IMAGES: UTAH DOT FOR NCHRP PROJECT 24-29

Scour and Safe Bridges

Advancing the State of the Practice

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(*Above*:) Composite photograph of the September 2003 flood flow in Montezuma Creek, San Juan County, Utah, which eroded the claystone and sandstone abutments of the SR-262 Bridge. Water flowed from left to right over a 6-foot-high (2-m-high) knick point to the left of the shadow of the bridge railing crossing the stream. The bridge has a 66-foot-long (20-m-long) span.

Scour is a process of erosion caused by the flow of water, air, or ice over susceptible earth materials. The effects of past glacial scour are visible in some locations, but glacial scour is not an important concern in day-to-day activities. Similarly, some soft geologic formations reveal features sculpted by flowing air, and sandstorms in parts of the southwestern United States and elsewhere can pit car windows and paint. Nevertheless, wind scour is not a concern, because most materials are not susceptible to erosion by the low forces of flowing air.

Flowing water, however, can have sufficient energy to cause substantial erosion and to move blocks of rock. Therefore, scour produced by rivers and streams flowing under highway bridges is of the greatest concern to society.

Types of Water Scour

Flowing water causes three types of scour:

- **Degradation scour**, which occurs with the general lowering of stream channels;
- **Contraction scour**, which occurs when water moves faster through narrow reaches in stream channels, as at many bridge crossings; and
- **Local scour**, which occurs when water flows around obstructions in channels, generating complex flow patterns, increased flow velocities, and turbulence.

Sandy soil—particularly fine-grained sand—is most susceptible to scour, because flowing water can lift and transport the grains. Larger grain sizes, such as gravel and cobbles, require more energy to lift and transport, and smaller grain sizes, such as silt and clay, can exhibit cohesion that can be less susceptible to erosion.

Evaluating Scour

Hydraulic engineers evaluate scour at bridge sites by characterizing the flow of water in the channel upstream of the bridge, calculating the changes as the flow moves through the bridge opening, and estimating the flow properties in the channel downstream of the bridge. The evaluation estimates the scour prism—that is, the depth of scour under the bridge—and generally assumes that the channel is composed of sand.

The calculated depth of the scour hole in the sand adjacent to the bridge foundations determines whether the bridge is scour-stable or scour-critical. A multidisciplinary team of structural, hydraulic, and geotechnical engineers will confirm a scour-

PHOTO: MARK ANDERSON, U.S. GEOLOGICAL SURVEY

In 2007, flash flooding near Hermosa, South Dakota, caused scouring of bridge abutments at Battle Creek.

PHOTO: U.S. ENVIRONMENTAL PROTECTION AGENCY

US-34 in Greeley, Colorado, was breached by South Platte River floodwaters in late 2013. Floods and other hydrology effects sometimes are related to climate change.

critical assessment—that is, that the scour hole is a threat to the stability of the bridge.

State department of transportation (DOT) personnel inspect bridges regularly. They review bridge plans and other engineering information before visiting a bridge site. The inspectors examine the channel upstream and downstream of the bridge to assess the general conditions and to identify any features of erosion or sediment deposition and any accumulations of tree branches or other debris.

The evaluation also notes construction or changes in development in the upstream drainage basin that can alter the hydrology from the conditions assumed in forecasting the stream flow. The effects of climate change increasingly are considered in terms of potential influence on hydrology and stream flow—for example, wildfire caused by drought in the drainage basin above a bridge can increase runoff and sediment yield in tributary channels to the stream that passes under the bridge.

Certain characteristics of the stream channel and the bridge can influence scour response, including the locations of channel bends, the orientation of the bridge crossing, and the shape of the bridge piers. Inspectors examine the channel and the banks adjacent to and under the bridge for scour holes and other evidence of scour. Scour holes can form rapidly in sandy soil during flood flows, but these often are refilled with the same type of sandy soil when the flood flows dissipate; this makes detection of the scour features more challenging.

Scour Countermeasures

Countermeasures to reduce and manage the impacts of stream instability and scour on bridges include hydraulic, structural, and biotechnical features:

- ◆ The hydraulic approach focuses on controlling the water that flows past a bridge;
- ◆ The structural approach focuses on strengthening the bridge or on armoring the stream channel or banks; and
- ◆ The biotechnical approach focuses on stabilizing stream banks through the erosion resistance of vegetation.

Monitoring scour development from flood to flood is a method of scour management used for bridges with certain characteristics. The Federal Highway Administration's (FHWA's) Hydraulic Engineering Circular (HEC) 23, *Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Design Guidance* describes this approach.[1] The FHWA website offers technical resources for evaluating and dealing with scour,[2] and the Transportation Research Board (TRB) website has several resources posted.[3]

Oversight of Bridges

FHWA maintains the National Bridge Inspection Standards (NBIS) and oversees other regulatory policies and programs for the nation's bridges. Recent high-profile bridge failures, however, led the U.S. Congress to take a closer look at the safety, management, and oversight of bridges.

In a conference report, Congress recommended that FHWA "use a more risk-based, data-driven approach to its bridge oversight" to improve bridge safety.[4] Congress stated it would monitor FHWA's

Major floods can cause a bridge deck to become submerged, introducing an additional scour process that can erode the boundary at a pier site and increasing the net depth of the scour.

PHOTO: NCHRP WEB-ONLY DOCUMENT 175: *EVALUATION OF BRIDGE SCOUR RESEARCH—PIER SCOUR PROCESSES AND PREDICTIONS*

[1] https://www.fhwa.dot.gov/engineering/hydraulics/pubs/09111/.

[2] www.fhwa.dot.gov/engineering/.

[3] www.trb.org/Main/Search2.aspx?q=scour.

[4] House Report 111-366: Departments of Transportation and Housing and Urban Development and Related Agencies Appropriations Act, 2010.

PHOTO: FONDRIEST ENVIRONMENTAL

Researchers with Wayne State University and Lawrence Technological University collect field-scale pier scour data for Michigan DOT. State DOT personnel and affiliated researchers inspect bridges regularly for scour.

progress in identifying new approaches to bridge oversight, in completing the initiatives, and in achieving results. Congress directed FHWA to apply funds to focus on and perform these activities.

FHWA undertook a combination of activities that contribute to four primary outcomes:

- More rigorous oversight of bridge safety,
- Full compliance with the NBIS by all states,
- Improved information for safety oversight and condition monitoring, and
- Personnel qualified and equipped for bridge inspection.

Because hydraulic issues remain a leading cause of bridge failures, FHWA included efforts in conjunction with each of these activities to collect, understand, and deploy recent and robust guidance and techniques for accepted hydraulic and waterway-related practice.

Developing Resources

FHWA significantly revised HEC 18, *Evaluating Scour at Bridges*,[5] and HEC 20, *Stream Stability at Highway Structures*,[6] last updated in 2001, and released the revisions in 2012. At the same time, FHWA's National Highway Institute (NHI) revised the training course on Stream Stability and Scour at Highway Bridges (Course 135046) to reflect changes in the two hydraulic engineering circulars.

Over the past 10 years, research activities sponsored under TRB's National Cooperative Highway Research Program (NCHRP) have advanced the state of practice in bridge scour and stream stability analyses. These contributions to bridge scour technology also have been incorporated into the 2012 revisions to HEC 18 and 20.

Scour-Caused Bridge Failures

On March 10, 1995, at about 9 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 river, and seven people were killed. Built in 1967, each bridge was approximately 122 feet long and consisted of four concrete-slab spans supported by cast-in-place pile bents.

California DOT, in cooperation with FHWA and the U.S. Geological Survey, investigated the conditions that led up to the collapse. Findings indicated that the stream channel had degraded and, during the flood event, a combination of contraction scour and local pier scour undermined the stability of the structures. Stream channel changes in the vicinity of the bridges also had played a role in the failure.

This tragedy is only one example of bridge failures that have highlighted the national problem of scour. Stream instability, long-term stream aggradation or degradation, contraction scour, local scour, and lateral channel migration or erosion cause 60 percent of all U.S. highway bridge failures. In addition to the human toll, the failures cost millions of dollars in direct expenditures for replacement and restoration, as well as in substantial indirect costs from the disruption of transportation facilities.

[5] www.fhwa.dot.gov/engineering/hydraulics/pubs/hif12003.pdf.
[6] www.fhwa.dot.gov/engineering/hydraulics/pubs/hif12004.pdf.

Scour hole after the failure of the I-90 Bridge over Schoharie Creek, New York, April 5, 1987. The water flow was from right to left; cobbles and boulders on the creek bed provided an armoring layer that protected the underlying hard glacial till from erosion by flood flows at less than 20,000 cubic feet per second (566 cubic meters per second). Photo is from the forensic report prepared by Resource Consultants and Colorado State University in 1987 for the National Transportation Safety Board and the New York State Thruway Authority. (See also www.fhwa.dot.gov/engineering/hydraulics/pubs/09111/page05.cfm#figure517.)

Another example of national importance occurred in April 1987 during a near-record flood; the catastrophic failure of the Schoharie Creek Bridge on the New York State Thruway (Interstate 90) claimed 10 lives. The National Transportation Safety Board (NTSB) determined that the probable cause was severe scour in the glacial till beneath the spread footings of the 35-year-old bridge.

The scour hole that caused the failure of the Schoharie Creek bridge is shown in the photograph above. The cumulative effect of local pier scour, particularly in the previous 10 years, was considered the most significant hydraulic factor contributing to the failure, not the 1987 flood.

In response to the findings, FHWA issued a mandate to perform scour evaluations of all bridges over water. A summary released by FHWA nearly 10 years ago stated that the mandated evaluations by state DOTs had identified 26,471 of the 484,546 U.S. highway bridges over waterways as scour-critical.

Establishing Guidance

After the Schoharie Creek Bridge failure, FHWA established a national scour-evaluation program as an integral part of the National Bridge Inspection Program and developed the first editions of HEC 18 and HEC 20. In the past 20 years, the two documents, enhanced with updates, have established FHWA's recommended guidance for analyzing bridge scour and stream stability problems.

NHI's training course (NHI 135046) debuted in 1990 and has been presented more than 200 times to state DOTs and other bridge owners. The course has served as an important source of technology transfer on bridge scour and stream instability problems.

The 1989 revision and subsequent updates of the NBIS require procedures for underwater inspection. Each of the approximately 500,000 U.S. bridges over water must be inspected every two years—although longer intervals can be approved when justified. At least every five years, qualified divers must inspect the underwater structural members of bridges that state DOT personnel cannot evaluate visually for integrity and the effects of scour.

A technical advisory issued in 1991 covers procedures for evaluating bridge scour. Every bridge over a waterway, whether in service or in design, must be evaluated for scour to determine prudent protection measures. An interdisciplinary team conducts the evaluations, which include hydraulic studies and scour evaluation according to procedures in HEC 18 and HEC 20.

Advancing the State of Practice

Since 2001, NCHRP and FHWA have sponsored research projects to improve the state of practice in bridge scour and stream stability technology and to provide bridge owners with definitive guidance about design. The 22 projects listed in Table 1 (page 41) represent advances in this technology; the listed projects were completed between 2001 and 2013; the list is not comprehensive.

The common objectives of NCHRP Projects 24-27(01), 24-27(02), and 24-27(03) were to

TABLE 1 NCHRP and FHWA Bridge Scour Projects

Project Number	Project Title*	Completed
NCHRP		
24-07(02)	Countermeasures to Protect Bridge Piers from Scour	2006
24-14	Scour at Contracted Bridge Sites	2004
24-15	Complex Pier Scour and Contraction Scour in Cohesive Soils	2002
24-15(02)	Abutment Scour in Cohesive Soils	2008
24-16	Methodology for Predicting Channel Migration	2003
24-18	Countermeasures to Protect Bridge Abutments from Scour	2003
24-20	Prediction of Scour at Bridge Abutments	2006
24-24	Criteria for Selecting Numeric Hydraulic Modeling Software	2007
24-25	Guidelines for Risk-Based Management of Bridges with Unknown Foundations	2006
24-26	Effects of Debris on Bridge-Pier Scour	2007
24-27(01)	Evaluation of Bridge Scour Research: Pier Scour Processes and Predictions	2011
24-27(02)	Evaluation of Bridge Scour Research: Abutment and Contraction Scour Processes and Predictions	2011
24-27(03)	Evaluation of Bridge Scour Research: Geomorphic Processes and Predictions	2011
24-29	Scour at Bridge Foundations on Rock	2011
24-32	Scour at Wide Piers and Long Skewed Piers	2011
24-33	Development of Design Methods for In-Stream Flow Control Structures	In progress
24-34	Risk-Based Approach for Bridge Scour Prediction	In progress
FHWA		
RD-02-078	Bottomless Culvert Scour Study, Phase I	2003
HRT-05-072	Assessing Stream Channel Stability at Bridges in Physiographic Regions	2006
HRT-07-026	Bottomless Culvert Scour Study, Phase II	2007
HRT-12-034	Submerged-Flow Bridge Scour Under Clear-Water Conditions	2012
HRT-12-022	Pier Scour in Clear-Water Conditions with Nonuniform Bed Materials	2012

**For detailed information, go to www.trb.org/CRP/NCHRP/NCHRPProjects.asp?AreaID=24 and www.fhwa.dot.gov/bridge.*

◆ Evaluate critically the bridge-scour research completed since the early 1990s and

◆ Recommend the adoption of specific research results by AASHTO, which was developing new editions of two key highway hydraulic engineering guidance documents: *Policy for Design of Highway Drainage Facilities* and *Recommended Procedures for Design of Highway Drainage Facilities.*

The most recent revisions to FHWA's HEC 18 and HEC 20 have drawn on the results from the NCHRP Project 24-27 series.[7] In June 2008, NCHRP sponsored a joint workshop to evaluate present knowledge and future needs on abutment scour.[8] Panelists and principal investigators from NCHRP Projects 24-15, 24-20, and 24-27 attended this workshop, which produced recommendations for technical and editorial improvements, primarily to HEC 18, although several recommendations applied to HEC 20, as well.

In September 2010, FHWA and NHI initiated an update of Course 135046, Stream Stability and Scour at Highway Bridges. Extensive revisions were made to the supporting reference manuals for the course, which include HEC 18 and HEC 20, to incorporate the results of the NCHRP and FHWA projects listed in Table 1. The revisions to these manuals included other significant advances in scour technology available in the national and international literature.

FHWA has developed additional guidance and a standard template for bridge owners on preparing plans of action (POAs) for scour-critical bridges. Both HEC 18 and NHI Course 135046 reference and incorporate information from this new guidance. FHWA also has developed guidance on how to treat the scour susceptibility of bridges with unknown

[7] See NCHRP Research Results Digest 378, *Evaluation of Bridge Scour Research*, May 2012, www.trb.org/Publications/Blurbs/167759.aspx.

[8] See NCHRP Research Results Digest 334, *Joint Workshop on Abutment Scour: Present Knowledge and Future Needs: June 2008*, www.trb.org/Publications/Blurbs/160851.aspx.

PHOTO: WASHINGTON STATE DOT

Riprap installed by Washington State DOT to prevent scour along Tokul Creek. Research continues on bridge scour, scour countermeasures, and stream stability.

foundations. Again, this new guidance has been made part of HEC 18 and NHI Course 135046.

Expanding Evaluations

The current revised and updated edition of HEC-18, *Evaluating Scour at Bridges*, includes the following:

◆ Expanded discussion of the policy and regulatory bases for the FHWA scour program, including risk-based approaches for evaluations, developing POAs for scour-critical bridges, and understanding design philosophies and technical approaches;

◆ Expanded discussion of countermeasure design philosophy for new and in-service bridges;

◆ New chapter on soils, rock, and geotechnical considerations related to scour;

◆ New sections on contraction scour in cohesive materials, on pier scour in cohesive materials, and on pier scour in erodible rock;

◆ Updated section on abutment scour;

◆ Alternative approaches to abutment design;

◆ Alternative procedures for estimating pier scour;

◆ New guidance on pier scour with debris loading and on scour at wide and skewed piers;

◆ New approach to pier scour with coarse material;

Debris accumulation at a bridge pier diverts flow, enhances contraction, and causes turbulence that contributes to scour of channels and abutments.

◆ Revised guidance for vertical contraction, or pressure-flow, scour;

◆ Guidance for predicting scour at bottomless culverts; and

◆ Revised discussion of scour at tidal bridges, incorporating information covered in HEC 25, *Tidal Hydrology, Hydraulics, and Scour at Bridges*.[9]

Stream Stability

The revised and updated edition of HEC 20, *Stream Stability at Highway Structures*, now includes the following:

◆ A new section on predicting meander migration with historical aerial photography;

◆ Simplified record sheets for stream reconnaissance, with an updated methodology for rapid assessment of channel stability;

◆ Expanded discussion of the natural channel design approach applied by several state DOTs and resource agencies;

◆ A simplified but expanded discussion of sediment transport concepts and equations;

◆ A new chapter on channel stability concepts for gravel-bed rivers;

◆ A new section on channel stability concepts in nonalluvial channels—that is, cohesive beds and banks;

◆ Guidance for preparing stream stability evaluations in support of POA development; and

◆ New sections on techniques for analyzing stream stability, managing the impacts of roadways on stream ecosystems, and applying geomorphic concepts.

Solving the Problem of Scour

Transportation professionals have made considerable advances in solving the problem of scour. Research continues on bridge scour, stream stability, and scour countermeasures.

Although state DOTs realize the importance of anticipating the effects of climate change, procedures are needed for selecting appropriate ranges of input parameters to reflect climate change. The impacts of climate change on debris production and on runoff characteristics also require systematic consideration.

Society's general endorsement of sustainability and the genuine need for sustainable infrastructure underscore the importance of scour-safe bridges. Potential advances in scour countermeasures through applied bioengineering and use of recycled materials make future opportunities for scour management particularly exciting, as well as challenging.

[9] www.fhwa.dot.gov/engineering/hydraulics/hydrology/hec25.pdf.