Federal Highway Administration Bridge Scour Practice

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The national attention given to scour-associated highway bridge failures since 1987 coupled with the paucity of press coverage on this issue prior to that time suggests that scour failures are of recent vintage. This is, in fact, not so. For example, 17 highway bridges failed due to scour in the northeastern part of the Nation in the same relative time frame that the Schoharie Creek/New York Throughway bridge lost its battle to scour in April 1987, The Federal Highway Administration and State highway agencies have been conducting research on bridge scour and considering scour in the design process for many years. Periodic highway bridge failures due to scour from the 1950's onward have provided the impetus for continued investigation of the mechanics of such failures with some advances in the design process. It was not, however, until the 1987 Schoharie Creek bridge failure that sufficient national interest focused on the issue to generate the need for national direction within the Federal-aid highway program. In September 1988 the Federal Highway Administration published Technical Advisory 5140.20, Scour at Bridges, to address bridge scour in the overall context of the design process and in the inspection of existing structures within the National Bridge Inspection Standards Program. This paper presents the elements of the bridge scour challenge, the state-of-the-art basis of scour evaluation and countermeasures to protect bridges against scour, all based on the Federal Highway Administration Technical Advisory 5140.20 and Hydraulic Engineering Circular No. 18, both entitled Scour at Bridges. The national status of the program is also presented. All of these issues are presented from the perspective of the Federal Highway Administration's role in the bridge scour program.

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The Big Sioux River was on the rampage. Just upstream of its confluence with the Missouri River, the Interstate 29 crossing had been completed just the year before. One of the two bridges associated with this crossing fails due to scour - 1962. A vital bridge on the Interstate system in the northwestern part of the Nation, Interstate 80 over the John Day River in Oregon, was under siege during a series of storms that struck the entire west coast and fails due to scour - 1964. The northeast was being battered by heavy rains which swelled many streams. Schoharie Creek attacked the New York Thruway bridge over Schoharie Creek which fails due to scour - 1987. As well, a bridge carrying US 51 over the Hatchie River in Tennessee fails due to scour - 1989. Isolated incidents? Failures uncommon to United States highway experience? Flukes? The lack of national attention given to scour-associated highway bridge failures prior to 1987, coupled with the press coverage since then on isolated failures, suggests that scour failures are of recent vintage and limited in number. This is, in fact, not the case. For example, 17 highway bridges failed in the northeast due to scour in 1987 during the same time frame that the Schoharie Creek structure failed.

FEDERAL HIGHWAY ADMINISTRATION TECHNICAL ADVISORY

In September 1988 the Federal Highway Administration (FHWA) published Technical Advisory (TA) 5140.20, Scour at Bridges, to address bridge scour in the overall context of the bridge design process and the inspection of existing structures within the National Bridge Inspection Standards (NBIS) Program. The TA was formulated to provide guidance on developing and implementing a scour evaluation program for 1) designing new bridges to be scour-safe, 2) evaluating existing bridges for vulnerability to scour, 3) using effective scour countermeasures, and 4) improving scour estimating procedures. Scour evaluations of new and existing bridges should be conducted by an interdisciplinary team comprised of structural, hydraulic and geotechnical engineers.

NEW BRIDGES

New bridges over waterways with scourable beds should be designed to withstand the effects of scour without failing for the worst conditions resulting from floods equal to or less than the 100-year flood. All bridge foundations should be checked to ensure that failure does not occur for scour resulting from a superflood; i.e., a 500-year event. The geotechnical analysis should be performed on the basis that all stream bed material in the scour prism above the total scour line for the scour design flood has been removed and is not available for bearing or lateral support with a safety factor of from 2 to 3. The geotechnical analysis for the superflood should incorporate a safety factor of 1.0. The FHWA publication Hydraulic Engineering Circular (HEC) No. 18, Scour at Bridges, discussed below, should be followed in conducting and documenting the results of scour evaluation studies.

EXISTING BRIDGES

All existing bridges over waterways with scourable beds should be evaluated for the risk of failure from scour during the occurrence of a 500-year flood with a geotechnical safety factor of 1.0.

The three basic elements of the TA relative to the NBIS Program for existing structures are 1) screen all existing bridges to prioritize the order of scour evaluations on the basis of scour susceptibility, 2) evaluate scour of all bridges with scourable beds to determine whether the bridges are scour critical, and 3) establish a plan of action for each identified scour critical bridge. State highway agencies have been requested by FHWA to have all existing bridges screened by March 1991. No date has been suggested for completion of the evaluation phase of the process. A scour critical bridge is defined as one that is in imminent danger of scour failure based on analyzed conditions, using state-of-the-art scour technology. The FHWA expects scour procedures set forth in HEC No. 18 to be used for all Federal-aid highway design and within the NBIS Program for evaluating existing bridges. A State highway agency can use other technology if it is judged by FHWA to be sound design practice. The scour procedures were initially issued as an attachment to the TA and entitled "Interim Procedures for Evaluating Scour at Bridges" in September 1988. A plan of action for each structure determined to be scour critical should include monitoring its scour performance with contingency for closure and/or scheduling timely design and construction of scour countermeasures. The HEC No. 18 scour procedures discussed below should be followed in conducting and documenting the results of scour evaluation studies.

HYDRAULIC ENGINEERING CIRCULAR NO. 18

These procedures contain the state-of-the-art technology for evaluating scour at highway bridges. Chapter 1 gives the background of the problem and the general state of knowledge. Basic concepts and definitions are presented in Chapter 2. Chapter 3 gives recommendations for designing bridges to resist scour. Chapter 4 presents equations for calculating scour depths within bridge waterways, at piers and abutments. Chapter 5 provides procedures for conducting scour analyses and evaluations at existing bridges. Chapter 6 presents guidelines for inspecting bridges for scour. Chapter 7 gives a plan of action for installing countermeasures to strengthen bridges that are considered vulnerable to scour.

CHAPTER 1 - INTRODUCTION

The most common cause of bridge failures is from floods, and the scouring of bridge foundations is the most common cause of damage to bridges during floods. Studies by FHWA in 1973 and 1978 indicated damage to bridges about equally distributed between piers and abutments. Transportation Research Record 950 contains a number of case histories of scour problems at bridges. About 85 percent of the 577,000 bridges in the National Bridge Inventory are over waterways. Some risk of scour failure must be accepted from future floods in this large target population since it is not economically feasible to install scour countermeasures at all sites. Every bridge over a scourable stream should, however, be assessed as to its vulnerability to scour.

It was well recognized when the TA was published in 1988 that the recommended scour technology lacked field verification. This is still true. While this technology represents the best available methodology, experience with the scour equations since that time clearly shows that further research and development is vital to the pursuit of more satisfactory scour solutions. This is being accomplished through monitoring of bridge sites by a number of State highway agencies and through research studies by FHWA and others. The U. S. Geological Survey has been retained by FHWA to evaluate the scour data from the individual state monitored field scour studies for the purpose of validating improvements in the scour prediction equations. Additional State highway agencies are encouraged to initiate Highway Planning and Research studies for obtaining field measurements of scour.

CHAPTER 2 - BASIC CONCEPTS AND DEFINITIONS OF SCOUR

Total scour at a highway crossing resulting solely from a bridge is comprised of two components. These are 1) contraction scour caused by the constriction of the waterway through the crossing and 2) local scour generated by the obstruction of piers and abutments. Degradation, aggradation and lateral migration in the reach of waterway adjacent to the crossing should also be considered. Scour produced by the bridge is determined by the procedures in HEC No. 18 while bed and bank movement unique to the adjacent channel reach can be evaluated from the FHWA publications HEC No. 20, Stream Stability at Highway Structures, and Highways in the River Environment. The concept of clear-water and live-bed scour is discussed in conjunction with bridge scour.

CHAPTER 3 - DESIGNING BRIDGES TO RESIST SCOUR

Hydraulic studies of bridge sites are a necessary part of the preliminary design of bridges. These studies should address both the sizing of the waterway area and foundation design to resist scour. The scope of the analysis is commensurate with the importance of the highway and the consequences of failure. Since the best current technology is based on laboratory model studies, a designer must apply sound engineering judgement in comparing scour results with available hydraulic data to arrive at a practicable foundation design. Available hydraulic data include 1) performance of contiguous existing structures during past floods, 2) effects of regulation and control of flood discharges, and 3) the relative stability of the stream reach. A bridge hydraulic design procedure is presented which is to be accomplished for both the 100- and 500-year floods. Scour is part of the design procedure. A checklist of design considerations provides the practitioner with valuable insights to lessen the risk of failure.

CHAPTER 4 - ESTIMATING SCOUR AT BRIDGES

Before the various scour estimating methods for determining contraction and local scour can be applied, it is necessary to 1) obtain the rigid boundary channel hydraulics; 2) estimate the long-term stream bed changes; 3) adjust the rigid boundary channel hydraulics to reflect the stream bed elevation changes; and 4) compute the bridge hydraulics. A scour design approach is presented which is the basis for the scour portion of the overall bridge hydraulic design process documented in Chapter 3.

Contraction scour is computed by comparing the conditions at an actual bridge site to those in four typical bridge site model solutions and choosing the most appropriate. Abutment scour solutions have proved to be the least reliable of the scour solutions within HEC No. 18. The original Interim Procedures recommended use of a matrix of field site conditions with the potential use of seven differing solutions for abutment scour. HEC No. 18 permits consideration of a single solution with the alternative of using the seven equations recommended in 1988. Riprap protection of abutments is rather common design practice in the Nation. Should it be determined in the original design process or in an evaluation of an existing bridge that riprap will protect an abutment for the superflood, it may be unnecessary to determine abutment scour. A single pier scour equation is presented. Little refinement has evolved in plotting total scour depths based on the contraction, abutment and pier scour solutions other than summing the appropriate components. This chapter also contains sample solutions.

CHAPTER 5 - ESTIMATING THE VULNERABILITY OF EXISTING BRIDGES TO SCOUR

A prodigious amount of work is necessary to accomplish an evaluation of the 577,000 bridges on the National Bridge Inventory. Some State highway agencies are well into this endeavor while others are just getting started. The former group are commended for their diligent efforts. The others are encouraged to persevere. A recommended procedure for accomplishing this gigantic task is presented. The short-term goal is to evaluate existing bridges with known problems. The long-term goal is to evaluate all existing bridges. Background information on many bridges is lacking. Foundation type and depth may be unknown. Unless a bridge lacking foundation data has a visible scour problem, State highway agencies may set such structures aside for potential future evaluation. The FHWA is investigating a risk management approach as well as potential instrumentation for addressing this issue.

CHAPTER 6 - INSPECTION OF BRIDGES FOR SCOUR

The factors to be considered in scour evaluation require a broader scope of study and effort than those considered in a bridge inspection. Whereas the major purpose of bridge inspection is to identify changed conditions which may reflect an existing or potential problem, a scour evaluation is an engineering assessment of what might possibly happen in the future and what steps can be taken now to eliminate or minimize future damage. The NBIS Program involves inspections on a 2-year cycle of the 577,000 bridges in the National Bridge Inventory. The FHWA December 1988 publication "The Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges" specifies the bridge and channel hydraulics and scour data that are evaluated and reported within the NBIS. Typically the inspections are accomplished by bridge engineers. Item 60, Substructure; Item 61, Channel and Channel Protection; Item 71, Waterway Adequacy; and Item 113, Scour Critical Bridges, are included. This chapter presents material covering bridge inspection for all of these items with emphasis on Item 113. Should an inspector observe conditions of an emergency or potentially hazardous nature, there must be a positive means of promptly communicating these findings to proper agency personnel. Hydraulic and geotechnical engineers should be informed immediately of existing or potential problems so action can be taken to further evaluate the bridge.

CHAPTER 7 - PLAN OF ACTION FOR INSTALLING SCOUR COUNTERMEASURES

Scour countermeasures are features incorporated into the original bridge design or at a later date to make a bridge less vulnerable to damage or failure. Certainly the best solution for original design is to set the foundation sufficiently below the total scour level that the potential for failure is minimized. Other enhancements to scour reduction or minimization during initial design are streamlining bridge elements to minimize obstructions to flow and locating a bridge to avoid adverse flood flow patterns. In developing a plan of action for an existing scour critical bridge, considerations are 1) monitoring the site with contingency for closure; 2) installing temporary countermeasures such as riprap with monitoring during high flows; 3) scheduling countermeasure construction; and 4) designing countermeasures. Typical countermeasures included are riprap, guide banks (spur dikes), and channel improvements. Design procedures or references are presented for the countermeasures.

STATUS OF THE BRIDGE SCOUR PROGRAM

The FHWA initiated biannual status reports on bridge scour in 1990. State highway agencies are reporting data on the numbers of bridges 1) over waterways; 2) screened as low risk, scour susceptible, and with unknown foundations; 3) analyzed for scour; 4) scour critical; 5) with countermeasures; and 6) monitoring planned. Through March 1990, 24 percent of the 475,731 bridges reported over waterways had been screened. Of those screened, 73,407 were assessed as safe, 23,057 were determined to be scour susceptible, and 17,174 had been identified with unknown foundations. About 8 percent of the scour susceptible bridges had been analyzed for scour. About 35 percent of the bridges analyzed were scour critical. This represents data from the State highway agencies' March 31, 1990 status reports. Consistently improved information will be forthcoming from subsequent reports. Some States are doing all of the scour evaluations in-house while others are contracting much of the work to consultants. As well, the U. S. Geological Survey is accomplishing some of the work for States.

SUMMARY

The FHWA and State highway agencies as well as other parties have conducted research for many years to improve the estimating procedures for determining scour at bridges. The National Cooperative Highway Research Program

Synthesis of Highway Practice No. 5, "Scour at Bridge Waterways," 1970, summarized technology available at that time which was a mixture of analytical and empirical methodology. Significant research work within this discipline has been accomplished since that time. Even so, the best available current technology represented by HEC No. 18 needs improvement. Ongoing and proposed research within the highway hydraulic community addresses scour needs and will result in improved methodology. The incorporation of scour within the overall bridge hydraulic design process is well on its way. Within the NBIS Program, the evaluation of scour for existing bridges with acknowledged scour problems is also well on its way. The evaluation of a large percentage of existing bridges is, however, just getting underway. This endeavor will require the training of additional hydraulic engineers, professional dedication in the identification and treatment of scour critical bridges, and a greater commitment of resources by State highway agencies in its accomplishment.

REFERENCES

"Scour at Bridge Waterways," NCHRP Synthesis of Highway Practice No. 5, Transportation Research Board, Washington, D. C., 1970

Second Bridge Engineering Conference, Volume 2, Transportation Board Record 950, Transportation Research Board, Washington, D. C., 1984

Technical Advisory 5140.20, "Scour at Bridges," Federal Highway Administration, Washington, D. C., 1988

"Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges," Federal Highway Administration, U. S. Department of Transportation, Washington, D. C., 1988

Hydraulic Engineering Circular No. 18, "Scour at Bridges," Federal Highway Administration, U. S. Department of Transportation, Washington, D.C., 1990

Hydraulic Engineering Circular No. 20, "Stream Stability at Highway Structures," Federal Highway Administration, U. S. Department of Transportation, Washington, D. C., 1990

E. V. Richardson, D. B. Simons, P. Julien, "Highways in the River Environment," Federal Highway Administration, U. S. Department of Transportation, Washington, D. C., February 1990