

OFFICE MANUAL

Plans of Action for

Scour Critical Bridges

Idaho Transportation Department



Prepared for

Idaho Transportation Department

P.O. Box 7129

Boise, Idaho 83707

By

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1. INTRODUCTION

1.1 Purpose

This manual is intended for use by those responsible for the safety of Idaho bridges that may be threatened by scour. The purpose of this document is to enable engineers, bridge inspectors and maintenance personnel to prepare appropriate and cost-effective responses to scour conditions at each scour critical bridge in Idaho. To that end, this manual provides guidance on:

1. Prioritizing attention to Idaho's scour critical and unknown-foundation bridges
2. Understanding basic scour concepts
3. Developing a monitoring and/or countermeasure response for a given bridge based on priority and scour critical categorization
4. Inspection and monitoring strategies for each scour critical category

Additional technical background useful for the implementation of the recommended minimum responses are included in the appendices to this manual.

1.2 Background

The most common cause of bridge failure is from floods scouring bed material from around bridge foundations. Scour is the engineering term for the water-induced erosion of the soil surrounding bridge foundations (piers and abutments). During the spring floods of 1987, 17 bridges in New York and New England were damaged or destroyed by scour. In 1985, 73 bridges were destroyed by floods in Pennsylvania, Virginia, and West Virginia. A 1973 national study for the Federal Highway Administration (FHWA) of 383 bridge failures caused by catastrophic floods showed that 25 percent involved pier damage and 75 percent involved abutment damage. A second, more extensive study in 1978 indicated local scour at bridge piers to be a problem about equal to abutment scour problems.

Minimizing future flood damage to Idaho's bridges requires attention to developing and implementing improved procedures for protecting bridges against scour. Because it is not economically feasible to construct all bridges to ensure absolute invulnerability from scour damage, some risks of failure from future floods may have to be accepted. However, the added cost of making a bridge less vulnerable to scour is small when compared to the total cost of a failure, which can easily be 2 to 10 times the cost of the bridge itself.

Each bridge identified as scour critical in National Bridge Inventory (NBI) Item 113 (designated by Code 3, 2, 1, or 0) should have a monitoring and closure plan, addressing the inherent public safety hazard. For scour critical bridges whose failure would cause severe economic disruption, a hydraulic or structural countermeasure plan addressing the underlying scour conditions should be developed. Any unknown-foundation bridge (Item 113 code U) should be programmed for further action in accordance with the prioritization for unknown-foundation bridges presented in this manual. The bridge owner should make every attempt to determine the foundation type and depth. Once the foundation has been determined, a scour evaluation should be performed to determine whether the bridge is actually scour critical. Until the foundation is determined and the scour depths are known, a monitoring plan with closure protocols should be implemented.

This manual subdivides the ITD scour critical bridges into four categories based on lifetime risk of failure and annual probability of failure. It describes the minimum monitoring and/or countermeasure response required for each category. The required responses vary from simple high-flow monitoring plans and bridge closure protocols to a full Plan of Action covering both monitoring and countermeasure development.

1.3 Manual Organization

This manual is organized as follows:

- Basic scour concepts and definitions are presented in Chapter 2
- Description of the prioritization and categorization strategy for scour critical and unknown foundation bridges is presented in Chapter 3
- Management strategies for developing countermeasure responses for each scour critical bridge category are presented in Chapter 4
- Chapter 5 describes the required content of Plans of Action for each scour critical bridge category
- **Appendix A** presents the priority ranking and categorization for scour critical and unknown foundation bridges
- **Appendix B** presents a detailed description of the prioritization strategy
- **Appendix C** presents the full Plan of Action template for Idaho scour critical bridges
- **Appendix D** presents technical background information to aid in implementing the recommended minimum response for each scour critical bridge category
- **Appendix E** presents a review of the HEC-18 recommended bridge scour inspection procedures
- A compact disc is provided at the back of this manual containing a Microsoft Access database file. This database is a compilation of information taken from the bridge files and scour evaluation reports and is provided for ease of reference in planning efforts. The user should refer to bridge plans and/or scour reports on file with the ITD to verify any information taken from this database if the information is to be used for design..

2. BASIC CONCEPTS AND DEFINITIONS OF SCOUR

2.1 General

Scour is the result of the erosive action of flowing water, excavating and carrying away material from the bed and banks of streams and from around the piers and abutments of bridges. Different materials scour at different rates. Loose granular soils are rapidly eroded by flowing water, while cohesive or cemented soils are more scour-resistant. However, ultimate scour in cohesive or cemented soils can be as deep as scour in sand-bed streams. Under constant flow conditions, scour will reach maximum depth in sand- and gravel-bed material in hours; cohesive bed 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, several floods may be needed to attain maximum scour.

Measuring the magnitude of scour is complicated by the cyclic nature of the scour process. Scour can be deepest near the peak of a flood, but hardly visible as floodwaters recede and scour holes refill with sediment.

Designers and inspectors need to carefully study site-specific subsurface information in evaluating scour potential at bridges, giving particular attention to foundations on rock. Massive rock formations with few discontinuities are highly resistant to scour during the lifetime of a typical bridge.

The type of scour at highway crossings and encroachments is an important factor. Clear-water scour occurs where there is no transport of bed material upstream of the crossing or the material being transported from the upstream reach is transported through the downstream reach at less than the capacity of the flow. Live-bed scour occurs where there is transport of bed material from the upstream reach into the crossing.

This chapter provides a brief overview of scour concepts. For more detailed information, refer to the following documents published by the Federal Highway Administration (FHWA):

- HEC-11 - "Design of Riprap Revetment" (Brown and Clyde 1989)
- HEC-18 - "Evaluating Scour at Bridges" (Richardson et al. 2001)
- HEC-20 - "Stream Stability at Highway Structures" (Lagasse et al. 2001)
- HEC-23 - "Bridge Scour and Stream Instability Countermeasures" (Lagasse et al. 2001)
- HDS 6 - "River Engineering for Highway Encroachments" (Richardson et al. 2001)

2.2 Total Scour

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

1. Long-term aggradation and degradation of the river bed
2. General scour at the bridge
 - a. Contraction scour
 - b. Other general scour
3. Local scour at the piers or abutments

These three scour components are added to obtain the total scour at a pier or abutment. This assumes that each component occurs independently of the other, which may not always

be true, but provides for a conservative design. In addition, lateral migration of the stream channel must be assessed when evaluating total scour at bridge piers and abutments.

2.2.1 Aggradation and Degradation

Aggradation and degradation are long-term streambed elevation changes due to natural or man-induced causes. Aggradation involves the deposition of material eroded from the channel or watershed upstream of the bridge. Degradation involves the lowering or scouring of the streambed due to a deficit in sediment supply from upstream.

The streambed may be aggrading, degrading, or in relative equilibrium in the vicinity of a bridge crossing. Long-term aggradation and degradation do not include the cutting and filling of the streambed in the vicinity of the bridge that might occur during a runoff event (see general and local scour below). A long-term trend may change during the life of the bridge. Such changes may be the result of natural processes or human activities. The engineer must assess the present state of the stream and watershed and then evaluate potential future changes in the river system. From this assessment, the long-term streambed elevation changes can be estimated.

2.2.2 Clear-Water and Live-Bed Scour

There are two classifications for scour: clear-water and live-bed scour. Clear-water scour occurs when there is no movement of the bed material in the flow upstream of the crossing or the bed material being transported in the upstream reach is transported in suspension through the scour hole at the pier or abutment at less than the sediment transport capacity of the flow. At the pier or abutment, the acceleration of the flow and vortices created by these obstructions cause the bed material around them to move. Live-bed scour occurs when there is transport of bed material from the upstream reach into the crossing. Live-bed local scour is cyclic in nature; that is, the scour hole that develops during the rising stage of a flood refills during the falling stage.

Typical clear-water scour situations include: (1) coarse-bed material streams, (2) flat gradient streams during low flow, (3) local deposits of larger bed materials that are larger than the biggest fraction being transported by the flow (rock riprap is a special case of this situation), (4) armored streambeds where the only locations that tractive forces are adequate to penetrate the armor layer are at piers and/or abutments, and (5) vegetated channels or overbank areas.

During a flood event, bridges over streams with coarse-bed material are often subjected to clear-water scour at low discharges, live-bed scour at the higher discharges and then clear-water scour at the lower discharges on the falling stages. Clear-water scour requires more time to reach its maximum than does live-bed scour (**Figure 2.1**). This is because clear-water scour occurs mainly in coarse-bed material streams. In fact, local clear-water scour may not reach a maximum until after several floods. Maximum clear-water pier scour is about 10 percent greater than the equilibrium live-bed pier scour.

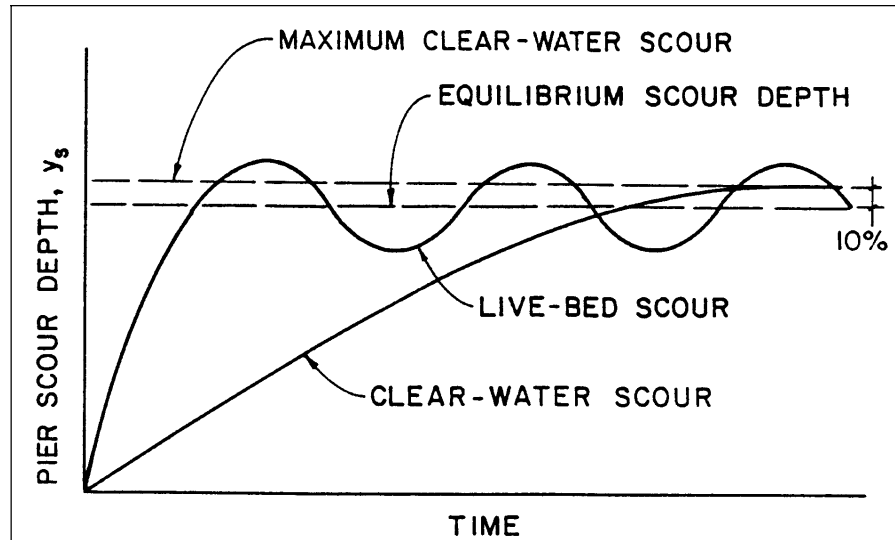


Figure 2.1. Pier scour depth in a sand-bed stream as a function of time.

2.2.3 General Scour

General scour is a lowering of the streambed across the stream or waterway bed at the bridge. This lowering may be uniform across the bed or non-uniform, that is, the depth of scour may be deeper in some parts of the cross section. General scour may result from contraction of the flow, which results in removal of material from the bed across all or most of the channel width, or from other general scour conditions such as flow around a bend where the scour may be concentrated near the outside of the bend. General scour is different from long-term degradation in that general scour may be cyclic and/or related to the passing of a flood. Also, long-term degradation is usually associated with a longer segment of the river whereas general scour is more of a local issue due to a scour-inducing feature of the channel geometry (flow constriction, a bend, etc).

2.2.4 Local Scour

Local scour is the removal of material from around piers, abutments, spurs, and embankments. It is caused by an acceleration of flow and resulting vortices induced by obstructions to the flow. Local scour can be either clear-water or live-bed scour.

2.2.5 Lateral Stream Migration

In addition to the types of scour mentioned above, naturally occurring lateral migration of the main channel of a stream within a floodplain may affect the stability of piers in a floodplain, erode abutments or the approach roadway, or change the total scour by changing the flow angle of attack at piers and abutments. Factors that affect lateral stream movement also affect the stability of a bridge foundation. These factors are the geomorphology of the stream, location of the crossing on the stream, flood characteristics, and the characteristics of the bed and bank materials. HEC-20 and HDS 6 provide detailed information on lateral stream migration.

The following sections provide a more detailed discussion of general scour, local scour, and lateral stream migration.

2.3 General Scour

2.3.1 Contraction Scour

Contraction scour occurs when the flow area of a stream at flood stage is reduced, either by a natural contraction of the stream channel or by a bridge. It also occurs when overbank flow is forced back to the channel by roadway embankments at the approaches to a bridge. In order for continuity of flow to be satisfied, a decrease in flow area results in an increase in average velocity and bed shear stress through the contraction. Hence, there is an increase in erosive forces in the contraction and more bed material is removed from the contracted reach than is transported into the reach. This increase in transport of bed material from the reach lowers the bed elevation. As the bed elevation is lowered, the flow area increases and, in the riverine situation, the velocity and shear stress decrease until relative equilibrium is reached; i.e., the quantity of bed material that is transported into the reach is equal to that removed from the reach, or the bed shear stress is decreased to a value such that no sediment is transported out of the reach. Contraction scour causes removal of material from the bed across all or most of the channel width.

Live-bed contraction scour is typically cyclic; for example, the bed scours during the rising stage of a runoff event and fills on the falling stage. The cyclic nature of contraction scour causes difficulties in measuring contraction scour depths after a flood.

Typical conditions that can cause contraction scour are (1) natural stream constrictions, (2) long highway approaches to the bridge over the floodplain, (3) ice formations or jams, (4) natural berms along the banks due to sediment deposits, (5) debris, (6) vegetative growth in the channel or floodplain, and (7) pressure flow (the condition in which the bridge low chord is submerged).

Figure 2.2 shows the conditions after live-bed contraction scour at the I-5 bridges near Coalinga, California. The failure occurred March 10, 1995, and seven people were killed. The photo is looking downstream.



Figure 2.2. Live-bed contraction scour contributed to failure of the I-5 bridges near Coalinga, CA.

2.3.2 Other General Scour

Other general scour conditions can result from erosion related to the planform characteristics of the stream (meandering, braided or straight), variable downstream control, flow around a bend, or other changes that decrease the bed elevation. General scour conditions can occur at bridges located upstream or downstream of a confluence.

2.3.3 Tips for Assessing General Scour Potential

1. Sand-bed channels typically experience live-bed scour.
2. Clear-water scour occurs mainly on coarse-bed channels or on well-vegetated floodplain areas.
3. Significant contraction scour can occur if a large fraction of the total upstream flow is captured by roadway approach embankments and forced through the bridge opening.
4. Flow through relief bridges or over roadway approach embankments can reduce the flow and contraction scour in the main channel bridge opening.
5. Where abutments are set back from the main channel, the contraction scour in the main channel may be occurring under the live-bed conditions, while the contraction scour in the setback overbank area can be clear-water scour.
6. If there is no overbank flow, only a change in channel width (including bridge piers in the flow) and the average flow depth in the channel will influence live-bed contraction scour.
7. Large substructure elements (piers, pile caps, pile groups) can increase contraction scour significantly.
8. Submergence of the bridge superstructure causes pressure flow (vertical contraction scour) that can increase scour by a factor of 2 or 3.

2.4 Local Scour

The basic mechanism causing local scour at piers or abutments is the formation of vortices (known as the horseshoe vortex) at their base (**Figure 2.3**). The horseshoe vortex results from the pileup of water on the upstream surface of the obstruction and subsequent acceleration of the flow around the nose of the pier or abutment. The action of the vortex removes bed material from around the base of the obstruction. The transport rate of sediment away from the base region is greater than the transport rate into the region, and, consequently, a scour hole develops. As the depth of scour increases, the strength of the horseshoe vortex is reduced, thereby reducing the transport rate from the base region. Eventually, for live-bed local scour, equilibrium is reestablished between bed material inflow and outflow and scouring ceases. For clear-water scour, scouring ceases when the shear stress caused by the horseshoe vortex equals the critical shear stress of the sediment particles at the bottom of the scour hole.

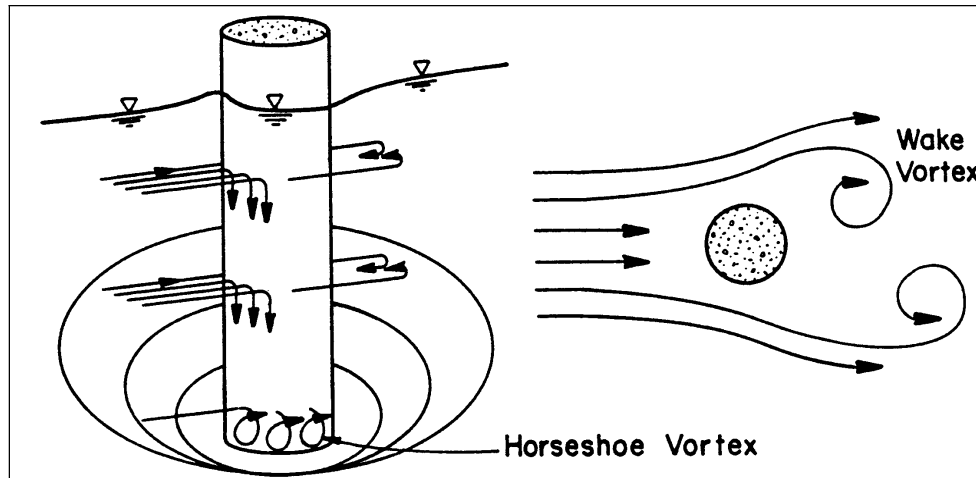


Figure 2.3. Schematic representation of scour at a cylindrical pier.

In addition to the horseshoe vortex around the base of a pier, there are vertical vortices downstream of the pier called the wake vortex (Figure 2.2). Both the horseshoe and wake vortices remove material from the pier base region. However, the intensity of wake vortices diminishes rapidly as the distance downstream of the pier increases. Therefore, immediately downstream of a long pier there is often deposition of material.

2.4.1 Tips for Assessing Pier Scour Potential

1. Flow velocity affects local scour depth. The greater the velocity, the deeper the scour.
2. Pier width has a direct influence on depth of local scour. As pier width increases, there is an increase in scour depth. There is a limit to the increase in scour depth as width increases. Very wide piers require special adjustments to the scour prediction equations to avoid excessive conservatism in the results.
3. The length of a pier has no appreciable effect on scour depth if the pier is aligned with the flow. However, the angle of attack of the flow to the pier has a large effect on local scour at long piers. Increasing the angle of attack on a long wall pier from 0° to 45° can increase pier scour depth by a factor ranging from 1.0 to 3.5.
4. Bed material characteristics such as size, gradation, and cohesion can affect local scour. Bed material in the sand-size range has little effect on the local scour depth. Likewise, larger size bed material that can be moved by the flow or by the vortices and turbulence created by the pier will not affect the maximum scour, but will affect the time it takes to attain it. Very large particles in the bed material, such as coarse gravels, cobbles or boulders, may armor the scour hole. The size of the bed material also determines whether the scour at a pier or abutment is clear-water or live-bed scour.

Fine bed material (silts and clays) will have scour depths as deep as sand-bed streams. This is true even if bonded together by cohesion. The effect of cohesion is to influence the time it takes to reach maximum scour. With sand-bed material the time to reach maximum depth of scour is measured in hours and can result from a single flood event. With cohesive bed materials it may take much longer to reach the maximum scour depth, the result of many flood events.

5. The shape of the nose of a pier or an abutment can have up to a 20 percent influence on scour depth. Streamlining the front end of a pier reduces the strength of the horseshoe vortex, thereby reducing scour depth. Streamlining the downstream end of piers reduces the strength of the wake vortices. A square-nose pier will have maximum scour depths about 20 percent greater than a sharp-nose pier and 10 percent greater than either a cylindrical or round-nose pier. The nose shape effect is negligible for flow angles in excess of five degrees.
6. Ice and debris can potentially increase the effective width of the piers, change the shape of piers and abutments, increase the projected length of an abutment, and cause the flow to plunge downward against the bed. This can increase both local and contraction scour. The magnitude of the increase is still largely undetermined. Debris can be taken into account in the scour equations by estimating how much the debris will increase the width of a pier or length of an abutment. Debris and ice effects on contraction scour can also be accounted for by estimating the amount of flow blockage (decrease in width of the bridge opening) in the equations for contraction scour.

2.4.2 Tips for Assessing Abutment Scour Potential

Figure 2.4 presents the various types of abutments including spill-through, vertical wall, and vertical wall with flared wingwalls.

1. The potential for lateral channel migration, long-term degradation, and contraction scour should be considered when assessing abutment scour potential.
2. Riprap and guide banks can be used to protect an abutment from failure.
3. Riprap or some other bank protection should always be used to protect the abutment from lateral erosion or channel migration.
4. Abutment scour will be most severe where the approach roadway embankment leading to the abutment obstructs a significant amount of overbank flow.
5. Scour can also occur at the downstream end of the abutment as the flow expands through bridge opening.
6. Abutment scour will increase if the abutment (embankment) is skewed in an upstream direction (into the flow).
7. Abutment scour will decrease if the abutment (embankment) is skewed in a downstream direction (away from the flow).
8. A vertical wall abutment can have twice the scour depth as a spill-through (sloping) abutment.

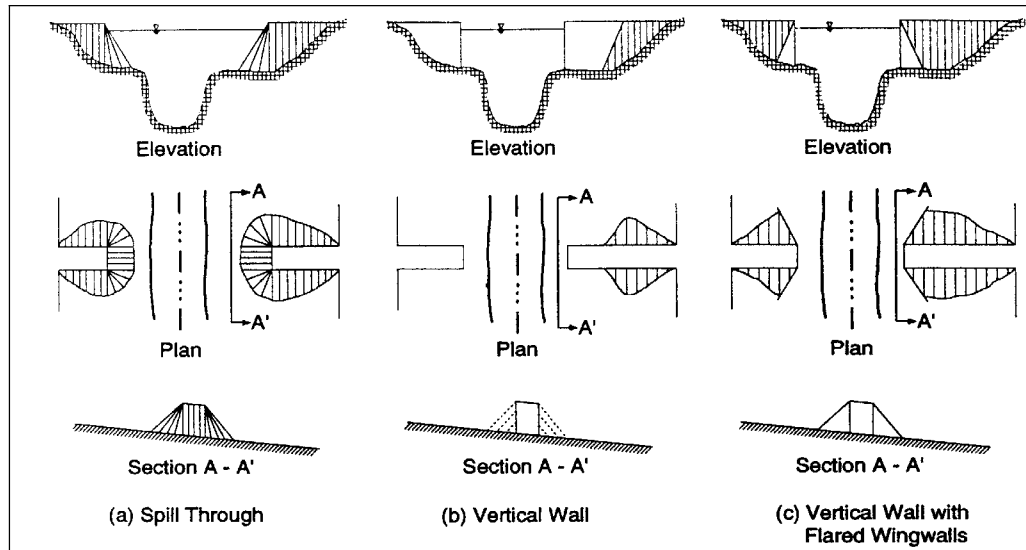


Figure 2.4. Types of abutments.

2.5 Lateral Shifting of a Stream

Streams are dynamic. Areas of flow concentration continually shift banklines, and in meandering streams having an "S-shaped" planform, the channel moves both laterally and down valley. A braided stream has numerous channels that are continually changing. In a braided stream, the deepest natural scour occurs when two channels come together or when the flow comes together downstream of an island or bar. This scour depth has been observed to be 1 to 2 times the average flow depth.

A bridge is static. It fixes the stream at one place in space. A meandering stream whose channel moves laterally and down valley into the bridge reach can erode the approach embankment and can affect contraction and local scour because of changes in flow direction. A braided stream can shift under a bridge and have two channels come together at a pier or abutment, increasing scour. Descriptions of stream morphology are given in HDS 6 and HEC-20.

Factors that affect lateral shifting of a stream and the stability of a bridge are the geomorphology of the stream, location of the crossing on the stream, flood characteristics, and the characteristics of the bed and bank material. It is difficult to anticipate when a change in planform may occur. It may be gradual or the result of a single major flood event. Also, the direction and magnitude of the movement of the stream are not easily predicted. While it is difficult to evaluate the vulnerability of a bridge due to changes in planform, it is important to incorporate potential planform changes into the design of new bridges and design of countermeasures for existing bridges. These factors are discussed and analysis techniques are presented in HEC-20.

Countermeasures for lateral shifting and instability of the stream may include changes in the bridge design, construction of river control works, protection of abutments with riprap, or careful monitoring of the river in a bridge inspection program. Serious consideration should be given to embedding foundations located on floodplains to the same elevations as those in the main channel. Control of lateral shifting requires river training works or bank stabilizing by riprap, or other revetment material. The design of these works is beyond the scope of this manual. Design methods are given by FHWA in HEC-23, HDS 6, HEC-11, and similar publications. The USACE and AASHTO provide additional guidance.

3. PRIORITIZATION STRATEGY AND CATEGORY DEFINITION

3.1 General

An effective response program for scour critical bridges and those with unknown foundations requires a systematic method of prioritizing the bridges. This chapter presents the prioritization strategy for the 198 scour critical bridges and 536 unknown foundation bridges in Idaho. The method used to prioritize these bridges is based on **lifetime risk**, defined as the lifetime cost of failure multiplied by the lifetime probability of failure (Equation 3.1) and for scour critical bridges, the estimated annual probability of failure.

$$\text{Risk} = \text{TotalCostFailure} \times P_{\text{Failure}} \quad (3.1)$$

The probability of failure and failure cost values are based on an expanded HYRISK methodology (Pearson et al. 2000). The methodology was modified and expanded to incorporate information developed by ITD as part of the scour assessment program along with information from the NBI database. The assumptions and methods used to develop the cost and probability of failure over the lifetime of a bridge are discussed in the remainder of this chapter.

The lifetime risk is the expected cost of bridge failure due to scour, delivered by combining the cost of failure with the probability of failure. A bridge may have a very high cost of failure (a long bridge with a very high average daily traffic (ADT)) but a very low probability of failure. The lifetime risk for this bridge may be quite low. Conversely, a bridge with a lower cost of failure but with a high probability of failure may have a higher lifetime risk.

3.2 Total Cost of Bridge Failure

The total cost of bridge failure due to scour is the sum of the cost of reconstruction, time and mileage costs due to the detour around the failed bridge, and the assumed cost of any fatalities (Equation 3.2).

$$\text{TotalCost} = \text{Re constructionCost} + \text{DetourTimeCost} + \text{DetourMileageCost} + \text{FatalityCost} \quad (3.2)$$

Each of the four costs is estimated based on information in the NBI, information from ITD, and judgment. The reconstruction cost equals the total deck area multiplied by the cost per unit area. The total deck area is extracted from the National Bridge Inventory (NBI) for the bridge. The unit cost of the bridge replacement, \$90/ft², was determined using cost estimation documents provided to Ayres Associates by ITD personnel. The reconstruction cost is adjusted upward to account for additional costs due to unexpected, early replacement. This cost factor varies with the ADT and was determined using information from National Highway Institute (NHI) Course 135048, "Countermeasure Design for Bridge Scour and Stream Instability." It is assumed that high-ADT bridges would be replaced on an accelerated schedule. The reconstruction cost is presented in Equation 3.3:

$$\text{Re constructionCost} = \text{CostFactor} \times \text{Cost / Area} \times W \times L \times EF \quad (3.3)$$

where W is the width of the bridge deck (NBI Item 52), L is the bridge length (NBI Item 49), EF is a factor equal to 1.2 (based on communication with ITD personnel) that accounts for engineering and traffic control costs. **Table 3.1** gives the Cost Factor as a function of ADT.

Cost Factor	Average Daily Traffic (ADT)
1.0	ADT < 100
1.1	100 < ADT < 500
1.25	500 < ADT < 1000
1.5	1000 < ADT < 5000
2.0	ADT > 5000

The time cost due to the detour around the failed bridge equals the cost per hour of traffic passing through the detour multiplied by the time required to traverse the detour, multiplied by the ADT and the duration of the detour. The duration of the detour varies with ADT and was determined using materials found in NHI Course 135048. ADT and detour length are extracted from the NBI record for the bridge. It is assumed that high-ADT bridges would be replaced on an accelerated schedule. The time cost is shown in Equation 3.4:

$$\text{Time Cost} = \text{Duration} \times \text{Length} \times \text{ADT} \times ((\text{TCP} \times \text{O} \times (1 - \text{ADTT})) + (\text{ADTT} \times \text{TCT}))/\text{DS} \quad (3.4)$$

where Duration is the assumed time it takes to complete the reconstruction (**Table 3.2**), Length is the total length of the detour (NBI Item 19), TCP is the time cost per person (assumed \$7.05/hour), O is the occupancy (assumed to be the default HYRISK value of 1.56), ADTT is the fraction of the ADT that are trucks (NBI Item 109), TCT is the time cost per truck (assumed \$20.56/hour), and DS is the speed of the detour (assumed 64 km/hour).

Duration of Detour	Average Daily Traffic (ADT)
3 years	ADT < 100
2 years	100 < ADT < 500
1.5 years	500 < ADT < 1000
1 year	1000 < ADT < 5000
½ year	5000 < ADT

The mileage cost due to the detour around the failed bridge equals the duration of the detour multiplied by the cost per kilometer driven, the ADT, and the detour length. The mileage cost of the detour is presented in Equation 3.5:

$$\text{Mileage Cost} = \text{Duration} \times \text{Length} \times \text{ADT} \times \text{Cost/Length} \quad (3.5)$$

where the cost per length is the HYRISK default value of \$0.16/kilometer.

The assumed cost per fatality is \$500,000. This value assignment is obviously subjective and could vary more considerably based on both economic and sociological factors. The number of lives lost is assumed to vary depending on the ADT and functional classification as shown in **Table 3.3**. High-ADT crossings, interstates and principal arterials are assumed to have more potential for fatalities.

Number of Lives Lost	Average Daily Traffic (ADT)
0	ADT < 100
1	100 < ADT < 500
2	500 < ADT < 1000
2	1000 < ADT < 5000
5	ADT > 5000 (Not Interstate or Arterial)
10	ADT > 5000 (Interstate or Arterial)

3.3 Annual and Lifetime Probability of Failure

The annual and lifetime probability of bridge failure due to scour is determined using an extended form of the HYRISK approach to estimating the annual probability of failure. A 50-year bridge design life is assumed, based on ITD bridge design standards. This design life is adjusted to account for superstructure and substructure condition (coded in the NBI), recognizing that bridges in good condition often remain in service past their design life. The remaining service life of the bridge is then determined based on the year of last major reconstruction, coded in the NBI.

If the bridge has failed due to scour (NBI Item 113 equals 0), then the annual probability of failure is assumed equal to 1.0.

If the bridge is considered scour critical for low-flow conditions, with an observed severe scour or substructure condition, the annual probability of failure is 0.5, corresponding to a 2-year event. The bridge is considered scour critical by inspection if so indicated in the scour report text or if the Item 113 code is 1 or 2. The annual probability of failure is 0.1 if the bridge is scour critical for the 10-year event. Failure probability information is not given explicitly in the ITD scour reports and is qualitatively determined using the hydrology, hydraulic, and scour information presented in the scour reports.

The HYRISK approach is used to determine the annual probability of failure for bridges considered scour critical in the 500-year event without a determination for smaller floods, and for all unknown foundation bridges. HYRISK determines the annual probability of failure based on the frequency of roadway overtopping and scour vulnerability. Frequency of roadway overtopping is determined using the Waterway Adequacy NBI Item 71 and the bridge functional classification. Scour vulnerability is determined as a function of the reported Channel Protection (Item 60) and Substructure Condition (Item 61) NBI ratings. A reality check of the computed annual probability of failure is made by converting the annual failure probability to the expected life of the bridge, and checking it against the bridge age. If the 90th percentile expected lifetime of the bridge is less than the actual bridge age, the annual probability of failure is adjusted downward such that the 90th percentile expected bridge life equals the actual bridge age.

The resulting annual probability of failure is further modified to account for foundation and bridge structural designs that reduce the probability of bridge failure under high scour conditions (pile foundations, redundant load paths, etc.). The lifetime probability of failure is determined from the annual probability of failure and the remaining bridge service life. The total risk is equal to the lifetime probability of failure due to scour multiplied by the total cost of bridge failure (Equation 3.1). Appendix A details the ranking of the scour critical bridges, using the approach outlined above, as well as the ranking of the unknown foundation bridges. Appendix B details the full methodology and tables for this prioritization strategy.

3.4 Limitations of the HYRISK Method

For the scour critical and unknown-foundation bridges in Idaho, long detour lengths tend to dominate the total cost of failure. Bridges with long detour lengths are predominately located in rural areas with relatively low ADT. The assumed duration of the detour increases with decreased ADT. The combination of a long detour length with long detour duration tends to increase the total failure cost of these relatively small rural bridges, thus increasing their total risk under this prioritization strategy.

It appears that the HYRISK methodology predicts higher annual probabilities of bridge failure than might be expected. While this method may overestimate risk, it is internally consistent and appropriate for ranking purposes.

3.5 Application of Priority Rankings to Scour Critical Bridges

Scour critical bridges are subdivided into four categories based on lifetime risk and annual probability of failure. Each category corresponds to a recommended minimum response level described in this document.

Category A: Vital Scour Critical Bridges. Lifetime risk of failure for these 37 bridges exceeds \$5,000,000. This lifetime risk cutoff value was set in consultation with the ITD Scour Committee.

Category B: Extreme Scour Critical Bridges. The lifetime risk is less than \$5,000,000, but the calculated annual probability of failure equals or exceeds 10 percent. There are 12 extreme scour critical bridges in Idaho.

Category C: Severe Scour Critical Bridges. The lifetime risk is less than \$5,000,000. The annual probability of failure is between 1 and 10 percent, or less than 1 percent, but the bridge is founded on spread footings. There are 109 severe scour critical bridges in Idaho.

Category D: Moderate Scour Critical Bridges. The annual probability of failure is less than 1 percent and driven pile foundation. There are 37 moderate scour critical bridges in Idaho.

The recommended minimum response level for each category is presented in Chapter 4 of this manual. Appendix C presents a template for a full Plan of Action for scour critical bridges in Idaho.

The categorization was partially validated in a qualitative sense by conducting field visits to five bridge sites: State Route 75 over the Big Wood River (Category A); County Road 61 over South Fork Boise River (Category B); County Road 21 over Mores Creek at Dunnigan Creek Road (Category A); and State Route 55 over South Fork Payette River (Category A). The field visit observations supported the categories that had been assigned to these bridges by the prioritization/categorization scheme.

3.6 Unknown Foundation Bridges

Unknown foundation bridges should be prioritized for further action based on lifetime risk, determined as described above. The bridge owner should make every attempt to determine the foundation type and depth. Once the foundation has been determined, a scour evaluation should be performed to determine whether the bridge is actually scour critical. Until the foundation is determined and the scour depths are known, a monitoring plan with closure protocols should be implemented.

4. SCOUR CRITICAL RESPONSE CATEGORIZATION

Idaho has 198 scour critical bridges, based on 2002 NBI records and available scour reports. These bridges have a significant probability of failure due to scour processes under high-flow conditions. Some action is necessary at each of these bridges to prevent scour-related bridge failure and/or to protect public safety in the event of such a failure. This section subdivides Idaho's scour critical bridges into four categories and recommends a minimum response level for each category. It should be noted that scour critical bridges represent a significant hazard to the traveling public compared to bridges that are not classified as scour critical, and that the monitoring, inspection, and countermeasure activities at these bridges should reflect that status.

The four categories of scour critical bridges are Category A: Vital Bridges, Category B: Extreme Scour Critical Bridges, Category C: Severe Scour Critical Bridges, and Category D: Moderate Scour Critical Bridges. The classification criteria and minimum recommended response level for each category are described below. Appendix C presents the ITD Plan of Action template, which provides a framework for developing response plans for individual bridges.

4.1 Category A: Vital Scour Critical Bridges

This category represents bridges whose lifetime economic risk of failure exceeds \$5,000,000, as computed by the extended HYRISK methodology discussed in Chapter 3 and described in Appendix B. See Appendix A for a listing of the 37 Category A scour critical bridges in Idaho. These bridges, due to the economic risk of failure, should not be allowed to fail. Consequently, a full Plan of Action including both monitoring and countermeasures should be developed and implemented in a timely manner to prevent scour-related failure of the bridge, (see Appendix C for the Plan of Action template). In the interim period before scour countermeasures are installed, each Category A bridge should be treated as a Category B, C, or D bridge, depending on the annual probability of failure and the structural features of the bridge. Successful installation of structural or hydraulic scour countermeasures at these bridges may allow their reclassification from scour critical status to low-risk status in the NBI.

It is impracticable to develop a generic Plan of Action to fit all of the bridges in Category A, because the characteristics of these bridges vary widely. For example:

- Number of spans varies from one to more than ten
- Most are rated scour critical because of computed scour depths for severe floods, but others because of observed scour that has already occurred
- Some have abutments on spread footings and others have pile foundations
- Most have spill-through abutments but some have vertical wall abutments
- Bed sediments at bridges in this category vary from clay to fine sand to cobbles and boulders

Some of the crossings are over streams with small, steep watersheds, where extreme floods are likely to be flashy, requiring a very rapid monitoring and/or closure response. By contrast, some are over the Snake River, with a watershed of over 69,000 square miles and regulated flood flows. Floods on the Snake River will rise more slowly than on the smaller, steeper streams. Much more warning will be provided, and the flood duration will be much longer due to the flow regulation and large volume of upstream storage.

4.2 Category B: Extreme Scour Critical Bridges

These bridges have a predicted annual probability failure in excess of 10 percent, estimated by the extended HYRISK method. In other words, they are considered extremely vulnerable to scour (see Appendix A for a listing of the 12 Category B bridges in Idaho). These bridges should be closed under high-flow conditions due to the substantial probability of bridge failure. A closure plan should be developed and implemented by the bridge owner detailing closure trigger events, closure methods, a recommended detour route, and contact information for the District Engineer and traffic enforcement personnel. Field crews sent to close the bridge should be provided with adequate signage and materials for closing the bridge and marking the detour route. Once a bridge is closed due to high flow, it should be inspected for stability prior to reopening the bridge to traffic.

The typical response plan for a Category B bridge will not initially call for hydraulic or structural countermeasures. At some of the bridges in this category, however, the economic cost of frequent bridge closures may lead the owner to consider hydraulic and structural countermeasures as a cost-effective alternative. An example of such a case would be where the bridge conveys a vital access route. Successful installation of structural or hydraulic scour countermeasures at these bridges may allow their reclassification from scour critical status to low-risk status in the NBI (Code 7 under Item 113). Appendix C shows the Plan of Action template.

4.3 Category C: Severe Scour Critical Bridges

Bridges in this category typically have a predicted annual probability of failure between 10 percent and 1 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. Appendix A presents a listing of the 109 Category C bridges in Idaho. 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. The cost-effectiveness of scour countermeasures at these bridges may be determined using the methods outlined in NHI course 135048 and the economic risk rating developed as part of this effort. Successful installation of structural or hydraulic scour countermeasures at these bridges may allow their reclassification from scour critical status to low-risk status in the NBI (Code 7 under Item 113). Appendix C shows the sample Plan of Action template.

4.3.1 Water Surface Elevation-Based Scour Monitoring

Direct monitoring of the streambed elevations during flood flow conditions is the most accurate method for determining whether a bridge foundation element is approaching a scour critical bed elevation. Appendix D of this manual describes fixed and mobile scour monitoring equipment in more detail. Appendix C of this manual presents a sample table of scour critical elevations useful for direct streambed monitoring and for the analysis required to develop water surface elevations for monitoring purposes.

However, if direct streambed sounding is not feasible, then a scour critical water surface elevation may be estimated and used as part of the scour monitoring plan. However, additional hydraulic, scour, and structural analysis beyond what has been performed for the scour assessment program may be necessary to adequately develop a water surface elevation-based monitoring plan for most Category C bridges. In addition, the decision to close a scour critical bridge must be made more conservatively (closure trigger set for less severe conditions) when using a water surface elevation bridge closure trigger. This added conservatism is required because monitoring scour indirectly based on the water surface elevation incorporates the assumptions and uncertainty of the scour prediction method. Consequently, bridges may be closed more frequently than necessary, resulting in economic losses and inconvenience to the traveling public.

Additional structural and geotechnical analysis should be undertaken as necessary to determine the scour critical bed elevation for each bridge foundation element. This analysis may be very simple, as with spread-footing foundations, or more complex, as with pile foundations. Hydraulic and scour analyses should then be performed to determine the 10-, 25-, 50-, 100-, and 500-year scour elevation and upstream water surface elevation at each bridge foundation element. The critical foundation element and the approximate return interval for the flood event that produces scour critical conditions at the bridge, T_i , may be estimated from this information.

The predicted water surface elevations (WSELs) and predicted post-scour ground elevations (scour GRELs) at all scour critical foundation elements for the 10-, 25-, 50-, 100-, 500-year, and scour critical elevation should be plotted against return interval, T . Using this plot, the approximate scour critical recurrence interval T_i and the standard recurrence intervals T_{i-1} and T_{i-2} may be determined for each bridge (see **Figure 4.1** for an example plot).

For example, the maximum scour critical GREL of any foundation element for the bridge represented in Figure 4.1 is 4403.6 ft-NGVD. This GREL corresponds (approximately) to the 70-year event (T_i). The first standard recurrence interval below the scour critical recurrence interval corresponds to the 50-year event and is labeled T_{i-1} . The second standard recurrence interval below the scour critical recurrence interval corresponds to the 25-year event and is labeled T_{i-2} .

If the scour critical recurrence interval is within 5 years of the first standard recurrence interval below the scour critical recurrence interval, or if scour depths are expected to develop suddenly (flashy stream conditions), then serious consideration should be given to adjusting the trigger recurrence intervals downward. For the hypothetical bridge conditions plotted on Figure 4.1, if the scour critical recurrence interval were the 55-year event, then the first standard recurrence interval would be the 25-year event, and the second standard recurrence interval would be the 10-year event, depending on how quickly scour conditions may develop at the site.

If the return interval of the scour critical event determined by this analysis exceeds the 100-year event, then the bridge should be reclassified as a Category D bridge, unless the bridge has shallow foundations subject to sudden, catastrophic failure.

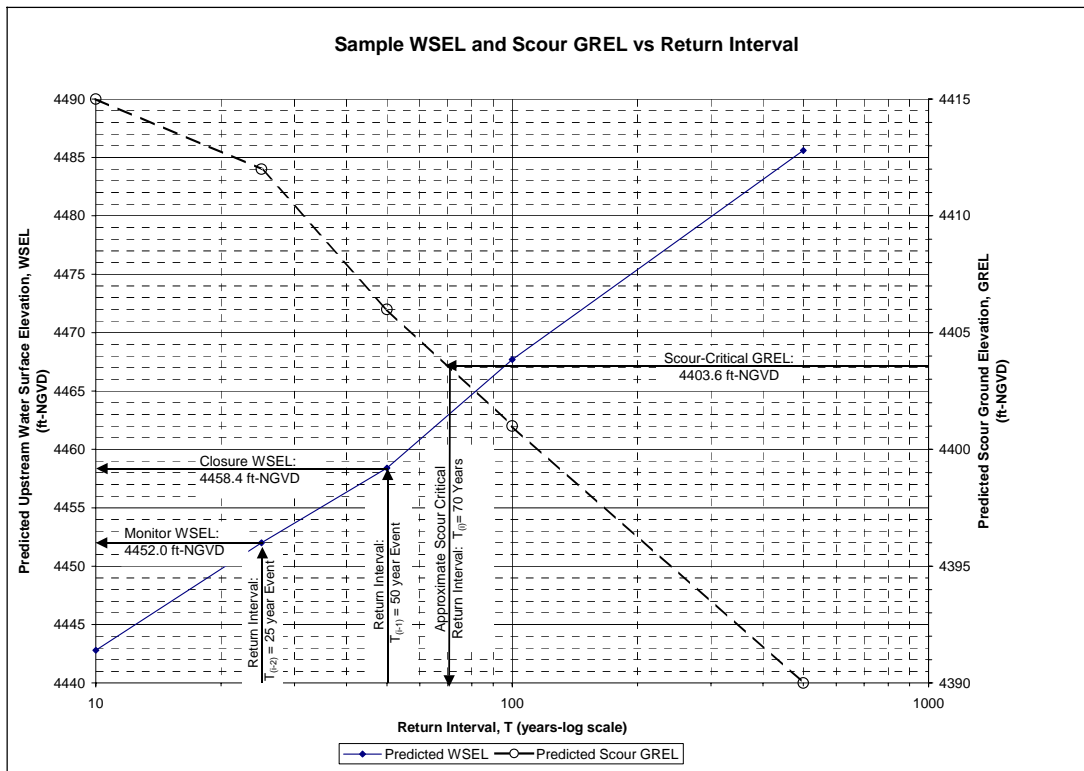


Figure 4.1. Sample WSEL and scour frequency curves.

4.3.2 Monitoring

Continuous bridge monitoring for Category C bridges should commence when $WSEL(T_{i-2})$ is equaled or exceeded at the upstream bridge face, or if other severe flow conditions are predicted at the bridge. Severe flow conditions triggering monitoring for Category C bridges are defined as the rainfall or stream discharge event corresponding to the T_{i-2} return interval, or if debris buildup, stream migration, or other conditions at the bridge are observed and have been identified as contributing to the bridge scour status by the scour assessment.

The elevations corresponding to the monitoring WSEL (typically $WSEL(T_{i-2})$) and the bridge closure WSEL (typically $WSEL(T_{i-1})$) should be clearly marked at the upstream bridge abutment wingwalls or other area using reflective signage legible from the roadway or from an accessible viewing point within the right-of-way. Example sign layouts are given in **Figure 4.2**. If practicable, the measured down distance from the top of bridge rail to the closure WSEL should be marked with reflective signage on the bridge rail at the location where measurements would be made.

A single, mobile monitoring crew may be able to adequately monitor several Category C bridges during the initial phases of a flood event. Once the scour monitoring WSEL has been exceeded at a bridge, however, a monitoring crew should be immediately dispatched to continuously monitor scour conditions at that bridge and close the bridge to traffic if necessary.

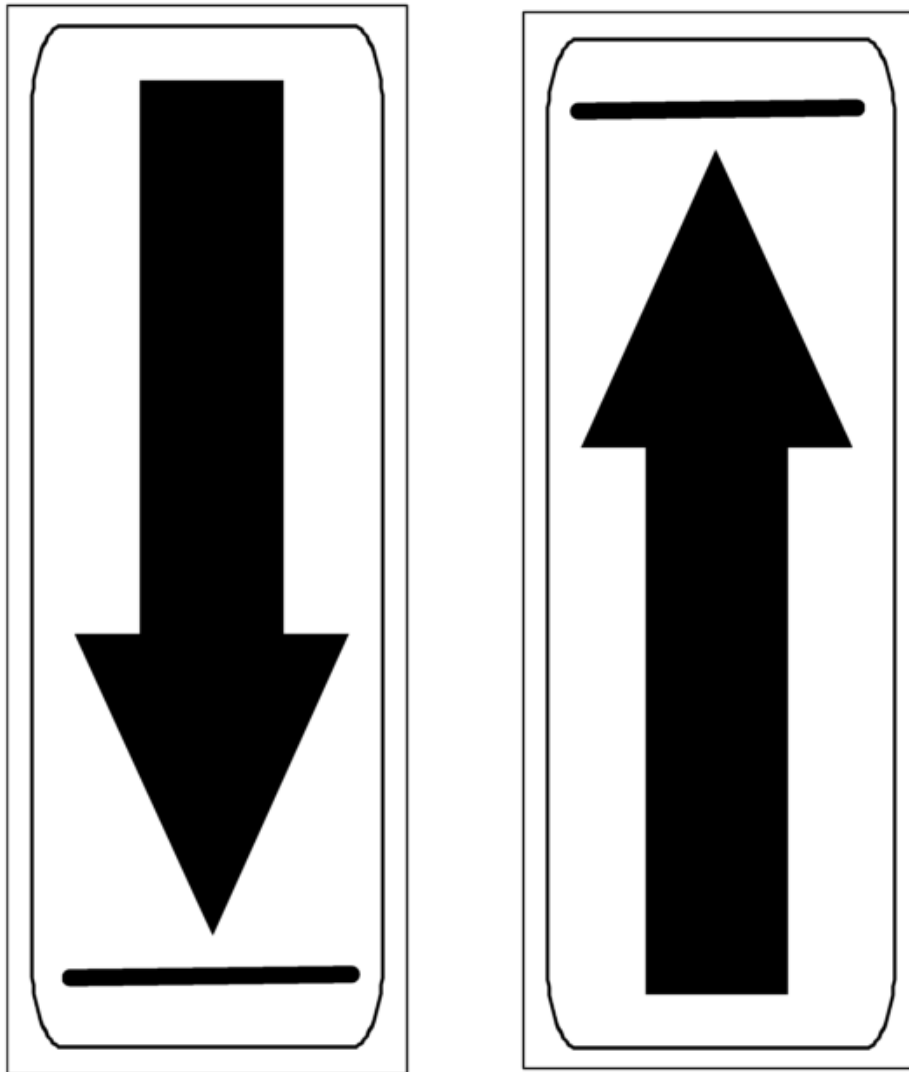


Figure 4.2. Example scour monitoring WSEL (left) and scour closure WSEL marking signs.

4.3.3 Bridge Closure Criteria

The bridge should be closed if the water surface elevation exceeds the marked closure WSEL (T_{i-1}). The bridge should also be closed if any other evidence of bridge distress is noted. Evidence of bridge distress includes, but is not limited to:

- Bridge movement under load
- Joint deflection
- Bridge deck sagging
- Pressure flow conditions
- Excessive debris buildup
- Bridge or approach embankment overtopping
- High-velocity flow impinging directly on abutments or unarmored embankments
- Abutment armor failure

Furthermore, if, at any time, monitoring personnel do not feel the bridge is safe or if they are uncomfortable working on the bridge due to flood conditions at the bridge, they should close the bridge to traffic and stay off of the structure until it has been inspected for stability.

The bridge monitoring team should be given sufficient information, training, and equipment to perform the scour monitoring, observe the WSEL marks, take measuredown readings to the WSEL with a weighted tape measure, and perform an emergency closure of the bridge, if necessary. See the Appendix of the field manual for a partial list of materials required for these tasks. In addition, an information card with necessary bridge data, a detour route, emergency contact information for traffic enforcement and the district engineer, and closure directions should be provided to the monitoring team for each bridge (see the Appendix of the field manual for a sample information card).

4.4 Category D: Moderate Scour Critical Bridges

These bridges have predicted 500-year scour depths that would be expected to cause bridge instability, but the predicted annual probability of failure is less than 1 percent and the bridges have structural features (driven pile foundations) that tend to reduce the probability of catastrophic failure due to scour (see Appendix A for a listing of the 37 Category D bridges in Idaho).

The typical response plan for a Category D bridge will not initially call for hydraulic or structural countermeasures. It will focus on a monitoring and closure strategy. These bridges should be observed under high-flow conditions and closed if any signs of bridge distress are observed. Furthermore, if, at any time, monitoring personnel do not feel the bridge is safe or they are uncomfortable working on the bridge due to flood flow conditions, they should close the bridge to traffic and stay off of the structure until it has been inspected for stability.

The monitoring team should be provided with sufficient training to monitor the bridge, equipment and signage to effect an emergency bridge closure, detour route information, and contact information for the bridge engineer and traffic enforcement personnel (see Appendix C for the Plan of Action template).

4.5 Scour Critical Bridge Inspection Frequency and Procedures

The inspection procedure and frequency for every scour critical bridge should be assessed for adequacy given the increased risk of bridge failure due to scour processes. All scour critical bridges should be inspected on the regular biennial (24-month) schedule and after severe flood events.

Post-flood scour inspection should be performed after any event exceeding the 2-year flood for Category A and Category B scour critical bridges. Post-flood scour inspection should be performed for Category C scour critical bridges after any event exceeding the T_{i-2} event, once a predicted scour depth/WSEL/frequency curve has been developed for the bridge. In the interim period, Category C bridges should be inspected after any flood exceeding the 10-year discharge and otherwise treated as Category B bridges. Post-flood scour inspection should be performed for Category D bridges for any flood exceeding the 50-year discharge.

The regular inspection frequency, normally biennial, may also be increased for scour critical bridges depending on the site and crossing characteristics. For example, if a bridge is scour critical due to channel lateral migration or ongoing channel degradation, more frequent regular inspections may be necessary to adequately monitor the scour conditions and channel bank positions at the bridge. Alternatively, a fixed monitoring program may substitute for an increased inspection frequency. The parties preparing the response to scour critical conditions at a given bridge should recommend an adequate inspection frequency or proposed fixed scour monitoring program. See Appendix E for a review of the HEC-18 recommended bridge scour inspection procedures. Appendix D presents an overview of scour monitoring systems and methods.

ITD staff should implement a scour coordination system to enable bridge owners, bridge inspectors, maintenance personnel, and the scour committee to adequately monitor and react appropriately to bridge scour issues as they develop. Several states have implemented "flag" systems, which formalize communication channels, notification procedures, and immediate responses when bridge inspectors or maintenance personnel identify scour conditions affecting the safety of the traveling public at a bridge.

5. SCOUR CRITICAL PLANS OF ACTION BY CATEGORY

There are 198 scour critical bridges in Idaho, according to the current National Bridge Inventory (NBI). The bridges have been prioritized in terms of risk and annual probability of failure according to the scheme described in Chapter 3. A database file has been developed that contains a summary of information taken from the scour reports for most of the scour critical bridges. The compact disc at the back of this manual contains the database file. This database file (created in Microsoft ACCESS) and the NBI are useful resources for future use in preparing Plans of Action.

5.1 Prioritizing Plan of Action Development

The Scour Critical Plan of Action should be immediately developed and implemented on all Category B bridges and on Category A bridges that have a predicted annual probability of failure in excess of ten percent. The remaining Category A, C, and D bridges should then be addressed in order of scour category and, within each category, economic risk. The prioritization should be revisited on a regular basis, say every five years, or as new inspection information becomes available, traffic rates change, or new scour assessments are completed. Occasionally, situations may arise to justify implementing a response out of priority. For example, if an extremely high spring runoff is expected on a certain river for a particular year, scour critical bridges over that river may be addressed out of priority in order to minimize the risk of damage during the spring runoff.

5.2 Basic Elements of the Idaho Scour Critical Bridge Plan of Action

The full Idaho Transportation Department Scour Critical Bridge Plan of Action consists of four sections. An outline of the full Plan of Action is given below.

I. General

A. Cover Page summarizing general bridge information and a summary of recommended actions. The cover page should include the seal and signature of the preparing engineer, the approval signature of ITD staff and the bridge owner, an executive summary providing background on the bridge and the reasons for the recommendations, and a quick reference table that describes the inspection, monitoring, and countermeasures plans. The cover page should also include the Plan of Action implementation schedule.

B. The Plan of Action Narrative Summary. This summary presents the information and findings for the bridge and presents the recommendations for inspection, monitoring, and countermeasure design based on the bridge category and individual conditions at the bridge.

II. Monitoring

A. Scour Inspection. This element describes the recommended bridge scour inspection frequency and any additional necessary special inspection features beyond the standard scour inspection procedures.

B. Scour Monitoring

1. General Monitoring: Description, key elements, distress signs.
2. WSEL Based Monitoring: Description, Table of Elevations and Measuredown Information.
3. Direct Bed Measurement Monitoring: Table of Elevations and Measuredown Information.

III. Bridge Closure

This section describes the necessary steps to perform an emergency and full closure for the bridge, should the bridge monitoring team determine that the bridge is not safe for traffic. This section should include a narrative description of the closure procedure for both emergency closure and full closure, traffic control plan and signage for the emergency closure and the full closure, a detour map, contact information for the bridge owner, ITD District Engineer, ITD bridge maintenance staff, and traffic control authorities. It is expected that the monitoring staff will be authorized to perform an emergency bridge closure, and that the full closure, with detour signage and complete traffic barriers, will be performed by ITD maintenance staff.

IV. Scour Countermeasures: Design Plan and Implementation Schedule

Attachments

The bridge plan and elevation drawings; the closure detour map and signing plan; and monitoring equipment checklist should be attached, along with the scour summary table and countermeasure design alternative information, if applicable.

Each scour critical bridge in Idaho has been categorized into four scour critical categories depending on economic risk and annual probability of failure, determined using the extended HYRISK method described in the report narrative and in Appendix B. The minimum response level for each category of scour critical bridge will determine which elements of the full Plan of Action apply to a given bridge. The individual implementation of the Plan of Action for a given bridge will vary from this minimum response level depending on its current scour categorization, current economic risk of failure, and other factors not directly examined as part of this document, such as whether the bridge is part of an emergency evacuation route.

The minimum Plan of Action for each Category A bridge contains Sections I, II, III, and IV of the ITD Scour Critical Bridge Plan of Action.

The minimum Plan of Action for each Category B bridge consists of Section I and Section III of the ITD Scour Critical Bridge Plan of Action.

The minimum Plan of Action for each Category C bridge contains Sections I, II (A) and II (B), and III of the ITD Scour Critical Bridge Plan of Action.

The minimum Plan of Action for each Category D bridge contains Sections I, II (A), II (B.1.a), and III of the ITD Scour Critical Bridge Plan of Action.

Please note that the response levels for each scour category represent minimum responses and that additional steps should be taken as necessary and as resources allow to further safeguard the traveling public and Idaho's transportation infrastructure. The full Plan of Action Template is presented in Appendix C. The scour critical response for each scour critical bridge in Idaho should be implemented by the bridge owner in a timely manner, in coordination with ITD personnel.

The remaining sections of this chapter provide guidance on the implementation of a Plan of Action for Idaho bridges, following the sequence shown in the Plan of Action Template in Appendix C.

5.3 General Bridge Information

The first section on the cover page includes the bridge number, its district and county, the route it carries and the stream it crosses. It also provides a brief description of the location (such as distance and direction from the nearest town) along with the NBIS code under item 113 and the foundation status.

5.4 Summary of Recommended Actions

This section is also on the cover page and provides a complete at-a-glance summary of the Plan of Action for a given bridge. Without looking past the cover, bridge managers can determine:

- Whether the bridge requires immediate closure
- What scour inspection regime is required beyond the regular biennial inspections.
- Whether high-flow monitoring is called for
- Whether fixed-instrument monitoring is recommended and of what type
- What, if any, countermeasures have been recommended, and whether they have been installed

More detailed descriptions of the recommendations are provided within the body of the Plan of Action.

5.5 Authority and Acknowledgment

As a practical matter, each Plan of Action will be prepared by an individual or a small team of engineers. It should incorporate, however, the contributions and review of an interdisciplinary team. Engineers with expertise in inspection, maintenance, structural engineering, hydraulics, geotechnical, and traffic engineering all have a role in creating an effective response to scour conditions at the bridge. The individual responsible for preparing the Plan of Action is most likely to be a hydraulic engineer, but could come from any of these disciplines, provided he or she is conversant in scour issues and that input is sought and obtained from the others. That individual should sign in the "Prepared by" block on the cover page. The approval signature should come from the District Engineer or higher-level official. The District Engineer is named as responsible for certain key decisions in the Plan of Action, and therefore must be familiar with the Plans of Action for the bridges in the district.

The cover page of the Plan of Action provides convenient access to the essence of the planned response. It is intended that the information on the cover alone will suffice for many bridge management activities, such as database development, scheduling inspections, allocating emergency response resources during widespread flooding, etc.

5.6 Narrative

After the cover page, the Plan of Action contains a brief narrative report that documents the recommendations. The narrative should comprise about 2 to 3 pages of text. It provides the reader with an explanation of the logic behind the recommendations.

5.6.1 Purpose

This text is expected to be very similar for most or all bridges. It simply explains the needs for and benefits of a Plan of Action.

5.6.2 Bridge History and Description

This section tells when the bridge was constructed, when any rehabilitations occurred, and the scour history of the bridge. It also describes the number of spans and types of substructure foundations. All of this information is readily obtained from the NBI, from archived bridge inspection reports, and from scour reports for the bridge.

5.6.3 Summary of Scour Assessment

The Plan of Action is typically implemented only for bridges rated scour critical. It is assumed, therefore, that a scour assessment of some type has been prepared for the bridge of interest. Typically, the scour assessment will estimate the scour depth at some or all of the substructure elements for floods of certain recurrence intervals. This section of the Plan of Action provides a summary of that information. Of particular interest are the predicted scour depths and post-scour elevations at any abutment or pier for which a calculation has been made. It will report the amount of each type of scour: long-term degradation or aggradation, contraction or other general scour, and local scour. This information is useful in determining what types of countermeasures would be most effective and which substructure elements need the closest monitoring during high flows.

5.6.4 Inspection and Monitoring Requirements

The text in this section of the narrative provides support for and detailed explanation of the recommended inspection and monitoring program. Section 5.7 describes the content of a good inspection and monitoring program.

5.6.5 Countermeasure Selection

The narrative summarizes the process of eliminating countermeasure types from consideration and developing designs for the types that were considered. Section 5.9 describes the countermeasure selection process in detail.

5.6.6 References

Any document that was significant in implementing the Plan of Action at a bridge, along with other useful resources, should be cited here. Examples include:

- Bridge plans
- Original hydraulic design documentation
- Scour report
- FEMA floodplain maps and the Flood Insurance Study Report
- Topographic maps
- Aerial photography
- Post-flood high water mark measurements
- Internet addresses for real-time streamflow gages

5.7 Recommendations for Scour Inspection and Monitoring

Immediately after the narrative sections, the template provides a fill-in table that allows for thorough description of the inspection and monitoring plan. This plan should be tailored to each individual bridge depending on its unique scour critical situation.

5.7.1 Inspection

All scour critical bridges should be inspected on the regular biennial (24-month) schedule and after severe flood events.

Post-flood scour inspection should be performed after any event exceeding the 2-year flood for Category A and Category B bridges. Post-flood scour inspection should be performed for Category C bridges after any event exceeding the T_{i-2} event, once a predicted scour depth/WSEL/frequency curve has been developed for the bridge. In the interim period, Category C bridges should be inspected after any event exceeding the 10-year flood event and otherwise treated as a Category B bridge. Post-flood scour inspection should be performed for Category D bridges for any event exceeding the 50-year flood event.

The regular, 24-month inspection frequency may also be increased for scour critical bridges depending on the site and crossing characteristics. For example, if a bridge is scour critical due to channel lateral migration or ongoing channel degradation, more frequent regular inspections may be necessary to adequately monitor the scour conditions at the bridge. Alternatively, a fixed monitoring program may substitute for an increased inspection frequency. The parties preparing the response to scour critical conditions at a given bridge should recommend an adequate inspection frequency or proposed fixed scour monitoring program. See Appendix E for a review of the HEC-18 recommended bridge scour inspection procedures. Appendix D includes an overview of scour monitoring systems and methods.

Both routine biennial inspections and post-flood inspections should include stream cross sections along the bridge faces and local scour depth measurements at the ends of piers, and at the four corners of each abutment (two wingwall ends plus the two inside corners). **Figure 5.1** is a plan-view schematic showing where measurements are needed. These measurements will be taken using portable monitoring instruments such as probes, portable sonar, etc. The cross sections at each bridge face and the local scour depth measurements should later be plotted to scale on a common vertical datum on grid paper and compared to

cross section plots from previous inspections. Note the vertical datum tie on all plots and measuredowns. Any shifting of the thalweg (channel minimum invert elevation) or any vertical trends noted from the plots should be evaluated for potential impacts to bridge stability and the bridge scour rating.

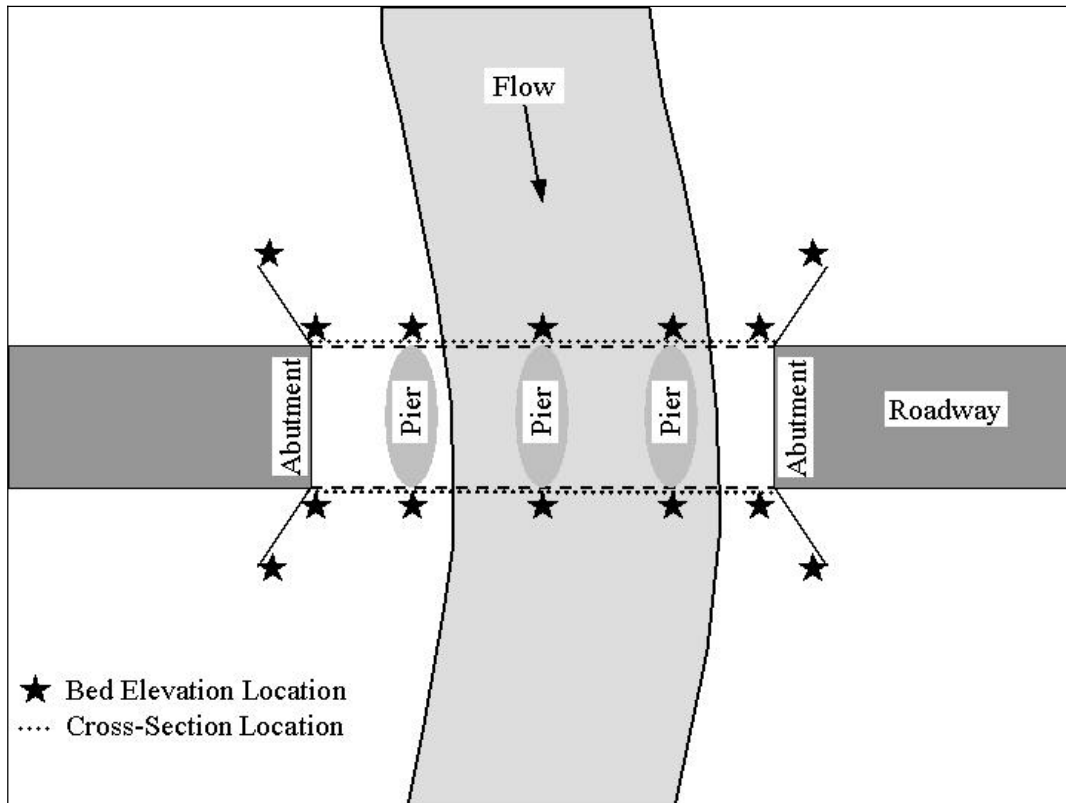


Figure 5.1. Scour inspection measurement locations.

In addition to the elevation measurements, the inspections should look for visible scour problems such as undercut banks, undermined abutments, dislodged protection riprap, exposed footings at piers or abutments, road washouts, etc. Look for signs of stream channel migration, such as freshly scoured banks on one side of the channel and new gravel bars on the other side. Long-term degradation can progress in the form of upstream-migrating headcuts. The inspector should examine the downstream reach for any signs of headcuts. Debris can aggravate scour problems. The inspector must note any significant debris buildup on the bridge and maintenance forces should be arranged to clear the buildup. The inspector should also look upstream to identify any potential debris sources, such as fallen or falling trees in or near the channel.

The inspector should examine previous inspection reports, and if they noted any visible scour problem, the current inspection should look for improvement or worsening of that problem. It is helpful to include photographs of visible problems in the inspection report.

ITD staff should implement a scour coordination system to enable bridge owners, bridge inspectors, maintenance personnel, and the scour committee to adequately monitor and to react appropriately to bridge scour issues as they develop. Several states have implemented

"flag" systems, which formalize communication channels, notification procedures, and immediate responses when bridge inspectors identify scour conditions or structural problems affecting the safety of the traveling public at a bridge.

5.7.2 High-Flow Monitoring

Monitoring during high flows is a critical activity for bridges that could be destroyed or substantially damaged by a single flood. 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. The Plan of Action includes a table (Section II under Recommendations for Scour Inspection and Monitoring) that indicates:

- Description of the type of monitoring to use
- Instruction on when to start high-flow monitoring
- Where to focus measurement efforts during high-flow monitoring
- Reminder to check the condition of any previously installed countermeasures
- What to do as a result of certain findings during the monitoring

All scour critical bridges should be evaluated for signs of bridge distress prior to and during WSEL or bed elevation monitoring activities. Such signs would include:

- 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
- 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 qualitative signs of structural distress are apparent at any time, the crew should implement an emergency bridge closure, call for a formal or full bridge closure, and should avoid getting on the bridge if at all possible.

The type of scour monitoring will depend on the availability of resources. If necessary or desirable, fixed bed-level monitoring devices may be installed at any scour critical bridge.

For Category A bridges, high-flow monitoring may not be necessary once scour countermeasures are installed. Prior to scour countermeasure installation, Category A bridges should be treated as Category B, C, or D bridges, depending on the predicted annual probability of failure. Category B bridges are closed during flood conditions and consequently require no high-flow monitoring. Teams monitoring Category C bridges ideally will be equipped with portable bed elevation monitoring equipment suitable for flood flow conditions at the bridge. However, when direct bed elevation monitoring is not feasible, Category C bridges should have two water surface elevations marked at the upstream face of the bridge: T_{i-2} , the monitoring trigger WSEL, and T_{i-1} , the scour closure trigger WSEL. The procedure to develop and mark these WSELs is outlined in Section 4. Category D bridges should be qualitatively monitored for signs of bridge distress as described above.

For bridges where direct bed monitoring is to be used, the type of bed monitoring instrument will depend on the site conditions. In many cases a simple probe will be most effective. Some conditions, such as water flowing fast and deep, may make the use of a probe impractical. See Appendix D and HEC-23 for guidance on portable monitoring instrument selection. In the case of a bridge where some fixed-instrument monitoring has already been installed, it can provide information to supplement the portable monitoring. In rare cases, all of the high-flow monitoring can be accomplished by previously installed fixed instruments, as long as the instruments cover all of the threatened substructure elements.

High-flow monitoring ideally should be triggered at a particular bridge by the water surface elevation reaching some pre-determined elevation associated with a certain recurrence interval, such as the 25-year flood. The Idaho scour reports typically do not report a computed water surface elevation for floods smaller than the 500-year event. The original hydraulic design documentation for the bridge, or a FEMA Flood Insurance Study for the stream may provide water surface elevations for more moderate floods. If a computed water surface elevation for a moderate flood cannot be determined, then other types of events can be used as the trigger. Category C bridges and some Category A bridges will have a monitoring WSEL set as part of the Plan of Action.

For bridges where scour monitoring and scour closure trigger WSELs have been established, the bridge monitoring crew may initiate continuous WSEL monitoring when the scour monitoring WSEL has been exceeded. The bridge should be closed immediately if the WSEL exceeds the marked scour closure WSEL. A simple weighted tape may be employed to check measuredowns to the WSEL from a fixed bridge element, typically the bridge guardrail, at scour critical bridge elements.

For Category D bridges, practical definitions of high-flow events as triggers for high-flow monitoring are listed below in descending order of preference. The operative definition should be chosen based on availability of information.

- 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

Once the predetermined monitoring trigger event has occurred for Category A and C bridges, assuming that immediate closure is not warranted and the bridge is safe to occupy, the monitoring crew will begin the measurement process. They will periodically measure the bed elevations or water surface elevations at critical substructure elements and compare the measured WSELs or bed elevations to the scour closure elevations for those elements. The field crew should be provided with the scour-closure WSEL or bed elevations for all bridge substructural elements and which elements are most critical. 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.

If scour is causing the bed elevation to fall rapidly toward the scour critical elevation, but significant embedment remains, the crew should call for emergency protection. If the critical elevation has been reached, or will be reached soon, the crew should perform an emergency closure to traffic and contact the District Engineer, ITD maintenance personnel, and traffic control authorities to implement a full bridge closure. If scour countermeasures were previously installed and are found to be failing or non-functional, the crew should call for a bridge closure.

5.7.3 Fixed-Instrumentation Monitoring

The ITD has not historically made extensive use of fixed scour monitors. They may be very valuable, however, for some situations. Under the right circumstances, a fixed monitor can be considered a scour countermeasure. Appendix D and HEC-23 provide extensive guidance on the application of fixed scour monitoring. If they are to be incorporated in a bridge's Plan of Action, the template provides a fill-in table to describe the instrument to be used, where to install it, and the sampling time interval. The Plan of Action should also indicate how often to download the data and whether to use telemetry to allow remote data downloads.

5.7.4 Tables of Scour Critical Bed and Water Surface Elevations

For Category A and C bridges, the scour critical elevations must be known, or reasonably estimated, if the inspection and monitoring plan is to be effective. Ideally, engineers with structural and foundations expertise should determine the scour critical elevation for each substructure element analytically. For certain foundation types, a scour critical elevation can be reasonably estimated without extensive analysis. A spread-footing foundation, for instance, can be assumed scour critical at the base of the footing. A buried-footing foundation with piles extending below it may also be considered scour critical at the base of the footing, as further scour would expose the piles, which may not be designed to tolerate any exposure to the flow. The scour critical elevation of driven-pile or drilled-shaft foundation cannot be accurately estimated without analysis, since these foundation types depend upon some amount of friction and lateral support from the soil to function properly. For in-field analysis or emergency purposes, if less than 50 percent of the original pile design embedment remains, then the bridge element may be assumed scour critical.

The inspection and monitoring crews need to know the critical bed elevation or WSEL triggering closure. They also need a convenient way to measure the bed elevation or WSEL in relation to the closure trigger elevation. One example of a measurement reference is a known-elevation benchmark set near the bridge structure. The crew would need a level and tripod to use this method. An independent benchmark allows the monitoring crew to precisely check for vertical displacement of the bridge deck. A method requiring fewer instruments and quicker setup is to establish a known elevation at the top of the rail or the top of curb above every substructure element to be monitored. As an alternative, a tight, level string line of known elevation could be stretched across the waterway immediately adjacent to the bridge deck. This taut wire placement could be facilitated by setting posts off of the corners of the bridge with hooks or eye bolts at equal elevation. The string or wire would be stretched between the posts through the hooks by the monitoring crew when they arrived at the site.

The Plan of Action includes a table for filling in the monitoring and closure trigger bed elevations or WSELs for each monitored abutment and pier. The table also indicates what reference line is to be used and what the elevation of the reference line is above each element.

5.8 Bridge Closure and Emergency Protection Installation

The District Engineer, in urgent consultation with the Hydraulics Engineer, the Bridge Engineer, the Bridge Inspection Engineer and the Maintenance Supervisor, should approve the placement of emergency protection. Emergency scour protection should only be considered for bridges with a direct streambed scour monitoring approach, due to the inherent uncertainties of a WSEL-based scour monitoring strategy. Maintenance crews will install the protection. They should have a ready stockpile of adequately sized riprap available for such emergencies. It should be noted that in flashy streams, emergency protection approaches are likely to be futile, because of the short duration and high intensity of scour-causing conditions. Furthermore, attempting to implement emergency countermeasures may place workers and equipment at significant risk during extreme flooding.

The District Engineer must also approve a full bridge closure and initiate the bridge closure plan, which should be part of the Plan of Action. Bridge monitoring crews should be authorized to perform an emergency bridge closure if signs of bridge distress are noted, or if measured WSELs or scour depths exceed the relevant closure criteria. Most important to the bridge closure plan is to identify the key contacts. These are the Bridge Inspection Engineer, the Bridge Engineer, the Traffic Engineer, the State Highway Patrol and local law enforcement agency, and the ITD or local authority public affairs office. The full closure of the bridge, including additional physical barriers and detour signs, will be placed by maintenance or traffic crews according to the maps and plans attached to the Plan of Action.

5.9 Countermeasure Recommendations and Schedule

Category A scour critical bridges include countermeasure recommendations as part of the minimum response to scour conditions due to the high economic risk of scour failure of these bridges. Category B, C, and D bridges should be scheduled for countermeasure design and installation by category and, within each category, in decreasing economic risk order, as resource availability allows. Appendix A presents the Scour Categorization and Ranking for scour critical and unknown foundation bridges in Idaho.

Inspection and monitoring can safeguard public safety and alert bridge managers to developing problems. However, inspection and monitoring cannot prevent a bridge from failing. The prioritization results in Appendix A show that significant costs are associated with bridge failure. If there is a reasonably high probability of failure at a particular bridge, and that failure is to be avoided, the inspection and monitoring plan must be connected to a plan and schedule for implementing scour countermeasures.

The Plan of Action template includes a check-box table indicating the types of countermeasures considered and the approximate cost of each, along with the preference ranking of each type. The selection of countermeasures should consider the scour critical conditions of the bridge, such as:

- Why is the bridge rated scour critical?
- Are the abutments, one or more piers, or both, threatened by scour?
- What type of scour is most critical to protect against (i.e., long-term degradation, lateral migration, contraction scour or local scour)?

In addition to the scour critical conditions, site-specific constructability issues may govern the type of countermeasure selected. Examples of such constraints may be:

- Vertical clearance (headroom) for working beneath the bridge
- Feasibility of dewatering portions of the channel or the ability to install the countermeasure underwater
- Potential risk posed by construction excavation adjacent to piers or abutments already having shallow embedment
- FEMA floodway regulations that prohibit placing an obstruction inside the regulatory floodway unless it is proven not to cause a rise in the 100-year flood level
- Environmental protection requirements

With scour critical conditions and constructability issues known, the engineer can develop conceptual countermeasure designs that are suitable and effective. The countermeasure matrix in Appendix C and HEC-23 should be consulted as design resources. The conceptual design of each countermeasure type should go far enough to enable a reasonable estimate of the cost. For instance, the conceptual design of riprap-based countermeasures should include the median riprap size and the thickness of the riprap mat to be placed, along with appropriate toe-down depths. For each countermeasure type considered and found suitable, an approximate cost estimate should be developed.

Some of Idaho's scour critical bridges are small single spans where contraction scour alone, without considering abutment scour, is expected to threaten the abutments. This situation typically calls for a full-channel armor across the bridge opening, using riprap, articulating concrete block, or grout-filled mats. Alternatively, the contraction scour could be addressed by lengthening the bridge (widening the opening) or providing a relief culvert. If the contraction scour is eliminated, then only the abutments of the bridge require revetment.

Other Idaho bridges are scour critical because of predicted pier scour at a few of the piers. In this case, protection of the individual piers with well-designed pier armoring is indicated. If some scour can be tolerated, then fixed-instrument monitoring of the bed level at the critical piers may be more cost effective.

Another possible case is where the bridge is barely rated scour critical for a 500-year flood and is rated stable for moderate floods. This condition describes many Category D bridges. Under this scenario, if the foundations have significant embedment, then a countermeasure may not be necessary, and diligent inspection on the biennial schedule and after floods may be adequate.

The Plan of Action should indicate the schedule for countermeasure implementation. This schedule should be developed in consultation with agency management for realistic programming into capital or maintenance budgets.

5.10 Attachments

The Plan of Action should include several attachments. At a minimum, the bridge plan and elevation drawings and the detour map and signing layout should be attached. The scour summary table and backup information documenting the design of countermeasure alternatives are also valuable attachments.

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