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BRIDGE SCOUR AND STREAM INSTABILITY COUNTERMEASURES - CURRENT PRACTICE IN THE UNITED STATES

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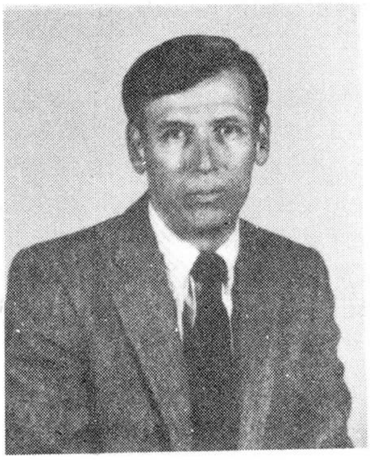

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SUMMARY
This paper provides an overview of the U.S. Federal Highway Administration (FHWA) publication, Hydraulic Engineering Circular Number 23 (HEC-23), "Bridge Scour and Stream Instability Countermeasures" published in July 1997. The HEC-23 manual provides experience, selection, and design guidelines in the form of a countermeasure matrix as an aid to identifying types of countermeasures which have been used by State Highway Agencies for bridge scour and stream instability problems. The matrix supports the selection of appropriate countermeasures considering such characteristics as the functional application, suitable river environment, and estimated allocation of maintenance resources. References are included for each type of countermeasure. Design guidelines for eight countermeasures are also provided in HEC-23.

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1. INTRODUCTION AND MAGNITUDE OF THE PROBLEM

On March 10, 1995, at about 9:00 p.m., the southbound and northbound bridges on Interstate 5 over Arroyo Pasajero in California collapsed during a large flood. Four vehicles plunged into the creek, resulting in seven deaths. The two bridges were built in 1967. Each bridge was approximately 32 meters (m) long and consisted of four concrete-slab spans supported by 3 bents with 6 drilled shafts (0.41 m in diameter). After a period of degradation, the piles were reinforced with a 3.66 m high web wall. Long-term degradation, contraction scour, and local scour from the March 10 flood exposed the piles approximately 7.6 m below the original streambed. This scour depth was 2.4 m below the pile steel reinforcement and they collapsed due to the force of water and debris on the piles and web wall.

The Arroyo Pasajero tragedy is only the latest in a series of bridge failures in the U.S. that have highlighted the national problem of bridge scour. The catastrophic failure of the Schoharie Creek bridge on the New York Thruway in April 1987, which cost ten lives, focused attention in the U.S. on the bridge scour problem; and the subsequent failure of the U.S. 51 bridge over the Hatchie River in April 1989, which cost eight lives, broadened the concern to stream stability problems, as well. The damages and economic costs of the Mississippi River floods in 1993 and floods in Georgia in 1994 underscored the vulnerability of the nation's transportation system to bridge scour and stream instability.

There are more then 575,000 bridges in the U.S. National Bridge Inventory. Approximately 84 percent of these bridges are over water. Highway bridge failures cost millions of dollars each year as a result of both direct costs necessary to replace and restore bridges, and indirect costs related to disruption of transportation facilities. In the U.S., stream instability, long-term streambed aggradation or degradation, contraction scour, local scour, and lateral scour or erosion cause 60 percent of these failures.

Following the failure of the Schoharie Creek bridge in April 1987, the Federal Highway Administration (FHWA) issued a Technical Advisory (TA) that established a national scour evaluation program as an integral part of the National Bridge Inspection Program. To support the implementation of this program, the FHWA contracted for development of a training course on Stream Stability and Scour at Highway Bridges. This course is based on FHWA's Hydraulic Engineering Circular (HEC) No. 18, entitled, "Evaluating Scour at Bridges" [1] and HEC-20, "Stream Stability at Highway Structures" [2]. These two documents, prepared by the authors of this paper, establish the current state-of-the-art for the analysis of bridge scour and stream stability problems in the U.S. The training course, based on these documents, is the principal vehicle for technology transfer to state highway and transportation departments for initial scour screening, follow-on scour evaluation, and design of foundations for new and replacement bridges.

2. SCOUR PROCESSES

Scour is the result of the erosive action of flowing water, excavating and carrying away material from the bed and banks of streams. Different materials scour at different rates. Loose granular soils are rapidly eroded by flowing water, while cohesive or cemented soils are more scour resistant. However, ultimate scour in cohesive or cemented soils can be as deep as scour in sand-bed streams. Scour depths of up to 36 m have been measured at bridge piers, while depths of 5 to 12 m are common.

Total scour at a highway crossing consists of three components: (1) long-term aggradation or degradation, (2) contraction scour, and (3) local scour. Generally, total scour is the algebraic sum of the components. HEC-18 [1] presents procedures, equations, and methods to analyze these scour components in both riverine and coastal areas. The equations for estimating contraction and local scour are based on laboratory experiments with limited field verification, and those recommended in HEC-18 are considered to be the best available for estimating scour depths.

Aggradation and degradation are long-term streambed elevation changes due to natural or man-induced causes which can affect long reaches of a river. Aggradation involves the deposition of material eroded from the channel or watershed upstream of the bridge; whereas, degradation involves the lowering or scouring of the bed of a stream due to a deficit in sediment supply from upstream.

Contraction scour in a river involves the removal of material from the bed across all or most of the channel width in the bridge reach as the result of increased velocities and shear stress on the bed. Contraction scour often occurs when the bridge approach embankments encroach onto the floodplain or into the main channel.

Local scour involves removal of material from around piers, abutments, spurs, and embankments. It is caused by an acceleration of flow and resulting vortices induced by the flow obstructions. Determining the magnitude of both contraction scour and local scour is complicated by the cyclic nature of scour. Both types of scour can be deepest near the peak of a flood, but hardly visible as floodwaters recede and scour holes refill with sediment. This fact contributed to the Schoharie Creek bridge failure.

In addition to the types of scour mentioned above, naturally occurring lateral migration of the main channel of a stream within a floodplain may increase pier scour, erode abutments or the approach roadway, or change the total scour by changing the flow angle of attack at piers. As described in HEC-20 [2], factors that affect lateral stream movement are the geomorphology of the stream, location of the crossing on the stream, flood characteristics, and the characteristics of the bed and bank materials. Lateral instability was the primary cause of the Hatchie River bridge failure.

3. THE NATIONAL RESPONSE

Following the catastrophic failure of the Schoharie Creek bridge, the FHWA established a national scour evaluation program. The 1988 revision of the National Bridge Inspection Standards (NBIS) requires an inspection program that includes procedures for underwater inspection. Specifically, each of the more than 575,000 bridges in the U.S. are to be inspected at regular intervals not to exceed two years (longer intervals can be used when justified and approved). Bridges with underwater members that cannot be evaluated visually for scour and structural integrity must be inspected by divers at least every five years.

Results of each bridge inspection are documented according to the guidelines provided in the "Recording and Coding Guide for Structure Inventory and Appraisal of the Nation's Bridges" [3], more commonly referred to as the "Coding Guide." The Coding Guide requires coding more than 100 separate items at each inspection. Relevant to stream stability and bridge scour are items 60 (Substructure), 61 (Channel and Channel Stability), 71 (Waterway Adequacy), 92 and 93 (Underwater Critical Feature Inspection), and 113 (Scour-Critical Bridges). The two-year cycle bridge inspections are the basis for coding items 60, 61, 71, 92, and 93. Item 113 coding is based on scour evaluations in accordance with the FHWA T 5140.23.

T 5140.23 [4], provides guidance on the development and implementation of procedures for evaluating bridge scour. The TA indicates that every bridge over a waterway, whether existing or under design, should be evaluated for scour in order to determine prudent measures to be taken for its protection. The evaluations are to be conducted by an interdisciplinary team of hydraulic, geotechnical, and structural engineers.

The TA specifies that new bridges must be designed assuming that all streambed material in the computed scour prism has been removed and is not available for bearing or lateral support. Existing bridges found to be scour-critical, either from field observations or from results of the analytical scour evaluation, require development of a Plan of Action. The Plan of Action should include instructions regarding the type and frequency of inspections, particularly as it may relate to the need to close a bridge, if necessary, and a schedule for the timely design and construction of scour countermeasures. Initial scour susceptibility screening was completed for the most part by October 1992. FHWA established January 1997 as the target date for completing scour evaluations of all bridges identified as scour-susceptible. The results of this national bridge scour screening program, as of January 1998, are shown in Table 1.

The number of bridges with "unknown" foundations points to a significant shortcoming of record-keeping in the U.S. in relation to bridge construction programs. An unknown foundation rating means that after office and field reviews, it was uncertain what the structural foundation condition was or what pile lengths were for pile-supported foundations. Thus, for 20 percent of the bridges over water in the U.S., an in-depth scour evaluation cannot be completed. Except for Interstate bridges, unknown foundation bridges are to be monitored until such time as technology becomes available to determine foundation conditions in-situ.

Table 1. National Bridge Scour Screening Program Results.

Categories	Number of Bridges	Percentage
EVALUATION COMPLETE		
Low risk bridges	301,658	62.2
Scour critical	17,030	3.5
EVALUATION NEEDED		
Scour susceptible	66,523	13.7
Not screened	2,580	0.5
EVALUATION DEFERRED		
Unknown foundations	97,599	20.1

4. TECHNOLOGY TRANSFER TO SUPPORT THE NBIS

To support the implementation of bridge scour evaluations for the NBIS, the FHWA, through the National Highway Institute (NHI) contracted for development of a training course on Stream Stability and Scour at Highway Bridges. The FHWA scour evaluation program specifically requires analytical evaluation of scour and appropriate training of inspectors. The procedures described in HEC-18 [1] and HEC-20 [2] are not typically taught in undergraduate engineering programs, and for the most part were not historically incorporated in the bridge design process. Thus, much of this technology is new to engineers and designers charged with completing scour evaluations and/or designing or approving new bridges. Therefore, a training course was needed to facilitate technology transfer from HEC-18 and HEC-20 to bridge design professionals. In addition, bridge inspectors, who are well versed in pavement and steel bridge inspection procedures, need an understanding of scour and stream instability and specific instruction in the factors important to scour-critical bridges in order to provide follow-on scour inspections.

Given this background, the training course, "Stream Stability and Scour at Highway Bridges" was developed during 1988-1990 by the authors of this paper. Course objectives included:

- Identify stream stability and scour problems at bridges
- Understand problems caused by stream instability and scour
- Estimate magnitude of scour at bridge piers and abutments and in the bridge reach
- Propose potential countermeasures for stream instability and scour problems

The course was designed to provide comprehensive training in the understanding and prevention of hydraulic-related failures of highway bridges. The effects of stream instability, scour, and stream aggradation and degradation are covered. Countermeasures to these problems are also provided. HEC-20 provides a multi-level step-wise approach to the problem, including reconnaissance-level geomorphic analyses and basic engineering analysis techniques such as the application of the standard computer models to develop hydraulic variables for scour evaluation. HEC-18 provides specific computational procedures for the various scour components under riverine and tidal flow conditions. A revised metric version of the course (and supporting documents) as well as an abbreviated version of the course designed to meet the specific needs of bridge inspectors were introduced in January 1996. To date, these courses have been presented more than 100 times to State Highway Agencies, federal agency personnel, and consultants.

In July of 1997, the FHWA National Highway Institute issued Hydraulic Engineering (HEC) No. 23, "Bridge Scour and Stream Instability Countermeasures." [5] This document provides experience and selection for a wide range of countermeasures and specific design guidelines for several countermeasures frequently used by State Highway Agencies.

5. SUMMARY

Recent catastrophic bridge failures in the United States and a nation-wide screening of bridges over water for scour vulnerability have focused national attention on the bridge scour problem. In the last ten years, the U.S. has made a substantial investment in field data gathering, research, and development of analytical techniques to determine the scope of the problem, plan remedial actions for existing bridges, and design new bridges to be safe from the effects of scour and stream instability. Training courses on scour and stream stability problems at bridges are available from the Federal Highway Administration National Highway Institute, and Hydraulic Engineering Circulars 18, 20, and 23 issued by the Federal Highway Administration provide technical guidelines for analyzing and evaluating the bridge scour problem in the United States

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