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Design and Evaluation of Bridges for Scour in the United States of North America

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Summary

The catastrophic failures of several bridges in the United States of North America has focused national attention towards the need to develop technology for designing new bridges and for evaluating existing bridges over waterways for the effect of total scour around the bridge foundations. The FHWA, an agency of the United States Department of Transportation, has taken the lead in developing and disseminating technology and guidance on stream stability, scour, and scour countermeasures for highway bridges over waterways. The FHWA has disseminated state-of-the-art technology through its Hydraulics Engineering Circular (HEC) -18, "Evaluating Scour at Bridges," HEC-20, "Stream Stability at Highway Structures," and HEC-23, "Scour and Stream Instability Countermeasures." This paper will discuss how the technology presented in these HEC's is used in the United States of North America for designing new bridge foundations and for evaluating the stability of the foundation of existing bridges over waterways for the safety of the public users.

1. Introduction

The FHWA has been proactive in disseminating state-of-the-art technology and guidance for the design of new bridges and the evaluation of bridges susceptible to scour since 10 people lost their lives during the failure of the New York Thruway bridge over the Schoharie Creek in New York in 1987. Other failures include: the I-29 crossing of the Big Sioux River in South Dakota in 1962; the I-80 crossing of the John Day River in Oregon in 1964; 73 bridges destroyed by flooding in Pennsylvania, Virginia and West Virginia in 1985; 17 bridges in New York and New England states in the spring of 1987; the US 51 bridge over the Hatchie River in Tennessee in 1989 (eight people were killed); the I-5 bridges over Arroyo Pasajero in California in 1995 (seven people were killed); and the bridge over the Wantagh Parkway in New York in 1998.

The scour evaluation of bridges over waterways were established by the FHWA in 1991. State departments of transportation (DOTs) have been reporting progress towards completing their scour evaluations in a biannual basis. The current status is presented later on in this paper. In addition, the FHWA recommends that new bridges be designed for scour from floods equal to or less than the 100-year flood. The current editions of HEC-18 and HEC-20, third and second edition, respectively, contain updated technology for calculating total scour and for assessing stream instability of channels. In addition, FHWA has published HEC-23 to provide DOTs with state-of-the-art guidance for the selection and design of bridge scour and stream instability countermeasures.

2. The National Approach

The Federal Highway Administration (FHWA) maintains an inventory of bridges through its National Bridge Inventory. The bridge inventory contains a database of over 575,000 bridges as reported by DOTs. About 84% of these bridges, or 484,060, are over waterways. The Technical Advisory (TA) 5140.20, "Scour at Bridges," released by FHWA in 1988, contained guidance for designing new bridges for scour and for conducting scour evaluations on existing bridges over waterways. Techniques for estimating scour were presented in an attachment to the TA, the FHWA's Interim Procedures for Estimating Scour at Bridges. The guidance contained in this TA and its attachment has been followed by DOTs for designing new bridges and for evaluating the condition of existing bridges from scour. TA 5140.20 was superseded in 1991 by TA 5140.23, "Evaluating Scour at Bridges," which introduced the FHWA's Hydraulic Engineering Circular No. 18 (HEC-18), which superseded the FHWA Interim Procedures. The TA 5140.23 is very comprehensive and focuses on the development and implementation of a scour evaluation program for designing new bridges to resist damage from scour, evaluating existing bridges for vulnerability to scour, using scour countermeasures, and improving the state-of-practice for estimating scour at bridges.

2.1 Recommended Five Step Process

The guidance from the TA gives a five step procedure to follow:

1. An interdisciplinary team of hydraulic, geotechnical and structural engineers should conduct scour evaluations.
2. New bridges should be designed to be scour safe for a superflood on the order of magnitude of a 500-year flood.
3. All existing bridges over waterways with scourable beds should be evaluated for the risk of scour failures for such a superflood.
4. A plan of action should be develop for all bridges that are determined to be scour critical.
5. All bridges should be inspected for scour during the regular two year bridge inspection cycle.

FHWA also has three technical publications that provide technical guidance: HEC-18--provides guidance for developing a scour evaluation program and analyzing bridges for scour; HEC-20--provides guidance for analyzing the effect of stream instability on bridges; and HEC-23--provides guidance for the selection of suitable countermeasures to mitigate potential damage to bridges and highways at stream crossings.

2.1.1 Interdisciplinary Team

In designing new and evaluating the existing condition of bridges for scour, a careful evaluation of the hydraulic, geotechnical and structural aspects of the bridge foundations is required. An interdisciplinary team of experienced engineers is needed to make engineering judgements resulting from the complex nature of streams, flow patterns, oil and structure design. In addition, the team should establish priorities for scour evaluations, determine if the bridge is scour critical and recommend countermeasures and monitoring schedules to mitigate the potential effect of scour on the stability of bridge foundations.

2.1.2 Guidance for Designing New Bridges for Scour

New bridges over waterways on scourable streambeds should be designed for scour from floods equal to or less than the 100-year flood and checked for the potential scour resulting from the magnitude of a superflood (i.e., a 500-year event or 1.7 times the magnitude of the 100-year event). The geotechnical analysis should assume that the streambed material within the scour prism (total scour) is not available for bearing or lateral support. For the superflood condition, the geotechnical analysis for the superflood should incorporate a factor of safety of 1.0.

Prior to estimating total scour it is necessary to identify any potential for streambed aggradation or degradation as well as any potential for lateral streambed migration. With this information available and knowing the streambed characteristics then one can estimate total scour for a new bridge following these steps, as recommended in HEC-18:

Step 1. The designer should select a flood event or events that are expected to produce the worst scour condition.

Step 2. Water surface profiles for the flood flows should be developed. Hydraulics variables such as velocity and depth of water should be calculated.

Step 3. Estimate total scour. Check for geotechnical safety factors commonly accepted by the department of transportations.

Step 4. Plot total scour depths.

Step 5. Evaluate the results and apply engineering judgement.

Step 6. Evaluate bridge type, size and location based on results.

Step 7. Perform a foundation analysis on the basis that all streambed material in the total scour prism has been removed and is not available for bearing or lateral support of the bridge foundation.

Step 8. Repeat Steps 2 through 7 for a superflood condition. Check that the foundation have a minimum factor of safety of 1.0 (ultimate load) under this condition.

2.1.3 Guidance for Evaluating Existing Bridges for Scour

Existing bridges over riverine or tidal waterways should be evaluated to assess their vulnerability to floods and to determine if they are scour critical (foundations are unstable) or low risk to scour. The FHWA recommended that these evaluations should be conducted by the interdisciplinary team. In addition, the FHWA recommends that the evaluations should be made for the magnitude of a superflood condition (i.e., 500-year flood). Steps 1 through 7 presented for designing new bridges could be followed for the scour evaluation of a bridge for the superflood condition.

If a bridge is found to be scour critical, the bridge owner should have an action plan with specific procedures to follow to make the bridge less vulnerable to scour for the safety of the public users. The procedures may include among others specific instructions to close the bridge during floods and the timely installation of scour countermeasures. The equations presented in HEC-18 are recommended by the FHWA for evaluating scour at bridges.

2.1.4 Evaluation Procedure

Step 1. Bridges over waterways should be screened by an interdisciplinary team into five categories: 1) low-risk; 2) scour susceptible; 3) unknown foundations; 4) tidal waterways; 5) scour critical

Step 2. Bridges identified as scour susceptible bridges, unknown foundations and over tidal waterways should be prioritized for evaluation by conducting a preliminary office and field review using factors identified by the interdisciplinary team.

Step 3. Conduct office and field scour evaluations of the bridges which were prioritized under step 2. Steps 1 through 7 presented under "Guidance for Designing New Bridges for Scour" should be followed. The 500-year flood condition should be used during the evaluation.

Step 4. Bridges identified as scour critical should have a plan of action for correcting the scour problem.

Step 5. Remaining bridges (low-risk) should be evaluated giving priority status to the functional classification of the highway and bridges that are vital links in the transportation network of a city or region.

2.1.5 Plan of Action

A plan of action for each scour critical bridge should be developed by the interdisciplinary team. The plan of action should include:

- instructions for the type and frequency of inspections to be made at the bridge site;
- monitoring the bridge scour performance with contingency to closure;
- and/or scheduling timely design and construction of scour countermeasures.

3. Hydraulics Engineering Circular No. 18

HEC-18 contains the stat-of-the-art methodology for designing new bridges over waterways to resist the effect of scour around its foundations and for estimating scour at existing bridges over waterways. The third edition of HEC-18 presents the latest advances in technology including: conversion to the metric system of units; the addition of a gradation correction factor for the pier scour equation; and equation for estimating the correction factor for the flow angle of attack with respect to a pier; an interim procedure for estimating pier scour considering the effect of debris; and updated information on scour detection equipment. In addition, clarification has bed added for: estimating pier scour for exposed footings; pile caps located at different elevations in the flow; the effect of multiple columns skewed to the flow; preliminary information on scour resulting from pressure flow; and criteria for designing the foundation depth of a bridge abutment. Furthermore, HEC-18 presents basic concepts and definitions of scour; guidelines for designing bridges to resist scour, guidelines for estimating scour at existing bridges; guidelines for inspecting bridges for scour; and guidelines for establishing a plan of action for installing scour countermeasures.

4. Hydraulics Engineering Circular No. 20

HEC-20 contains guidelines for identifying stream instability problems that may control the location of a bridge. Factors which affect stream stability are classified as geomorphic, hydraulic, location and design factors. A qualitative assessment process leading to a quantitative analysis is given. A three-level approach is suggested in analyzing stream stability. In addition, HEC-20 presents guidelines for the selection of countermeasures for stream instability.

5. Hydraulics Engineering Circular No. 23

HEC-23 provides guidelines for the selection and design of stream stability and scour countermeasures which have been successfully used by DOTs. A matrix of the different countermeasures giving appropriate use of each is presented in HEC-23. This matrix presents the countermeasures by groups: hydraulics, structural and monitoring. It provides a fast way of identifying which countermeasure is appropriate foi specific condition. In addition, it rates each countermeasure on its functional application, suitable river environment, degree of maintenance needed, and installation experience.

6. Status of the Scour Evaluation Program in the United States

The FHWA initiated semiannual status reports on bridge scour on February 5, 1990. Several years have passed since the FHWA initiated the requirement that DOTs submit a biannual status report. The current status, as of April 15, 1998, reported by DOTs is presented in the following table:

Table 1

EVALUATIONS CATEGORIES	NBI Item 113	EVALUATIONS TOTALS	
		NUMBER	PERCENT
Evaluations Completed			
• Low Risk	4,5,7-9	312,294	80.3%
• Scour Critical	0-3	18,090	4.7%
Evaluations Needed			
• Scour Susceptible	6	58,027	14.9%
• Not Screened	6	315	0.1%
TOTAL EVALUATIONS		388,726	100%
• Evaluation Deferred	6	95,334	

The FHWA has continued its proactive approach towards completing the scour evaluations by encouraging its field offices to continue to work in partnership with DOTs management officials to encourage them to develop an action plan that is responsive towards completion of their scour evaluations. FHWA has also provided DOTs that have not made substantial progress towards completing their scour evaluations with example action plans to assist them in developing a revised action plan for the completion of their scour evaluations.

Since technology for the evaluation of bridges with unknown foundations and bridges subject to the influence of tides was not available at the time of initiating the bridge scour evaluations, FHWA exempted these bridges. To date, 95,334 bridges under these categories are pending an evaluation. These categories are represented in Table 1 as "Evaluations Deferred." Since technology needed to evaluate these bridges is now being phased into practice, FHWA has requested that DOTs begin their evaluations of these bridges, as applicable. Guidelines for evaluating bridges over tidal waterways is currently available thanks to the 12 State Pooled-Fund project, led by South Carolina DOT, which produced a users manual titled "Tidal Hydraulic Modeling for Bridges" dated December 1997. Non-destructive tests for identifying unknown foundations have been evaluated and field tested under the National Cooperative Highway Research Project 21-5 titled "Nondestructive Testing for Unknown Subsurface Bridge Foundations."

7. Conclusion

The FHWA will continue being proactive towards the scour evaluations and design of bridges over waterways. FHWA is currently working on updates to its three major publications, HEC's -18, -20, and -23 to continue to provide DOTs with the state-of the-art technology on scour, stream stability and countermeasures. Furthermore, FHWA, in partnership with AASHTO and NCHRP will participate on a scanning tour with the purpose of visiting other countries to investigate their technology on scour countermeasures for potential application in the United States.

8. References

1. Federal Highway Administration memorandum dated February 26, 1998.
2. Federal Highway Administration memorandum dated March 16, 1998.
3. Richardson, E.V., and Davis, S. R., Hydraulic Engineering Circular No. 18, "*Evaluating Scour at Bridges*," third edition, November 1995.
4. Hydraulics Engineering Circular No. 20, "*Stream Stability at Highway Structures*," second edition, November 1995.
5. Hydraulics Engineering Circular No. 23, "*Bridge Scour and Stream Stability Countermeasures*," July 1997.
6. Zevenbergen, Lyle, et. al., "*Tidal Hydraulic Modeling Users Manual*," December 1997.
7. Federal Highway Administration, "*Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges*," December 1995.

8. National Cooperative Highway Research Project No. 21-5, "*Nondestructive Testing for Unknown Subsurface Bridge Foundations*," August 1995.
9. Morris, J. L. and Pagán-Ortiz, Jorge E., "*Bridge Scour Evaluation Program in the United States,*" ASCE Water Resources Engineering Conference, San Francisco, CA, August 1997.