COMPREHENSIVE SCOUR ANALYSIS AT HIGHWAY BRIDGES
HEC-18

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ABSTRACT

In 1988 The Federal Highway Administration issued FHWA Technical Advisory T5140.20 entitled “Scour at Bridges”. It required the States to evaluate the scour risk at all bridges over water. Accompanying the Advisory was the publication “Interim Procedures for Evaluating Scour at Bridges.” The “Interim Procedures” delineated the scour problem at highway encroachments and crossings as 1) stream instability and channel movement, 2) long term degradation or aggradation, 3) live-bed or clear-water contraction scour and 4) local scour at piers and abutments. The “Interim Procedures” provided guidance and equations for evaluating scour. This was the first time a manual was written that gave comprehensive methods and recommended equations for the hydraulic analysis to determine scour depths for design of foundations of new bridges or evaluation of existing bridges and to protect the river environment. Subsequently, the “Interim Procedures” were updated and issued as Hydraulic Engineering Circulars 18. The Fourth Edition of HEC-18 is summarized in this paper.

INTRODUCTION

In September 1988 The Federal Highway Administration issued FHWA Technical Advisory T5140.20 entitled “Scour at Bridges”. It required the states to evaluate the scour risk at all bridges over water. Accompanying the Advisory was the publication “Interim Procedures for Evaluating Scour at Bridges.” The “Interim Procedures” delineated the scour problem at highway encroachments and crossings as 1) stream instability and channel movement, 2) long term degradation or aggradation, 3) live-bed or clear-water contraction scour and 4) local scour at the piers and abutments. The “Interim Procedures” provided guidance for determining stream instability, channel movement, and long term elevation changes as well as methods to counteract them. It included equations to determine live-bed or clear-water contraction scour depths, based on the work of Emmett Laursen. To determine local pier scour depths, it recommended the “so called” Colorado State University Equation from FHWA’s Publication “Highways in the River Environment.” This pier scour equation was selected because a study of many pier scour equations by FHWA Research Engineer Sterling Jones (1983) showed this equation was the best fit. It enclosed all available scour depth research data and gave the smallest scour depths. Recent studies indicate this is still the case (Mueller, 1996 & Mueller and Jones, 1999).

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To determine local abutment scour depths, the “Interim Procedures” delineated seven abutment conditions (cases) such as abutment in the channel, at the bank, or set back and considering live-bed or clear-water scour. For each case it provided equations (Liu, et al, 1961) or (Laursen, 1980) to determine scour depths and/or methods to protect the abutments.

The “Interim Procedures” (written by Everett V. Richardson & Stanley R. Davis) were the first comprehensive manual that gave detailed recommendations to determine stream instability, delineated the three components of scour at highway bridges (long term aggradations or degradation, contraction scour and local scour), and gave equations or methods to determine scour depths and/or countermeasures to protect highway bridges and encroachments from stream instability and scour.

The TA was written by Stanley Davis, Chief of FHWA’s Hydraulics and Geotechnical Branch, with input by staff. Many drafts were prepared and reviewed by Stanley Gordon, Chief of the Bridge Division, FHWA legal staff and others before the TA was approved for dissemination. The TA was effective in implementing a national scour evaluation program that met the requirements of the Congress. While it presented policies and guidance for the program, it also permitted a degree of flexibility so that the states could carry out the program in a manner consistent with their existing organizations and procedures.


BACKGROUND

At 9:00 am on April 5, 1987 the Interstate (I-90) Highway Bridge over Schoharie Creek in Upstate New York collapsed killing 10 people. Four passenger cars and one truck fell 60 feet into the Creek. The failure received national television and newspaper coverage.

The National Transportation Safety Board investigated the accident and issued their findings in a highway accident report entitled “Collapse of New York Thruway (I-90) over the Schoharie Creek near Amsterdam New York, April 5, 1987.”
1987" (NTSB 1988). Drs. Richardson and Lagasse were Consulting Engineers for the Safety Board’s investigation, which included a physical model study made at Colorado State University. The Safety Board’s findings were that scour of pier 3 caused the failure. All 5 piers were founded on spread footings without piles.

The U.S. Congress held hearings on the failure, where people such as Ralph Nader testified that the Federal Government should take over the design and construction of all highway roads and structures. FHWA officials and all State Highway Engineers and State political officials such as Governors opposed such move. But Congress instructed FHWA to strengthen its oversight of the design, construction and inspection of all bridges. In particular, Congress instructed FHWA to evaluate and determine the vulnerability of failure from scour of all bridges over water in the Federal bridge inventory and to periodically report back to Congress on the progress of the evaluation and condition of all bridges in the inventory as to their vulnerability to failure by scour. The FHWA was charged with the task of strengthening the National Bridge inspection program. FHWA responded by issuing Technical Advisory T5140.20 entitled “Scour at Bridges” and the accompanying “Interim Procedures for evaluating Scour at Bridges” requiring the States to evaluate the scour risk at all bridges over water.

HEC-18 EVALUATING SCOUR AT BRIDGES (FOURTH EDITION)

Design Philosophy (Chapter 2)

Bridge foundations should be designed to withstand the effects of scour without failing for the worst conditions resulting from floods equal to the 100-year flood or a smaller flood if it would cause scour depths deeper than the 100-year flood. Bridge foundations should be checked to ensure that they will not fail due to scour resulting from the occurrence of a super-flood in the order of magnitude of a 500-year flood. Chapter 2 amplifies on the design philosophy and gives a general design procedure, concepts and a step by step detailed design procedure. Also, some miscellaneous hydraulic factors, such as drag forces on superstructures, ice forces and the design of spread footings placed on tremie seals or soils are described.

Basic Concepts and Definitions of Scour (Chapter 3)

The four components of a comprehensive scour analysis are defined and illustrated. These are: 1) Long term aggradation and degradation of the river bed. 2) General scour at the bridge (contraction scour or other general lowering of the bridge cross section. 3) Local scour at piers and abutments. 4) Lateral shifting of the stream. How sediment transport affects bridge foundations (that is the difference between clear-water and live-bed scour) is discussed in detail.

Long-term Aggradation and Degradation (Chapter 4)

The factors affecting long-term stream bed elevation changes, methods for evaluating these changes and the use of computer models are discussed. The role of geology, river mechanics, sediment transport, geomorphology and fluvial geomorphology are presented.
General Scour (Contraction Scour) (Chapter 5)

General scour is the general decrease in the elevation of the stream bed across the bridge opening. It does not include the local scour or the long term bed elevation changes. It can be cyclic, That is, there can be cutting and filling of the stream bed during the passage of a flood. Contraction scour is a main cause of general scour but other factors may cause general scour as well.

**Contraction Scour Equations**

Contraction scour occurs when the bridge and its approaches encroach either on the stream channel or the stream’s flood plain. This increases the stream velocity and sediment transport capacity. HEC-18 describes, with sketches, five cases of contraction scour at bridge crossings with two conditions of erosion (live-bed or clear-water). The cases are:

1. Bridge abutments project into the stream channel with or without overbank flow.
2. Bridge abutments at edge of the channel with overbank flow.
3. Bridge abutments setback from the channel and overbank flow.
4. Bridge crosses the stream at a narrow section.
5. Bridge piers significantly obstruct the flow (with or without debris) in the previous cases.

The “Interim Procedures” and HEC-18 give equations to determine contraction scour depth for each erosion condition. These are given below:

**Live-bed** contraction scour occurs at a bridge when the bridge opening contracts the flow and there is transport of bed material in the upstream reach into the bridge section. With live-bed contraction scour the area of the contracted section increases until, in the limit, the transport of sediment out of the contracted section equals the sediment transport in.

The equation, a modified version of Laursen’s 1960 equation for live-bed scour in a long contraction, is:

\[
y_2/y_1 = (Q_2/Q_1)^{6/7} (W_1/W_2)^k
\]

**Clear-water** contraction scour occurs when (1) there is no bed material transport from the upstream reach into the bridge cross section, or (2) the material transported in the upstream reach is transported through the bridge section in suspension and at less than the capacity of the flow. With clear-water contraction scour the area of the contracted section increases until the velocity of the flow or the shear stress on the bed is equal to the critical velocity or critical shear stress of a representative particle size in the bed material.

The “Interim Procedures” and HEC-18 recommended equation, based on a development given by Laursen in 1963 is:

\[
y_2 = ((K_u Q_2^2)/(D_m^{2/3} W^2))^{3/7}
\]
\[ y_s = y_2 - y_0 = \text{average contracted scour depth} \]

HEC-18 states that scour depths with live-bed contraction scour may be limited by coarse sediments in the bed material. Where coarse sediments are present HEC-18 recommends calculating contraction scour using both equations and taking the smaller scour depth.

**Determination of Local Scour at Piers Chapter 6**

The "Interim Procedures," based on the study by Sterling Jones (1983) recommended the CSU equation for both live bed and clear-water conditions. The equation was developed for the FHWA Publication "Highways in the River Environment, Environmental and Hydraulic Considerations" (Richardson, et al 1975). The succeeding HECs recommended a modified CSU equation. The modifications were to add additional corrections factor (Ks) based of new research and field experience. The 4th HEC-18 Edition equation for local pier scour is:

\[ y_s/a = 2.0 \, K_1 \, K_2 \, K_3 \, K_4 \, K_w \, (y_1/a)^{0.35} \, F_r^{0.43} \]

The variables are defined in notation and values are given for the Ks in HEC-18. Also, HEC-18 places a limit on the maximum value of \( y_s/a \).

**Scour Depth Determination for Complex Piers**

The 4th Edition of HEC-18 based on the research and papers of Jones (1989), Salim and Jones (1996, and 1999), Jones and Sheppard (2000), delineated a method for determining local scour depths for piers with complex geometry. Figure 1 illustrates the components of a complex pier and the methodology used. The reader is referred to the 4th Edition of HEC-18 for the development, an example problem and guidance in using the method.

![Figure 1. Definition sketch for scour at a complex pier (Jones and Sheppard, 2000).](image)

**Evaluating Local Scour at Abutments** (Chapter 7)

The components of the local scour at abutments are illustrated in Figure 2. Note the horizontal vortex that produces scour depths at the upstream corner and side
of the abutment. This is the scour depth determined by most abutment scour
equations. But note also the wake vortex. This vortex erodes the downstream face of
the abutment and approach embankment, causing abutment failure. Often this wake
vortex causes a major scour problem. Erosion from the wake vortex can be easily
controlled by recognizing the problem and placing riprap on the downstream face of
the abutment and approach embankment.

Figure 2. Schematic representation of abutment scour (HEC-18).

Equations for predicting local scour depths are mainly based on laboratory
Little or no field data is available. The problem, as stated in HEC-18 is:

"The reason the equations in the literature predict excessive conservative abutment
scour depths for the field situation is that, in the laboratory flume, the discharge
intercepted by the abutment is directly related to abutment length; whereas, in the
field, this is rarely the case.”

The “Interim Procedures” and HEC-18 identified abutment site conditions,
angle to the flow (skew), discharge intercepted by the abutment and approach
embankment and abutment shape as scour depth factors. Researchers identified the
same factors, but unfortunately used abutment and approach length as a substitute for
discharge. Common abutment shapes are 1) vertical wall abutments, 2) vertical wall
abutments with wing walls and spill-through abutments.

**Abutments Local Scour depth Equations**

HEC-18 recommends two equations for both live-bed and clear-water scour.
They are Froehlich’s (1989) and HIRE (Richardson, et al 2001). The latter is based
of scour depths measure at the end of spurs in the Mississippi River and is applicable
when the ratio of the projected abutment and embankment length to the flow depth is
greater than 25.

Froehlich’s (1989) live-bed abutments scour equation
\[ \frac{y_s}{y_i} = 2.27 K_5 K_6 \left( \frac{L'}{y_i} \right)^{0.43} Fr^{0.61} + 1.0 \]

HIRE live-bed abutment scour equation

\[ \frac{y_s}{y_1} = 4 Fr^{0.33} \left( K_5 / 0.55 \right) K_6 \]

**Comprehensive Example Scour Problem (Chapter 8)**

A comprehensive hydraulic analysis from a paper by Arneson et al (1991) of scour at a bridge crossing using the procedure and equations given in HEC-18 is presented. The analysis uses SI units in Chapter 8. But in Appendix H uses English units. The hydraulic variables were obtained using FHWA’s WSPRO computer program. WSPRO’s input and output is given in Appendix G.

**Chapters 9 to 13 and Appendixes**

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<td>107 publications are cited.</td>
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**APPENDIX**

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| B | EXTREME EVENTS |
| C | CONTRACTION SCOUR AND CRITICAL VELOCITY EQUATIONS |
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| G | WSPRO INPUT AND OUTPUT FOR EXAMPLE PROBLEMS |
| H | COMPREHENSIVE SCOUR PROBLEM, ENGLISH UNITS |
| I | FHWA TECHNICAL ADVISORY T 5140.23 |
| J | FHWA 1995 CODING GUIDE FOR NATIONAL BRIDGES |
| K | UNKNOWN FOUNDATIONS |
| L | SCOUR IN COHESIVE SOILS |
NATIONAL HIGHWAY INSTITUTE

The FHWA’s National Highway Institute established a short course titled “Stream Stability and Scour at Highway Bridges in 1991 using the “Interim Procedures” as the course text. Subsequent courses used the current edition of HEC-18 as the course text. At first, bridge inspectors attended the 3 day course. But FHWA and NHI established a 1-day course for inspectors titled “Stream Stability and Scour at Highway Bridges for Inspectors” (FHWA NHI, 2009). This course concentrates on visual keys to detecting scour and stream instability problems and emphasizes guidelines to complete the hydraulic and scour-related coding requirements. With the increase in knowledge of scour and stream instability countermeasures NHI and FHWA established a new course entitled “Countermeasure Design for Bridge Scour and Stream Instability.” It uses HEC-23 (Lagasse, et al, 2001, 2009) as the course text. In the period 1991 to 2005 Ayres Associates, Inc. presented the scour courses to more than 5,700 students in 45 States. However, engineers and highway officials in all 50 States have attended the course.

CONCLUSION

In 1988 the U.S. Department of Transportation, Federal Highway Administration as part of Technical Advisory T5140.20 “Scour at Bridges” released a manual titled “Interim Procedures for Evaluating Scour at Bridges. “ The “Interim Procedures” delineated the scour problem at highway encroachments and crossings as 1) stream instability and channel movement, 2) long term degradation or aggradation, 3) live-bed or clear-water contraction scour and 4) local scour at the piers and abutments. The “Interim Procedures” provided guidance for determining stream instability, channel movement, and long term elevation changes as well as methods to counteract them. This was the first time that a manual was written that gave a comprehensive method with recommended equations for the hydraulic analysis to determine scour depths for the design of foundations of new bridges or evaluation of existing bridge foundations. In succeeding years the “Interim Procedures” were updated and issued as Hydraulic Engineering Circulars HEC-18. The Fourth Edition was issued in May 2001.

FHWA (1991) updated the advisory to T51140.23 titled “Evaluating Scour at Bridges.” In 1992 the American Association of State Highway and Transportation Officials (AASHTO, 1992) addressing the problem of stream stability and scour stated “The probable depth of scour shall be determined by subsurface exploration and hydraulic analysis. Refer to Article 1.3.2 and FHWA Engineering Circular (HEC) 18 for general guidance regarding hydraulic studies and design.”

NOTATION

\( a = \) Pier width, m (ft)
\( f = \) Upstream projection of a footer from pier stem, m (ft)
\( D_m = \) Diameter of the smallest nontransportable particle in the bed material in the contracted section (taken as 1.25 \( D_{50} \)) m (ft)
\( D_{50} \) = Median diameter of the bed material, m (ft)

\( y_1 \) = Average depth in the upstream main channel, or directly upstream of the pier or abutment, m (ft).

\( y_2 \) = Average depth in the contracted section, m (ft)

\( y_s \) = Scour depth in the contracted section, m (ft)

\( y_0 \) = Existing depth in the contracted section before scour, m (ft)

\( Q_1 \) = Discharge in upstream channel TRANSPORTING SEDIMENT. \( \text{m}^3/\text{s} \) (\( \text{ft}^3/\text{s} \))

\( Q_2 \) = Discharge in the contracted channel or in the setback overbank area at the bridge. It is associated with the width \( W \), \( \text{m}^3/\text{s} \) (\( \text{ft}^3/\text{s} \))

\( W_1 \) = Bottom width of the upstream channel that is transporting bed material, m (ft)

\( W_2 \) = Bottom width of the contracted section less pier widths, m (ft)

\( k \) = Exponent determined below

<table>
<thead>
<tr>
<th>( V*/w )</th>
<th>( k )</th>
<th>Mode of Sediment Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.50</td>
<td>0.59</td>
<td>Mostly contact bed material transport.</td>
</tr>
<tr>
<td>0.50 to 2.0</td>
<td>0.64</td>
<td>Some suspended bed material transport.</td>
</tr>
<tr>
<td>&gt;2.0</td>
<td>0.69</td>
<td>Mostly suspended bed material discharge</td>
</tr>
</tbody>
</table>

\( K_u = 0.025 \) SI units

\( K_u = 0.0077 \) English units

\( V_* \) = Shear velocity in the upstream section \( (gy_1 s_1)^{0.5} \) m/s (ft/s)

\( s_1 \) = Slope of the energy grade line in the upstream channel, m/m (ft/ft).

\( w \) = Fall velocity of the \( D_{50} \) of the upstream bed material, m (ft)

\( K_1 \) = Correction factor for pier shape, HEC-18

\( K_2 \) = Correction factor for angle of attack = \( (\cos 0 + L/a \sin 0)^{0.65} \)

Maximum value of \( L/a \) is 12

\( K_3 \) = Correction factor for bed condition given in 4th Edition HEC-18

\( K_4 \) = Correction factor for armoring by bed material size 4th Edition HEC-18

\( K_5 \) = Coefficient for abutment shape = 1.0 for vertical wall abutment; 0.82 for vertical—wall with wing walls and 0.55 for spill-through.

\( K_6 \) = Coefficient for angle of embankment to flow. = \((0/90)^{0.13} \) (0<90 if embankment points downstream and 0>90 if embankment points upstream

\( K_w \) = Correction factor for pier width in shallow flows. HEC-18

\( L \) = Pier length, or abutment embankment length normal to the flow m (ft)

\( L' \) = Length of active flow obstructed by abutment & embankment m (ft)

\( A_e \) = Flow area obstructed by abutment & embankment \( m^2 \) (\( ft^2 \))

\( Q_e \) = Flow obstructed by abutment & embankment \( \text{m}^3/\text{s} \) (\( \text{ft}^3/\text{s} \))

\( V_e = Q_e / A_e \) m/s (ft/s)

\( Fr \) = Froude Number directly upstream of the pier or abutment

REFERENCES


SCOUR STUDIES BY FRED CHANG

In Fall 1957, late Dr. H. K. Liu was conducting a study on abutment scour in the Hydraulic Laboratory. Dr. M. Skinner was the assistant and Fred Chang was working under them as a graduate assistant. The project was supported by then the Bureau of Public Roads (USBPR). Mr. Carl Izzads served as the contracting official. The experiments were conducted in an 8-ft wide flume. Some experimental runs were continued for 2, 3 days to study a long-term variation of scour at the toe of vertical wall abutments and wing-wall abutments. After Dr. Liu passed away in 1961, Dr. V. J. Yevjdevich continue scour study.

Fred Chang work under him to conduct an analytical investigation on scour around bridge piers. This investigation was also supported by USBPR. In 1962, Dr. H. W. Shen joined with CSU. Scour studies continued under the sponsorship of USBPR. Mr. Y. Ogawa from Hokkaido University, Japan, Dr. V. Schneider (now USGS), and Dr. T. W. Wang, Professor at Taiwan University, were graduate assistants working under Dr. Shen’s supervision.

Fred Chang started teaching at South Dakota State University in Brookings, South Dakota, in 1963, where he had conducted several research projects related to scour. These projects included:

Scour Reduction at Bridge Piers- sponsored by USBPR in cooperation with South Dakota Department of Transportation. The study included the reduction of scour at piers by installing smaller piles upstream of the piers. This technique is affected by flow direction, the reduction of scour was observed as much as 40%. The experiments at SDSU was conducted in a 1-ft wide flume. In Summer 1965, Fred Chang conducted a similar study at CSU in a 6-ft wide flume in the Foothill Hydraulics Laboratory with the courtesy of Dr. Simons, Director of the Laboratory. This project continued until 1971, the third stage study in which field tests were conducted.

Scour Protection at Culvert Outlets by using an Impact Wall- sponsored by USBPR in cooperation of South Dakota Department of transportation (1968-1970). An impact wall was installed perpendicular to the centerline of the culvert with its upper edge at the elevation of the culvert invert. Between the culvert outlet and the impactwall the ground was preshaped in a scour hole and the bed was covered with riprap stones of the size which would be just suspended in the expected maximum flow.

Since he moved to Washington, D.C. in 1972, he has been working closely with the Federal Highway Administration, participating in various hydraulics and scour projects. Those studies related to scour are:

Richardson’s supervision. In 1987, working with SUTRON Inc., he was involved in development of riprap design criteria. In 1992 through 1995, during three summers, he worked with Dr. Roy Trent and Mr. Sterling Jones of FHWA under an IPA contract between University of the District of Columbia and FHWA to study restoration of degraded channel and scour at bridge crossings.

In 1984-86 I (Ev) worked a contract with Washington based consulting firm (U.S. Indians president) to write a Scour manual. Frank Johnson (retired FHWA chief Hydr. Eng) worked for the firm as my supervisor. The firm was awarded the No. Big contract on the basis of the U.S. Indians ownership. The firm director was a FHWA employee who had a 1/4 joint ownership. Subsequently a FHWA internal investigation voided the contract as not a beneficial Indian owned.
However I had written so much of the Manual that it was easy for me (Ell) to write the initial procedures for scour analysis that went out to the site. Direct of transportation with TA.
STREAM STABILITY AT HIGHWAY STRUCTURES
Third Edition

This document provides guidelines for identifying stream instability problems at highway stream crossings. It is a dual unit update of the second edition published in 1995. The HEC-20 manual covers geomorphic and hydraulic factors that affect stream stability and provides a step-by-step analysis procedure for evaluation of stream stability problems. Stream channel classification, stream reconnaissance techniques, and rapid assessment methods for channel stability are summarized. Quantitative techniques for channel stability analysis, including degradation analysis, are provided, and channel restoration concepts are introduced.

In addition to minor editorial revisions, the following substantive changes have been made in this revised edition of HEC-20: corrected definition of density of water, \( p \), (p. xi); revised definition of grain roughness \( k_s \), for gravel and coarse bed material (p. 6.15) and corrected multiplier for kinematic viscosity in Appendix A (Table A.7).

16. This document is available to the public through the National Technical Information Service, Springfield, VA 22161 (703) 487-4650

17. Key Words
bridge design, bridge stability, channel classification, stream reconnaissance, quantitative techniques, highway structures, scour, hydraulics, sediment, stream geomorphology, stream stability, channel restoration

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CHAPTER 1

INTRODUCTION

1.1 PURPOSE

The purpose of this document is to provide guidelines for identifying stream instability problems at highway-stream crossings. Techniques for stream channel classification and reconnaissance, as well as rapid assessment methods for channel instability are summarized. Qualitative and quantitative geomorphic and engineering techniques useful in stream channel stability analysis are presented.

1.2 BACKGROUND

Approximately 83 percent of the 583,000 bridges in the National Bridge Inventory (NBI) are built over streams. A large proportion of these bridges span alluvial streams that are continually adjusting their beds and banks. Many, especially those on more active streams, will experience problems with aggradation, degradation, bank erosion, and lateral channel shift during their useful life. The magnitude of these problems is demonstrated by the average annual flood damage repair costs of approximately $50 million for highways on the Federal-aid system.

1.3 COMPREHENSIVE ANALYSIS

This manual is part of a set of Hydraulic Engineering Circulars (HEC) issued by the Federal Highway Administration (FHWA) to provide guidance for bridge scour and stream stability analyses. The three manuals in this set are:

- HEC-18 Evaluating Scour at Bridges
- HEC-20 Stream Stability at Highway Structures
- HEC-23 Bridge Scour and Stream Instability Countermeasures

The Flow Chart shown in Figure 1.1 illustrates the interrelationship between these three documents and emphasizes that they should be used as a set. A comprehensive scour analysis or stability evaluation must be based on information presented in all three documents.

While the flow chart does not attempt to present every detail of a complete stream stability and scour evaluation, it has sufficient detail to show the major elements in a complete analysis, the logical flow of a typical analysis or evaluation, and the most common decision points and feedback loops. It clearly shows how the three documents tie together, and recognizes the differences between design of a new bridge and evaluation of an existing bridge.

The HEC-20 block of the flow chart outlines initial data collection and site reconnaissance activities leading to an understanding of the problem, evaluation of river system stability and potential future response. The HEC-20 procedures include both qualitative and quantitative geomorphic and engineering analysis techniques which help establish the level of analysis necessary to solve the stream instability and scour problem for design of a new bridge, or for the evaluation of an existing bridge that may require rehabilitation or countermeasures.
This document is the fourth edition of HEC-18. It presents the state of knowledge and practice for the design, evaluation and inspection of bridges for scour. There are two companion documents, HEC-20 entitled "Stream Stability at Highway Structures," and HEC-23 entitled "Bridge Scour and Stream Instability Countermeasures." These three documents contain updated material from previous editions and the publication, "Interim Procedures for Evaluating Scour at Bridges," issued in September 1988 as part of the FHWA Technical Advisory T 5140.20, "Scour at Bridges." T5140.20 has since been superseded by T 5140.23, "Evaluating Scour at Bridges" dated October 28, 1991. This fourth edition of HEC-18 contains revisions obtained from further scour-related developments and the use of the 1995 edition by the highway community.

The major changes in this fourth edition of HEC-18 are: change in nomenclature to using General Scour to include both contraction scour and other general scour components, changing the order of Chapters 2 and 3 so that the policy chapter entitled "Designing Bridges to Resist Scour" comes before the chapter entitled "Basic Concepts and Definitions of Scour," and separating Chapter 4 into separate chapters dealing with each of the major scour components. In addition, a new Kc, to account for coarse bed material in the pier scour equation, improved methods to compute scour for complex pier configurations, example problems, and additional information on computer programs for modeling tidal hydraulics are given. There is no change in the recommendations regarding abutment scour. Finally, minor errors in the text and figures have been corrected.
CHAPTER 1
INTRODUCTION

1.1 PURPOSE

The purpose of this document is to provide guidelines for the following:

1. Designing new and replacement bridges to resist scour
2. Evaluating existing bridges for vulnerability to scour
3. Inspecting bridges for scour
4. Improving the state-of-practice of estimating scour at bridges

1.2 BACKGROUND

The most common cause of bridge failures is from floods scouring bed material from around bridge foundations. Scour is the engineering term for the erosion caused by water of the soil surrounding a bridge foundation (piers and abutments). During the spring floods of 1987, 17 bridges in New York and New England were damaged or destroyed by scour. In 1985, 73 bridges were destroyed by floods in Pennsylvania, Virginia, and West Virginia. A 1973 national study for the Federal Highway Administration (FHWA) of 383 bridge failures caused by catastrophic floods showed that 25 percent involved pier damage and 75 percent involved abutment damage. A second more extensive study in 1978 indicated local scour at bridge piers to be a problem about equal to abutment scour problems. A number of case histories on the causes and consequences of scour at major bridges are presented in Transportation Research Record 950.

From available information, the 1993 flood in the upper Mississippi basin, caused 23 bridge failures for an estimated damage of $15 million. The modes of bridge failures were 14 from abutment scour, two from pier scour, three from pier and abutment scour, two from lateral bank migration, one from debris load, and one from unknown cause.

In the 1994 flooding from storm Alberto in Georgia, there were over 500 state and locally owned bridges with damage attributed to scour. Thirty-one of state-owned bridges experienced from 15 to 20 feet of contraction scour and/or long-term degradation in addition to local scour. These bridges had to be replaced. Of more than 150 bridges identified as scour damaged, the Georgia Department of Transportation (GADOT) also recommended that 73 non-federal aid bridges be repaired or replaced. Total damage to the GADOT highway system was approximately $130 million.

The American Association of State Highway and Transportation Officials (AASHTO) standard specifications for highway bridges has the following requirements to address the problem of stream stability and scour:

- Hydraulic studies are a necessary part of the preliminary design of a bridge and should include...estimated scour depths at piers and abutments of proposed structures.
- The probable depth of scour shall be determined by subsurface exploration and hydraulic studies. Refer to Article 1.3.2 and FHWA Hydraulic Engineering Circular (HEC) 18 for general guidance regarding hydraulic studies and design.
- ...in all cases, the pile length shall be determined such that the design structural load may be safely supported entirely below the probable scour depth.
1.3 COMPREHENSIVE ANALYSIS

This manual is part of a set of HECs issued by FHWA to provide guidance for bridge scour and stream stability analyses. The three manuals in this set are:

- **HEC-18** Evaluating Scour at Bridges
- **HEC-20** Stream Stability at Highway Structures (6)
- **HEC-23** Bridge Scour and Stream Instability Countermeasures (7)

The Flow Chart of Figure 1.1 illustrates graphically the interrelationship between these three documents and emphasizes that they should be used as a set. A comprehensive scour analysis or stability evaluation should be based on information presented in all three documents.

While the flow chart does not attempt to present every detail of a complete stream stability and scour evaluation, it has sufficient detail to show the major elements in a complete analysis, the logical flow of a typical analysis or evaluation, and the most common decision points and feedback loops. It clearly shows how the three documents tie together, and recognizes the differences between design of a new bridge and evaluation of an existing bridge.

The HEC-20 block of the flow chart outlines initial data collection and site reconnaissance activities leading to an understanding of the problem, evaluation of river system stability and potential future response. The HEC-20 procedures include both qualitative and quantitative geomorphic and engineering analysis techniques which help establish the level of analysis necessary to solve the stream instability and scour problem for design of a new bridge, or for the evaluation of an existing bridge that may require rehabilitation or countermeasures. The "Classify Stream," "Evaluate Stability," and "Assess Response" portions of the HEC-20 block are expanded in HEC-20 into a six-step Level 1 and an eight-step Level 2 analysis procedure. In some cases, the HEC-20 analysis may be sufficient to determine that stream instability or scour problems do not exist, i.e., the bridge has a "low risk" of failure regarding scour susceptibility.

In most cases, the analysis or evaluation will progress to the HEC-18 block of the flow chart. Here more detailed hydrologic and hydraulic data are developed, with the specific approach determined by the level of complexity of the problem and waterway characteristics (e.g., tidal or riverine). The "Scour Analysis" portion of the HEC-18 block encompasses a seven-step specific design approach which includes evaluation of the components of total scour (see Chapter 3).

Since bridge scour evaluation requires multidisciplinary inputs, it is often advisable for the hydraulic engineer to involve structural and geotechnical engineers at this stage of the analysis. **Once the total scour prism is plotted, then all three disciplines must be involved in a determination of structural stability.**

For a new bridge design, if the structure is stable the design process can proceed to consideration of environmental impacts, cost, constructability, and maintainability. If the structure is unstable, revise the design and repeat the analysis. For an existing bridge, a finding of structural stability at this stage will result in a "low risk" evaluation, with no further action required. However, a Plan of Action should be developed for an unstable existing bridge (scour critical) to correct the problem as discussed in Chapter 12 and HEC-23. (7)
Figure 1.1: Flowchart for scour and stream stability analysis and evaluation.
Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Design Guidance-Third Edition

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