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National Bridge Scour Program—Measuring Scour of the Streambed at Highway Bridges

WHAT IS BRIDGE SCOUR?

Scour or erosion of the streambed and banks near the foundations (piers and abutments) of a bridge is often referred to as "bridge scour." The traveling public gives little thought to the foundations of the bridges they cross. This is a credit to the bridge engineers; however, designing the foundations of a bridge over a stream is not as simple as it may seem. Bridges are static structures constructed in a dynamic river environment. Rivers adjust their boundaries (bed and banks) to efficiently transport water and sediment. Some of these adjustments are a direct consequence of the construction of the bridge and others are independent of the bridge, but both may have significant impacts on the bridge.

Changes in streambed elevation and stream planform due to natural or human-induced causes can affect the reach of the river near the bridge. These changes may occur slowly over many years or may be catastrophic, occurring during a single flood. These changes occur independent of the bridge but can severely affect the stability of the bridge foundations (fig. 1).

During a flood, water is transported in the river channel and spills out into the floodplain. When a roadway and bridge are constructed to cross a stream, the embankments used to elevate the roadway above the floodplain stop the downstream flow of water in the floodplain and force the flow through the bridge opening. When floodplain flow is forced through the bridge, the flow velocity increases, which often causes erosion of the channel bed and banks at and immediately downstream of the bridge. This scour is commonly referred to as contraction scour.

Figure 1. Channel degradation caused by in-channel gravel mining in Cache Creek, California.

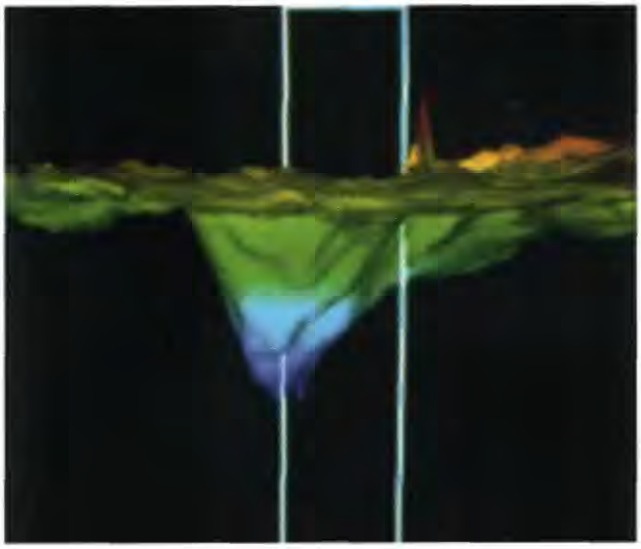

Figure 2. Computer visualization of local pier scour (23 feet deep) measured at State Route 51/150 over the Mississippi River near Chester, Illinios during the 1993 flood.

When water flows around a fixed obstruction, such as a bridge pier or abutment, the flow accelerates and rotates, forming vortices, which have a high potential to erode the streambed. The scour is restricted to the area affected by the vortex and is commonly referred to as local scour. Local scour can be very significant; scour of more than 20 feet was observed at some piers during the 1993 flood on the Mississippi River (fig. 2).

A PROBLEM OF NATIONAL SCOPE

Scour at bridges is a problem of national scope and is not limited to a few geographical areas (table 1). Scour of the streambed near bridge piers and abutments has resulted in more bridge failures than all other causes in recent history (Murillo, 1987). The damage and destruction of bridges can have a dramatic impact on economics and on the safety of the traveling public. A sample of total highway damage repair costs caused by selected floods are given in table 2.

Table 1. Summary of bridges damaged or destroyed by selected floods

Location	Number of Bridges Damaged or Destroyed
Colorado, 1965	63
South Dakota, 1972	106
Pennsylvania, West Virginia, and Virginia, 1985	73
New York and New England, 1987	17
Midwest, 1993	>2,500
Georgia, 1994	>1,000
Virginia, 1995	74
California, 1995	45

Approximately 19 percent of federal-emergency funds used for highway restoration are allocated to bridge restoration. In the period 1980-90, the Federal government spent an average of $20,000,000 annually to fund bridge-restoration projects (Rhodes and Trent, 1993). In addition to the actual cost of repairs are the indirect costs associated with the disruption to the local economy and the cost of longer commutes and detours. Rhodes and Trent (1993) reported that the cost to the local economy can exceed by five times the direct repair costs.

Bridge scour is more than an economic problem; 3 bridge failures in the last 15 years have resulted in the loss of 25 lives. The New York State Thruway Bridge over Schoharie Creek in New York failed in 1987, resulting in the loss of 10 lives. Eight people lost their lives when the U.S. 51 bridge over Hatchie River in Tennessee failed in 1989. In 1995, seven people died when the I-5 bridge over Arroyo Pasajero in California failed.

Bridge scour problems are not only relevant to existing bridges, but are also important to the safe design of new bridges that will be resistant to the effects of hydrologic hazards. On average, over 2,800 new bridges were built annually from 1990 to 1997.

Research and data collection by the U.S. Geological Survey (USGS) to better understand hydraulic and sediment-transport processes at highway crossings are important to the development of better methods for predicting the behavior of rivers. This research and data collection will allow engineers to design and maintain safe, economical bridges over our Nation's waterways.

Table 2. Total highway damage repair costs for selected floods

Flood Location and Year	Repair Costs
Midwest – 1993	$178,000,000
Georgia – 1994	$130,000,000
Virginia – 1995	$ 40,000,000

WHY DO WE NEED FIELD DATA?

In 1988, the Federal Highway Administration (FHWA) issued a technical advisory mandating the evaluation of scour potential at all existing bridges and the scour-resistant design of new bridges. Since this mandate, design engineers have repeatedly questioned the validity of design methods based on laboratory flume studies of scour. The experience of many design engineers indicated that the methods developed in the laboratory overestimated scour significantly. The lack of and need for reliable and complete field data on scour at bridges has also been a recurring conclusion of many researchers.

"In order to apply with confidence the relationships proposed for predicting the scour at bridge piers and abutments, field measurements are needed to verify the conformity of model and prototype. Some of these measurements should be made at sites of extremely simple geometry ... Other measurements should be made at sites of complex geometry which perhaps cannot be modeled in the laboratory." (Laursen, 1962)

"Although laboratory research on alluvial channels may lead to more reliable predictions of scour and fill based on hydraulic theory and empirical equations, the scour and fill problem is inherently complicated, and evaluations based on field experiences are needed." (Culbertson and others, 1967)

"Field data are essential. We must spend considerable effort to collect more accurate field data and classify them according to types of scour and their reliability." (Shen, 1975)

"Very little field data have been collected to verify the applicability and accuracy of the various design procedures for the range of soil conditions, streamflow conditions, and bridge designs encountered throughout the United States." (Richardson and others, 1993)

Despite the recognized need for the collection of field data, very few data were collected until the late 1980's. This deficiency is primarily a reflection of the difficulty in collecting the necessary data. Accurate and complete field measurements of scour are difficult to obtain because of the streamflow patterns that occur at bridges during floods, inability to get skilled personnel to bridge sites during floods, and problems associated with existing measuring equipment.

TECHNOLOGY MAKES IT POSSIBLE

The USGS, in cooperation with the FHWA, recognized the need to develop equipment and procedures to collect data and study bridge scour in the field. Scour holes that develop during a flood may refill with sediment during the flood recession; therefore, data must be collected during the flood or methods must be used to determine the maximum depth of scour that occurred during the flood. Through funding from

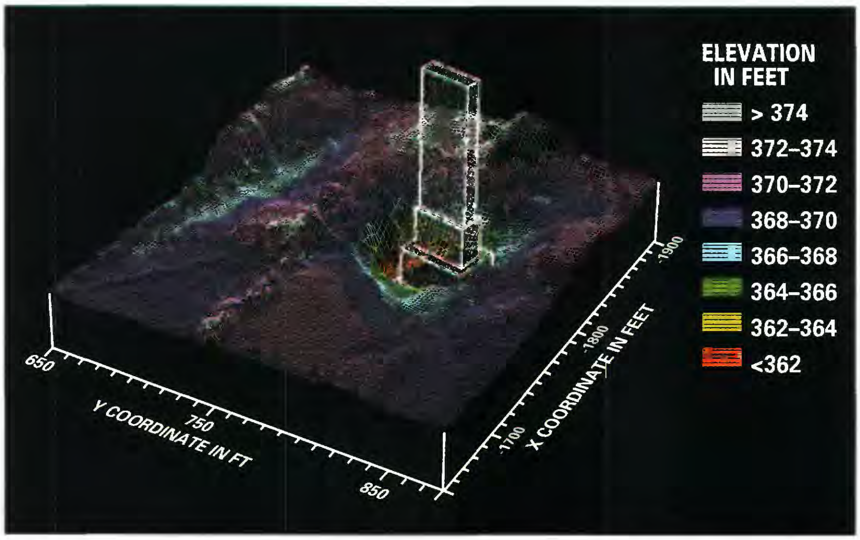

Figure 3. Detailed mapping of scour hole, measured with an echo sounder, at pier 9 on the I-255 bridge over the Mississippi River near St. Louis during the 1993 flood.

the FHWA, the USGS worked to develop equipment and procedures to allow collection of data during floods (Mueller and Landers, 2000) and to evaluate the maximum depth of scour after a flood has receded (Placzek and Haeni, 1995).

A field data set collected during a flood should include water-surface elevations, a map of the streambed, a map of the water-velocity magnitudes and directions, photographs to document the site conditions, and samples of the bed material. Recent developments in acoustic technology allow efficient and accurate measurements of the streambed and the water velocities by use of echo sounders (fig. 3) and acoustic Doppler current profilers (fig. 4). The positions of the data are measured using a land-based range-azimuth positioning system or differentially corrected global positioning system. All of the equipment can be easily transported and deployed on boats typically available in most USGS District offices. The equipment can also be deployed on a remote-control boat, which was developed to allow data collection in locations too hazardous for manned boats (fig. 5), thereby reducing the risk to field personnel.

Surface-geophysical techniques have been used successfully to map the subbottom stratigraphy in lakes and rivers; the USGS transferred these techniques to study bridge scour. Low frequency acoustics (continuous seismic-reflection profiling) and ground-penetrating radar can be used to map the maximum depth of scour that has occurred at a bridge (fig. 6). These techniques require considerable skill in collecting and interpreting the data, but when properly applied provide information on the maximum depth of scour that cannot be efficiently collected any other way.

CHASING FLOODS AND MEASURING SCOUR

The USGS works with the FHWA on the national level and with many state highway departments to collect bridge scour data during floods. USGS personnel are deployed on short notice both locally and nationally to measure scour. These efforts have resulted in nearly 500 measurements of local pier scour, 18 measurements of contraction scour, and 12 measurements of abutment scour covering 17 states. These data has been entered into a national data base that have more than 200 variables defined for each site. These data are used by researchers both nationally and internationally to validate laboratory research and to develop improved design guidance.

The USGS works closely with the FHWA and state highway departments during and after floods to ensure public safety. Measurements of the streambed elevation during a flood are valuable information needed by state highway departments to make decisions on bridge closures. The USGS provides expertise and equipment during floods to assist in making measurements where traditional equipment may fail to make accurate measurements. In addition, the USGS assists in the post-flood assessment of sites where bridges have been damaged or destroyed by floods (fig. 6).

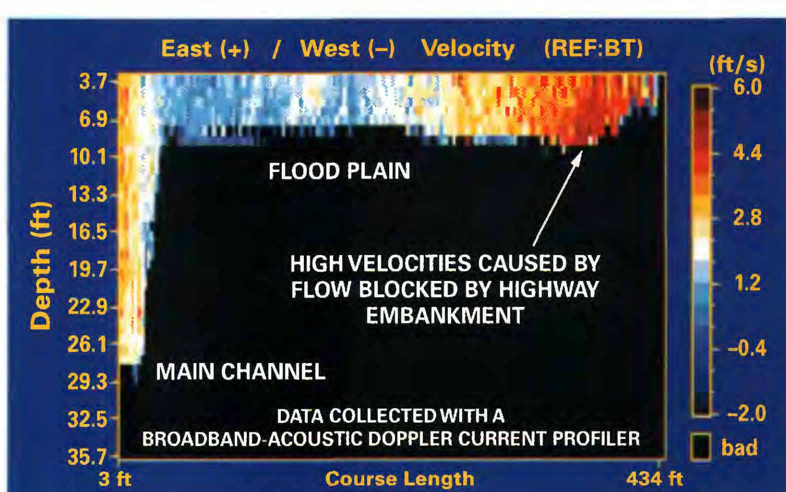

Figure 4. Velocity distribution, measured with an accoustic Doppler current profiler (ADCP), near the left abutment of U.S. 45 over the Skillet Fork River near Mill Shoals, Illinois.

Figure 5. Remote-control boat developed to collect bridge scour data in hazardous conditions.

SCOUR MONITORING

Scour monitoring can be a cost-effective method of protecting the traveling public from potential bridge failures caused by scour. When the computation of the potential depth of scour indicates that a bridge may be in jeopardy during a (100- to 500-year) flood, the bridge owner must develop and implement a plan to protect the bridge (Richardson and others, 1993). This could be a structural modification, such as adding crutch piles or protecting the area with riprap. At bridges with low traffic volumes or at sites where the bridge has experienced a major flood without significant scour, the bridge owner may choose to monitor the depth of scour during floods and close the bridge if the scour reaches a critical level.

The USGS has developed and tested a variety of both fixed and portable instruments to monitor scour at bridges during floods. Fixed instrumentation can be installed at a bridge to continuously monitor the streambed elevation. Some of the technologies tested for fixed installations include acoustic transducers, scour chains, conductance probes, piezo electric film, sliding collars, and mechanical switches. Simple, portable scour-monitoring equipment that employs acoustic technology has also been developed for use by State highway agencies.

Figure 6. USGS personnel using ground-penetration radar to estimate depth of scour after the failure of the I-5 bridge over Arroyo Pasajero in California.

IMPROVING PUBLIC SAFETY

The USGS has been working with the FHWA and state highway departments for nearly 50 years to study, assess, and improve the construction of highways and bridges to resist damage and destruction by hydrologic hazards. The experience of the USGS in field data collection and analysis of floods and sediment-transport processes continues to provide data and research that are important to the design and maintenance of a safe and economical transportation system. The cooperative efforts of the USGS, the FHWA, and state highway departments have resulted in many improvements to current practice, but many unknowns remain. Continued research and data collection are needed to provide the public with a transportation system that is both economical and resistant to damage from floods.

— *David S. Mueller*

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