

6. **If the trigger is flood warnings or rainfall depths,** once the warning is issued or the rainfall depths are exceeded travel to the bridge site and conduct an inspection to verify conditions, then initiate bridge closure per the Plan of Action. Section 5.1 summarizes bridge closure actions.

4.4 Step-By-Step Procedure for Scour Category C

The monitoring requirements for Category C are the most demanding and involve detailed on-site inspection activities, including both qualitative and quantitative monitoring procedures. For bridges with established scour monitoring and scour closure *water surface elevations*, no direct *streambed elevation monitoring* is required. The water surface elevation at the upstream face of the bridge will be monitored visually using signs posted on the abutments, piers or other elements visible from the bridge deck or road shoulders, or measured using a weighted tape, and compared to the closure water surface elevation reported in the Plan of Action.

For direct *streambed elevation* monitoring, the type of instrument used depends on the site conditions. In many cases simple physical probing will be most effective. Some conditions, such as water flowing fast and deep can make the use of a physical probe impractical. In these cases sonar type instrumentation may be better suited. Appendix C provides guidance on portable monitoring instrument selection. Fixed scour monitoring instrumentation will rarely be available. When available, however, it can provide valuable information to supplement portable monitoring.

The following sections describe the step-by-step instructions for either water surface elevation or streambed elevation monitoring protocol. For additional information on water surface elevation monitoring techniques, see Appendix B, and for streambed elevation monitoring, Appendix C.

Step-by-step instructions for Water Surface Based Monitoring

1. Look for signage on or near the bridge depicting critical water surface elevations. Whenever feasible the minimum scour monitoring water surface elevation and the scour closure water surface elevation have been marked with signs affixed to the upstream abutment wingwall or some other location visible from the bridge deck or road shoulders. The Plan of Action will report the location and configuration of the monitoring signs if they have been placed.

2. Visually check the current water surface elevation compared to the signage, allowing direct visual monitoring of the water surface elevation immediately upstream of the bridge deck. Go to Step 5.

3. If no signage is present, use a weighted tape to measure the height of the referenced bridge element above the water surface elevation (the top of the bridge rail is a common reference).

4. Read the scour monitoring and scour closure trigger water surface elevations tabulated in the Plan of Action, and compare these values to those measured in Step 3.

5. If the scour monitoring water surface elevation has been exceeded, continuous qualitative bridge monitoring for signs of bridge distress should commence. In addition, a visual or measuredown water surface elevation check should be performed regularly and the data recorded.

6. If the bridge shows signs of distress, or if the scour closure trigger water surface elevation has been exceeded, the bridge should be immediately closed to traffic and a formal bridge closure initiated, per the Plan of Action. Section 5.1 provides additional information on bridge closure.

Step-by-step Instructions for Streambed Elevation Monitoring

1. Before beginning streambed elevation monitoring, make sure that immediate closure is not warranted and the bridge is safe to occupy.
2. The Plan of Action will identify where streambed measurements should be taken, and which locations are most critical. If no locations are identified, **Figure 7** is a plan-view schematic showing typical measurement locations for high-flow monitoring.

3. Using the appropriate instrumentation (see Appendix C), the monitoring crew should begin the streambed elevation measurement process.

4. Depending on how rapidly conditions are changing, periodically measure and take note of the streambed elevations at critical substructure elements. Compare the measured streambed elevations to the scour critical elevations for those elements.

5. The crew may also judge that another pier or abutment should be monitored closely if high velocity flow is impinging on the element at a high angle of attack, or if that element has an excessive buildup of debris.

6. It is also important to measure and note the water surface elevation upstream and downstream of the bridge. The water surface elevation values can provide valuable information to engineers trying to characterize the severity of the flood. If, during the course of monitoring, a large difference in the water surface elevation is noticed from the upstream to the downstream side of the bridge, it may be a sign of a severe debris blockage developing beneath the water surface. The structural loading caused by this situation could lead to failure of the bridge. Make notes and take pictures, as feasible, of this or any other unusual conditions.

7. If scour is causing the streambed elevation to fall rapidly toward the scour critical elevation, but significant embedment remains, the crew should consider calling for emergency protection (see Section 5.2), if such protection can practically be installed under high-flow conditions. Emergency protection should only be considered at bridges with direct streambed measurement scour monitoring strategies.

8. If the critical elevation has been reached is expected to or be reached soon, the crew should call for a bridge closure, as per the Plan of Action. Section 5.1 provides additional information on bridge closure.

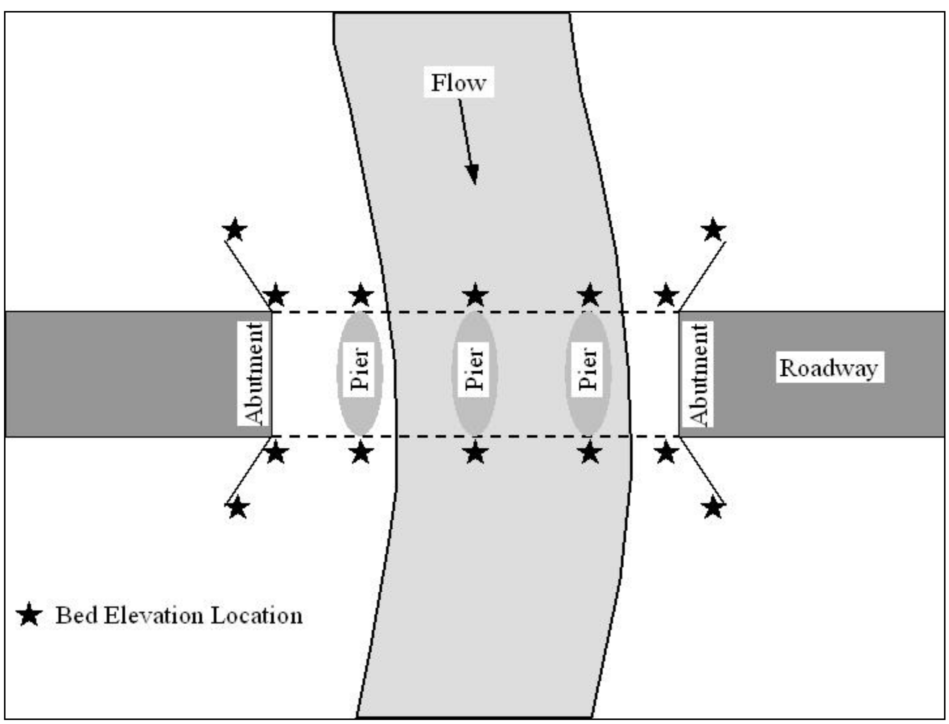

Figure 7. Streambed elevation measurement locations for high-flow monitoring.

4.5 Step-By-Step Procedure for Scour Category D

The appropriate response for Category D involves on-site inspection activities and qualitative monitoring procedures. Qualitative monitoring methods are based primarily on visual observation of conditions at the bridge.

Step-by-step Instructions

1. If **overtopping of the bridge deck** is occurring, immediate closure action is required. Even if the overtopping is small (e.g., several inches), or only in a localized area, immediately close the bridge per the Plan of Action. Section 5.1 provides additional information on bridge closure.

2. Approach **roadway overtopping** is equally dangerous and can quickly lead to failure from abutment scour. On a long bridge, you might approach from one direction and not be immediately aware of approach roadway overtopping from the other direction. If roadway overtopping is occurring, immediately close not only the bridge, but the flooded roadway, as even small depths of water on the roadway can sweep a car downstream.

3. **Pressure flow** (when the low chord of the bridge is mostly or fully submerged on the upstream side of the bridge) is a dangerous condition. The scour potential is intensified under pressure-flow conditions and the lateral force of the flowing water against the bridge deck may cause the bridge to fail. If pressure flow is occurring immediately close the bridge per the Plan of Action. Section 5.1 provides additional information on bridge closure.

4. If any of the following signs of distress in bridge structure are noted, immediately close the bridge per the Plan of Action and as summarized in Section 5.1:

   - Vertical or lateral displacement of the superstructure
   - Excessive horizontal or vertical separation at bridge deck joints
   - Visible damage to the bridge deck, low chord, or substructure
   - Sinkholes in the roadway behind the abutments
   - Massive debris buildup, especially if near the low chord

5. If any of the following signs of dramatic channel changes are occurring in the bridge reach, carefully observe the effects on the bridge structure and close the bridge, as deemed necessary. Conditions to watch for include:

   - High-velocity flow impinging at a high angle of attack on a pier or abutment
   - Main channel banks eroding and shifting
   - Other erosion evidence including falling trees along the bankline or noticeable shifting of the main channel flow path

5. EMERGENCY PROCEDURES

5.1 Bridge Closures

During high-flow monitoring, the crew may decide to call for a bridge closure if:

- Bridge is showing clear signs of structural distress
- Streambed has lowered to the scour critical elevation at a pier or abutment
- Streambed has lowered nearly to the scour critical elevation and is falling rapidly
- Water surface elevation has risen to the predetermined bridge closure WSEL
- Previously installed scour countermeasures are judged to be failing under high flow
- Bridge is already under severe hydraulic conditions and it is communicated to the crew that a higher flood wave is approaching from upstream

If the crew chief decides that a closure should be called for, he or she must contact the office of the District Engineer (for ITD-owned bridges), or in the case of local-government-owned bridges, whoever has the authority to order the closure. The contact protocol for the closure should be delineated as part of the Plan of Action. At a minimum, the Bridge Inspection Engineer, the Bridge Engineer, the Maintenance Supervisor, the State Highway Patrol or local law enforcement agency, and the IDT or local authority public affairs coordinator should be contacted regarding the closure.

The Plan of Action should include a detour map and signing layout plan in case of a bridge closure. The barriers for the closure and the detour signage are to be installed by ITD or local government maintenance forces. After the closure has been called for the monitoring crew should remain at the bridge site until the bridge closure crew or law enforcement arrives at the scene. If the bridge becomes unsafe for traffic while the crew is waiting for a formal bridge closure, the crew should perform an emergency closure of the bridge. The monitoring crew should be equipped with the necessary signage and temporary traffic barriers and authorized to perform an emergency closure, if necessary.

Once a bridge has been closed, it should remain closed until the flood has passed. As soon as possible after the flood, a full inspection of the bridge foundations, substructure, and superstructure should be conducted. For ITD-owned bridges the District Engineer has the authority to reopen the bridge to traffic once it has been assessed as structurally sound.

5.2 Emergency Protection

The high-flow monitoring crew may find it necessary to call for emergency protection. Emergency protection efforts usually involve placing rock riprap to slow or arrest the scour at a pier or abutment, or to stabilize an eroding bankline. Depending on the type of problem being addressed, the riprap may be placed:

- At the nose (upstream end) of a pier
- At the corners of a threatened abutment

- Along the toe of a bankline that is determined to be migrating dangerously toward a pier or abutment. The revetment, such as riprap, should be placed as close as practicable to the bankline toe. It may not be feasible or safe to attempt to place revetment in this location under high-flow conditions.

- Along the roadway embankment slope, if the floodwaters are actively eroding the embankment section

The methods employed for placing the emergency protection will depend to some extent upon the size of the bridge, its load rating and its condition. Other factors are the extent of the flooding. For instance, placing riprap at a pier in the middle of a long bridge during high flow must be done from the bridge deck, probably using the bucket of a hydraulic excavator. The width or load rating of the bridge may not accommodate the necessary equipment. Placing large rock from a bridge deck may itself cause damage to the structure. Placing riprap along a bankline is possible only if the equipment can reach the bankline. If significant overbank flooding is occurring, there will typically be no way to quickly and safely reach the bankline.

Contraction scour is a general lowering of the entire streambed beneath the bridge. If contraction scour is occurring during the emergency situation, it may render the emergency protection measures futile. Riprap placed locally at a pier experiencing contraction scour will simply be lowered with the rest of the streambed.

As with a bridge closure, the decision authority to place emergency protection rests with the District Engineer for ITD-owned bridges. The District Engineer may consult with the Hydraulics Engineer, the Bridge Engineer and the Maintenance Supervisor. As with any roadside activity, all appropriate traffic control measures must be taken.

Another important form of protection is the removal of debris from the bridge. Removing debris from the nose of a pier, for instance, can prevent significant additional scour from that flood event. Debris removal during high flow is usually accomplished from the bridge deck using a bridge inspection truck, crane, or excavator arm. It may not be feasible at bridges with a large bridge deck overhang because of the difficulty in reaching the pier nose under the deck and in pulling the debris away from the pier against the flow.

5.3 Monitoring Countermeasure Performance

If it is known that scour protection countermeasures (such as riprap at piers or abutments) have previously been installed at the bridge, but the bridge is still considered scour-critical, the monitoring effort should include probing (if possible) or visual inspection to assess the condition of the countermeasures. If the countermeasures are judged to be failing or non-functional during the high flows, the crew should call for a bridge closure or emergency repair work.

APPENDIX A
Triggers for High-Flow Monitoring or Bridge Closure

APPENDIX A

Triggers for High-Flow Monitoring or Bridge Closure

The Plan of Action should identify some trigger event that signals the start of high-flow monitoring, or in the case of a Category B bridge, the need to close the structure. This could be the water surface elevation reaching some pre-determined elevation associated with a certain recurrence interval, such as the 25-year flood. If a computed water surface elevation for a moderate flood cannot be determined, then other types of events can be used as triggers.

Practical definitions of high-flow events as triggers for monitoring activities are listed below in descending order of preference. The operative definition should be chosen based on availability of information.

- Predetermined water surface elevation, where one has been computed and marked on the bridge or otherwise indicated to the monitoring team
- On streams with real-time discharge gages, such as the Snake and Kootenai Rivers, discharge readings at or above the 50-year rates or smaller floods as appropriate
- Water level rises to the computed 10- or 50-year water surface elevation (where known)
- Stream is at or above the bank-full stage and is rising rapidly
- Official flood warnings have been issued for a given stream reach or geographic region, and the stage is rising at the bridge of interest
- Storm is occurring that is expected to produce a rainfall depth on the watershed exceeding the value indicated on the NOAA Atlas Depth-Duration-Frequency maps for a 10- or 50-year recurrence interval

Many of the scour critical bridges in Idaho cross steep streams subject to flashy, short duration flooding. The flowrate in such streams can increase from negligible to severely high levels in a matter of hours. If a bridge over a flashy stream is to be monitored, the crew and equipment must be mobilized to the bridge as quickly as possible. For such bridges, a crew should be placed on high alert for mobilization, or even sent to the most at-risk bridges, as soon as high rainfall for the watershed is forecast or the National Weather Service begins issuing flood warnings for the area.

APPENDIX B
Water Surface Elevation Based Monitoring

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Water Surface Elevation Based Monitoring

Direct streambed elevation monitoring during high-flow conditions is the most accurate method for determining whether a bridge foundation element is approaching a scour closure streambed elevation. However, if direct streambed sounding is not feasible, then a scour monitoring and a scour closure trigger water surface elevation (WSEL) may be determined using hydraulic, structural, geotechnical, and scour analyses. For bridges using WSEL-based scour monitoring, the monitoring and closure WSEL's should ideally be marked at the upstream side of the bridge, using reflective signage visible from the roadway. The signage should be installed on the pier(s), and/or wing-walls or abutment ends. **Figure B.1** illustrates typical monitoring and closure WSEL signs. For additional monitoring guidance, measuredown distances to the monitoring and closure WSEL's from the bridge rail or other fixed datum are tabulated in the Plan of Action, similar to the template shown in **Table B.1**.

The WSEL may be monitored visually, using the WSEL signage affixed to the bridge or other visible location. If signs denoting the relevant WSELs are not visible or have not been placed, the monitoring crew should measure the vertical distance from the reference line (identified in the table from the Plan of Action) to the actual WSEL, and compare this to the monitoring and/or closure measuredown heights listed on the table. This measurement is best performed with a weighted tape, as a surveying rod or other rigid measurement device is likely to break or be ripped from the monitor's grasp by high-velocity high flows.

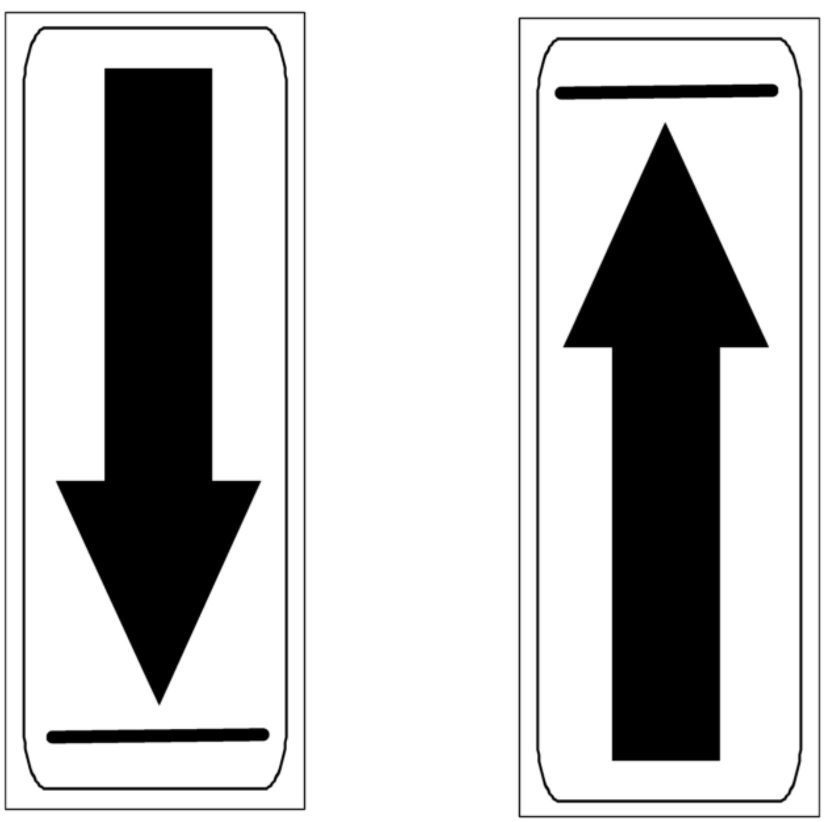

Figure B.1. Typical scour monitoring WSEL (left) and scour closure WSEL marking signs.

Table B.1. Table of Monitoring, Closure, and Scour-Critical Water Surface Elevations from Plan of Action (template)				
Reference Line for Measurements (circle one):	Top of Rail	Top of Curb	String Line	Other
Describe “Other:				

Substructure Element	**1. Ref. Elevation** (ft-DATUM)	**2. Monitor WSEL** (ft-DATUM)	**3. Closure WSEL** (ft-DATUM)	**4. Scour Critical WSEL** (ft-DATUM)	**5. Dist. Ref. to Closure WSEL** (ft-DATUM)
Abutment 1 (Indicate north, south, east or west end of bridge)					
Abutment 2 (Indicate north, south, east or west end of bridge)					
Monitored Pier 1 (Indicate station on bridge plan & elevation dwg.)					
Monitored Pier 2 (Indicate station on bridge plan & elevation dwg.)					

Notes on Table B.1:

1. See Figure B.2 for definition sketch.
2. Ref. Elevation = Elevation of the reference line (i.e., top of rail) above the substructure element.
3. Monitor WSEL = Water surface elevation at which to commence active WSEL monitoring at the bridge site for a given substructure element. The WSEL at the bridge triggering monitoring (the minimum T_{i-2} for any bridge element) should be reported to the monitoring crew and be marked at the bridge abutments and the critical bridge substructure element with reflective signage visible from the roadway.
4. Closure WSEL = Water surface elevation at which to close the bridge to traffic. The WSEL at the bridge triggering closure should be reported to the monitoring crews and be marked at the bridge abutments and the critical bridge substructure element with reflective signage visible from the roadway.
5. Scour Critical WSEL = Water surface elevation approximately corresponding to the scour-critical bed condition at the bridge substructure element.
6. Distance Ref. to Closure WSEL = The vertical distance between the reference elevation and the corresponding closure trigger WSEL for the bridge substructure element. The distance from the reference elevation to the closure WSEL should be reported to the monitoring crews and be marked at the critical bridge substructure element with reflective signage visible from the roadway.

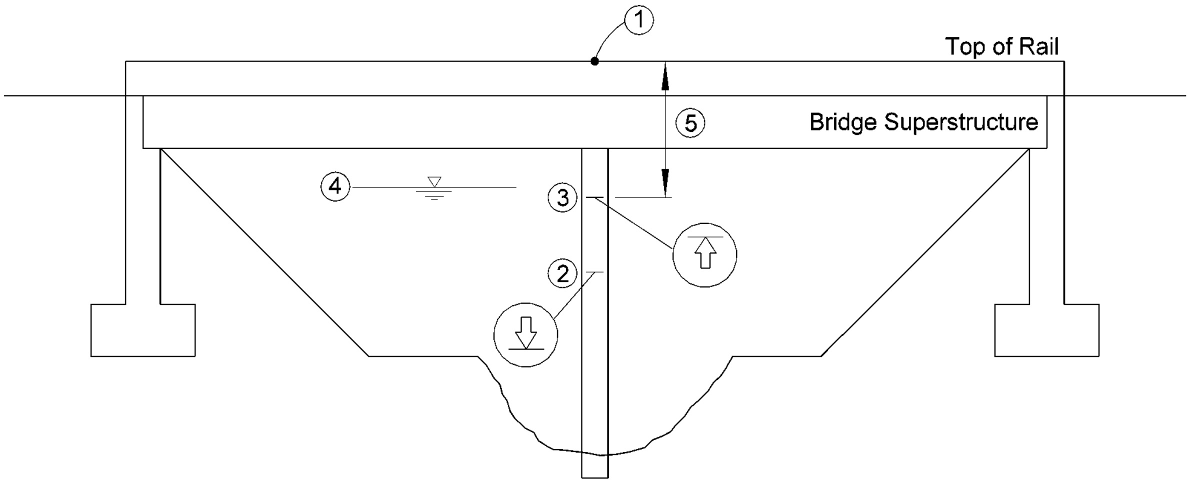

Figure B.2. Definition sketch for column headings in Table B.1.

APPENDIX C
Streambed Level Monitoring Equipment

APPENDIX C

Streambed Level Monitoring Equipment

At some bridges, the Plan of Action may call for direct monitoring of the streambed during high flows. **Table C.1** below is a template of the Table of Scour Critical Bed Elevations that will be provided in the Plan of Action if streambed monitoring is required.

<table>
<tr><td colspan="6">Table C.1. Table of Scour Critical Elevations from Plan of Action (template).</td></tr>
<tr><td colspan="2">Reference Line for Measurements (circle one):</td><td>Top of Rail</td><td>Top of Curb</td><td>String Line</td><td>Other</td></tr>
<tr><td colspan="6">Describe “Other:</td></tr>
<tr><td>Substructure Element</td><td>1. Ref. Elevation (ft-DATUM)</td><td>2. Bottom of Footing Elevation (ft-DATUM)</td><td>3. Pile Tip Elevation (ft-DATUM)</td><td>4. Scour Critical Elevation (ft-DATUM)</td><td>5. Dist. Ref. to Scour Critical (ft)</td></tr>
<tr><td>Abutment 1 (Indicate north, south, east or west end of bridge)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Abutment 2 (Indicate north, south, east or west end of bridge)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Monitored Pier 1 (Indicate station on bridge plan & elevation dwg.)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Monitored Pier 2 (Indicate station on bridge plan & elevation dwg.)</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Notes on Table C.1:

1. See **Figure C.1** for definition sketch.
2. Ref. Elevation = Elevation of the reference line (i.e., top of rail) above the substructure element.
3. Pile Tip Elevation = Elevation of the highest pile tip for particular substructure element.
4. Scour Critical Elevation = Scour elevation at which the substructure element is assumed at risk of failure, considering appropriate loading conditions.
5. Dist. Ref. to Scour Critical = The vertical distance measured down from the reference line to the scour critical elevation for particular substructure element.
6. Add more monitored piers as necessary

Many different types of devices have been used for monitoring scour at bridges. The two basic categories of scour monitoring devices are portable instruments and fixed instruments. A single portable instrument can be used to monitor scour at several different locations at a given bridge and can be moved from one bridge to another. A fixed instrument is kept stationary at a particular location, such as at the end of an at-risk pier. A fixed instrument can be used to monitor scour over long periods of time without an inspector or operator present.

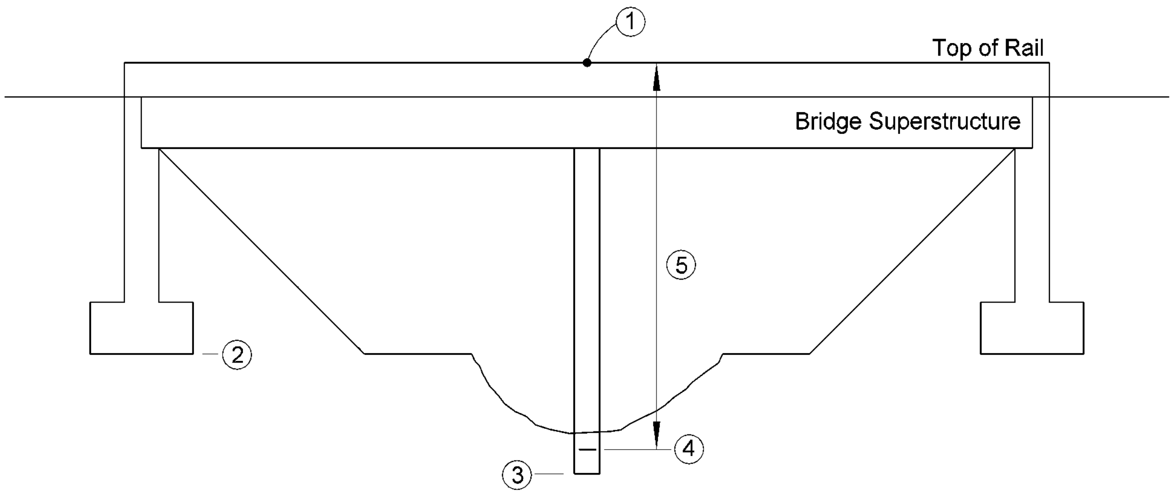

Figure C.1. Definition sketch for column heading in Table C.1.

The focus of this manual is on high-flow monitoring. Fixed monitors can be valuable during high-flow monitoring under certain circumstances. In most flood monitoring situations, however, flexibility and rapid mobility among multiple bridge sites is imperative. This section, therefore, will focus on portable monitoring devices. Two types of portable streambed level monitoring equipment are commonly used for high-flow scour monitoring: physical probes and sonar instruments.

A physical probe is any type of device that extends the reach of the inspector. The most common types of physical probes are sounding poles and sounding weights.

Sounding poles are long poles used to probe the bottom (**Figure C.2**). Sounding weights, sometimes referred to as lead lines, are typically torpedo-shaped weights suspended by measurement cables (**Figure C.3**).

Figure C.2. Sounding pole measurement.

Figure C.3. Lead-line sounding weight.

Both sounding poles and sounding weights can be deployed from the bridge deck. Sounding weight cables can be lowered by hand or from a reel mounted on a truck bed or portable frame. The United States Geologic Survey (USGS) has used sounding weights and similar instruments in their streamflow monitoring program for years. USGS stream-gaging techniques are documented in Water Supply Paper 2175 (can be downloaded from http://water.usgs.gov/pubs/wsp/wsp2175/). Information in Volume 1, Chapter 5 of this reference, related to sounding methods, is valuable for scour monitoring work. A visit to the local USGS office may also allow inspection of the equipment used for stream-gaging and guidance on the successful use of sounding weights under high flow conditions.

Sounding weights can also be deployed from a manned boat. During flood conditions, manned-boat deployment should be attempted only if the equipment and circumstances allow for the safety of the boat crew. The boat must have adequate size and power to prevent being swept downstream by the flow or being hung up on a bridge pier. The bridge must provide adequate vertical clearance and ample clear spans to allow a boat to safely pass under the bridge.

Physical probing can be difficult or impossible when the flow is both deep and fast, especially if the bridge deck is very far above the water. Under such circumstances, heavy sounding weights, properly deployed with sounding reels and cranes, have proven easier to use than sounding poles.

Apart from the challenge of high-flow deployment, physical probing is relatively simple to understand and implement. It is not affected by air entrainment or high sediment loads. It is well suited to lower-profile bridges over relatively small channels. To convert the sounding information to elevation data, the measurement should be referenced to the pavement, curbline, or guard rail or other location with a known elevation (e.g., from the bridge plans).

Sonar instruments have also been successfully used to monitor streambed elevations under high-flow conditions at bridges. Applications of single beam sonar range from fish finders to precision survey-grade fathometers. Low-cost fish-finder type sonar instruments have been widely used for bridge scour investigations (**Figure C.4**).

A sonar instrument can be deployed from the bridge deck, by attaching it to a probe or a mechanical arm, or by tethering it to a float. Under the mechanical arm category, a truck mounted articulating crane has been developed (**Figure C.5**) and has proven successful in testing under actual flood conditions with velocities in excess of 10 fps. Float platforms have included kneeboards (**Figure C.6**) and pontoon-style floats (**Figure C.7**). Tethered float platforms can be suspended from a pole or a bridge inspection truck to help control the movement of the float under the bridge.

Sonar instruments do not have to be positioned at the streambed to measure the streambed elevation, but the sonar transducer must be in the water. Sonar monitoring is more viable than physical probing, therefore, under high-flow conditions that are deep and fast. A disadvantage of sonar monitoring is that its accuracy is negatively affected when large quantities of debris are present, under high turbulence conditions, when significant air entrainment occurs, and when the flow carries a high sediment load. To convert the sonar data to elevation data, the elevation of the water surface and the distance the transducer is underwater typically must be known. The water surface elevation can be defined by a drop-line measurement from a known point on the bridge deck.

Figure C.4. Portable sonar in use.

Figure C.5. Sonar instrument deployed by a truck mounted articulating crane.

Figure C.6. Kneeboard float.

Figure C.7. Pontoon float.

APPENDIX D
Equipment List for Field Monitoring Crews

APPENDIX D

EQUIPMENT LIST FOR FIELD MONITORING CREWS

General

- Emergency Bridge Closure Signage and temporary traffic barriers
  [To Be Determined By ITD Staff. See MUTCD.]
- Survey Crew Signage
  [To Be Determined by ITD Staff. See MUTCD.]
- Cellular Telephone, Pay Telephone card, 2-Way Radio
- Contact List
- Plan of Action with field-ruggedized tables and maps
- General Procedures (Field Manual)
- Detour Map with written directions and signage list
- Safety Equipment
  - Flares
  - Flashlight
  - Safety Line
  - Harness
  - Vehicle Flashers
  - Reflective Vests
  - Hard Hat
- 1st Aid Kit
- Food and Water
- Rain Gear
- Duct Tape
- Baling Wire

Monitoring Equipment

- Field Notebook and Pencil
- Compass/GPS unit
- Binoculars
- Stopwatch
- Watch
- Measurement Wheel
- Tape (english/metric)
- Wire Line, Stakes
- Marking Paint
- Waterproof Disposable Cameras
- Photo Log
- Any special equipment listed in Plan of Action
  (Surveying Equipment, Etc.)
- For WSEL-Based Monitoring
  - Spot Light
  - Weighted Tape
  - Laminated Table of Measuredown Information
- For Direct Bed Monitoring
  - Spot Light
  - Equipment will vary with Method (to be specified as part of Plan of Action).