

**MINNESOTA DEPARTMENT OF TRANSPORTATION**

**BRIDGE SCOUR EVALUATION PROCEDURE  
FOR MINNESOTA BRIDGES**

**March 15, 1995**

## Introduction

This document describes the policy of the Minnesota Department of Transportation (Mn/DOT) with regard to the evaluation of bridges over water for foundation scour throughout the state. The priorities of the evaluation program are to identify bridges that may be vulnerable to scour problems in order to:

- Minimize risk to the public due to bridge failure by monitoring bridges during floods and closing if necessary.
- Maintain transportation network and protect investment in infrastructure by identifying and prioritizing bridges that require repair or replacement.
- Evaluate, monitor, repair and replace bridges using cost-effective strategies.

The methods used to minimize the risks of scour to Minnesota's transportation network include:

- Design new bridge foundations to withstand maximum predicted scour.
- Evaluate existing bridges and identify those vulnerable to scour.
- Develop and implement a plan of action to monitor, repair, or replace vulnerable bridges.
- Perform routine bridge inspection including a check for evidence of scour; underwater inspection of bridges over major waterways is performed every four years.
- Incorporate research on predicting scour, monitoring bridges, and repairing or installing scour protection. Evaluate data collected during monitoring of state bridges in order to make better predictions.

Prior to 1988, scour was considered in the design of new bridges over major waterways, and where scour problems had occurred in the past. Also, scour was analyzed and repairs constructed when scour problems were detected. A comprehensive evaluation program of all existing bridges began in 1988 after the issuance of Federal Highway Administration Technical Advisory T 5140.20 "Scour At Bridges" and Interim Procedures For Evaluating Scour At Bridges. Since that time, the Technical Advisory has been enhanced and updated. FHWA guidelines allow each state considerable latitude in developing their state specific scour evaluation program in order to account for state specific conditions with respect to hydrology, geomorphology, and state bridge design practices. The Mn/DOT policy has been designed to minimize risk to the citizens of Minnesota and the driving public in general while evaluating bridges in a cost effective manner.

## Minnesota Bridge Scour Evaluation Program

Minnesota has a total of 19,719 bridges, of which 6,936 have or will require evaluation by January 1997. These include 117 Interstate, 901 U.S or Trunk Highway, 3277 County, 423 City, 2127 Township, and 91 miscellaneous bridges. To date the Minnesota Bridge Scour Program has consisted of three (3) parts which follow procedures described in FHWA publications HEC-18, "Evaluating Scour At Bridges" and HEC-20, "Stream Stability At Highway Structures". The parts include: primary screening, Level II scour analysis, and developing and implementing an action plan which may include countermeasures and/or monitoring during floods. Mn/DOT issued formal Screening Guidelines in 1990 and virtually all bridges underwent a primary screening which was completed in 1992. Since that time many of the bridges on the Interstate and State systems ( high priority bridges ) have been evaluated by performing Level II analysis and where appropriate, countermeasures designed and constructed. In addition, Mn/DOT has developed a monitoring program for both emergency and regular monitoring of bridges for scour.

Due to the large number of Minnesota bridges yet to be evaluated, the substantial cost associated with performing Level II analyses, and the FHWA completion target date of January 1, 1997, Mn/DOT has added two additional components to the bridge scour program which can in most instances determine the scour susceptibility of a bridge before embarking on a Level II analysis. Procedures for secondary screening and Level I analyses have been added to the scour program and formalized in this Bridge Scour Policy.

The Minnesota bridge scour program will now include five parts which are designed to minimize the cost and effort of determining the scour susceptibility of bridges remaining to be evaluated by first screening obviously scour stable and scour susceptible bridges into their respective groups with a minimum of effort using a secondary screening procedure. Scour susceptible bridges then proceed on to a Level I analysis or in some cases, a monitoring program. If a bridge is found to be scour susceptible or scour critical at the completion of a Level I analysis, it can be evaluated with a Level II analysis or go directly into design of scour countermeasures. Level I analysis is relatively simple and inexpensive compared to a more rigorous and costly Level II analysis. Using the secondary screening and Level I analysis before proceeding to the Level II methods will allow a bridge to be found scour stable or scour critical with a reduced amount of engineering effort expended. A flowchart illustrating the interrelationships of each of the program parts is shown on Figure 1. Each part of the scour evaluation program is described briefly below. Detailed procedures for each part are given in the appendices.

### Primary Screening

Procedures for bridge scour screening were developed and issued in 1991 by the Office of Bridges & Structures. Screening was performed for State bridges by Mn/DOT and for local government bridges by the County Engineers or under their direction. Screening was performed for all bridges. Culverts were not screened. The results of the screening are shown in Table 1.

The screening results in a bridge being rated as "low risk", "unknown foundation", or "scour susceptible". The criteria for determining low risk bridges included: no evidence of scour at piers and abutments and no channel lowering or shifting; Piers on long piling (> 40 feet) or on spread footings on erosion resistant rock; abutments on long piling (> 40 feet) or spread footings on erosion resistant rock or having adequately maintained protection in place. A copy of the Bridge Scour Screening Procedure and Guidelines is provided in Appendix A.

Road System	Unknown Foundation	Scour Susceptible	Low Risk	Total
Interstate	0	72	45	117
U.S. & Trunk Hwy	6	670	225	901
County	267	1905	1195	3277
City	60	214	149	423
Township	362	1170	595	2127
Other	24	51	16	91
Total	719	4082	2135	6936

### Secondary Screening

Procedures for secondary screening were developed by a Bridge Scour Policy Task Force convened by the State Aid For Local Transportation Division in 1994. The Task Force consisted of Mn/DOT personnel, county engineers, and consultants. Secondary screening will be performed or supervised by a professional engineer familiar with the bridge being screened or expert in the methods of bridge scour evaluation.

The engineer fills out a questionnaire which covers seven (7) parameters related to performance of the bridge under scour conditions. The seven parameters considered are: historical scour performance, scour resistant foundations, debris and blockage, geomorphic conditions, hydraulic conditions, structural conditions, and special low risk conditions. Completion of the questionnaire allows the engineer to rate the bridge as low risk for failure due to scour; scour susceptible, analysis required; limited risk to public, monitor in lieu of evaluation; or scour critical, monitoring required. Completed worksheets and any backup data are filed with the bridge owner. A copy of the worksheet and detailed instructions for its completion are provided in Appendix B.

## Level I Scour Evaluation

A Level I scour evaluation, as described in this policy document, is a site specific study of a bridge to determine its vulnerability to conditions which cause foundation scour and stream stability problems at the bridge. The team performing the evaluation should be thoroughly familiar with FHWA publications HEC-18 and HEC-20. They should also be competent in the fields of hydraulics, geotechnical, and structural engineering.

The evaluation consists of the following 4 tasks, listed in the order of execution, including: office data collection, review and evaluation of collected data, site visit and field assessment, and scour analysis. For the scour analysis, hydraulic conditions at the bridge are estimated by a single stream cross section analysis using Manning's equation for the average cross section properties downstream of the bridge and extrapolating the water surface through the bridge section. No water surface profile modelling with WSPRO or HEC-2 type computer programs is performed. A pre-printed Minnesota DOT Level I Scour Evaluation Report Form (Report Form) has been developed and should be used for reporting the results of scour evaluations. No custom report should be written. A copy of the Level I report form and instructions are provided in Appendix C. Attached to the report should be pertinent collected data, a completed pre-printed Minnesota Bridge Scour Field Assessment Form (Field Form), and any computations made to support the scour rating.

Although engineering judgement is required to determine whether a Level I analysis yields results which are adequate to reasonably rate the bridge for scour, the following considerations may provide guidance in recommending a Level II analysis.

- Allowable scour is exceeded and the methodology for the specific location is questionable.
- Complex hydraulic or geomorphic conditions exist which exceed the capabilities of the single section analysis method.
- Confluence upstream or downstream
- Contraction scour is significant
- Dam or water control located downstream which controls the water surface elevation
- Factors that influence velocity distributions such as channel bends
- Irregular channels with major overbank flows
- Pressure flow
- Roadway or bridge overtopping is involved

## Level II Scour Analysis

A Level II scour analysis is a study of bridge scour which requires more precision in estimating potential depth of scour and therefore requires more precise estimates of hydraulic conditions, which in turn requires water surface profile computer modelling. The extent of computer modelling is that of using one dimensional models such as WSPRO or HEC-2. Reasons for requiring greater precision may include: the bridge in question has been found to be scour critical in a Level I evaluation and additional information is needed to design countermeasures; and the water surface profile is known to be significantly different than governed by uniform flow.

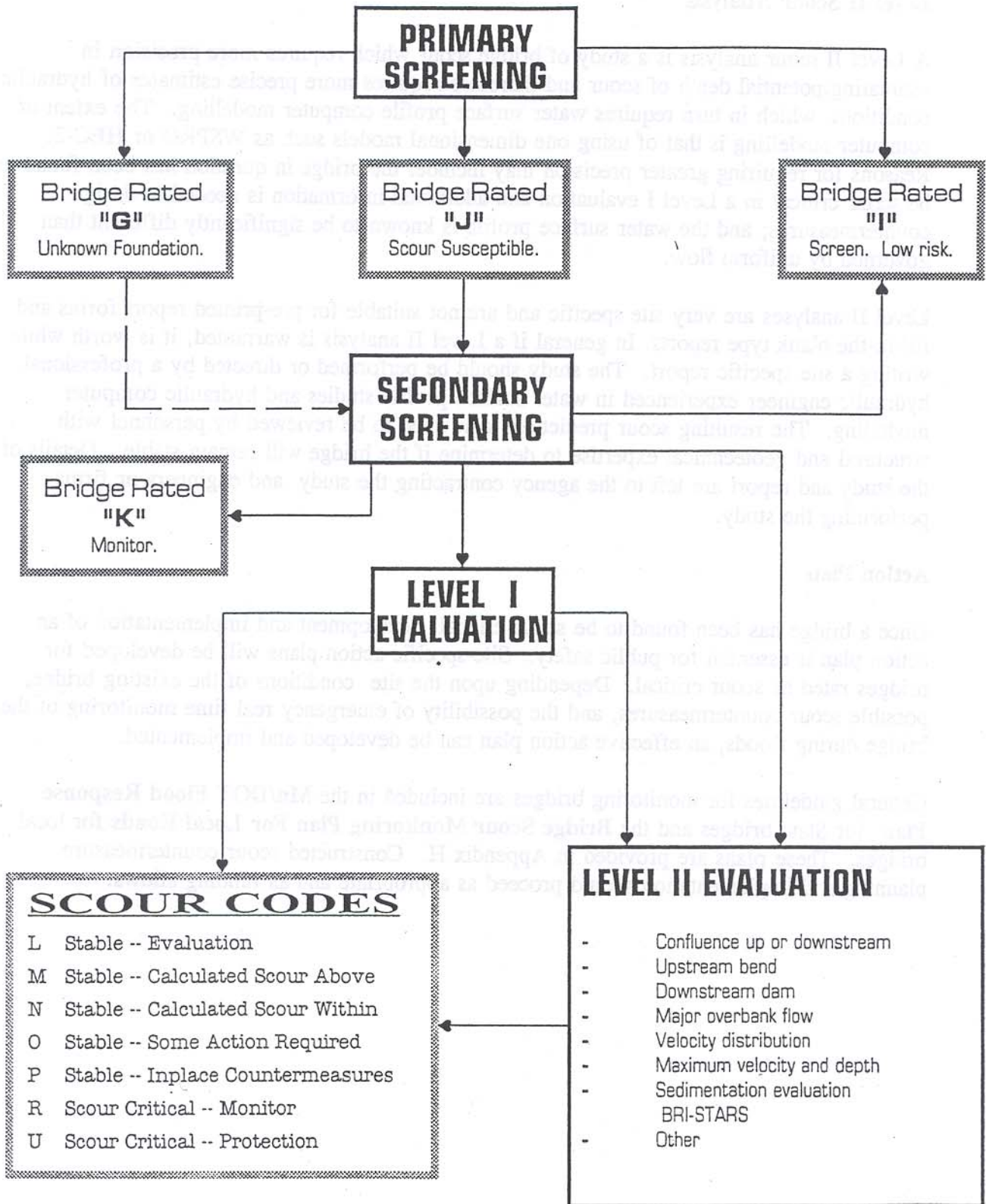
Level II analyses are very site specific and are not suitable for pre-printed report forms and fill-in-the-blank type reports. In general if a Level II analysis is warranted, it is worth while writing a site specific report. The study should be performed or directed by a professional hydraulic engineer experienced in water surface profile studies and hydraulic computer modelling. The resulting scour predictions may need to be reviewed by personnel with structural and geotechnical expertise to determine if the bridge will remain stable. Details of the study and report are left to the agency contracting the study and engineers or firms performing the study.

## Action Plan

Once a bridge has been found to be scour critical, development and implementation of an action plan is essential for public safety. Site-specific action plans will be developed for bridges rated as scour critical. Depending upon the site conditions of the existing bridge, possible scour countermeasures, and the possibility of emergency real time monitoring of the bridge during floods, an effective action plan can be developed and implemented.

General guidelines for monitoring bridges are included in the **Mn/DOT Flood Response Plan** for State bridges and the **Bridge Scour Monitoring Plan For Local Roads** for local bridges. These plans are provided in Appendix H. Constructed scour countermeasure planning and implementation should proceed as appropriate and as funding allows.

# MINNESOTA BRIDGE SCOUR PROGRAM



## APPENDICES

- A. Primary Screening
- B. Secondary Screening
- C. Level I Scour Evaluations and Reports
- D. Minnesota Bridge Scour Field Assessment Form
- E. Scour Rating Codes
- F. Bridge Stability Guidelines
- G. Mn/DOT Flood Response Plan
- H. Bridge Scour Monitoring Plans For Local Roads
- I. Design Aids
  - Roughness Coefficients
  - Sediment Grade Scale
  - Soil Triangle
  - Non-scour Velocities For Soils
  - Contraction Scour Article by E.V. Richardson & J.R. Richardson
  - Effects of Footing Location on Bridge Pier Scour by Sterling Jones
  - Example: Methods of Calculating Pier Scour When Footing Is Exposed
- J. Sample Action Plans
- K. Task Force Membership

## **APPENDIX A**

### **PRIMARY SCREENING**

## BRIDGE SCOUR SCREENING PROCEDURE

6/19/91

### Purpose of Screening:

The purpose of screening is to classify bridges that have not already been evaluated for scour as either low risk for scour problems or scour susceptible. Bridges that are scour susceptible will require further evaluation. After the bridge has been screened, the scour code in the bridge inventory must be updated. Screening of all bridges and updating the bridge inventory data should be completed by FHWA's March 31, 1992 target date.

### Criteria for Low Risk Bridges:

The criteria for determining low risk bridges is described in the attached Screening Guidelines. The criteria are summarized below:

- o No evidence of scour at the piers and abutments or of channel lowering or shifting.
- o Piers, if existing, are on long piling or have spread footings on erosion resistant rock (granite, basalt, quartzite, or gneiss which is not highly broken or fractured).
- o Abutments are on long piling, spread footings on erosion resistant rock, or have adequately maintained protection in place.

### Bridges Requiring Screening:

The bridges that require screening are those that currently have a scour coding in the bridge inventory of "F - No Evaluation, Foundation Known" (See attached Coding Guidelines for Scour). A list of the bridges for your county or city that the inventory system currently shows as coded "F" is included in the attachments.

Culverts should be coded as "E - Culvert" and no further screening or evaluation is required at this time.

Bridges which have substructures with unknown foundations should be coded as "G - No Evaluation, Foundation Unknown" and do not require any further screening at this time. These bridges should be considered scour susceptible, however, at this time, no good way to analyze them is available.

If you have already screened or evaluated your bridges and assigned codes, you may wish to review your procedure to see that it meets these guidelines. Only bridges that meet all of the low risk criteria listed above should be coded as low risk. All other bridges require further evaluation.

Screening Procedure:

To determine if a bridge meets the low risk criteria, information on the foundations, in-place scour protection, and scour history must be known about the bridge. Several worksheets (listed below) are included in the attachments and may be used to gather information and assign a screening code. Although these worksheets are optional, they will provide documentation of the reasons for your decision and can be filed for future reference.

- o Bridge Scour Screening - Inspection Worksheet:  
Worksheet to record information on scour history and in-place scour protection at a bridge.
- o Bridge Foundation Data Report for Piling Depth Classification:  
Worksheet, continuation sheet, and explanatory notes for determining the average piling depth for each of the bridge substructures.
- o Bridge Scour Screening - Coding Worksheet:  
Provides aid in assigning scour rating code as a result of screening.

Completed worksheets for several Mn/DOT bridges are included as examples. If you choose to use the worksheets, you can retain them for your records, but only the assigned scour code should be sent to Mn/DOT.

Scour Code Updating:

Submit the updated codes using the MBIPS system's Special Inspection data screen. Update items 18 and 19 (scour code and scour date) on the screen, and then upload data. To meet FHWA's screening completion deadline, the updated scour codes for bridges requiring screening (currently coded "F") should be submitted by February 15, 1992.

The Mn/DOT Central Office Hydraulics Staff will be contacting you within the next several months to discuss scour screening. If you have questions about the scour screening procedures, contact Andrea Hendrickson or Lisa Sayler of the Mn/DOT Central Office Hydraulics Section, at (612) 296-0826.

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file: SCRGUID2.WP

August 20, 1990  
LKS

#### Screening Guidelines:

Screening is being used to identify bridges which can be labelled low risk without further evaluation, and to place the other bridges in groups for further prioritization and evaluation. At present, the criteria for low risk foundations are:

#### GROUP - LOW RISK

##### Low Risk Criteria For Piers:

- A. Pier on spread footing on erosion-resistant bedrock (granite, basalt, quartzite, or gneiss) which is not highly broken or fractured. No known scour problems.
- B. Pier foundation of footing/piling, pile bent, or caisson, with the pile depth over 40 ft. No known scour problems.

##### Low Risk Criteria For Abutments:

- A. Abutment foundations on spread footings on erosion-resistant bedrock (granite, basalt, quartzite, or gneiss) which is not highly broken or fractured. No known scour problems.
- B. Abutment foundations of footing/piling, pile bent, or caisson with the pile depth over 40 ft. No known scour problems.
- C. Abutments with slopes that have adequate scour protection. Adequate protection is defined as riprap equivalent to Class III random riprap (Mn/DOT Spec. 3601), grouted riprap, grouted fabric or gabions. Protection should be in good condition and require no repairs. No known scour problems.

All sub-structures must meet the low risk criteria, or the sub-structure's foundation must be well above the flood water elevation for the bridge to be rated as low-risk. All of the low-risk ratings are dependant on having no known scour problems, and may also depend on the condition of the protection. If conditions change at the site, the low risk rating should be reviewed, and possibly revised.

BRIDGE SCOUR SCREENING - CODING WORKSHEET

6/6/91

Bridge #: \_\_\_\_\_

Name: \_\_\_\_\_

Date: \_\_\_\_\_

This worksheet is an aid to complete scour screening. Prior to starting the worksheet, you need information on foundations, historical scour problems, and existing scour protection. Circle Yes or No for each question and follow the directions.

<p>1. Are there any existing or historical scour problems?</p> <ul style="list-style-type: none"> <li><input type="radio"/> Scour at any pier.</li> <li><input type="radio"/> Movement, scour, or erosion at either abutment.</li> <li><input type="radio"/> Channel lowering or lateral movement.</li> </ul>	<p>YES: Scour Susceptible, Code <u>J</u> Worksheet Complete.</p> <p>NO: Go to Question 2.</p>
<p>2. Are any of the bridge foundations unknown?</p>	<p>YES: Unknown Foundations, Code <u>g</u>, Worksheet Complete.</p> <p>NO: Go to Question 3.</p>
<p>3. Do both abutments meet any of the following criteria?</p> <ul style="list-style-type: none"> <li><input type="radio"/> Piling depth greater than 40 ft.</li> <li><input type="radio"/> Adequate scour protection: <ul style="list-style-type: none"> <li>Riprap (class III or larger), grouted riprap, or gabions, in good condition.</li> <li>Spread on erosion resistant bedrock: Granite, basalt, gabbro, quartzite, or gneiss (not highly broken or fractured).</li> </ul> </li> </ul>	<p>YES: Go to Question 4.</p> <p>NO: Scour Susceptible, Code <u>J</u> Worksheet Complete.</p>
<p>4. Do all piers meet any one of the following criteria:</p> <ul style="list-style-type: none"> <li><input type="radio"/> Piling depth greater than 40 ft.</li> <li><input type="radio"/> Spread on erosion resistant bedrock: Granite, basalt, gabbro, quartzite, or gneiss (not highly broken or fractured).</li> <li><input type="radio"/> No Piers.</li> </ul>	<p>YES: Go to Question 5.</p> <p>NO: Scour Susceptible, Code <u>J</u> Worksheet Complete.</p>
<p>5. Are Questions 1 and 2: NO <u>and</u> Questions 3 and 4: YES</p>	<p>YES: Low Risk, Code <u>I</u>.</p> <p>NO: Scour code should already be assigned.</p>

## **APPENDIX B**

### **SECONDARY SCREENING**

- **INSTRUCTIONS**
- **WORKSHEETS**

## INSTRUCTIONS FOR PERFORMING SECONDARY SCREENING OF MINNESOTA BRIDGES

The Minnesota Department of Transportation, State Aid for Local Transportation Division, has funded the development of a secondary screening procedure in order to reduce the time and cost of evaluating bridges over water for foundation scour. The screening procedure presented herein is meant to provide guidance in evaluating existing bridges for vulnerability to scour and not an exact procedure to determine the safety of a bridge against the potential ravages of scour. The variability of river geometry, scourability of bed materials, and magnitude and duration of floods make an exact analysis virtually impossible with the tools currently available. To streamline this complex process into a secondary screening procedure is difficult; however, with the use of engineering judgement and common sense, we believe a secondary screening can be helpful in reducing the number of bridges requiring a detailed analysis. Annual or biennial inspections to observe the dynamic nature of river geomorphics over time and to record the changes so they can be utilized as comparison during future inspections is essential.

This secondary screening is intended to reduce the number of bridges requiring a bridge scour analysis by examining seven (7) parameters related to performance of the bridge under scour conditions. The seven parameters considered are: historical scour performance, scour resistant foundations, debris and blockage, geomorphic conditions, hydraulic conditions, structural conditions, and special low risk conditions.

It is intended that a bridge will be screened by one or more professional engineers familiar with the bridge or expert in the subject of bridge scour, by answering the questions on a pre-printed form/questionnaire entitled Secondary Screening of Minnesota Bridges (Screening Form). Information required to perform a secondary screening includes: structure inventory sheet, USGS quadrangle map showing the water course at least one mile upstream and one mile downstream of the bridge, plan and elevation drawings of the bridge, bridge photographs, and bridge inspection reports. Additional information that is recommended when available are soil information/boring logs and hydraulic design data. Although a field review may not be necessary if the engineer doing the screening is familiar with the bridge, in many cases a field review is recommended because it allows the engineer to see and document the conditions as they exist currently. The engineer(s) performing the screening should fill out the Screening Form according to the following instructions.

Complete the questionnaire consisting of 7 sections in consecutive order (one for each parameter) by answering "yes", "no", or "unknown" to each question. Responses to questions in the various sections may result in rating the bridge without completing the questionnaire in total. Place an **X** by the appropriate scour screening rating code on the first page. Possible bridge scour ratings include:

- I Bridge screened, determined to be low risk for failure due to scour. *Additional evaluation will not be done at this time. Inspection of the channel under the bridge during the annual or biennial routine inspection must supply sufficient information about the channel and protection to maintain the low risk rating. If conditions change, the bridge should be evaluated and re-coded if necessary.*

- J Bridge screened scour susceptible, Level I or Level II evaluation required. *The evaluation should provide the information necessary to code the bridge for scour. The target deadline for completing all evaluations is January 1997.*
- K Bridge screened, determined to be of limited risk to public, monitor in lieu of evaluation and close if necessary. *For trunk highway bridges, monitoring should be completed in accordance with the Office of Bridges & Structures Flood Response Plan; for local roads, monitoring should be completed in accordance with the Bridge Scour Monitoring Plan For Local Roads.*
- O Bridge screened stable for scour, but action required. *The action required can include the annual or biennial inspection providing a front face cross section is taken and compared with previous cross sections. It may also include other actions that may not normally be checked during the routine inspection. Activities such as keeping an eye on lateral stream migrations, unstable stream banks, vegetation in the floodplain which can change the flow patterns, formation of islands or bars in the vicinity of the bridge, availability of debris in upstream channel, nearby upstream tributaries that may contribute substantial amounts of sediment, and other factors that may influence the flow distribution and flow patterns. Probing may be necessary to determine if erodible bed rock is still in place after major floods. A site specific action plan to record the elevations is required.*
- R Bridge has been evaluated to be scour critical. Scour action plan recommends monitoring the bridge during high flows and close the bridge if necessary. *The scour action plan should detail the what, when, where, & how of monitoring. A system of recording the data so it will be available for comparison with future data is very important.*

Each of the sections is described below.

1. HISTORICAL SCOUR PERFORMANCE: The intent of this section is to have the reviewer consider foundation or substructure undermining which is specifically attributed to pier scour, abutment scour, contraction scour, channel vertical degradation, or channel lateral migration, which has not been corrected by properly designed and constructed scour countermeasures. Minor changes to the bridge's "designed and constructed condition", such as minor channel cross section changes or the need for riprap replenishment, which should be addressed by normal maintenance, are not at issue. If the bridge has continuing scour problems, a scour evaluation study or a monitoring program is required.

State the primary screening code. This should be available from a computer printout of scour codes from data that has been submitted to the Mn/DOT Bridge Management Engineer by the bridge owner. Answer "yes", "no", or "unknown", to whether the bridge ever experienced scour caused foundation undermining that has not been adequately corrected. If the answer is "yes", go to 7. If "no" or "unknown", go to 2.

2. **SCOUR RESISTANT FOUNDATIONS:** The intent of this section is to give the reviewer a second chance to rate the bridge as low risk (I) in the event the opportunity was missed during the primary screening. Bridges of any size which are founded on erosion resistant bedrock such as granite, basalt, gabbro, quartzite and gneiss, provided it is not highly broken or fractured, can be rated as low risk for failure due to scour.

Certain foundation materials or foundations protected by scour countermeasures may be considered as stable for scour when used in streams with relatively small drainage areas. The specific conditions considered under this section for bridges with drainage area less than 400 square miles include: abutments protected by properly designed riprap, piers or abutments on piles with pile tips more than 40 feet below the lowest channel bottom, or pile foundations located in stiff clay with an unconfined compressive strength greater than 4000 psf (shear strength of 2000 psf). (Note, there is no reference to piling length in the stiff clay criteria.) It is necessary that the stiff clay classification be determined from soil boring data as recorded on the bridge plan or other soil boring logs and located in the approximate location and elevation of the foundation elements. A Standard Penetration Test in cohesive soils of approximately 15 blows per foot has been published in the literature as being correlated with an unconfined compressive strength of approximately 4000 lbs/ft<sup>2</sup>. Caution should be exercised when interpreting blow counts because wide variations in unconfined compression strength may exist for the same blow count. Sounding rod tests with a 50 lb hammer are not appropriate for determining the existence of stiff clay soils.

If all the substructure units of the bridge are founded on scour resistant material or protected by countermeasures, the bridge can be rated as low risk for scour without performing a scour evaluation study. Answer the four (4) questions for each substructure unit as "yes", "no", or "unknown". Place the answer in the table on page 2 of the Screening Form. If there is at least one "yes" in each column in the table, rate the bridge as "I" and proceed no further. If any column does not contain a yes, then go to 3.

3. **DEBRIS AND BLOCKAGE:** The obstruction of a bridge opening by debris and ice is a serious problem which can have grave consequences for the bridge by partially damming the water course and raising the head differential from one side of the bridge to the other and therefore raising the water velocity through the bridge. These conditions are difficult to predict quantitatively and therefore any possibility of blockage must be treated as a potential scour problem and the bridge will require a scour evaluation study or a monitoring program.

Answer the questions regarding debris and ice blockage. If the answer to either question is "yes" or "unknown", go to 7. If the answer to both questions is "no", go to 4.

4. **GEOMORPHIC CONDITIONS AFFECTING SCOUR RESISTANCE:** The reviewer must consider geomorphic conditions which may indicate a potential scour problem at the bridge. Comparing current channel bottom elevations with the bottom elevations shown on the bridge plan can reveal that degradation of the channel or contraction scour has occurred under the bridge. Observed bank erosion; channel and bridge geometry which might aggravate scour conditions such as significant channel bends upstream of the bridge; piers or abutments which are skewed to the direction of flow; and significant constriction of flood flows can all be indicative of potential scour problems. If such conditions exist at the bridge site, a scour evaluation study or a monitoring program is required.

Answer the five questions regarding geomorphic conditions. If the answer to any of the questions is "yes" or "unknown", go to 7. If the answer to all the questions is no, go to 5.

5. HYDRAULIC CONDITIONS AFFECTING SCOUR RESISTANCE: Water courses with small hydraulic gradients (and without the scour aggravating conditions discussed in Sections 1 through 4 above) should not develop velocities sufficient to cause serious scour problems. The reviewer should consider the channel slope in the vicinity of the bridge and observed flood velocities which indicate non-scouring conditions. In general, if the average cross sectional velocity through the bridge during significant flood events is less than 3 fps (and 5 fps in clay bed streams) the bridge can be considered low risk for scour and no scour evaluation study is required. The questions in this section are designed to identify low velocity conditions.

For water courses where the floodway width is less than 5 times the total bridge length, answer the four (4) questions related to water depth, slope, and flood peak discharge average velocity. If the answer to any of the questions is "yes", rate the bridge as "I" and proceed no further. If the answer to all of the questions is "no" or "unknown", go to 6.

6. STRUCTURAL CONDITIONS AFFECTING SCOUR RESISTANCE: Certain structural features of single span bridges provide a demonstrated toughness against scour problems. These features include concrete abutments on piles and timber abutments less than 6 feet high on piles. In addition, man made drainage ditches designed to allow low velocities, have also been demonstrated to be non-threatening to single span bridges. If the reviewer can identify these conditions without the aggravating scour conditions discussed in Sections 1 through 5 above, the bridge can be considered low risk for scour and a scour evaluation study is not required.

If the bridge is a single span and the effective flood plain width is less than 5 times the span length, answer the three (3) questions related to foundation structural details. If the answer to any of the questions is "yes", rate the bridge as "I" and proceed no further. If the answer to all 3 questions is "no" or "unknown", go to 7.

7. MONITORED REDUCED RISK BRIDGES: The bridge must meet one of the following criteria: Scheduled for replacement or installation of constructed scour countermeasures within 5 years; road classified as a Local Road or with an estimated ADT of less than 25; or overtopping the bridge or adjacent roadway on the average of every 5 years or less. This section is designed to identify bridges for which a monitoring program is a logical economic choice instead of continued scour evaluation studies. Bridges that are being monitored for scour can be considered to have a reduced risk to the general public. If a monitoring program is not in existence or will not be implemented, a scour evaluation study is required.

Other bridges that may not require a scour analysis are bridges that are founded on erodible or semi-erodible bedrock. These bridges are difficult to analyze because the tools are not available at this time. It is expected that bedrock will erode at a much slower rate than non-cohesive material, so that a close scrutiny during the routine inspection should be adequate to insure the integrity of the bedrock. Probing to determine the top of rock may be necessary to determine if there has been any change due to potential scour. Documenting the cross section taken at the bridge is recommended.

Answer the first three (3) questions related to risk. If the answer to any of the questions is "yes", and the local professional engineer having jurisdiction over the bridge inspection directs a monitoring program for the bridge, rate the bridge as "K" and monitor in accordance with the Scour Monitoring Plan. If the answer to (d) is yes, rate the bridge as "O", scour safe but action required in accordance with the above instructions. If the answer to all 4 questions is "no" or "unknown", rate the bridge as "J" and perform a level 1 scour evaluation or rate the bridge as "R" and monitor.

# SECONDARY SCREENING OF MINNESOTA BRIDGES

**S T A R T**

City \_\_\_\_\_  
 State of Professional Engineer performing Screening \_\_\_\_\_  
 Registration Number \_\_\_\_\_  
 Bridge Location \_\_\_\_\_  
 County \_\_\_\_\_  
 State \_\_\_\_\_  
 Project Number \_\_\_\_\_  
 Date \_\_\_\_\_  
 County \_\_\_\_\_  
 State \_\_\_\_\_

Complete the following questionnaire consisting of 7 critical (marked) and place an X by the appropriate score reflecting rating code listed below. Responses to questions in the various ordinal may result in rating the bridge without answering questions in all the boxes.

Low risk for failure due to Scour, Scour Code = 1  
 Scour susceptible, analysis required, Scour Code = J  
 Limited risk to public, monitor in lieu of evaluation, Scour Code = K  
 Scour safe, but action required, Scour Code = 0  
 Scour Critical, Monitoring required, Scour Code = R

**2. SCOUR RESISTANT FOUNDATIONS:**

Answer the following questions for each, i.e., bridge pier and abut. Place the answer in the circle on the next page.

a. Are the foundations embedded in scour resistant rock such as basalt, gneiss, granite, gneiss, or quartzite, based upon records, drawings or construction records? Rock type & construction records? Rock type & construction records?

b. (i) Is and fill are only for bridges with drainage areas less than 400 square miles.  
 (ii) For foundations with piling are the piling embedded in stiff clay. Is clay with a shear strength greater than 2000 psf?  
 c. Abutments only: are there adequately designed and functioning scour countermeasures in good stable condition protecting abutments?  
 d. Piers only: Is the average bottom of the pile tips more than 40 feet below the lowest, near-bottom elevation at the bridge site?

For each substructure unit, if the answer to all questions is "no" or "unknown", go to 3. If the answer to any question is "yes" or "unknown", the substructure unit has the potential to be protected, no further.

**2. DEBRIS AND BLOCKAGE:**

a. Does debris collect or build up at the bridge and block at least 10% of the low cross section?  
 b. Does ice in the form of large blocks collect or build up at the low cross section?  
 c. Are the answers to either of the above 2 questions "yes" or "unknown", go to 7. If the answer to both questions is "no", go to d.  
 d. If the answer to either of the above 2 questions is "yes" or "unknown", go to 7.

**4. GEOMORPHIC CONDITIONS AFFECTING SCOUR RESISTANCE:**

a. Is the stream bed degrading?  
 b. For natural streams, are there channel banks of greater than 30 degrees within a distance of 4 times the channel width upstream of the bridge?  
 c. Are the stream banks unstable?  
 d. Are the bridge abutments or piers skewed less than 90 degrees to the direction of flow?  
 e. Is the floodway with less than 100 feet of low flow, less than 100 feet from a channel width?  
 f. Is the floodway with less than 100 feet of low flow, less than 100 feet from a channel width?  
 g. Is the answer to any of the above 5 questions "yes" or "unknown", go to 7. If the answer to all the above questions is "no", go to 5.

**1. HISTORICAL SCORE PERFORMANCE:**

Code: a. What is the Primary Screening Code?  
 b. Has the bridge ever experienced scour related to the screening code being rated?  
 c. If the answer to b is "yes", go to 7. If "no" or "unknown", go to 2.

**STOP Bridge Rated "K"**

Limited risk to public. Monitor in lieu of evaluation.

If d is "YES"

**STOP Bridge Rated "Q"**

Safe, but action is required.

**STOP Bridge Rated "I"**

Low risk for failure due to scour.

**7. MAINTENANCE SCHEDULED FOR REPLACEMENT OR WITH LOW ESTIMATED AUL:**

a. Is the bridge scheduled for replacement or the addition of constructed scour countermeasures within 5 years?  
 b. Has the estimated average daily traffic (ADT) over the bridge less than 250?  
 c. Does the bridge or adjacent roadway sections more than 100 feet from the bridge have a record of closure and therefore inspection before resurfacing?  
 d. Is the bridge supported by spread footings on rock and are the rock conditions be adequately examined during a routine inspection?  
 e. Does the bridge have a monitoring program for the bridge, rate the bridge as "I". If the answer to d is "yes", rate the bridge as "I", but action required per instructions. If the answer to all 4 questions is "no" or "unknown", rate the bridge as "J" and perform a level 1 scour evaluation or see the bridge as "I" and monitor.

**6. STRUCTURAL CONDITIONS AFFECTING SCOUR RESISTANCE:**

If the bridge is a multiple span or the floodway width is greater than 5 times the total bridge length, go to 7. If the bridge is a single span and the floodway width is less than 5 times the span length, answer the following 3 questions.

a. Is the bridge supported by concrete abutments on piles?  
 b. Is the bridge supported by timber abutments less than 5 feet high on piles?  
 c. Is the bridge a single span with concrete abutments over a man made ditch with a width of less than 5 feet per mile or average ditch velocity less than 3 fps for a flood of magnitude 50 years or greater?  
 d. The answer to any of the above 3 questions is "yes", rate the bridge as "I" and log the no further. If the answer to all 3 questions is "no" or "unknown", go to 7.

**STOP Bridge Rated "J" OR Bridge Rated "R"**

Scour Susceptible. Level 1 Analysis Required. OR Scour Critical. Monitoring Required.

Any of a, b, c, or d = "YES"

**5. HYDRAULIC CONDITIONS AFFECTING SCOUR RESISTANCE:**

Based upon known hydraulic information and water surface profile, answer the following questions. If the answer to any of the above 4 questions is "yes", rate the bridge as "I" and monitor. If the answer to all 4 questions is "no", go to 6.

a. Flood depth less than 2 feet and stream slope within a mile of the bridge less than 1 foot per mile?  
 b. Flood depth less than 10 feet and stream slope within a mile of the bridge less than 1 foot per mile?  
 c. Flood depth less than 20 feet and stream slope within a mile of the bridge less than 0.5 feet per mile?  
 d. For floods of magnitude greater than 50 years, if the average velocity through the bridge less than 2 feet per second, wear courses or less than 5 feet in depth bed wear courses?

Any of a, b, c, d & e = "YES" or "UNKNOWN"  
 All a, b, c, d & e = "NO"

Both a & b = "NO"

Either a or b = "YES" or "UNKNOWN"

Any of a, b, c or d = "YES"

All a, b, & d = "NO" or "UNKNOWN"

All a, b, & c = "NO" or "UNKNOWN"

All a, b, c, & d = "NO" or "UNKNOWN"

## SECONDARY SCREENING OF MINNESOTA BRIDGES

Date: \_\_\_\_\_

Signature of Professional Engineer performing Screening: \_\_\_\_\_

Registration Number: \_\_\_\_\_

Bridge Location:

Bridge Number: \_\_\_\_\_

County: \_\_\_\_\_

Township: \_\_\_\_\_

Roadway: \_\_\_\_\_

Stream: \_\_\_\_\_

Complete the following questionnaire consisting of 7 sections, in consecutive order, and place an **X** by the appropriate **scour screening rating code** listed below. Responses to questions in the various sections may result in rating the bridge without completing the questionnaire in total.

\_\_\_\_\_ Low risk for failure due to scour, Scour Code = **I**

\_\_\_\_\_ Scour susceptible, analysis required, Scour Code = **J**

\_\_\_\_\_ Limited risk to public, monitor in lieu of evaluation, Scour Code = **K**

\_\_\_\_\_ Scour safe, but action required, Scour Code = **O**

\_\_\_\_\_ Scour Critical, Monitoring required, Scour Code = **R**

### 1. HISTORICAL SCOUR PERFORMANCE:

- a. What is the Primary Screening Code: \_\_\_\_\_
- b. Has the bridge ever experienced scour which caused foundation undermining that has not been adequately corrected? \_\_\_\_\_

If the answer to (b) is "yes", go to 7. If "no" or "unknown", go to 2.

### 2. SCOUR RESISTANT FOUNDATIONS:

Answer the following questions for each substructure unit. Place the answer in the table on the next page.

- a. Are the foundations embedded in scour resistant rock such as basalt, gabbro, granite, gneiss, or quartzite, if not highly weathered, broken or fractured, based upon record drawings or construction records? Rock type is \_\_\_\_\_.

(b), (c), and (d) are only for bridges with drainage areas less than 400 mi<sup>2</sup>:

- b. For the foundations with piling, are the piling embedded in stiff clay (a clay with a shear strength greater than 2000 psf)?
- c. Abutments only: are there adequately designed and functioning scour countermeasures in good stable condition protecting the abutments? (typical scour countermeasures include riprap, gabions, concrete paving)
- d. Piers only: Is the average bottom of the pile tips more than 40 feet below the lowest river bottom elevation at the bridge site?

	Left Abutment	Pier No. ____	Pier No. ____	Pier No. ____	Pier No. ____	Right Abutment
a.						
b.						
c.		N. A.	N. A.	N. A.	N. A.	
d.	N. A.					N. A.

If there is at least one "yes" in each column in the above table, rate the bridge as "I" and proceed no further. If "no" or "unknown", go to 3.

### 3. DEBRIS AND BLOCKAGE:

- a. Does debris collect or build up at the bridge and block at least 10% of the flow cross section? \_\_\_\_\_
- b. Does ice in the form of jams or frazil collect or build up at the bridge and block at least 10% of the flow cross section? \_\_\_\_\_

If the answer to either of the above 2 questions is "yes" or "unknown", go to 7. If the answer to both questions is "no", go to 4.

### 4. GEOMORPHIC CONDITIONS AFFECTING SCOUR RESISTANCE:

- a. Is the stream bed degrading? \_\_\_\_\_
- b. For natural streams, are there channel bends of greater than 30 degrees within a distance of 4 times the channel width upstream of the bridge? \_\_\_\_\_
- c. Are the stream banks unstable? \_\_\_\_\_

- d. Are the bridge abutments or piers skewed to the direction of flow? \_\_\_\_\_
- e. Is the effective flow width (width of flow during the 100 year flood) greater than 5 times the total bridge span or 5 times the bank full channel width? \_\_\_\_\_

If the answer to **any** of the above 5 questions is "yes" or "unknown", go to 7. If the answer to all the above questions is no, go to 5.

**5. HYDRAULIC CONDITIONS AFFECTING SCOUR RESISTANCE:**

Based upon known topographic information and water surface profile calculations or historical records or professional judgement, answer the following questions:

- a. Is flood depth less than 3 feet and stream slope, within a mile of the bridge, less than 5 feet per mile? \_\_\_\_\_
- b. Is flood depth less than 10 feet and stream slope, within a mile of the bridge, less than 1 foot per mile? \_\_\_\_\_
- c. Is flood depth less than 20 feet and stream slope, within a mile of the bridge, less than 0.5 feet per mile? \_\_\_\_\_
- d. For floods of magnitude greater than 50 years, is the average velocity through the bridge less than 3 fps in sand bed water courses or less than 5 fps in clay bed water courses? \_\_\_\_\_

If the answer to any of the above 4 questions is "yes", rate the bridge as "I" and proceed no further. If the answer to all of the above questions is "no" or "unknown", go to 6.

**6. STRUCTURAL CONDITIONS AFFECTING SCOUR RESISTANCE:**

If the bridge is multiple span, go to 7. If the bridge is a single span and the effective flood plain width is less than 5 times the span length, answer the following 3 questions. Otherwise, go to 7.

- a. Is the bridge supported by concrete abutments on piles? \_\_\_\_\_
- b. Is the bridge supported by timber abutments less than 6 feet high on piles? \_\_\_\_\_
- c. Is the bridge a single span with concrete abutments over a man made ditch with slope of less than 5 feet per mile or average ditch velocity less than 3 fps for a flood of magnitude 50 years or greater? \_\_\_\_\_

If the answer to any of the above 3 questions is "yes", rate the bridge as "I" and proceed no further. If the answer to **all** 3 questions is "no" or "unknown", go to 7.

7. **MONITORED REDUCED RISK BRIDGES:**

- a. Is the bridge scheduled for replacement or installation of constructed scour countermeasures within 5 years? \_\_\_\_\_
- b. Is the road classified as a Local Road or is the estimated average daily traffic (ADT) over the bridge less than 25? \_\_\_\_\_
- c. Does the bridge or adjacent roadway overtop more often than on average every 5 years, requiring closure and therefore inspection before reopening? \_\_\_\_\_
- d. Is the bridge supported by spread footings on rock and the can the rock condition be adequately examined during a routine inspection? \_\_\_\_\_

If the answer to either a, b, or c is "yes", and the local professional engineer having jurisdiction over the bridge inspection directs a monitoring program for the bridge, rate the bridge as "K". If the answer to d is yes, rate the bridge as "O", scour safe but action required in accordance with the instructions. If the answer to all 4 questions is "no" or "unknown", rate the bridge as "J" and perform a level 1 or level 2 scour evaluation or rate the bridge as "R" and monitor.

## **APPENDIX C**

### **LEVEL I SCOUR EVALUATIONS**

- **INSTRUCTIONS**
- **REPORT FORM**

## **INSTRUCTIONS FOR PERFORMING MINNESOTA DOT LEVEL 1 - SCOUR EVALUATIONS**

Instructions are provided below for performing a level 1 bridge scour evaluation in accordance with FHWA guidelines and Minnesota specific conditions reflected in the development of the Minnesota Department of Transportation Bridge Scour Evaluation Procedures. A level 1 scour evaluation entails performing a site specific qualitative study of a bridge to determine it's vulnerability to conditions which cause foundation scour and stream stability problems at the bridge. The team performing the review should be thoroughly familiar with FHWA publications HEC-18 and HEC-20. They should also be competent in the fields of hydraulics, geotechnical, and structural engineering.

A level 1 scour evaluation consists of the following 4 tasks, listed in the order of execution, including: office data collection, review and evaluation of collected data, site visit and field assessment, and scour evaluation. The pre-printed Minnesota DOT Level 1-Scour Evaluation Report Form (Report Form) should be used for reporting the results of scour evaluations. Attached to the report should be pertinent collected data, a completed pre-printed Minnesota Bridge Scour Field Assessment Form (Field Form), and any computations made to support the scour rating. A description of each task is given below.

### **OFFICE DATA COLLECTION**

The task to be performed in a level 1 bridge scour evaluation is the collection of available data related to geology, hydrology, and sediment transport in the drainage area upstream and in the vicinity of the bridge. This data should include: a bridge general plan and elevation with foundations depicted, topographic maps of the water course and drainage area, aerial photographs from different years for comparison, soil boring logs, pile driving records, soils/geologic maps, stream gage data, bridge hydraulic recommendation, bridge inventory sheet, bridge inspection reports, underwater inspection reports, hydrologic and hydraulic studies or other studies of the water course, and other appropriate data. All of the information collected should be identified on the first page of the form.

Peak flood discharges and approximate stages should be estimated for the 100 and 500 year floods, prior to the site visit. The discharge estimates help make the field observations more meaningful by allowing visualization of flow conditions for these extreme events.

### **REVIEW AND EVALUATION OF THE DATA COLLECTED**

In general, all of the information collected should be reviewed prior to a site visit and field assessment. The data which is used in rating the scour susceptibility of the bridge should be attached to the Report Form. Specific items of data should be reviewed as follows:

1. Review the plan and elevation of the bridge to determine the depth to the

bottom of the footings and their orientation with respect to the flow direction.

2. Review the aerial photographs for lateral migration of the water course. The photographs compared should be the most recent available and preferably one taken at least 20 years earlier.
3. Review the soils and geologic information to determine the ability of the bed and bank materials to resist scour. Also assess the drainage area susceptibility to soil erosion and therefore a continuing source of material for bed load and scour infilling. Soil boring information and pile driving records should be reviewed for stratigraphic and grain size information.
4. Review bridge inventory sheet, inspection reports, and underwater inspection reports for historical problems related to scour and stream stability.
5. Review available stream gage data, bridge hydraulic recommendations, FEMA floodway information, and other hydraulic/hydrologic studies and reports for information regarding flood hydrographs and peak discharges, water surface profiles, and associated channel velocities.

Answer the 7 questions on page 2 of the Report Form or summarize this information in narrative form. On USGS topographic maps, delineate the area tributary to the bridge. Use maps of an appropriate scale. Digitize or planimeter the area to determine its approximate size. Note that the tributary area map will be used to help determine land use, vegetation type, and land and water course slope, which in turn will provide background for assessing the potential for debris or ice problems. Prior to making a site visit, determine 100 year and 500 year flood peak discharges by analyzing gage records for the water course, transposing records from another water course, estimating flows from Minnesota regression equations or flood insurance studies. If there is no information available for  $Q_{500}$ , use  $1.7Q_{100}$ . Write the discharges in the space provided on page 2 of the Report Form. Attach discharge calculations to the scour evaluation report form.

## **SITE VISIT AND FIELD REVIEW**

Plan site visits to minimize travel time and cost. Equipment required should include: camera, sounding pole or equivalent, tape measure, hand auger, shovel, and notebook including the Minnesota Bridge Scour Field Assessment Form. Notes are easily made on copies of the bridge plan and elevation. It is recommended that the notebook taken to the field contain site specific information from the office data collection. Water surface elevation at the time of the site visit should be noted and referenced to a known elevation on the bridge. Depth and approximate velocity measurements should be taken at the upstream fascia. If measurements indicate the stream bed has lowered at the bridge, it may be necessary to profile the thalweg upstream and downstream in an effort to determine if degradation is localized or not. Visualize the angle of attack on the piers and abutments during bank full and flood stage. Note the potential for and location of roadway overtopping and the possibility of pressure flow under the

bridge. Photograph the bridge from upstream and downstream and photograph the water course looking upstream and downstream from the bridge. Evaluate the site upstream and downstream of the bridge. If the channel and floodplain are reasonably uniform, one representative cross section will be adequate. If the channel and cross section are not uniform, take one cross section downstream and one upstream. Note the presence of any erosion or scour at foundation units or elsewhere. Summarize observed conditions at the bridge related to scour in the space provided on page 2 of the Report Form. Attach field notes, photographs, and Field Form. Draw a cross section of the channel and flood plain and note bank heights, bottom width, side slopes, roughness coefficients, etc.

## SCOUR EVALUATION

Upon completion of the site visit and field review, a preliminary estimate of scour depth should be made. The following step by step procedure is recommended:

1. Determine  $Q_{100}$ ,  $Q_{500}$ , and  $Q_{\text{overtopping}}$  ( $Q_{OT}$ ), if appropriate. (This may have been done prior to the site visit.) Utilize the USGS regression equations, gaging data, Flood Insurance Studies and other studies as available. If  $Q_{OT}$  is less than  $Q_{500}$  or  $Q_{100}$ , the  $Q_{OT}$  will usually generate the highest average velocity through the bridge which needs to be evaluated.
2. Evaluate cross section data and determine a representative cross section to utilize for single section stage discharge analysis.
3. Determine appropriate "n" values from field notes and photographs. (See Table 8-1 from the AASHTO Model Drainage Manual in appendix I)
4. Determine slope from quadrangle map or other source.
5. Utilizing an appropriate computer program or hand calculations, calculate normal depth for a range of discharges which include  $Q_{100}$ ,  $Q_{500}$ , and  $Q_{OT}$  at the representative cross section. At locations where the downstream cross section is substantially different from the approach cross section, the flow distribution between the main channel and the overbank flow at the approach section which is necessary for the contraction scour calculation, can be estimated by using the Q and water surface elevation between the main channel and the overbank. In cases where backwater effects have significant impact on scour calculations, a Level II analysis may be justified.
6. Calculate the mean velocity through the bridge by dividing the appropriate discharge by the area bounded by the surveyed channel bottom elevation at the front face of the bridge and the estimated or calculated water surface elevation. If part of the discharge is overtopping the road, this quantity must be deducted from the quantity flowing under the bridge.

7. Calculate contraction scour by utilizing both the live bed and the clear water contraction scour equations as given in HEC 18 and select the smaller scour depth. With stratified bed materials, the depth of scour can be determined by using the clear water scour equation and successive mean diameter of the bed material layers.
8. Calculate pier scour using the CSU equation given in HEC 18. The average velocity should be adjusted as follows: (a) If the pier is located in the outside of a bend, use  $1.7 V_{ave}$  or (b) for other locations, use  $1.25 V_{ave}$ . If the footing is exposed, use the guidance given in HEC 18.
9. Evaluate the potential for abutment scour. Check the adequacy of the existing riprap on the abutments, using the criteria from HEC-18 to determine if it is stable for the calculated discharges. If it is not stable for the maximum discharge, determine the minimum discharge for which it is stable. If there is no riprap in place, or existing riprap is not adequate, determine the size of riprap required by the HEC-18 criteria. For situations where a bridge abutment projects into the floodway obstructing more than 25 percent of the conveyance capacity of the unobstructed floodway, abutment scour may require a more detailed evaluation than is appropriate for a Level 1 evaluation.
10. Plot the predicted contraction scour and pier scour on a cross section of the bridge.
11. Evaluate the bridge for structural stability. The memo from Don Flemming, State Bridge Engineer, entitled **Guidelines for Evaluation of Stability of Existing Pile Foundations When Exposed by Scour** and included in Appendix F, can be utilized in this evaluation.

Complete the summary tables on page 3 and 4 of the Report Form and rate the bridge in accordance with scour rating codes below. If coded L, M, or N, scour stable, no further action is required. If coded R or U, scour critical, or O, stable but action required, or P, stable due to protection, a scour action plan is required. If inconclusive or additional information is required, a Level II analysis may be required.

	Scour Rating Code	Description
L	STABLE-EVAL	Scour evaluation complete, bridge judged to be low risk of failure due to scour.
M	STABLE-SCOUR ABOVE FOOTING	Bridge foundations determined to be stable for calculated scour conditions; calculated scour depth from the scour prediction equations is above top of footing.

N	STABLE - SCOUR IN FTG OR PILE	Bridge foundations determined to be stable for calculated scour conditions; calculated scour depth from the scour prediction equations is within limits of footing or piles.
O	STABLE - ACTION REQUIRED	Bridge foundations determined to be stable for predicted scour conditions; Scour action plan requires additional action.
P	STABLE DUE TO PROTECTION	Countermeasures have been installed to correct a previously existing problem with scour. Bridge is no longer scour critical. Scour countermeasures should be inspected at least once every 4 years and after major flows, or as recommended in the scour action plan. Report any changes that have occurred to countermeasures.
R	CRITICAL - MONITOR	Bridge has been evaluated to be scour critical. Scour action plan recommends monitoring the bridge during high flows and closing if necessary.
U	CRITICAL-PROT REQUIRED	Bridge has been evaluated to be scour critical. Scour action plan recommends this bridge as a priority for installation of countermeasures. Until countermeasures are installed, monitor the bridge during high flows and close if necessary.

**Complete a Report Form. Attach office data, field notes including Field Assessment Form, and calculations. File as part of the permanent scour evaluation record.**

MINNESOTA DOT LEVEL 1 - SCOUR EVALUATION REPORT FORM

Bridge Number: \_\_\_\_\_  
County: \_\_\_\_\_  
Township: \_\_\_\_\_  
Roadway: \_\_\_\_\_  
Stream: \_\_\_\_\_

This bridge has been evaluated for scour and is rated as: \_\_\_\_\_

The action recommended for this bridge is: \_\_\_\_\_

Signature of Professional Engineer: \_\_\_\_\_ Date: \_\_\_\_\_

This form presents the background data, evaluation parameters, and appropriate preliminary calculations to determine the susceptibility of the subject bridge to foundation scour in accordance with a phased approach recommended in Federal Highway Administration guidelines.

OFFICE DATA COLLECTION

The following information has been collected and is attached as part of this scour evaluation ( place an X adjacent to the items obtained ). The information should be reviewed prior to a site visit and field review.

- \_\_\_\_ Bridge general plan and elevation with foundations depicted
- \_\_\_\_ Topographic maps of the water course and tributary area
- \_\_\_\_ Aerial photographs, years \_\_\_\_\_
- \_\_\_\_ Soil boring logs
- \_\_\_\_ Pile driving reports
- \_\_\_\_ Soils/geologic maps
- \_\_\_\_ Stream gage data
- \_\_\_\_ Bridge Hydraulic Recommendation
- \_\_\_\_ Bridge Inventory Sheet
- \_\_\_\_ Bridge inspection reports
- \_\_\_\_ Underwater inspection reports
- \_\_\_\_ Hydraulic/hydrologic or other studies of the water course as follows \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

\_\_\_\_ Other appropriate data (describe ) \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**REVIEW AND EVALUATION OF THE DATA COLLECTED**

Are the piers or abutments supported by piles or caissons? \_\_\_\_\_

Is the bridge perpendicular to the water course? \_\_\_\_\_

Are the piers or abutments parallel to the flow or at a skew? \_\_\_\_\_

Has there been any lateral migration of the stream in the vicinity of the bridge? \_\_\_\_\_

What is the evidence of lateral migration? \_\_\_\_\_

Is there a history of scour problems at the bridge? \_\_\_\_\_

Are the footings founded on a material resistant to scour, such as rock or stiff clay? \_\_\_\_\_

Hydrologic conditions at the bridge are as follows (attach backup or calculation) :

Q(100)= _____ cfs	Stage _____
Q(500)= _____ cfs	Stage _____
Q(Overtopping) _____ cfs	Stage _____

**SITE VISIT AND FIELD REVIEW**

Briefly summarize observed conditions at the bridge related to scour. Attach Minnesota Bridge Scour Field Assessment Form. \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

HYDROLOGIC AND HYDRAULIC SUMMARY			
Drainage Area			
Flood Frequency (YR)			
Discharge (cfs)			
W.S. Elevation			
Maximum depth (ft)			
Average velocity (fps)			
Pier scour (ft)			
Contraction scour (ft)			
Total scour (ft)			

### FOUNDATION SUMMARY SHEET

Structure Name <sup>1</sup>				
Type of Foundation				
Type of Piling				
Pile Diameter (inches)				
Located in Main channel (Yes/No)				
Original Ground Elev. Date: _____				
Current Ground Elev. Date: _____				
Thalweg Elevation Date: _____				
Top of Footing Elevation				
Bottom Footing/Pile Cap Elevation				
Average Bottom of Pile Elevation				

### SCOUR SUMMARY SHEET

Flow Frequency & Event	Q _____ = _____ cfs			
Calculated Contraction Scour (feet)				
Calculated Local Scour (feet)				
Total Scour (feet)				
Contraction Scour Elevation				
Total Scour Elevation				
Length of Pile Exposed (feet)				
Length of Pile Embedded (feet)				

<sup>1</sup> Use structure name identified on the bridge plan sheet. ie. North Abutment, Pier 1

The bridge is rated as \_\_\_\_\_ (see detailed ratings in instructions). If coded L, M, or N, scour stable, no further action is required. If coded R or U, scour critical, or O, stable but action required, or P, stable due to protection, a scour action plan is required. If inconclusive or additional information is required, a Level II analysis may be required.

Attach office data, Field Assessment Form, survey notes, and calculations and file as part of the permanent scour evaluation record.

**APPENDIX D**

**MINNESOTA BRIDGE SCOUR**

**FIELD ASSESSMENT FORM**

Minnesota Bridge Scour Field Assessment Date: \_\_\_\_\_ Crew: \_\_\_\_\_  
 01/06/95

Bridge No. \_\_\_\_\_ Route: \_\_\_\_\_ County: \_\_\_\_\_  
 Stream: \_\_\_\_\_ Location: \_\_\_\_\_

**Bridge:**

Does bridge geometry differ from plan? Yes/No If so, explain on back of sheet.

Take Cross-Section at Upstream Face of Bridge: at minimum, measure elevation (to nearest .5') at pier foundations, abutments foundations, toe of abutment slope & thalweg. Additional measurements between foundations are recommended. Attach sketch.

Water surface elevation: \_\_\_\_\_

Abutment Direction as on plan	Location (ft) Set Back, At Bank, or In Channel & Distance from Bank	Protection Type, Size Condition & Extent	Existing Scour None, Local Scour Footing Exposed, Piles Exposed	Guide Banks Yes/No

Pier Number as on plan	Location (ft) In Channel, At Bank or on Flood Plain	Angle of Attack		Debris type/amount none, brush, branches, trees	Protection Type, Size Condition & Extent	Existing Scour None, Local Scour Footing Exposed, Piles Exposed
		Low Flow	High Flow			

Piers numbered \_\_\_\_\_ to \_\_\_\_\_

Additional Comments: \_\_\_\_\_

\_\_\_\_\_

Are there observed or potential scour problems at bridge, describe any problems.

Yes No

- Abutments tilting/moving in: \_\_\_\_\_
- Approach panel cracking or settlement: \_\_\_\_\_
- Slopes washing in/sloughing: \_\_\_\_\_
- Scour holes near abutments/piers: \_\_\_\_\_
- Bed deposits downstream: \_\_\_\_\_
- Damage to riprap/abutments/piers: \_\_\_\_\_
- Bridge Railing Sagging: \_\_\_\_\_
- Debris potential: \_\_\_\_\_
- Ice problem potential: \_\_\_\_\_
- Highwater Mark: \_\_\_\_\_
- Other: \_\_\_\_\_

**Channel**

		Manning n	Channel/Floodplain Material & Cover Description
Channel			
Upstream Flood plain			
Downstream Flood plain			

Channel Bed Material:	Type	&	Size
	silt/clay, sand, gravel, cobble/boulder, bedrock		fine, medium, coarse
Upstream:	Under Bridge:		Downstream:

Circle conditions that apply:

River Form:            Straight • Meandering • Braided • Man Made • \_\_\_\_\_

Stream Size:           Small (< 100 ft) • Medium (100-500 ft) • Large (> 500 ft)

Flow Characteristic: Intermittent • Perennial

Check yes for any conditions that apply and describe

Yes No

- Bridge located near bend: upstream/downstream/in bend
- Evidence of lateral migration: \_\_\_\_\_
- Evidence of bank mass wasting: \_\_\_\_\_
- Islands/bars: upstream/downstream/under bridge
- Angle of Attack on bridge: Flood Flow: \_\_\_\_\_ Normal Flow: \_\_\_\_\_
- Evidence of aggradation: \_\_\_\_\_
- Evidence of degradation: \_\_\_\_\_
- Nearby bridges/culverts: \_\_\_\_\_
- Nearby dam/control structure: \_\_\_\_\_
- Channel Modification: \_\_\_\_\_
- Nearby tributaries: \_\_\_\_\_
- Nearby confluence: \_\_\_\_\_

Banks	Bank Height	Bankfull Channel Width	Vegetation/Cover	Material silt/clay, sand, gravel, cobbles, boulders, bedrock	Protection	Erosion none, mass wasting, fluvial
Up- stream						
Down- stream						



**Sketch:**

Draw plan view of bridge and river. Show approximate location of any countermeasures, existing erosion or scour, debris, islands/bars, river bends, direction of flow, and/or other nearby structures.

The sketch area consists of approximately 25 horizontal lines spaced evenly down the page, providing a grid for drawing the plan view of the bridge and river. The lines are faint and extend across most of the width of the page.

**APPENDIX E**

**SCOUR RATING CODES**

CODE	LITERAL	DESCRIPTION
A	NON-WATERWAY	Bridge not over waterway.
B	CLOSED-SCOUR	Bridge is closed to traffic; field review indicates that failure of piers and/or abutments due to scour is imminent or has occurred.
C	CLOSED-NOT SCOUR	Bridge is closed to traffic for reasons other than scour.
D	OBS SCOUR-IMM PROT REQ	Bridge is scour critical; field review indicates that extensive scour has occurred at bridge foundations. Immediate action is required to provide scour countermeasures.
E	CULVERT	Culvert structure. Scour calculation, evaluation, and/or screening has not been made.
F	NO EVAL-FOUND KNOWN	Bridge Structure. Scour calculation, evaluation, and/or screening has not been made. All substructure foundations are known.
G	NO EVAL-FOUND UNKNOWN	Scour calculation, evaluation and/or screening has not been made. Bridge on unknown foundations.
H	FOUND ABOVE WATER	Bridge foundations (including piles) well above flood water elevations.
I	SCREEN-LOW RISK	Bridge screened, determined to be low risk for failure due to scour.
J	SCREEN-SCOUR SUSC	Bridge screened, determined to be scour susceptible.
K	SCREEN- LIMITED RISK	Bridge screened, determined to be of limited risk to public, monitor in lieu of evaluation and close if necessary.
L	STABLE-EVAL	Scour evaluation complete, bridge judged to be low risk for failure due to scour.
M	STABLE-SCOUR ABOVE FTG	Bridge foundations determined to be stable for calculated scour conditions; calculated scour depth from the scour prediction equations is above top of footing.
N	STABLE-SCOUR IN FTG/PILE	Bridge foundations determined to be stable for calculated scour conditions; calculated scour depth from the scour prediction equations is within limits of footing or piles.
O	STABLE-ACTION REQUIRED	Bridge foundations determined to be stable for scour conditions; Scour action plan requires additional action.
P	STABLE DUE TO PROT	Countermeasures have been installed to correct a previously existing problem with scour. Bridge is no longer scour critical. Scour countermeasures should be inspected at least once every 4 years and after major flows, or as recommended in the scour action plan. Report any changes that have occurred to countermeasures.
R	CRITICAL- MONITOR	Bridge has been evaluated to be scour critical. Scour action plan recommends monitoring the bridge during high flows and closing if necessary.
U	CRITICAL-PROT REQ	Bridge has been evaluated to be scour critical. Scour action plan recommends this bridge as a priority for installation of countermeasures. Until countermeasures are installed, monitor bridge during high flows and close if necessary.

**APPENDIX F**

**BRIDGE STABILITY GUIDELINES**

DEPARTMENT : Transportation  
Office of Bridges and Structures

DATE : January 10, 1995

STATE OF MINNESOTA  
**Office Memorandum**

TO : Engineering Personnel  
Office of Bridges and Structures

FROM : Donald J. Flemming  
State Bridge Engineer



PHONE : 582-1100

SUBJECT : Guidelines for Evaluation of Stability of Existing  
Pile Foundations when Exposed by Scour

The following guidelines may be used with discretion by registered engineers for determination of stability of existing bridge substructure units supported by pile foundations (see attached diagrams showing pile and scour parameters for various types of piers) if estimated scour depths are sufficient to expose piling. Estimated scour depths to be used are those furnished by the Hydraulics Engineer for the lesser of overtopping or 500 year flood.

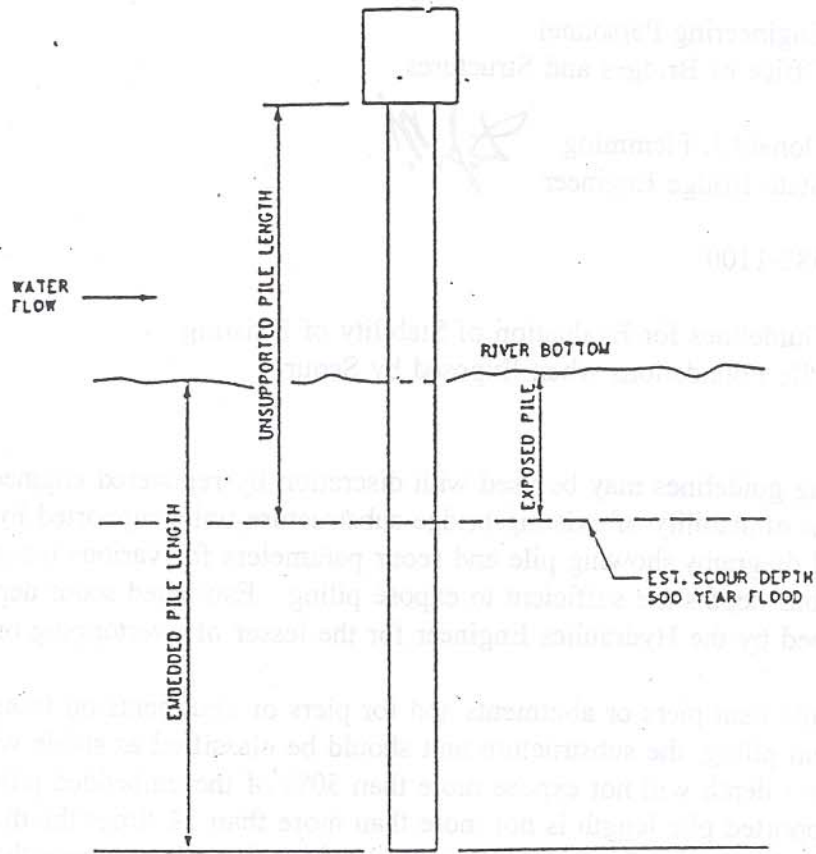
- (1) For pile bent piers or abutments and for piers or abutments on footings supported by friction piling, the substructure unit should be classified as stable with respect to scour if scour depth will not expose more than 50% of the embedded piling, and the unsupported pile length is not more than more than 24 times the diameter of a "CIP" pile, 24 times the nominal section depth of an "H" pile, or more than 16 times the average diameter of a timber pile.
- (2) For pile bent piers or abutments and for piers or abutments on footings supported by end bearing piling, the substructure unit should be classified as stable with respect to scour if at least 5 feet of the pile will remain embedded in dense material and the unsupported pile length meets the criteria in (1) above.

The substructure unit shall be considered stable if the foundation satisfies one of the above criteria.

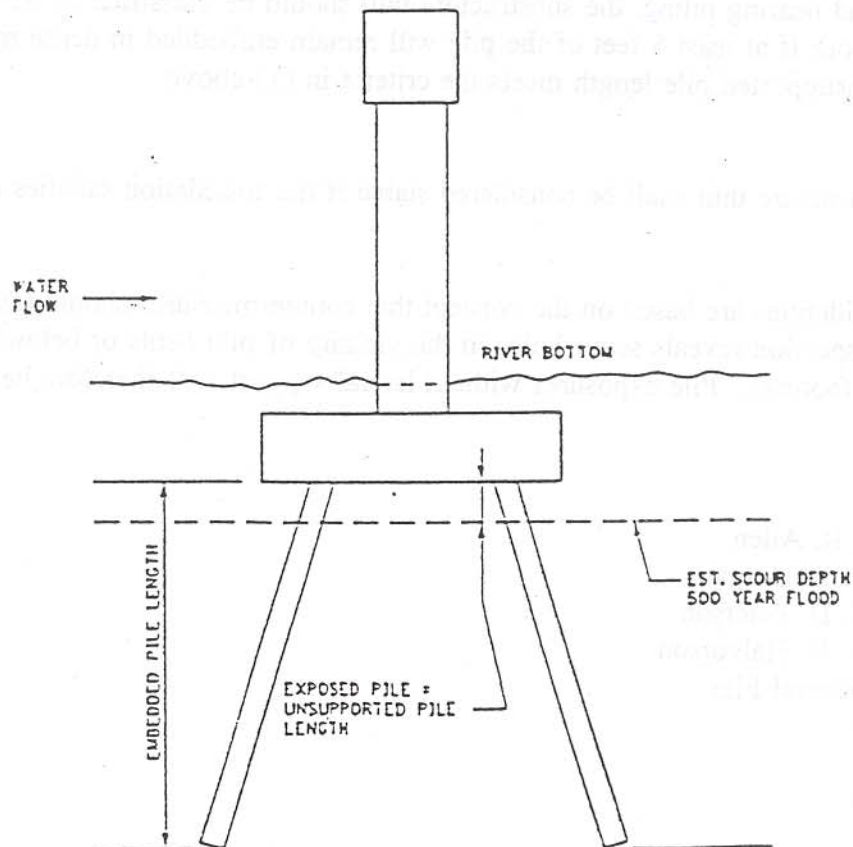
These guidelines are based on the concept that countermeasures should (and will) be taken where inspection reveals scour holes in the vicinity of pile bents or below the bottom of concrete footings. Pile exposures without lateral support will therefore be of relatively short duration.

cc: J. R. Allen  
D. L. Dorgan  
G. D. Peterson  
D. V. Halvorson  
General File

## PILE BENT PIER



## PIER ON PILE SUPPORTED FOOTING



**APPENDIX G**

**MN/DOT FLOOD RESPONSE PLAN**

**OFFICE OF BRIDGES AND STRUCTURES  
TRUNK HIGHWAY BRIDGES FLOOD RESPONSE PLAN**

1/12/95

**Purpose**

Bridges are vulnerable to damage and failure during flooding. Scour may undermine the bridge foundations or remove the protection from the abutment slopes. To protect the public and the bridges, the bridges should be monitored during flooding. Monitoring generally requires measuring the river bed elevation at the bridge. Monitoring may indicate that the bridge should be closed, corrective action should be taken immediately (such as removing debris), or that protection should be installed as soon as practical.

Each district is responsible for monitoring their bridges. This Flood Response Plan contains recommendations to the Districts on monitoring bridges and the support available from the Bridge Office.

**Priority**

Monitoring is recommended for all bridges during significant flooding. However, the extent, frequency, and the flood stage to begin monitoring will vary. The District is responsible to determine which bridges will be monitored, the Bridge Office recommendations are as follows:

Bridge Monitoring Recommendation			
Priority	Bridge Description	Scour Code	Recommended Action
High	Scour critical with action plan	R, U	Follow action plan
High	Limited Risk, Monitor in lieu of evaluation	K	Follow general guidelines
High	Known scour problems with no action plan	Any Code	Follow general guidelines
High	Others with action plans	O, P	Follow action plan
Secondary	Scour susceptible bridges	F, G, J	Follow general guidelines
Secondary	Stable and low risk bridges	H, I, L, M, N	Follow general guidelines

Action Plans have been prepared for scour critical bridges and contain details on monitoring a specific bridge site. The Action Plan is on file in the District and at the Office of Bridges and Structures. Bridges that do not have an action plan should be monitored using the general guidelines listed in this plan.

## Monitoring Tools

Sounding weights and/or sonar are normally used to monitor the river bed elevations at the bridge. Both methods are usually used from the bridge deck. However, the measurements taken along the bridge fascia may not be located at the site of maximum scour which is usually close to the pier or abutment. Ice and debris may limit the locations and can cause inaccurate readings.

Each District should have at least one sonar unit. Three portable winches with 35 and 100 pound weights are available. They are located in the Metro Division, District 1 - Duluth and District 6 - Rochester. If one of these units is needed, the scour coordinator from that District should be contacted.

If Mn/DOT is unable to monitor a certain bridge, the United States Geological Survey may be able to assist in monitoring that bridge with their equipment. Contact the Bridge Office Flood Coordinator if this is necessary.

A boat may be required to monitor pier scour at bridges over major rivers. Since safety of the operating personnel is a prime consideration, the boat must be of sufficient size and equipped properly to navigate around piers during flood stage.

## Pre-flood Preparation

The District must be prepared to monitor when flooding occurs. Personnel who will monitor the bridges must have access to the necessary equipment and have adequate training. The District should have a plan for checking water surface elevations after rainfall or snowmelt, and notification procedures must be defined.

The District should conduct a pre-flood site investigation on all bridges with a high monitoring priority. The purpose of the pre-flood investigation is to prepare the bridge for monitoring and would include:

- Mark the locations at which measurements will be taken and measure baseline river bed elevations.
- Mark and survey a reference point elevation to measure the water surface elevation.
- Mark the water surface elevation at which monitoring should begin. Use Bridge Scour Monitoring Sign symbol.

## Monitoring Frequency

Flooding that warrants monitoring of trunk highway bridges may occur any year. The District is responsible for determining if bridges are undergoing flooding conditions that require monitoring. The Bridge Office Flood Coordinator can be contacted by the District to assist in determining when monitoring shall commence and be suspended.

Action plans give the beginning flood stage at which monitoring is recommended. General guidelines are:

### Begin monitoring:

- Scour Critical Bridges: As recommended in action plan
- Limited Risk and Scour Susceptible Bridges:
  - During significant flooding (water nears design high water elevation)
  - River nears elevation that has caused problems in past
  - Unusual conditions (such as large amount of debris)
- Stable or low risk Bridges:
  - River nears historic high water or design high water elevation
  - Unusual conditions (such as large amount of debris)

### Initial Monitoring:

Compare the measured bed elevation to the base line elevation. Determine if the bed has lowered significantly, a significant bed change is defined as:

- 5 ft: Large rivers (river channel over 100' wide)
- 2 ft: Medium/small rivers (river channel less than 100' wide)

### Continued Monitoring:

- Significant bed changes are not detected: monitor once per day until flood crest begins to recede.
- Significant bed changes are detected: monitor a minimum of twice per day and contact the District Scour Coordinator or Bridge Office Flood Coordinator.
- Monitor continuously if river bed nears the critical scour elevation.

## Monitoring Procedure

Monitor all critical piers and abutments to determine if the channel bottom elevation is changing.

- Maximum pier scour is expected to occur near the front face of the pier. If flood water is attacking the pier at a skew angle, the deepest scour is expected on the front or side that the flow impacts.
- Maximum abutment scour typically occurs at the toe of the abutment slope or the upstream corner of a vertical abutment.

- Bridges with abutment slopes should be monitored both at the toe of the abutment slope and next to the abutment foundation. If the foundation is undermined, the approach fill may be endangered.
- Foundations protected by countermeasures should be monitored. Riprap is not typically designed to withstand a 100 year or 500 year flood event. Monitor to verify that the riprap remains in place.

Measure for scour from the upstream face of the bridge if possible. However, if this is not possible due to ice or debris, measure from the downstream face. The notes should state where monitoring was taken and if ice or debris were present (since they can increase the amount of scour). A sample monitoring form is attached.

To measure river bed elevations:

- Measure the water surface elevation by measuring down from the bridge
- Determine bed elevation from water depth and known water surface elevation
- Record data. Include a water surface elevation, reference locations from a pier or the end of bridge. Elevations should be tied to MSL datum.

### Action

For bridges with monitoring action plans (scour code R or U), follow the action plan recommendation to close the bridge if the riverbed lowers to the critical scour elevation. For bridges without an action plan, close the bridge if scour threatens the bridge stability.

- Notify the proper authorities
- Detour traffic (use Trunk Highways where practical)
- Review bridges on detour route for scour code and monitor if necessary.
- Check bridge after flood recedes/make recommendations for repair/protection

If large amounts of debris are at bridge, remove the debris if possible. If scour occurs at the bridge, consult with Bridge Office to see if protection should be installed.

### Reporting

Report results of monitoring to the District Scour Coordinator daily. If scour reaches the critical river bed elevation, the monitoring personnel should take appropriate action and contact the District Scour Coordinator.

The District Scour Coordinator and Bridge Office personnel should regularly contact the Bridge Office Flood Coordinator to notify him of the flood monitoring results. The Flood Coordinator is responsible for coordinating all Bridge Office responses. In the event of wide spread flooding, the Bridge Office Flood Coordinator will provide the State Bridge Engineer with daily status reports.

After flooding has subsided, the District Scour Coordinator should summarize the bridges that were monitored and the results for the Bridge Office Flood Coordinator. The District may request that the Bridge Office review a specific bridge(s).

## Bridge Office Services to the Districts

- The Bridge Office Flood Coordinator will monitor the following data sources to detect flooding which may effect Mn/DOT bridges.
  - River Flood Forecasts issued by the River Forecast Center.
  - Weekly Precipitation Maps issued by the Minnesota DNR.
  - Contact with other State and Federal agencies, including: National Weather Service; River Forecast Center; Corps of Engineers; Minnesota DNR; State Climatologist; United States Geological Survey.
- Contact District as soon as flooding is probable to alert them of flooding potential, offer our services and set up a line of communication.
- Act in an advisory capacity to provide technical expertise on flood monitoring techniques, identify bridges that should be monitored, analyze flood monitoring results, and determine bridge stability.
- Provide additional flood monitoring resources when available, including: staff, equipment and use of consultants through contracts.
- Provide on-going investigation of new technologies to improve monitoring efforts.
- Provide on-going training to District personnel.



DISTRICT SCOUR COORDINATORS

D-1	David Davidson, Resident Engineer Duluth	(218) 723-4840 Ext. 3420 PROFS: DLD100
D-2	Robert Kleinschmidt Bemidji	(218) 755-3814 PROFS: REK000
D-3	Kieth Englesby St. Cloud	(218) 654-5539 PROFS: KCE000
D-4	Mike Ginnaty Detroit Lakes	(218) 847-1512 PROFS: MTG000
D-6	Steve Kirsch, District Bridge Engineer Rochester	(507) 285-7388 PROFS: SRK000
D-7	Dick Keenan, Resident Engineer Mankato	(507) 389-6863 PROFS: RNK000
D-8	Jack Kopacek, Maintenance Pre-Operations Engineer Willmar	(612) 231-5195 PROFS: GRK000
Metro	Terry Morovec, Bridge Inspection Supervisor Waters Edge	(612) 582-1418 PROFS: TDM000

r:\apps\hyd\scour\monitor.wp1

**APPENDIX H**

**BRIDGE SCOUR MONITORING PLANS**

**FOR LOCAL ROADS**

January 1, 1995

## BRIDGE SCOUR MONITORING PLAN FOR LOCAL ROADS

### PURPOSE

Bridges are vulnerable to damage and failure during flooding due to scour. Scour may undermine the bridge foundations or remove the protection from the abutment slopes. To protect the public and the bridges, federal safety standards require all bridges over 20' in length be monitored for scour, closed during flooding, or evaluated for scour. The scour evaluation may include two levels of screening and a detailed analysis when necessary. There are four scour rating codes which indicate monitoring for scour during flooding is necessary. These ratings are as follows:

- J Bridge screened, determined to be scour susceptible (since this bridge is scour susceptible it should be monitored during high flows and closed if necessary until an evaluation can be made).
- K Bridge screened, determined to be of limited risk to public, monitor in lieu of evaluation and close if necessary.
- R Bridge has been evaluated and determined to be scour critical. Scour Action Plan recommends monitoring the bridge during high flows and closing if necessary.
- U Bridge has been evaluated and determined to be scour critical. Scour Action Plan recommends this bridge as a priority for installation of countermeasures. Until countermeasures are installed, monitor bridge during high flow and close if necessary.

Monitoring generally requires measuring the river bed elevation near the footings and abutments. It could indicate that a bridge should be closed due to scour.

Each road authority is responsible for monitoring its bridges. This Bridge Scour Monitoring Plan for Local Roads contains guidelines to the road authority on procedures to be used to monitor bridges and the technical support that might be available. If a Scour Action Plan for a specific bridge has been developed, it may contain some of the general requirements of this plan.

## **PRIORITY**

As indicated above, bridges rated J, K, R, and U are required to be monitored during flooding events. In addition, monitoring is recommended for all bridges during significant (25 year frequency) flooding or when debris and ice buildup. The extent, frequency, and the flood stage to begin monitoring may vary with each bridge. The road authority is responsible to determine when bridges will be monitored. For bridges rated R and U, a Scour Action Plan based on an hydraulic evaluation must be prepared and contain details on monitoring each specific bridge site. The Scour Action Plan for each bridge should be on file with the county and with the township and readily available to the personnel charged with doing the monitoring. Bridges rated J or K that do not have a Scour Action Plan must be monitored using the general guidance listed in this plan. This guide plan can be used as a basis for monitoring other bridges, including many of those with unknown foundations.

## **MONITORING TOOLS**

Sounding weights and/or sonar are normally used to monitor the river bed elevations at the bridge, a pole may be possible on shallow streams. Scour measurements are usually taken from the bridge deck along the upstream side of the bridge. Measurements taken along the bridge fascia (railing) may not be located at the site of maximum scour which is usually close to the pier or abutment, but should be accurate enough to indicate if problems exist. Ice and debris may limit the locations or could cause inaccurate readings.

The County or the Minnesota Department of Transportation District Office may be able to assist in monitoring some bridges with their equipment upon request. If you are unable to monitor a specific bridge, the road should be closed during flooding.

## **SAFETY**

Extreme care should be used while monitoring bridges during flood stages. A minimum of a two person crew is recommended.

## PRE-FLOOD PREPARATION

The road authority must be prepared to monitor when flooding occurs. Personnel who will monitor the bridges must be informed, trained, and have access to the necessary equipment. The road authority should check water surface elevations after heavy rainfall or snow melt being alert for significant flooding.

The road authority should conduct a pre-flood site investigation on all bridges identified for monitoring or subject to debris or ice buildup. The following actions should be taken:

Mark the locations on the bridge at which measurements will be taken and measure baseline river bed elevations at these locations from the road surface or other appropriate data.

Determine the water surface elevation at which monitoring should begin, usually at or below the highest flood of record or design high water if known.

## MONITORING METHODS

Monitoring can be accomplished at the discretion of the local road authority using any combination, or all of the following methodologies:

1. Visual Observation by checking
  - Approach roadway and abutment slopes for erosion
  - Bridge rails (sags or bends)
  - Water action (noticeable changes, eddies, etc.)
2. Measurement of channel bed elevations at piers or abutments using
  - Sonar (depth finders)
  - Probes/measuring rods
  - Cable and weights

Compare the measured bed elevation to the base line stream bed elevation taken prior to the flooding. Determine if the bed has lowered significantly. A significant bed change is defined as the depth identified in the Scour Action Plan or established by the County Engineer or as set by the road authority or if these are not available, the following general guide can be used.

- 5 feet: Large rivers (river channel greater than 100' wide).
- 2 feet: Medium/small rivers (river channel less than 100' wide).

Records of channel bed measurements can provide a valuable documented record of the monitoring. The records may be used to adjust the frequency of monitoring in the future.

## MONITORING FREQUENCY

Flooding that warrants monitoring of bridges may occur at any time any year.

As a general guide monitoring is recommended when:

1. River nears historic high water.
2. The design high water elevation is reached (if known).
3. Unusual conditions (such as large amount of debris affects 10% of opening).
4. Prior to opening the bridge if closed.

If significant bed changes are not detected: monitor once per day until flood crest begins to recede.

If significant bed changes are detected: contact the County Engineer and monitor a minimum of twice per day.

## MONITORING LOCATIONS

Measure for scour from the upstream face of the bridge if possible. However, if this is not possible due to ice or debris, measure from the downstream face. The notes should be kept on file. The notes should include the date and if ice or debris were present (since they can increase the amount of scour). A sample monitoring form is attached.

Monitor the stream bed at the middle of each span and at all piers and abutments locations and at the toe of abutment slopes to determine if the channel bottom elevation is changing at these locations.

Maximum pier scour is expected to occur near the front face of the pier. If flood water is attacking the pier at a skew angle, the deepest scour is expected on the front or side that the flow impacts.

Maximum abutment scour typically occurs at the toe of the abutment slope or the upstream corner of a vertical abutment.

Bridges with abutment slopes should be monitored both at the toe of the slope and next to the abutment. If the foundation is undermined, the approach fill may be endangered.

## APPROPRIATE ACTION

Close the bridge if the riverbed erosion exceeds the maximum allowed depth; there are signs of bridge movement; riprap shows signs of disturbance; or inspector is uncertain about danger.

Install proper road closed signs.

Notify the proper authorities (including the county highway department).

Detour traffic (if necessary).

Review bridges on detour route for scour and monitor (if necessary).

Check bridge after flood recedes/make recommendations for repair/protection.

During flooding, if large amounts of debris are at bridge, remove the debris if possible. If scour occurs at the bridge, consult with your County Engineer to see if protection should be installed.

## REPORTING

Report results of monitoring to the County Engineer. If scour reaches a critical point, the monitoring personnel should take appropriate action including closing the bridge and contacting the County Engineer.

## YOUR COUNTY ENGINEER

The County Engineer is responsible for bridge safety inspections and can act in an advisory capacity to provide technical expertise on flood monitoring techniques, identify bridges that should be monitored, analyze flood monitoring results and determine bridge stability.

The engineer may provide additional flood monitoring resources when available including: staff, equipment, or suggest the use of consultants through contracts.  
The engineer may know of new technologies related to improve monitoring efforts.

BRIDGE NO. \_\_\_\_\_  
 DISTRICT \_\_\_\_\_  
 COUNTY \_\_\_\_\_  
 TOWNSHIP \_\_\_\_\_  
 CITY \_\_\_\_\_  
 ROUTE \_\_\_\_\_  
 STREAM \_\_\_\_\_

**BRIDGE SCOUR MONITORING GUIDE PLAN  
 FOR SPECIFIC BRIDGE**

**Bridge: Use Channel Diagram for Specific Bridge**

Critical monitoring points have been labeled alphabetically beginning at A and ending at I. The bridge channel bed elevation (or depths) during normal conditions have been determined at mid span along the bridge fascia (railing) and at the critical monitoring points at abutments and piers as indicated above. During monitoring, these channel bed elevations (or depths) are to be measured and compared on the monitoring form attached. For reference the MN DOT Structural Inventory is also enclosed.

**Channel Bed Depths (From Low Steel), (Top of Rail), (Bridge Deck), or (\_\_\_\_\_))**

Points	A	B	C	D	E	F	G	H	I	Etc.
Location*	2	25	30	45	60	75	90	95	118	
Normal Depth**	4	12	12	12	12	12	12	12	4	
Maximum Allowed	9	17	17	17	17	17	17	17	9	

\* Distance from right end of bridge looking upstream.  
 (Distance measured from \_\_\_\_\_)

\*\*Depth measured from (Top of Railing), (Bridge Deck), (Top of Curb),  
 (Low Steel), Other (\_\_\_\_\_)

**SAMPLE LETTER**  
**REGARDING BRIDGE SCOUR MONITORING**

Name \_\_\_\_\_  
Chairman, \_\_\_\_\_ Township

RE: Monitoring for Bridge Scour

Dear Chairman:

The Federal Government requires that all bridges over 20 feet in length be inspected and evaluated for scour (stream bed or channel erosion during flooding). There have been several catastrophic bridge failures in the nation due to scour. There are many bridges in Minnesota that have already been determined to be scour susceptible and are either having scour preventive measures installed or are being monitored during periods of flooding.

The State has developed a bridge scour screening process and scour rating system. The common ratings for bridges with known foundations which require monitoring are:

- J Bridge screened, determined to be scour susceptible (since this bridge is scour susceptible it should be monitored during high flows and closed if necessary until an evaluation can be made).
- K Bridge screened, determined to be of limited risk to public, monitor in lieu of evaluation and close if necessary.
- R Bridge has been evaluated and determined to be scour critical. Scour Action Plan recommends monitoring the bridge during high flows and closing if necessary.
- U Bridge has been evaluated and determined to be scour critical. Scour Action Plan recommends this bridge as a priority for installation of countermeasures. Until countermeasures are installed, monitor bridge during high flow and close if necessary.

The County, using State guidelines, has determined the rating for the following township bridges. These ratings require monitoring of each bridge during flooding to protect the public.

SAMPLE LETTER (CONTINUED)

Bridge No.	Scour Code	Foundation Type	Maximum Scour Depth Footing      Abutment
-----	-----	-----	-----

We have developed and enclosed a copy of a Bridge Scour Monitoring guideline for bridges rated J or K. Use the Scour Action Plan for each of the above listed bridges rated R or U. We have estimated the maximum depth of scour that should be allowed at each pier or abutment for the above listed bridges. If scour, as determined by monitoring, exceeds this maximum allowable depth, the bridge will have to be closed until flood waters recede and an inspection can be made. It is the Township's responsibility to monitor these bridges during flooding. By monitoring bridges and closing them if there is the danger of failure, the road authority can minimize the risk to the public. The Bridge Scour Monitoring Plan for Local Roads dated January 1, 1995 has been developed as a guide for bridge monitoring.

The local road authority may perform a complete hydraulic evaluation on any bridge rated K if they desire. An evaluation may result in an official recommendation to monitor for scour or to install additional scour protection. On many low volume roads, monitoring the bridge is a cost effective method of protecting the public.

Sincerely,

County Engineer

BRIDGE NO. \_\_\_\_\_  
 DISTRICT \_\_\_\_\_  
 COUNTY \_\_\_\_\_  
 TOWNSHIP \_\_\_\_\_  
 CITY \_\_\_\_\_  
 ROUTE \_\_\_\_\_  
 STREAM \_\_\_\_\_

## BRIDGE SCOUR MONITORING FORM FOR LOCAL ROADS

POINT	***										WATER	DEBRIS	
	A	B	C	D	E	F	G	H	I	I			
LOCATION*	2	25	30	45	60	75	90	95	118				Y/N
NORMAL DEPTH**	4	12	12	12	12	12	12	12	4				
MAXIMUM ALLOWED	9	17	17	17	17	17	17	17	9				
DATE													
DATE													
DATE													
DATE													
DATE													
DATE													
DATE													

\* Distance from right end of bridge looking upstream (distance measured from \_\_\_\_\_).  
 \*\*Depth measured from (top of railing), (bridge deck), (top of curb), (low steel), other \_\_\_\_\_.  
 \*\*\*Depth measured from above to water.

## **APPENDIX I**

### **DESIGN AIDS**

- **Roughness Coefficients**
- **Sediment Grade Scale**
- **Soil Triangle**
- **Non-scour Velocities For Soils**
- **Practical Method For Calculating  
Contraction Scour by E.V. Richardson  
and J.R. Richardson**
- **Effects of Footing Location on Bridge Pier  
Scour by Sterling Jones**
- **Example: Methods of Calculating Pier Scour  
When Footing Is Exposed**

# Open Channel Flow (continued)

Table 8-1

## UNIFORM FLOW

Values of Roughness Coefficient  $n$  (Uniform Flow)

Type Of Channel and Description	Minimum	Normal	Maximum
<b>EXCAVATED OR DREDGED</b>			
a. Earth, straight and uniform	0.016	0.018	0.020
1. Clean, recently completed	0.018	0.022	0.025
2. Clean, after weathering	0.022	0.025	0.030
3. Gravel, uniform section, clean	0.022	0.027	0.033
b. Earth, winding and sluggish			
1. No vegetation	0.023	0.025	0.030
2. Grass, some weeds	0.025	0.030	0.033
3. Dense Weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. Earth bottom and rubble sides	0.025	0.030	0.035
5. Stony bottom and weedy sides	0.025	0.035	0.045
6. Cobble bottom and clean sides	0.030	0.040	0.050
c. Dragline-excavated or dredged			
1. No vegetation	0.025	0.028	0.033
2. Light brush on banks	0.035	0.050	0.060
d. Rock cuts			
1. Smooth and uniform	0.025	0.035	0.040
2. Jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. Dense weeds, high as flow depth	0.050	0.080	0.120
2. Clean bottom, brush on sides	0.040	0.050	0.080
3. Same, highest stage of flow	0.045	0.070	0.110
4. Dense brush, high stage	0.080	0.100	0.140
<b>NATURAL STREAMS</b>			
1. Minor streams (top width at flood stage < 100 ft)			
a. Streams on Plain			
1. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and some stones	0.035	0.045	0.050
5. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055

# Open Channel Flow (continued)

Table 8-1 (CONTINUED)

## UNIFORM FLOW

Values of Roughness Coefficient  $n$  (Uniform Flow)

Type Of Channel and Description	Minimum	Normal	Maximum
6. Same as 4, but more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
b. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
1. Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
2. Bottom: cobbles with large boulders	0.040	0.050	0.070
2. Flood Plains			
a. Pasture, no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050
b. Cultivated area			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
c. Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees in winter	0.035	0.050	0.060
3. Light brush and trees, in summer	0.040	0.060	0.080
4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. Dense Willows, summer, straight	1.110	0.150	0.200
2. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3. Same as above, but with heavy growth of sprouts	0.050	0.060	0.080
4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
5. Same as above, but with flood stage reaching branches	0.100	0.120	0.160

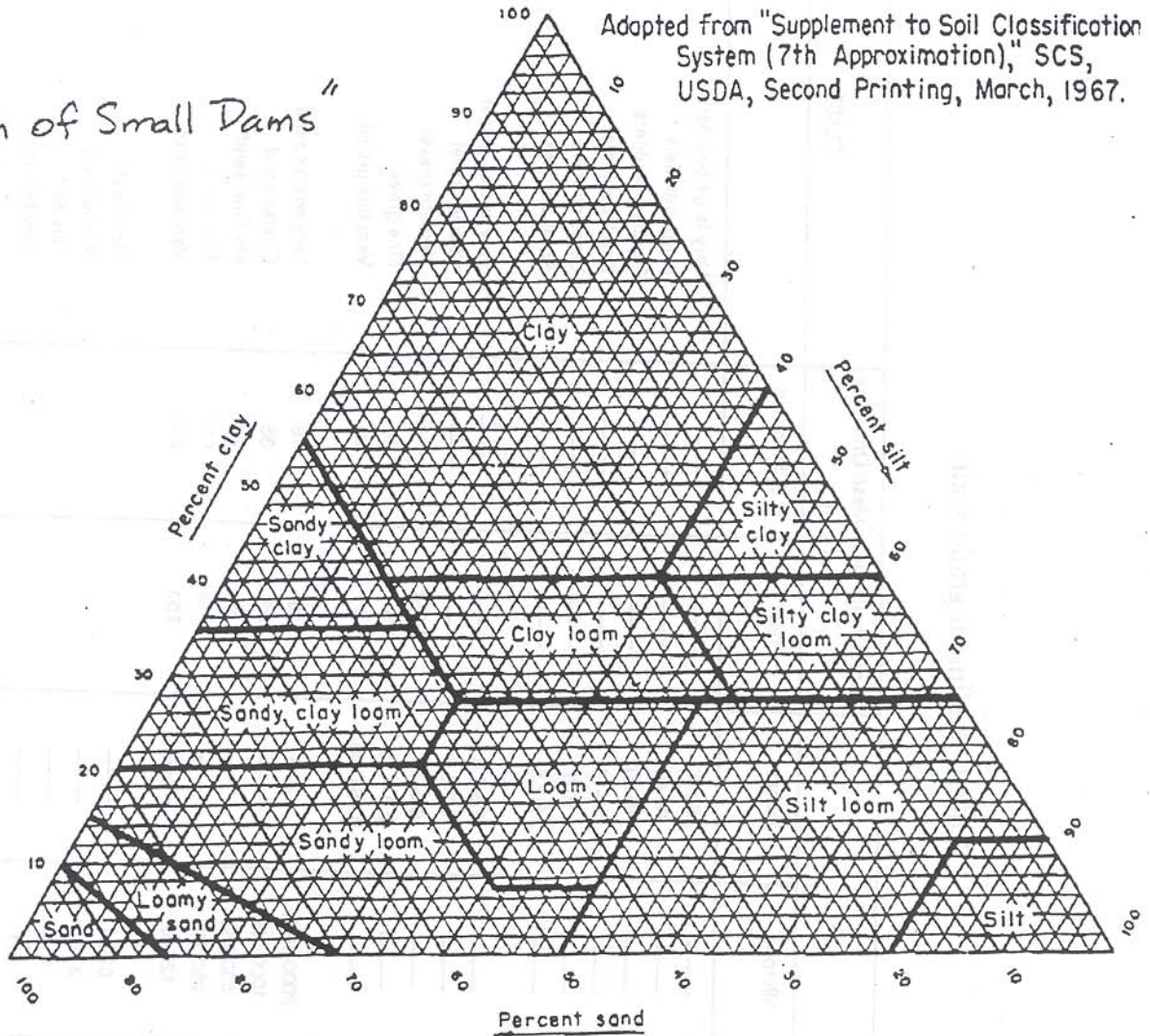
Table 1. Sediment grade scale.

SIZE		Approximate Sieve Mesh Openings per Inch			CLASS
Millimeters	Microns	Inches	Tyler	U.S. Standard	
4000-2000	—	160-80	—	—	Very large boulders
2000-1000	—	80-40	—	—	Large boulders
1000-500	—	40-20	—	—	Medium boulders
500-250	—	20-10	—	—	Small boulders
250-130	—	10-5	—	—	Large cobbles
130-64	—	5-2.5	—	—	Small cobbles
64-32	—	2.5-1.3	—	—	Very coarse gravel
32-16	—	1.3-0.6	—	—	Coarse gravel
16-8	—	0.6-0.3	2-1/2	—	Medium gravel
8-4	—	0.3-0.16	5	5	Fine gravel
4-2	—	0.16-0.08	9	10	Very fine gravel
2-1	2000-1000	—	16	18	Very coarse sand
1-1/2	1000-500	—	32	35	Coarse sand
1/2-1/4	500-250	—	60	60	Medium sand
1/4-1/8	250-125	—	115	120	Fine sand
1/8-1/16	125-62	—	250	230	Very fine sand
1/16-1/32	62-31	—	—	—	Coarse silt
1/32-1/64	31-16	—	—	—	Medium silt
1/64-1/128	16-8	—	—	—	Fine silt
1/128-1/256	8-4	—	—	—	Very fine silt
1/256-1/512	4-2	—	—	—	Coarse clay
1/512-1/1024	2-1	—	—	—	Medium clay
1/1024-1/2048	1-0.5	—	—	—	Fine clay
1/2048-1/4096	0.5-0.24	—	—	—	Very fine clay

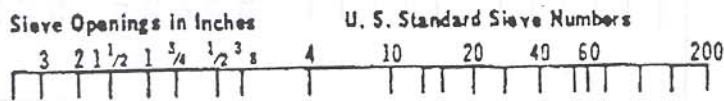
FOUNDATIONS AND CONSTRUCTION MATERIALS

Design of Small Dams

Adapted from "Supplement to Soil Classification System (7th Approximation)," SCS, USDA, Second Printing, March, 1967.



COMPARISON OF PARTICLE-SIZE SCALES



USDA	GRAVEL		SAND					SILT	CLAY
			Very Coarse	Coarse	Medium	Fine	Very fine		
UNIFIED	GRAVEL		SAND			SILT OR CLAY			
	Coarse	Fine	Coarse	Medium	Fine				
AASHTO	GRAVEL OR STONE			SAND		SILT - CLAY			
	Coarse	Medium	Fine	Coarse	Fine	Silt	Clay		

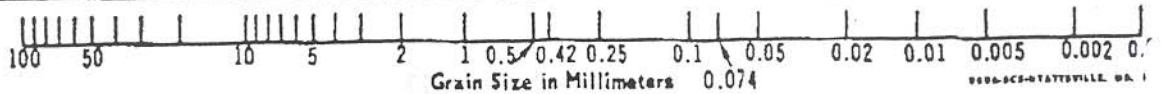


Figure 5-4.—Soil triangle of the basic soil textural classes. (U.S. Soil Conservation Service). 288-D-2782.

## NON-SCOUR VELOCITIES FOR SOILS

Soil Type	Grain Dimensions		Approximate Non-scour Velocities (FPS)			
	mm	feet	Mean Depth (ft)			
			1.3	3.3	6.6	9.8
For non-cohesive soils						
Boulders	> 256	> 0.840	15.1	16.7	19.0	20.3
Large cobbles	256-128	0.840-0.420	11.8	13.4	15.4	16.4
Small cobbles	128-64	0.420-0.210	7.5	8.9	10.2	11.2
Very course gravel	64-32	0.210-0.105	5.2	6.2	7.2	8.2
course gravel	32-16	0.105-0.0525	4.1	4.7	5.4	6.1
Medium gravel	16-8.0	0.0525-0.0262	3.3	3.7	4.1	4.6
Fine gravel	8.0-4.0	0.0262-0.0131	2.6	3.0	3.3	3.8
Very fine gravel	4.0-2.0	0.0131-0.00656	2.2	2.5	2.8	3.1
Very course sand	2.0-1.0	0.00656-0.00328	1.8	2.1	2.4	2.7
Coarse sand	1.0-0.5	0.00328-0.00164	1.5	1.8	2.1	2.3
Medium sand 0.38	0.5-0.25	0.00164-0.000820	1.2	1.5	1.8	2.0
Fine sand	0.25-0.125	0.000820-0.000410	0.98	1.3	1.6	1.8
For compact cohesive soils						
Sandy loam (heavy)			3.3	3.9	4.6	4.9
Sandy loam (light)			3.1	3.9	4.6	4.9
Loess (settled)			2.6	3.3	3.9	4.3

Derived from "Highways in the River Environment" FHWA-HI-90-016 Table 3.5.2

0.00123

into the contracted reach is equal to the amount of sediment being transported out (live-bed scour), or (2) the critical velocity ( $V_c$ ) or critical shear stress ( $\tau_c$ ) of the effective mean diameter of the bed material is equal to the mean velocity ( $V$ ) or mean shear stress ( $\tau_0$ ) of the flow (clear-water scour). In some cases, although there is sediment being transported into the contraction (live-bed scour), the depth of contraction scour is limited by the size of the bed material in the contracted section (clear-water scour).

The Federal Highway Administration (FHWA) in HEC-18 (Richardson et al., 1993) gives two practical equations to compute contraction scour. These equations are based on Laursen's (1960, 1963) live-bed and clear-water scour at long contractions. In addition, HEC-18 gives Neill's (1968) and Laursen's (1963) equations for determining the critical velocity. The potential for limiting the depth of scour by the critical velocity or shear stress of the effective bed material size being equal to the flow mean velocity or shear stress with live-bed contraction scour conditions, both the live-bed and clear-water equations should be used to calculate the scour depth for live-bed contraction scour and the smaller depth used. Both equations compute the scour depths for a long contraction and most bridge contractions are of short length. Therefore, calculated scour depths are conservative. A major problem in calculating contraction scour when there is overbank flow is determining the distribution of the flow between the main channel and other areas. The FHWA computer program WSPRO (Arneson, 1991) is an excellent method for determining the flow distribution.

#### Equation for Critical Velocity

Neill's (1968) and Laursen's (1963) general equation for critical velocity is:

$$V_c = K Y_1^{\frac{1}{6}} D_m^{\frac{1}{3}} \quad (1)$$

where

$V_c$  = Critical velocity which will transport bed materials of size  $D_m$  and smaller, ft/s  
 $K$  = Coefficient that depends on  $S_s$  and an experimentally determined value for a beginning of motion parameter such as Shields.  
 $S_s$  = Specific gravity of bed material  
 $Y_1$  = Depth of upstream flow, ft

With  $S_s$  equal to 2.65,  $K$  equals 11.52 for Neill's equation, and 10.95 for Laursen's (see Equation 4).

#### PRACTICAL METHOD FOR CALCULATING CONTRACTION SCOUR

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 J. R. Richardson<sup>2</sup>, M. ASCE

#### Abstract

Total scour at bridge crossing waterways consists of long-term aggradation or degradation of the streambed, contraction scour and local scour at the piers and abutments. This paper will present practical equations for computing live-bed or clear-water contraction scour. With live-bed conditions, both equations need to be used and the smaller scour depth used.

#### Introduction

Contraction scour occurs at bridge openings as a result of an increased discharge and velocity within the bridge or relief bridge opening caused by the encroachment of the highway embankments and abutments onto the floodplain or channel. During flood flows, water flowing over the floodplain are redirected to the bridge openings (main and relief bridges). The increase in velocity associated with the contraction of the flow results in a greater capacity of the flow to move bed material, resulting in an increase in flow depth as a result of erosion in the bridge opening (scour).

The depth of contraction scour for these conditions will continue to increase until one of two conditions is reached: (1) the amount of sediment being transported

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Live-Bed Contraction Scour Equation

A modified version of Laursen's (1960) equation for live-bed scour in a long contraction is

$$\frac{Y_2}{Y_1} = \left( \frac{Q_2}{Q_1} \right)^{\frac{2}{7}} \left( \frac{W_1}{W_2} \right)^{k_1} \quad (2)$$

$$Y_s = Y_2 - Y_1 = (\text{average scour depth}) \quad (3)$$

where

- $Y_1$  = Average depth in the upstream main channel, ft  
 $Y_2$  = Average depth in the contracted section, ft  
 $W_1$  = Bottom width of the upstream main channel, ft  
 $W_2$  = Bottom width of the main channel in the contracted section, ft  
 $Q_1$  = Flow in the upstream channel transporting sediment, cfs  
 $Q_2$  = Flow in the contracted channel, cfs  
 $k_1$  = Exponent determined below

$V_* / w$	$k_1$	Mode of Bed Material Transport
<0.50	0.59	Mostly contact bed material discharge
0.50 to 2.0	0.64	Some suspended bed material discharge
>2.0	0.69	Mostly suspended bed material discharge

- $V_* = (\tau / \rho)^{1/2} = (g y_1 S_1)^{1/2}$ , shear velocity in the upstream section, ft/s  
 $w$  = Fall velocity of bed material based on the  $D_{50}$ , ft/s  
 $g$  = Acceleration of gravity (32.2 ft/s<sup>2</sup>);  
 $S_1$  = Slope of energy grade line of main channel, ft/ft;  
 $\tau$  = Shear stress on the bed, lb/ft<sup>2</sup>, and  
 $\rho$  = Density of water (1.94 slugs/ft<sup>3</sup>).

The modification to Laursen's original equation was to eliminate the ratio of Manning's  $n$  between the upstream and bridge reach. The ratio was eliminated because normally the Manning's  $n$  does not change significantly and if it changed, it would be from a larger  $n$  value in the approach channel to a smaller value in the bridge reach. Laursen's equation does not correctly account for the increase in transport that will occur as the result of a lower  $n$  value in the bridge reach (a lower  $n$  value increases velocity and transport of bed material at the bridge).

Clear-water Contraction Scour Equation

Laursen's (1963) equation for clear-water scour in a long contraction is

$$Y_2 = \left[ \frac{Q^2}{120 D_m^3 W^2} \right]^{\frac{1}{7}} \quad (4)$$

where

- $Y_1$  = Depth of flow in the channel or on the floodplain prior to scour, ft  
 $Y_2$  = Depth of flow in the bridge opening or on the overbank at the bridge, ft  
 $Y_s$  = Depth of scour, ft  
 $Q$  = Discharge through the bridge or on the overbank at the bridge, cfs  
 $D_m$  = Effective mean diameter (feet) of the bed material (1.25  $D_{50}$ ) in the bridge, opening or on the floodplain, ft  
 $D_{50}$  = Median diameter (feet) of bed material in the bridge opening, or on the floodplain, ft  
 $W$  = Bottom width of the bridge channel, overbank width (set back distance), or relief bridge (less any pier widths), ft

Equation 4 differs from Laursen's original in that the effective mean bed material size ( $D_m$ ) is used instead of  $D_{50}$ . Research discussed in HIRE (Richardson et al., 1990) determined that the effective size of the bed material for riprap design and resistance to erosion is larger than the  $D_{50}$  size.

With stratified bed materials, the depth of scour can be determined by using Equation 4 with successive  $D_m$  of the bed material layers.

Example Problem

A bridge across a river measuring 400 ft wide with a large floodplain (1,000 to 2,000 ft) on the left side and a high bluff on the right side. The  $Q_{100}$  is 30,000 cfs and the left abutment is set back 200 ft. Core samples at the bridge cross section gives the following (0 is top of floodplain): 0 to 2 ft,  $D_{50}$  is 0.00013 ft; 2 to 10 ft,  $D_{50}$  is 0.0066 ft; 10 to 30 ft,  $D_{50}$  is 0.026 ft. Slope of the channel is 0.0019 ft/ft. WSPRO analysis gives the following flow distribution: the upstream main channel is 400 ft wide and discharge is 16,000 cfs with a flow depth of 9.0 ft. The flow in the overbank area is 14,000 cfs. At the bridge, the main channel is 400 ft wide and discharge is 25,450 cfs with a depth of 9.0 ft. The flow in the set back area (200 ft wide) on the left side is 4,550 cfs with an average depth of 4.0 ft. Determine the contraction scour in the overbank area and main channel.

Contraction Scour in Set Back Overbank Flow Area

Clear-water scour because there is no sediment transport on the floodplain.

$$D_m = 1.25 \times 0.0003 = 0.00038; Q = 4,550 \text{ cfs}; W = 200 \text{ ft}; Y = 4.0 \text{ ft}$$

From Equations 4 and 3:  $Y_s = 17.8 - 4.0 = 13.8 \text{ ft}$ . There is only 2 ft of the 0.00038 ft bed material; therefore, use  $D_{50} = 0.0066 \text{ ft}$ .

$$D_m = 0.0082 \text{ ft}; Y_s = 7.4 - 4 = 3.4 \text{ ft}$$

Thus, scour depth is 3.4 ft

Contraction Scour in Main Channel

Live-bed scour calculation.

$$\text{Shear velocity } (V_*') = (32.2 \times 9.0 \times 0.0019)^{0.5} = 0.74 \text{ ft/sec}; D_{50} \text{ fall velocity } (w) = 0.9 \text{ ft/sec}; V_*'/w = 0.83; K_1 = 0.64$$

$$\text{From Equations 2 and 3: } Y_s = 13.4 - 9 = 4.4 \text{ ft}$$

Clear-water scour calculation.

$$Q = 25,450 \text{ cfs}; W = 400 \text{ ft}$$

$$\text{With } D_m = 1.25 \times 0.0066 = 0.0082 \text{ ft}; Y_s = 17.9 - 9.0 = 8.9 \text{ ft}$$

$$\text{With } D_m = 1.25 \times 0.026 = 0.033 \text{ ft}; Y_s = 19.0 - 9.0 = 10.0 \text{ ft}$$

Scour depth is thus 3.0 ft because the coarser bed material below 10 ft would limit the depth of scour.

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# EFFECTS OF FOOTING LOCATION ON BRIDGE PIER SCOUR

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**ABSTRACT:** A laboratory study was conducted to investigate the effects of footing location on the depth of scour. None of the existing pier-scour equations have provisions for accounting for nonuniform pier configurations; rather they have a single characteristic pier dimension. This study was aimed at evaluating various techniques for characterizing the effective dimensions for a pier/footing combination when both are exposed to the flow field. The following three techniques were considered in the analysis: (1) Use of the footing width as the characteristic dimension when the footing occupies more than 10% of the flow depth; otherwise, use of the pier width (10% depth-switch); (2) use of a weighted pier width (weighted width technique); and (3) use of the dominant pier/footing component by making two computations with appropriate flow parameters and selecting the larger value (dominant component technique). The first technique was the Federal Highway Administration (FHWA) recommended procedure prior to this study, but both of the other techniques gave better results in this study. The third technique has subsequently been adopted for FHWA's *Hydraulic Engineering Circular No. 18* (HEC-18) on bridge scour. The second technique, however, is a simpler technique and is accurate.

## INTRODUCTION

Most laboratory studies of bridge-pier scour have used a uniformly shaped pier that extended below the bed. The resulting prediction equations are in terms of a single characteristic pier size. In practice, however, footings and pile groups often project into the flow and constitute a significant part of the obstruction that causes local scour. This paper examines the effects that pier-footing location has on local scour.

A site-specific model study of the Baldwin River Bridge, over the Connecticut Rivers, in Connecticut, was conducted at the Federal Highway Administration (FHWA) hydraulics laboratory. The study involved pier/footing configurations that could not readily be reduced to a single characteristic pier size. Often these configurations are such that one cannot be sure whether the irregularities might increase or decrease scour. This study explores what effect pier/footing location has on local scour, and how this information can be applied to scour-prediction equations that use a single characteristic pier size.

The Baldwin Bridge study was prompted by design discussions between state highway officials and consultants involved on the new Baldwin Bridge over the Connecticut River. The discussions revolved around appropriate assumptions to be made about local pier scour with regard to the effects of the footing, which is much larger than the pier. It seemed possible that the

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footing could act as a scour arrester, since it was to be near the stream bed. Alternatively, it could be a major obstruction once scour was initiated and the footing exposed. FHWA's circular on bridge scour (FHWA: "Evaluating" 1991) addresses this issue only briefly.

## EXPERIMENTAL PROCEDURES

The model study used the 21.3 m long by 1.8 m wide tilting flume located in the hydraulics lab of the Turner-Fairbank Highway Research Center, in McLean, Virginia. The flume is equipped with a sediment recess located 12.2 m from the upstream end. The model was tested in the sediment recess. A 1:50 scale model of the Baldwin Bridge pier design was tested under a variety of conditions to determine the general effects of the footing on local pier scour. The flume is not equipped with facilities to recirculate sediment, so the experiments do not simulate true live-bed scour. To approximate live-bed scour the flume was operated at velocities close to incipient motion for the given bed material. The bed material used for these experiments was uniform, with a median grain size ( $D_{50}$ ) of 0.38 mm.

Velocities at the threshold of clear water/live-bed scour were approximated in the runs to obtain maximum scour. Incipient-motion velocities were obtained by gradually lowering the flume tailgate to increase velocity while keeping flow depth constant by adjusting the flow rate. Incipient-motion velocity was determined when upstream bed material began to be transported. This procedure limits the capability of modeling exact flow conditions at the Baldwin site, but it does provide a way of measuring the relative effects of various design features.

The experiments were allowed to stabilize over a time period of 4 hr. At this time, the rate of change in the scour depth was negligible so it was assumed that most of the scour was achieved. Kaudkivi and Ettemd (1977) reported equilibrium periods much longer than 4 hr; however, their data were for larger grain sizes and a variety of gradations. Recognizing that additional scour may have occurred given a longer time frame, the writers believe that practical comparative conclusions can be drawn from the 4 hr experiments.

In the Baldwin Bridge study, the effects of the footing were the primary consideration. The model was fabricated so that the footing could easily be shifted up and down the pier to vary the vertical location of the footing in the flow field. The location of the footing was varied from a slight depression below the bed to an extension to the full depth of flow. The flow depth was either 12.4 cm, which modeled the flow depth for the Baldwin bridge site, or 29.2 cm, which was selected arbitrarily to give a wider range of results.

The footing/tremie seal (subsequently referred to as the footing) had substantial thickness because designers were concerned about earthquake forces and did not want exposed piles at the depth of maximum scour. The footing was modified as illustrated in Fig. 1 to include an extension on the upstream face for some of the runs because the basic footing had so little extension upstream of the pier that it was doubtful that it would have any effect on the diving currents associated with pier scour. The modified footing had an upstream footing extension that was approximately the same as the extension on each side of the pier. This configuration was included in an attempt to generalize some of the results.

Data for this study are summarized in Table 1. The footing location is expressed as percentage footing within the flow field. For example "footing

was the reference for those runs with no footing and those runs with the footing at or below the bed. The edge of the footing was the reference for those runs with the footing above the bed.

Fig. 2 shows the locations where the six velocity profiles were taken. Average approach velocity was obtained by averaging the three approach-velocity profiles. Three velocity points, at approximately 20%, 40%, and 80% of flow depth, were averaged in computing approach velocity. Tables 2 and 3 give the detailed velocity data for each location for runs 19 and 4, respectively.

### ANALYTICAL FRAMEWORK

Footing location with respect to the bed has a prominent effect on the size and depth of the scour hole that develops around the pier/footing. How far the footing extends from the pier, represented by the modified footing configuration, also has an effect on local scour patterns. The local-pier-scour equation recommended in FHWA *Hydraulic Engineering Circular No. 18* (HEC-18) (FHWA; "Evaluating" 1991) was selected as a frame of reference for this analysis. The equation is stated as

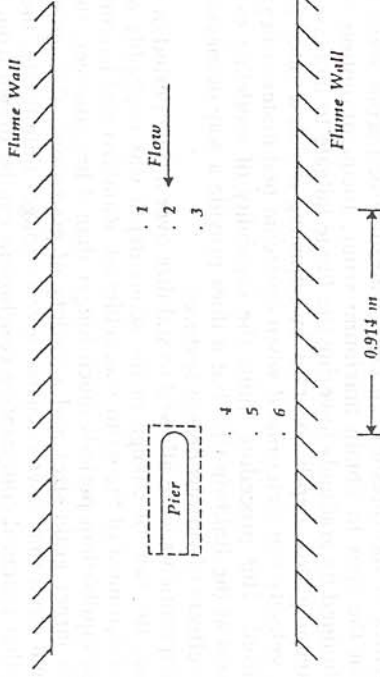


FIG. 2. Velocity Profile Locations (Plan View)

TABLE 2. Velocity Profile Data for Run Number 19

Depth (cm) (1)	Location					
	1 Velocity (cm/s) (2)	2 Velocity (cm/s) (3)	3 Velocity (cm/s) (4)	4 Velocity (cm/s) (5)	5 Velocity (cm/s) (6)	6 Velocity (cm/s) (7)
12.4	23.3	26.0	23.0	24.4	24.2	23.4
12.0	24.6	28.3	24.5	26.0	26.3	26.9
11.7	26.7	30.1	25.8	27.1	28.2	28.4
11.3	27.0	31.5	24.4	28.0	29.0	30.4
10.7	29.7	31.7	26.0	30.1	30.5	30.8
5.7	35.3	36.1	35.7	36.8	37.6	35.4
3.3	35.5	36.3	36.9	37.8	40.1	37.6

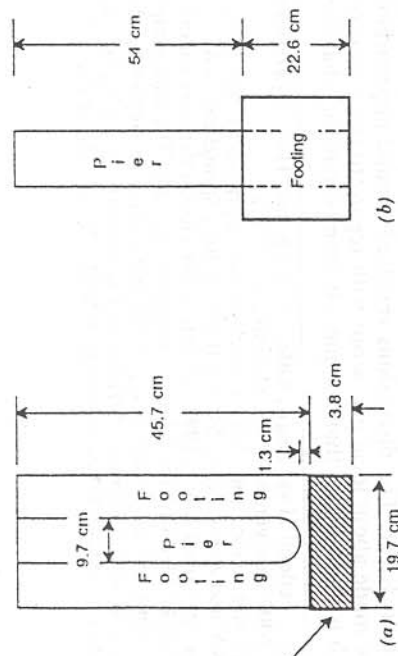


FIG. 1. (a) Plan; and (b) Elevation View of 1:50 Scale Baldwin Bridge Pier Model

TABLE 1. Summary of Baldwin Bridge Model Data

Run number (1)	Brief description (2)	Depth of flow, $V_a$ (cm) (3)	Average Appr., $V_a$ (cm/s) (4)	Scour Extent*			Maximum scour depth (cm) (8)
				Left (cm) (5)	Right (cm) (6)	Upstream (cm) (7)	
1	Footing 10% below bed	29.2	35.4	20.2	19.4	13.7	7.8
2	Footing flush with bed	29.2	35.1	8.1	8.7	14.0	6.6
3	Footing 10% into flow	29.2	36.0	25.5	25.4	20.4	11.6
4	Footing 25% into flow	29.2	36.1	29.9	34.0	28.0	15.5
5	Footing 38% into flow	29.2	34.1	19.2	23.0	27.4	14.2
6	Footing 50% into flow	29.2	35.7	35.4	36.2	34.1	17.8
7	Footing 100% into flow	29.2	36.3	35.3	32.9	41.5	21.1
8	Footing flush with bed	12.4	32.9	14.3	13.3	17.1	10.3
9	Footing 50% into flow	12.4	28.3	29.0	31.0	27.4	13.7
10	Footing 91% into flow	12.4	33.2	24.0	26.1	32.3	17.8
11	Footing 100% into flow	12.4	33.5	29.5	29.5	36.6	18.6
12	Modified footing 10% below bed	29.2	36.5	16.7	12.7	6.4	3.9
13	Modified footing flush with bed	29.2	35.9	6.0	5.6	13.4	5.3
14	Modified footing 10% into flow	29.2	34.3	20.4	22.1	17.1	8.7
15	Modified footing 25% into flow	29.2	34.6	28.4	27.2	24.5	13.1
16	Modified footing 38% into flow	29.2	36.4	20.1	23.8	28.0	15.7
17	Modified footing flush with bed	12.4	32.4	13.0	15.1	15.3	7.1
18	Pier only	29.2	32.3	14.0	14.2	14.4	8.9
19	Pier only	12.4	33.7	13.6	14.3	16.2	10.0

\* $D_{50} = 0.038$  cm

10% into flow" (column 2) means that the footing extends into the flow depth an amount equal to 10% of the flow depth. The "scour extent" (columns 5-7) was the distance measured from the edge of the pier or the edge of the footing to the point of no local pier scour. The edge of the pier

TABLE 3. Velocity Profile Data for Run Number 4

Depth (cm) (1)	Location					
	1 Velocity (cm/s) (2)	2 Velocity (cm/s) (3)	3 Velocity (cm/s) (4)	4 Velocity (cm/s) (5)	5 Velocity (cm/s) (6)	6 Velocity (cm/s) (7)
29.2	15.3	22.1	19.9	23.4	22.5	22.2
28.0	24.0	25.2	25.8	23.2	25.3	26.8
26.8	27.0	27.0	30.4	26.3	28.5	28.5
25.6	28.7	31.4	29.6	29.5	31.2	28.3
24.1	32.4	33.2	32.0	28.3	33.4	22.5
12.4	38.1	38.3	36.8	37.0	37.6	37.6
6.6	39.3	37.7	37.3	36.9	36.4	37.6

$$y_s = \frac{2.0}{2.1} K_1 K_2 \left(\frac{a}{y_a}\right)^{0.65} \left(\frac{V_a}{\sqrt{g y_a}}\right)^{0.43} \dots \dots \dots (1)$$

where  $y_s$  = depth of scour;  $y_a$  = depth of flow;  $K_1 = 1.1$  for a rectangular pier, 1.0 for a rounded pier;  $K_2 = 1.0$  for aligned flow;  $a$  = width of pier;  $V_a$  = average velocity approaching the pier; and  $g$  = acceleration due to gravity.

This basic prediction equation was used to evaluate how footing location above the bed affects scour depth. Although there are numerous other pier-scour equations in the literature (Jones 1984; Melville 1988), this form was selected because it is the one used in FHWA's HEC-18 and because it is applicable for the uniform bed material used in these experiments.

The HEC-18 equation is recommended for both live-bed-scor and clear-water computations, and provides equilibrium scour depths. According to HEC-18, (1) is most appropriate for plane-bed configurations typically experienced at most bridge sites using design flood frequencies. However, recognizing the variability of scour depths under a wide range of conditions, HEC-18 suggests that scour depths of 10–30% greater than predicted may occur. Raudkivi and Ettema (1983) and Raudkivi (1986) have confirmed the variability of equilibrium scour as hydraulic conditions change from those yielding clear-water scour to live-bed conditions with fully developed bed features. Since the experiments were run at velocities close to incipient motion, in each case, a consistent point of comparison between runs is established. The HEC-18 equation is therefore applicable to a comparative analysis of computed scour versus observed scour.

In practice, (1) can be rewritten in the following form, in which a design-scor prediction value is calculated directly

$$y_{s,D} = K_D K_1 K_2 g^{-0.22} a^{0.65} V_a^{0.43} y_a^{0.12} \dots \dots \dots (2)$$

where  $y_{s,D}$  = design depth of scour [equal to  $y_s$  in (1)];  $K_D = 2.0$ .

The HEC-18 scour equation, as represented in either (1) or (2), is a design equation that includes certain unspecified conservative assumptions. It is a design equation because it is formulated to provide an outside envelope of scour depth to allow designers insight in locating structural elements beneath the bed. To quantify the degree of conservatism imbedded in the equation, a prediction factor is defined as follows:

$$PF = \frac{y_{s,D}}{y_{s,M}} \dots \dots \dots (3)$$

where  $PF$  = prediction factor ( $PF > 1$  suggests a conservative design); and  $y_{s,M}$  = measured scour depth.

The experimental runs are designed to produce nearly maximum equilibrium scour because they were run at velocities close to critical shear velocity ( $v_{*c}$ ) for a sufficient period. The prediction-factor concept has relevance because, assuming equilibrium scour is reached at the clear water/live bed threshold ( $v_{*c}/v_{*c} = 1$ ), it provides a comparative estimate of the design cushion in the HEC-18 equation.

The concept of prediction factor is employed to evaluate three techniques for characterizing the effective dimension for the scour computation when both pier and the footing are exposed to the flow field. First, the technique previously considered for FHWA's HEC-18 involves use of the footing width as the characteristic dimension if it extends more than 10% into the flow field, but use of the pier width otherwise; called here the 10% depth switch. A second technique is to use a weighted pier width. The weighted pier width  $a'$  is calculated as the average of the pier and footing width weighted by the portion of the flow depth to which each is exposed; called here the weighted pier width technique. This approach was used in the past by Dongol (1989), whose methodology differed somewhat because he included the expected scour depth in the determination of the weighted pier width.

A third technique, which was adopted in FHWA's HEC-18, involves determining whether the footing or the pier is dominant by making two independent scour calculations and selecting the larger value of those calculations; called here the dominant component technique. This is the approach recommended by Jones (1989).

The key to the last approach is determining the appropriate depth and velocity for the scour calculation of the footing component. Rather than using the entire approach depth ( $y_a$ ) and the average approach velocity ( $V_a$ ), substitute the depth for which the footing extends into the flow ( $y_f$ ), and the average of the velocity distribution facing the footing  $V_f$ .

The parameter  $y_f$  can be directly ascertained by inspection. To calculate  $V_f$ , the Prandtl velocity distribution can be assumed, where

$$\frac{v_i}{v_*} = 2.5 \ln \left( \frac{29.7 y_i}{k_s} + 1 \right) \dots \dots \dots (4)$$

where  $v_i$  = local velocity at point  $i$ ;  $v_*$  = shear velocity;  $y_i$  = distance from bed to point  $i$ ;  $k_s$  = representative roughness size.

Expressions for  $V_a/v_*$  and  $V_f/v_*$  are obtained from (4) by integrating from  $y_i = 0$  to  $y_a$ ; and  $y_i = y_f$ , respectively. Dividing the equation for  $V_f/v_*$  by the equation for  $V_a/v_*$  and substituting  $D_{50}$  for  $k_s$  yields the following expression, which relies on easily obtainable parameters:

$$\frac{V_f}{V_a} = \frac{\ln \left( \frac{10.93 y_f}{k_s} + 1 \right)}{\ln \left( \frac{10.93 y_a}{k_s} + 1 \right)} \dots \dots \dots (5)$$

where  $V_f$  = average velocity in the flow zone below the top of the footings;

$V_a$  = average velocity for the full-depth flow;  $y_f$  = distance from bed to the top of the footing; and  $y_u$  = approach depth of flow.

### RESULTS

In general, the data in Table 1 show that when the footing is located at or below the streambed, local pier scour is reduced. The amount of reduction is dependent on how far away the footing extends from the pier. When the footing is placed into the flow field and becomes the dominant feature, scour depths and extent increase dramatically. The extent to which the modified footing reduced scour can be seen when the footing projects less than 25% into the flow field. Beyond this point, the modified footing has the same effect on scour as the footing with no extension.

Fig. 3 summarizes the comparison of prediction factors when applying the HEC-18 pier-scour equation to the data using the three techniques for characterizing effective pier width. Note that the prediction factors are the same for those runs (1, 2, 7, 8, 11, 12, 17, 18, and 19) with just one component exposed to the flow. Table 4 provides supplemental data required to compute these prediction factors.

For all 19 runs in this study, the computed prediction factors ranged from 1.10 to 3.48, suggesting that the design equation overpredicted scour between 10% and 248%. The prediction factor of 1.10 resulted from run 11, which was uniform obstruction footing, fully extended in the flow depth. This kind of agreement for this basic shape suggested that the HEC-18 equation was a reasonable equation to use in the analysis. This suggestion is further reinforced by frequent observation that maximum clear-water scour is approximately 10% greater than scour predicted by (1). At the other end of the spectrum, the maximum prediction factor occurred for run 12, which consisted of the modified footing placed slightly below the original bed and reflected the scour-arresting effects of that configuration.

Since none of the techniques evaluated in this paper included provisions to account for the scour-arresting effects of footings or other protective measures located at or below the bed, it is meaningful to compare the techniques for a subset of the data that excluded those runs. Table 5 sum-

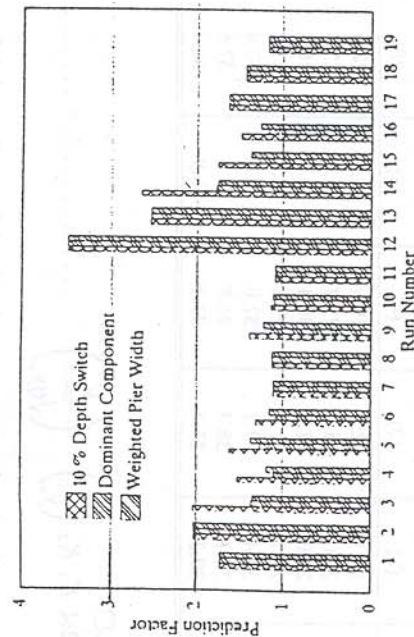


FIG. 3. Comparison of Prediction Factors

TABLE 4. Supplemental Data Required for Calculation of Prediction Factors

Run number (1)	Brief description (2)	$K_1$ (3)	$a$ (cm) (4)	$a'$ (cm) (5)	$V_f$ (cm/s) (6)	$y_f$ (cm) (7)
1	Footing 10% below bed	1.0	9.7	9.7	35.4	29.2
2	Footing flush with bed	1.0	9.7	9.7	35.1	29.2
3	Footing 10% into flow	1.1	19.7	10.7	26.5	2.9
4	Footing 25% into flow	1.1	19.7	12.2	30.5	-7.3
5	Footing 38% into flow	1.1	19.7	13.5	30.5	11.2
6	Footing 50% into flow	1.1	19.7	14.7	32.6	14.5
7	Footing 100% into flow	1.1	19.7	19.7	36.3	29.2
8	Footing flush with bed	1.0	9.7	9.7	32.9	12.4
9	Footing 50% into flow	1.1	19.7	14.7	25.9	6.2
10	Footing 91% into flow	1.1	19.7	18.8	32.6	11.2
11	Footing 100% into flow	1.1	19.7	19.7	33.5	12.4
12	Modified footing 10% below bed	1.0	9.7	9.7	36.6	29.2
13	Modified footing flush with bed	1.0	9.7	9.7	35.4	29.2
14	Modified footing 10% into flow	1.1	19.7	10.7	25.3	2.9
15	Modified footing 25% into flow	1.1	19.7	12.2	29.3	7.3
16	Modified footing 38% into flow	1.1	19.7	13.5	32.6	11.2
17	Modified footing flush with bed	1.0	9.7	9.7	32.4	12.4
18	Pier only	1.0	9.7	9.7	33.7	29.2
19	Pier only	1.0	9.7	9.7	34.9	12.4

TABLE 5. Summary Statistics for Prediction Factor Calculation

Grouping (1)	Methodology			Dominant component (4)
	10% depth switch (2)	Weighted pier width (3)		
All runs				
Average	1.71	1.52	1.54	1.54
Standard Deviation	0.61	0.59	0.58	0.58
Piers (runs 7, 11, 18, 19)				
Average	1.22	1.22	1.22	1.22
Standard Deviation	0.15	0.15	0.15	0.15
Baldwin Bridge Footing <sup>a</sup>				
Average	1.54	1.33	1.37	1.37
Standard Deviation	0.31	0.31	0.29	0.29
Modified Footing <sup>b</sup>				
Average	2.28	1.99	2.01	2.01
Standard Deviation	0.69	0.79	0.77	0.77
All Runs except 1, 2, 8, 12, 13, 17				
Average	1.53	1.26	1.29	1.29
Standard Deviation	0.43	0.20	0.18	0.18

<sup>a</sup>Runs 1, 2, 3, 4, 5, 6, 8, 9, 10.

<sup>b</sup>Runs 12, 13, 14, 15, 16, 17.

marizes a mean and standard deviation of the prediction factors. It also standard deviation of subsets of the data set. Runs 7, 11, 18, and 19 can be described as the more typical pier situation envisioned in the methodology. Nine runs are summarized as the specific Balwin Bridge footings; and the remaining six runs are the modified footings.

The first grouping incorporates all the runs, including those with the footing at or below the bed. The second grouping includes runs 7, 11, 18, 19, which are the typical pier situations generally used to derive pier-scour equations. The third and fourth groupings included footings at various locations in the flow as well as locations at or below the bed, where substantial scour reduction was observed. The fifth grouping omitted those runs with the footing at or slightly below the bed. The fifth group is considered to be the most significant one for comparing the three techniques for characterizing the pier/footing dimensions.

For the 10% depth rule, the footing width is used when the footing extends at least 10% into the flow field and the pier width is used in all other cases. For those cases in which the footing width was selected,  $K_1$ , the coefficient accounting for pier shape, was chosen to be 1.1, representing a rectangular pier. When the pier width was used,  $K_1$  was 1.0, representing a round nose shape for this mode. This technique resulted in a prediction factor of 1.53 and a standard deviation of 0.43 for the grouping that excluded the runs with footing locations at or below the bed.

With the dominant component technique, the prediction factor for their grouping was 1.29 and the standard deviation was reduced further to 0.18. Similarly, the weighted pier width approach yielded an average of 1.26 and a standard deviation of 0.20. The weighted pier width technique and the dominant component technique make equivalent improvements over the 10% depth technique. None of these techniques account for the scour-arresting effects of footings located at or slightly below the bed.

## CONCLUSIONS

Three conclusions may be drawn as a result of these analyses. The first is that the HEC-18 pier-scour equation is a design equation that includes an implicit overprediction factor. Based on the data described herein, this factor may be between 1.2 and 1.3 if the equation is applied for a pier that is typical of the conditions under which the equation was originally derived. This factor may become erratic if the equation is misapplied to compound situations in which the footing is partially exposed in the flow field.

The second conclusion is that both the dominant component and weighted pier width techniques are superior to the 10% depth approach in cases in which the footing extends into the flow field. The weighted pier width technique and the dominant component technique resulted in equivalent observations in the experimental data.

The third conclusion is that none of the three approaches addresses the significant arresting effects of scour caused by footings located at or below the bed. Footings at such locations can provide effective protection against local pier scour if they are extensive enough. By comparing the standard and modified footing it can be seen that the areal extent of the footing can be a significant factor in scour depth. The effects of such configurations could be addressed by deriving an adjustment factor for the pier-scour equation in terms of  $b_p/a$  and  $b_p/a$ , where  $b_p$  is the footing extension in front of the pier and  $b_s$  is the footing extension to the side of the pier. The data

available in this study were insufficient to explore these possibilities. Additional research is appropriate to take advantage of the natural selection that might be provided by slight modification in the plan dimensions and the optimum location of footings and pile caps.

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## APPENDIX II. NOTATION

The following symbols are used in this paper:

- $a$  = width of pier;  
 $a'$  = weighted pier width;  
 $b_f$  = extension of footing in front of pier;  
 $b_s$  = extension of footing to the side of the pier;  
 $D_{50}$  = median grain size;  
 $g$  = acceleration due to gravity;  
 $K_D$  = coefficient for design equation;  
 $K_1$  = coefficient for pier shape;  
 $K_2$  = coefficient for flow orientation;  
 $K_3$  = proposed coefficient for footing location;  
 $k_r$  = representative roughness size;  
 $PF$  = prediction factor;  
 $y_a$  = depth of flow;  
 $y_f$  = distance from bed to the top of the footing;  
 $y_l$  = distance from bed to point i;  
 $y_s$  = depth of scour;  
 $y_{s,D}$  = design depth of scour;  
 $y_{s,M}$  = measured depth of scour;

- $V_a$  = average velocity approaching pier;
- $V_f$  = average velocity in the flow zone below the top of the footing;
- $v_i$  = local velocity at point  $i$ ;
- $v_s$  = shear velocity;
- $v_{*c}$  = critical shear velocity for beginning of sediment movement.

## DESIGN-BASIS FLOOD FOR REHABILITATION OF EXISTING DAMS

By Anand Prakash,<sup>1</sup> Fellow, ASCE

**ABSTRACT:** Rehabilitation of existing dams in a cost-effective manner with the regard to hydrologic safety requires a rational method to determine the design-basis flood (DBF). Four methods are presented to determine the DBF based on economic considerations alone. These include the expected damage, incremental cost with and without price escalation, and modified expected damage approaches. The expected damage approach is presented to provide a basis for comparison with other approaches. One of the nondollar-denominated approaches includes no price escalation and the other provides for escalation of dollar-denominated damages attributable to dam failure that is likely to occur in the future. The modified expected damage approach considers probabilities of flood damages during the life of the rehabilitated dam, rather than the absolute probabilities. In most cases, however, consideration of nondollar-denominated consequences of rehabilitation are equally or more important. An approach based on a combination of the delphi and fuzzy-set methods is presented to evaluate rehabilitation alternatives with different DBFs and select the most cost-effective and acceptable DBF, based on both economic and nondollar-denominated factors.

### INTRODUCTION

The National Dam Inspection Act, public law 92-367 (August 8, 1972), authorized the U.S. Army Corps of Engineers to initiate a National Dam Inspection Program. This program involved a technical inspection and evaluation of each dam in the nation to determine if it constitutes a danger to human life and property because of inadequate hydraulic and hydrologic capability, structural stability, or operational limitations. Recommended guidelines for safety inspection of dams, developed to accomplish the objectives of this program, require that the design-basis flood (DBF) be based on the size and hazard classification of the dam ("Recommended Guidelines" 1976). DBF is the inflow flood hydrograph, expressed as a fraction of the probable maximum flood (PMF), or in terms of a recurrence interval, which must be passed by the dam with no potential for overtopping. Preliminary safety evaluations under this program have revealed that many of the existing dams would require upgrading to be able to safely pass the DBF. Feasibility studies for rehabilitation of such dams have indicated that the method of determining DBF based upon the size and hazard classification of the structure is somewhat arbitrary (*Safety of Dams* 1985). This practice has been widely criticized because it could result in underdesign or overdesign, unreasonably high costs of rehabilitation, and widely varying standards of safety in different climatic regions (*Evaluation Procedures* 1988). To determine the DBF for the rehabilitation of an existing dam in a rational manner, one must compare the risks and costs associated with a number of alternative designs based on different DBFs, then select the one with minimum risks and costs. For new dams, it is possible to include any prescribed

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EXAMPLE SHOWING METHODS OF CALCULATING PIER SCOUR WHEN FOOTING IS EXPOSED

DISK: PIER SCOUR  
FILE: EXPFTG

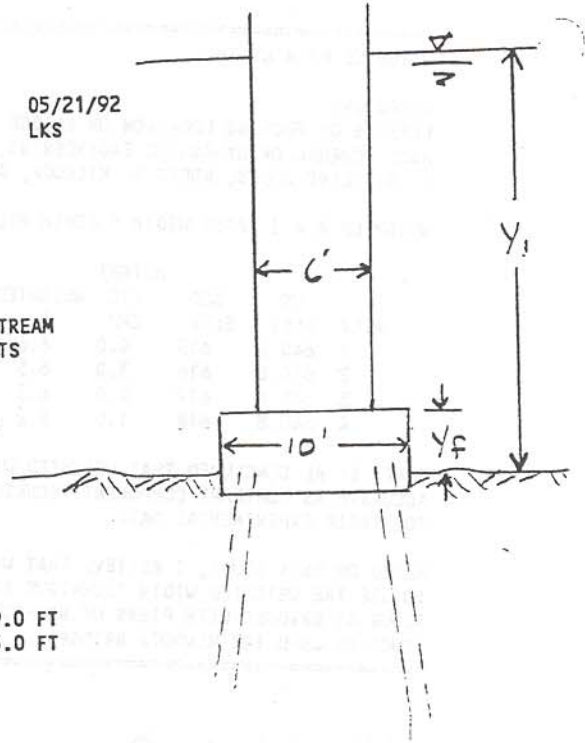
BRIDGE 4899 DESCRIPTION US 61 OVER MISSISSIPPI RIVER

05/21/92  
LKS

PREDICTED PIER SCOUR  
PIER FOOTING EXPOSED DURING HIGH FLOWS  
CHECK ALTERNATE METHODS OF PREDICTING PIER SCOUR

WS ELEV: 640.8 FT MEASURED BY USGS IN 4/69 (Q100=56,700)  
Q: 59300 CFS

USGS MEASURED NEAR PEAK OF 1969 FLOW FROM BRIDGE (PROBABLY DOWNSTREAM (SIDE), SINCE THIS IS A SAND BED STREAM, ASSUME THEIR MEASUREMENTS REFLECT ACTUAL CONTRACTION SCOUR



PIER #	VEL FT/S	BED ELEV FT	USGS MEASURED HYDRAULIC PARAMETERS
1	3.6	615	
2	4.4	616	
3	5.2	617	
4	5.4	618	

PIER	A:	FOOTING	AF:	TOP OF FTNG	619.0 FT
K1:	1.0	K1:	1.1	BOTTOM OF FTNG	615.0 FT
K2:	1.0	K2:	1.0		

CSU EQUATION  $YS/Y1 = 2.0 K1 K2 (A/Y1)^{.65} FR1^{.43}$  (9)

PREDICTED SCOUR BASED ONLY ON PIER WIDTH

PIER	WS ELEV	BED ELEV	Y1	V1	FR1	YS	1.1YS
1	640.8	615	25.8	3.6	0.12	8.2	9.0
2	640.8	616	24.8	4.4	0.16	8.9	9.7
3	640.8	617	23.8	5.2	0.19	9.5	10.4
4	640.8	618	22.8	5.4	0.20	9.6	10.5

PREDICTED SCOUR INCREASED 10%  
AS PER HEC-18 RECOMMENDATION  
ASSUME PLANE BED DURING FLOOD CONDITIONS

FOOTINGS EXPOSED, SO ALSO CHECK PREDICTED SCOUR BASED ON FOOTING WIDTH

=====

DOMINANT COMPONENT METHOD (FROM HEC-18)

COMPARE PREDICTED SCOUR BASED ON PIER WIDTH TO PREDICTED SCOUR BASED ON FOOTING WIDTH, EXPOSED HEIGHT, AND VELOCITY AT FOOTING ELEVATION

$VF/V1 = \ln(10.93(YF/KS) + 1) / \ln(10.93(Y1/KS) + 1)$

VF: AVERAGE VELOCITY WITHIN FOOTING  
YF: DISTANCE FROM BED TO TOP OF FOOTING  
KS: GRAIN ROUGHNESS, USE D50 OF BED MATERIAL  
KS (MM) 0.125 KS(FT) 0.0004 FINE SAND

PIER	WS ELEV	BED ELEV	Y1	V1	YF	VF	FRF	YSF	1.1YSF	PREDICTED SCOUR BASED ON FOOTING WIDTH, EXPOSED HEIGHT, AND VELOCITY, USE SCOUR CALCULATED BASED ON PIER WIDTH OR FOOTING WIDTH, WHICHEVER IS GREATER
1	640.8	615	25.8	3.6	4.0	3.1	0.27	9.1	10.1	
2	640.8	616	24.8	4.4	3.0	3.7	0.38	9.5	10.4	
3	640.8	617	23.8	5.2	2.0	4.2	0.53	9.5	10.5	
4	640.8	618	22.8	5.4	1.0	4.1	0.73	8.6	9.4	

CHECK PREDICTED SCOUR TO SEE IF IT MEETS PILE STABILITY CRITERIA

PIER	BED ELEV	MAX 1.1YS ELEV	SCOUR ELEV	BOTTOM FTNG	AVE PILE ELEV	AVE BOTTOM PILE	50% PILE EXP ELEV	PREDICTED SCOUR % EXP	PILE EMB	PILE EXP	
1	615	10.1	604.9	615.0	616.1	50.0	566.1	590.6	21%	38.8	10.1
2	616	10.4	605.6	615.0	616.1	50.0	566.1	590.6	19%	39.5	9.4
3	617	10.5	606.5	615.0	616.1	50.0	566.1	590.6	17%	40.4	8.5
4	618	10.5	607.5	615.0	616.1	50.0	566.1	590.6	15%	41.4	7.5

=====

WEIGHTED PIER WIDTH

BASED ON:  
EFFECTS OF FOOTING LOCATION ON BRIDGE PIER SCOUR  
ASCE JOURNAL OF HYDRAULIC ENGINEERING, VOL 118, NO. 2, FEB 1992  
J. STERLING JONES, ROGER T. KILGORE, AND MARK P. MISTICHELLI

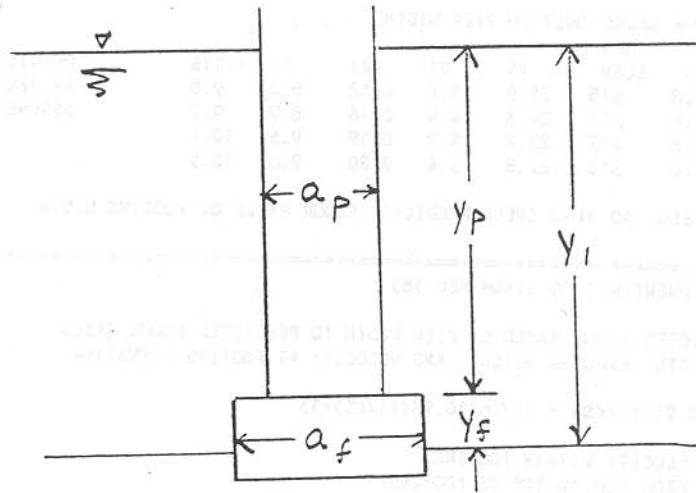
WEIGHTED A = [ (PIER WIDTH \* DEPTH PIER EXPOSED) + (FOOTING WIDTH \* DEPTH FOOTING EXPOSED) ] / TOTAL DEPTH

PIER	WS ELEV	BED ELEV	HEIGHT FTG EXP	WEIGHTED		V1	YS	1.1YS	% DIFFERENCE FROM HEC-18 METHOD
				A	Y1				
1	640.8	615	4.0	6.6	25.8	3.6	8.7	9.6	-5%
2	640.8	616	3.0	6.5	24.8	4.4	9.3	10.3	-2%
3	640.8	617	2.0	6.3	23.8	5.2	9.8	10.8	3%
4	640.8	618	1.0	6.2	22.8	5.4	9.8	10.7	2%

JONES ET AL CONCLUDED THAT WEIGHTED WIDTH TECHNIQUE WAS AS ACCURATE AS DOMINANT COMPONENT TECHNIQUE FOR PREDICTING SCOUR FOR THEIR EXPERIMENTAL DATA

BASED ON THIS STUDY, I BELIEVE THAT WE HAVE GOOD JUSTIFICATION TO USE THE WEIGHTED WIDTH TECHNIQUE FOR PREDICTING SCOUR AT BRIDGES WITH PIERS OF NON-CONSTANT WIDTH (SUCH AS USED FOR MENDOTA BRIDGE)

Weighted a



$$\text{Weighted } a_w = \frac{(a_f y_f + a_p y_p)}{y_1}$$

then use  $a_w$  and  $y_1$  in CSU equation

## **APPENDIX J**

### **SAMPLE ACTION PLANS**

## BRIDGE SCOUR ACTION PLAN

Bridge No: 36001

District: 1

Route : TH 217

Location: 0.1 Mi E of Jct TH 65

Stream: Little Fork River

County : Koochiching

Scour Code: R - CRITICAL MONITOR

Prepared: Andrea Hendrickson 10/5/94

Reviewed: Dave Halvorson 10/10/94

Updated:

### RECOMMENDED ACTION:

Bridge has been evaluated to be scour critical. District shall monitor bridge during high flows, and close the bridge if it is in danger of imminent failure.

### MONITORING PLAN:

- Start: During/Following a  $Q_{10}$  flood event where the water surface elevation  $\geq 1105.6$  and/or discharge  $\geq 17500$  cfs.
- Frequency of monitoring:  
W.S. Elev: Minimum 1 time per day following rainfall/snowmelt  
Bed Elev: as necessary, District Scour Coordinator will determine frequency based on site/weather conditions. Flood Response Plan contains general guidelines on frequency of monitoring.
- Method: Fathometer from the bridge deck.
- Location: Upstream face cross-section, with emphasis adjacent to piers 2, 3, 4 and east abutment foundations and at the east abutment slope toe.
- Look for: Evidence of pier scour.

The District should inspect the condition of the scour countermeasures on the east abutment. The inspection should emphasize bed elevations in the vicinity of the critical foundations and at the toe of the slope. Measured bed elevations should be compared to known riprap elevations and the bottom of footing elevation. Significant deviations between the current elevations and riprap design may indicate the protection is gone.

- Action: When critical scour elevation is reached immediately notify the designated district contacts listed under the Bridge Closure Plan below to initiate bridge closure and detour installation. The District in consultation with the Bridge Office will determine if the bridge is safe to be reopened. Upon reopening, the bridge should be continuously monitored until there is no potential for additional scour.

In the event of riprap failure the District in consultation with the Bridge Office must assess the extent of the countermeasure damage and the stability of the bridge abutment foundation.

**CRITICAL SCOUR DEPTH**

Start monitoring when water elev: 1105.6

Structure	Top of Footing	Bottom of Footing	Average Bottom of Piling	Critical Scour Elev.	Comments
Pier 2	1076.4	1073.4	1054.0	1064	
Pier 3	1075.7	1072.7	1058.3	1066	
Pier 4	1078.2	1075.2	1060.3	1068	
East Abut	1111.6	1108.6	1073.8	NA	Protected by Riprap.

Piers are numbered from west to east.

**IF RIVER BED IN VICINITY OF PIERS REACHES CRITICAL ELEVATION:**

Notify:

Traffic Control needed for River Bed Elevation Monitoring:

**BRIDGE CLOSURE PLAN:**

Detour:

Notification:

cc: D. J. Flemming  
 District Scour Coordinator  
 John Allen/Matt Lang  
 Steve Ryan



**BRIDGE SCOUR ACTION PLAN**

Bridge No: 9300  
District: Metro

Route: TH 5                      Location: 2.1 Mi SW of Jct TH 51  
County: Ramsey                Stream: Mississippi River

Scour Code: O 93 - STABLE, ACTION REQUIRED

Prepared/Updated By: Andrea Hendrickson 1/11/94  
Terry Moravec 12/30/94

**RECOMMENDED ACTION**

This bridge has been determined to be stable for the predicted scour, based on the assumption that the main channel thalweg does not migrate towards pier 2, piers are numbered south to north. The district shall take soundings or a cross-section at the bridge every four years, and after major flow events and plot it. If any movement of the main channel occurs, notify Bridge Hydraulics.

Pier 1 is a spread footing on St. Peter sandstone. Before the sandstone can be exposed to scour, a steep bank must be significantly eroded. The annual inspection should emphasize the condition of the slope at pier 1. Signs of major erosion should be reported to Bridge Hydraulics.

**APPENDIX K**

**TASK FORCE MEMBERS**

**Minnesota Bridge Scour Task Force Members:**

Steve Blanchard  
Mark Gieseke  
Chuck Howe  
Bruce Iwen  
Gary Person  
Lisa Sayler

Donald J. Flemming  
Dave Halvorson  
Gene Isakson  
Richard Larson  
Gary Peterson  
Joel Toso

Alan Forsberg  
Andrea Hendrickson  
W. Robert Ivarson  
James McCutcheon  
Mike Rardin

**Chairman:** Mark Gieseke

**Facilitator:** W. Robert Ivarson