JULY 2017

NCHRP PRACTICE-READY SOLUTIONS FOR

Bank Erosion and Bridge Scour

NCHRP NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

RESEARCH TOPIC HIGHLIGHTS

INTRODUCTION

Bank Erosion and Bridge Scour: NCHRP Research Improves Prediction and Prevention

SECTION 1

Bank Erosion Countermeasures

SECTION 2

Bridge Scour Countermeasures

SECTION 3

Predictive Equations for Scour

SECTION 4

Scour Special Cases

Bank Erosion and Bridge Scour: NCHRP Research Improves Prediction and Prevention

The most common cause of bridge failure is scour, which occurs when moving water erodes the soil and rock from around bridge piers and abutments, or from the banks or bed of the river channel spanned by the bridge. The sediment surrounding piers and abutments supports their foundations and is vital to the stability of bridges.

Consequently, one of the most important elements of bridge design is the ability to predict the effects of scour so that foundations can be designed to withstand these effects over the life of the bridge. Such predictions require the use of complex hydraulic equations, which are set out in FHWA's *Hydraulic Engineering Circular No. 18 (HEC-18)*, the go-to resource for designing bridges to withstand bridge scour. A second circular, *HEC-20*, addresses channel migration and stream stability. A third, *HEC-23*, details the design and use of countermeasures to prevent scour and stream instability. The most common countermeasure used is riprap—rock placed at piers, abutments, and stream banks to shield them from the flow of water.

After a series of scour-related bridge failures during floods in the 1980s, TRB's National Cooperative Highway Research Program (NCHRP) embarked on several research projects to better quantify and model the mechanisms of bridge scour and to develop effective, efficient countermeasures to its occurrence. This research led to a wealth of new knowledge about scour, followed by major updates to *HEC-23* in 2009 and to *HEC-18* and *HEC-20* in 2012.

The projects described here are selected from that research. Also presented are recent and ongoing efforts that will lead to further improvements of scour estimates—along with updates to FHWA's circulars—in the coming years.

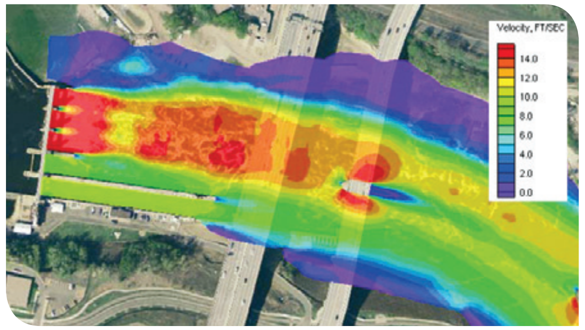

Image courtesy of Ayres Associates

Scour is difficult to model and predict because of the randomness in hydraulic phenomena.

Image courtesy of California Department of Transportation

WHY RESEARCH SCOUR?

Bridge scour is a complex and nuanced hydraulic phenomenon, yet estimating it is critical to preventing bridge failures. NCHRP research formed the foundation for significant advances in this field. NCHRP administered research that:

- Investigated methods for **preventing channel migration and stream bank erosion**, such as vegetation-based countermeasures, in-stream flow control structures, and geotextile filters.
- Established **practical guidance** on the use of bridge scour countermeasures at piers and abutments, and developed specifications for riprap design.
- Significantly **improved the accuracy of models** for estimating bridge scour at abutments and piers.
- Investigated many of the numerous **factors that affect bridge scour**, including debris, rock foundations, and wide and long skewed piers, and established methods to account for these factors as part of a calculation of total scour.

"Twenty years ago, there was a huge gap in bridge scour research. Since then, NCHRP has done an excellent job tackling the highest priority unknowns in this area."

—Peter Lagasse, Ayres Associates

SECTION 1

Bank Erosion Counter-measures

NCHRP Project 24-16, Methodology for Predicting Channel Migration. See *NCHRP Report 533* and CD-ROM set *CRP-CD-49*.

NCHRP Project 24-33, Development of Design Methods for In-Stream Flow Control Structures. See *NCHRP Report 795*.

NCHRP Project 24-39, Evaluation and Assessment of Environmentally Sensitive Stream Bank Protection Measures. See *NCHRP Report 822*.

NCHRP Project 24-40, Design Hydrology for Stream Restoration and Channel Stability at Stream Crossings. *NCHRP Research Report 853*, forthcoming.

NCHRP Project 24-42, Underwater Installation of Filters Systems for Scour and Other Erosion Control Countermeasures. In progress.

Predicting river channel migration and deploying bank erosion countermeasures, such as placing rocks and vegetation along banks to protect the soil from the flow of water, are critical to preventing bridge scour.

Predicting Channel Migration. Predicting channel migration has historically been difficult to do, even with the best computer models. In *NCHRP Report 533*, researchers provide engineers with a practical and empirical GIS-based methodology for predicting channel migration. CD-ROM set *CRP-CD-49* has ArcView extensions to streamline the measurement and analysis of migration data and aid in making predictions.

Protecting stream banks from erosion is critical to preventing scour at nearby bridges.

Image courtesy of New Jersey Department of Environmental Protection

Using Environmentally Friendly Methods to Prevent Bank Erosion. Use of vegetation can be an environmentally sensitive and aesthetic way to prevent stream bank erosion. NCHRP administered research to evaluate existing guidelines for the design, installation, monitoring, and maintenance of environmentally sensitive stream bank stabilization and protection measures. The resulting *NCHRP Report 822* provides updated design guidelines for three widely used treatments: live siltation and live staking with a rock toe, vegetated mechanically stabilized earth, and vegetated riprap.

Validating Design Methods for In-Stream Flow Control Structures. Natural resource agencies have encouraged state DOTs to use environmentally sensitive measures to protect rivers from erosion and scour. Among the measures suggested is construction of shallow, in-stream, low-flow structures across all or part of a stream channel. Researchers studied five of the most commonly used in-stream countermeasures in laboratory-scale flume experiments (presented in *NCHRP Report 795*). With criteria validated by engineering, the report is helping engineers to reduce the risk of failure for these countermeasures and increase their cost-effectiveness.

Designing Stream Restoration Projects. NCHRP Project 24-40 is developing a scientifically supported method for predicting how the regular flooding of rivers—caused by storms—affects their cross section and direction. The final report will include quantitative methods for estimating the impact of land use change, which is often occurring upstream from stream restoration work.

Ensuring the Proper Use of Countermeasure Filters. Through NCHRP Project 24-42, researchers are developing specific guidance on the design, construction, and maintenance of filters—usually geotextiles—that are used with countermeasures to prevent stream bank erosion and the resulting instability. The final report will help educate transportation agencies and contractors about the value and use of these filters, which are often omitted during construction.

Image courtesy of Ayres Associates

In NCHRP Project 24-39, researchers grew willow trees to maturity in a greenhouse to test how well they protect embankments from scour.

SECTION 2

Bridge Scour Countermeasures

NCHRP Project 24-07(2),Counter-measures to Protect Bridge Piers from Scour. See *NCHRP Report 593*.

NCHRP Project 24-18(A), Counter-measures to Protect Bridge Abutments from Scour. See *NCHRP Report 587*.

NCHRP Project 24-23, Riprap Design Criteria, Specifications, and Quality Control. See *NCHRP Report 568*.

Scour countermeasures are at once necessary and costly, making their selection, design, and construction important considerations for transportation agencies. NCHRP research has been critical in establishing practical guidance for using scour countermeasures.

Selecting and Designing Bridge Pier Scour Countermeasures. To develop guidance for using countermeasures, researchers conducted laboratory testing on small- and prototype-scale models that provided significant insight into the performance of various countermeasures. *NCHRP Report 593* includes practical selection criteria for bridge pier scour countermeasures; specifications for their design and construction; and guidelines for their inspection, maintenance, and performance evaluation. The report is accompanied by a spreadsheet containing an interactive version of the countermeasure selection methodology.

Validating Abutment Scour Countermeasures. Bridge abutments and their approach embankments are the most commonly damaged bridge components during floods. Typical methods to protect these components—mechanically stabilizing abutment slopes or realigning upstream flow—have not been completely successful. Researchers addressed the need for better countermeasure designs and selection criteria for two common forms of bridge abutments: the wing-wall and the spill-through. *NCHRP Report 587* provides validated selection criteria and guidelines for the design and construction of countermeasures to protect bridge abutments and approach embankments from scour damage. Solutions include flow-altering devices, such as guide banks and weirs, and nontraditional abutment scour countermeasures, including articulated or tied mats and blocks.

Improving Riprap Design. Before NCHRP research, most states had differing specifications for classifying riprap size and gradation, and construction practices were sometimes ineffective. *NCHRP Report 568* provides engineers with design guidelines; material specifications and test methods; construction specifications; and construction, inspection, and quality control guidelines for riprap at streams, riverbanks, bridge piers, and abutments.

Riprap placed around bridge piers can provide long-term protection against bridge scour.

Predictive Equations for Scour

NCHRP Project 24-20, Prediction of Scour at Bridge Abutments. See *NCHRP Research Results Digest 334*.

NCHRP Project 24-27(01), Evaluation of Bridge Scour Research: Pier Scour Processes and Predictions. See *NCHRP Web-Only Document 175*.

NCHRP Project 24-27(02), Evaluation of Bridge-Scour Research: Abutment and Contraction Scour Processes and Prediction. See *NCHRP Web-Only Document 181*.

NCHRP Project 24-27(03), Evaluation of Bridge-Scour Research: Geomorphic Processes and Predictions. See *NCHRP Web-Only Document 177*.

NCHRP Project 24-47, Revised Clear-Water and Live-Bed Contraction Scour Analysis. In progress.

Image courtesy of Lake County, Minnesota

Abutments and embankments are the most commonly damaged bridge components during floods.

NCHRP research has led to significant advances in the accuracy of models used to estimate bridge scour and determine the design depth of bridge foundations, resulting in major updates to *HEC-18* and *HEC-20*. Ongoing research is set to further improve these estimates.

Improving Abutment Scour Prediction. Researchers investigated the mechanics of scour around abutments to improve techniques for predicting abutment scour and designing bridge foundations with a sufficient depth to account for them. Before this project, scour equations were less complex and did not sufficiently allow for a variety of factors, such as abutment design, the changing geometry of embankments due to scour, and the type of soil involved. *NCHRP Research Results Digest 334* provides improved abutment scour prediction equations that reduce the overprediction of scour at abutments and prevent costly overdesign of foundations.

Conducting Nationally Coordinated Research. In the aftermath of several scour-related bridge failures in the 1980s, NCHRP—together with FHWA and the U.S. Geological Survey—embarked on coordinated research programs to quantify and model the mechanisms of bridge scour and develop effective, efficient countermeasures to its occurrence. NCHRP initiated three projects to explore these mechanisms and to provide recommendations for updating AASHTO drainage manuals and FHWA's circulars. Completed in 2011, these projects formed the foundation for major steps forward in scour prediction methods. Results from these projects are presented in the following online resources:

- *NCHRP Web-Only Document 175* examines how different parameters, such as variations in flow and sediment, influence scour and the design scour depth for piers. The report also evaluates the adequacy of existing methods for predicting pier scour.

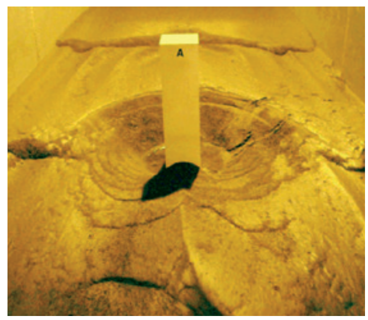

Image from NCHRP Report 593

Hydraulic laboratory tests on scale model bridge piers have helped researchers determine how riprap affects scour.

- *NCHRP Web-Only Document 181* identifies the research needed to fill the gaps in stream stability analysis practice.
- *NCHRP Web-Only Document 177* distinguishes between erodible and solid abutments when using scour formulas and introduces the importance of geotechnical failure caused by scour.

Improving Clear-Water and Live-Bed Contraction Scour Analysis. Currently, researchers are developing clear-water and live-bed contraction scour equations suitable for use in risk-based bridge design. These equations allow for a wide range of hydraulic conditions, contraction ratios, bed materials, and gradation uniformities, which will ultimately allow engineers to estimate a more realistic scour depth. The project is expected to be completed in 2019 and lead to an update of contraction scour equations in *HEC-18*.

Scour Special Cases

NCHRP Project 24-26, Effects of Debris on Bridge-Pier Scour. See *NCHRP Report 653.*
NCHRP Project 24-29, Scour at Bridge Foundations on Rock. See *NCHRP Report 717.*
NCHRP Project 24-32, Scour at Wide Piers and Long Skewed Piers. See *NCHRP Report 682.*
NCHRP Project 24-34, Risk-Based Approach for Bridge Scour Prediction. See *NCHRP Report 761.*
NCHRP Project 24-37, Combining Individual Scour Components to Determine Total Scour. In progress.

Bridge scour is an enormously complex phenomenon that is influenced by numerous variables. Several NCHRP projects have addressed these factors and their influence on total scour.

Impact of Debris. Composed primarily of tree trunks and limbs, waterborne debris often accumulates at bridges during floods and can obstruct, constrict, or redirect water flow past the bridge, sometimes resulting in significant bridge foundation scour. *NCHRP Report 653* provides guidelines for estimating the quantity of accumulated debris based on the density and type of woody vegetation and the riverbank condition upstream.

Bridge Foundations on Rock. *NCHRP Report 717* presents an updated methodology along with new design and construction guidelines for estimating scour on bridges with foundations built on rock rather than on soil. The new method no longer overestimates the extent and depth of scour in rock, which had previously required very expensive and difficult excavation.

Scour at Wide and Long Skewed Piers. Existing methods for predicting local scour at bridge piers, including those described in *HEC-18*, were developed on the basis of small-scale laboratory studies and do not consider factors relevant to wide piers and long skewed piers. *NCHRP Report 682* provides improved methods for what had been overpredicted local scour at such piers.

A Risk-Based Approach to Bridge Scour Prediction. Incorporating the uncertainties related to bridge scour prediction into hydraulic models can help improve scour estimates. In this project, researchers integrated Monte Carlo simulation into the most widely used hydraulic modeling software, HEC-RAS. The method described in *NCHRP Report 761* allows engineers to quantify their confidence in a hydraulic model's estimate instead of relying on intuition.

Estimates of Total Scour. Current *HEC-18* guidance suggests that total scour should be estimated by summing the individual components of scour—including contraction scour and local scour at piers and abutments. In NCHRP Project 24-37, researchers are trying to improve these calculations by determining the relationship between combined, independent estimates of the individual scour components and the total scour actually observed.

The accumulation of debris at bridges narrows the waterway, increasing water velocity and accelerating scour.

Image courtesy of Lake County, Minnesota

The National Academies of
SCIENCES • ENGINEERING • MEDICINE

TRB
TRANSPORTATION RESEARCH BOARD

CONTACT US

For more information about NCHRP research on bank erosion and bridge scour, please contact:

Waseem Dekelbab
Senior Program Officer
Transportation Research Board
wdekelbab@nas.edu
202-334-1409

Cover image courtesy of Minnesota DOT