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"Status of Scour Instrumentation Development"

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"Status of Scour Instrumentation Development"

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Abstract

Improved understanding of scour and sedimentation processes near and at highway bridges is dependant on collecting reliable field data. Field data collection programs, however, have been hindered by inadequacies in instrumentation and measurement technologies. Through a coordinated program of research, the Federal Highway Administration (FHWA), State Highway Agencies (SHAs), National Cooperative Highway Research Program (NCHRP), and other agencies are working on scour instrumentation. Investigations are underway to develop a wide range of equipment types for many purposes and needs, e.g., portable equipment to be used by field crews during floods for scour inspection or measurement of scour processes; fixed equipment to operate unattended during the flood for monitoring the maximum scour; and special geophysical techniques and direct methods for post-flood evaluation of refilled scour holes.

Introduction

The leading cause of bridge collapse and closure in the U.S. is due to scour. Scour can undermine a bridge abutment or footing, and can lead to loss of stability around supporting piles. Scour processes have been extensively researched using laboratory model studies. Such studies have provided valuable data and insights and are the basis for current scour prediction equations. Laboratory tests, however, are typically conducted with uniform fine grained bed materials of infinite depth which represent the most conservative scour condition. Scour predictions based on model results, furthermore, can vary considerably from what is experienced in the field. Variations might be due to dynamic dissimilarity between prototype and scale models, the vagaries of real world fluvial and hydraulic conditions, and other factors not represented in most laboratory models. Field measurements

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of scour are needed to put practical constraints and limits on prediction equations. Field data on sedimentation processes and stream stability problems at highway stream crossings on natural river systems are even more scarce than local scour data.

Few field projects to measure scour at bridges have been initiated until recently, primarily due to the lack of adequate instrumentation and measurement systems. Many logistical problems with equipment installation and deployment procedures exist. Problems include anticipating when and where a flood will occur, gaining access to the bridge during the flood, or destruction of equipment by forces of the flood. Progress is being made. Research projects on bridge scour instrumentation and measuring systems are currently underway and more are planned. These studies are designed to develop, evaluate, demonstrate and ultimately transfer instrumentation technology broadly for field use. Effective measurement systems can produce significant gains in ability to inspect and monitor bridges for scour during floods, and to collect the data needed to improve sediment transport relations and bridge scour prediction equations.

Real-time Scour Measurement

Equipment can be classified by several factors including function, purpose, application, and measurement technology. For measuring scour during flood events, there are two general classes of real-time measurement methods: portable equipment and in-situ (fixed) equipment. Portable equipment can be used to collect detailed bathometric survey data to real-time scour condition inspection for suspect or threatened bridges. Fixed equipment can be used to monitor scour critical bridges as an alternative to providing a scour countermeasure like riprap.

Portable Methods — Portable measurement methods provide the capability for field crews to chase floods when and where they occur and measure scour. These methods are well suited for use by bridge maintenance and inspection crews for detecting scour conditions at piers and abutments and taking cross sections of the channel at problem bridges. Standard flood survey procedures of the U. S. Geological Survey (USGS) use variations of this approach. Some of their records include historic evidence of local, contraction, and even general scour. Surveys conducted by the USGS from boats and bridge decks during spring floods of 1991 demonstrate the potential of portable methods (Trent, 1991).

Portable scour measuring systems have three components; *deployment, sounding, and horizontal positioning*. Deployment devices range from hand lines to vehicle mounted winches and cranes to manned and remote control boats. Sounding devices and transducers may be poles or weighted lines or a diverse range of echo sounders (includes acoustic fathometers, sonar, and fish finders). Horizontal positioning techniques range from qualitative observations of position around piers (for inspection) to stadia or range surveys to laser or sonic location-positioning systems. Each component of a scour measuring system needs to be matched and evaluated for performance under different operating conditions and data needs.

A new research study is being conducted for FHWA by the USGS to develop various types of portable equipment and deployment methods (Landers, 1991). A practical low-cost instrumentation package is being developed for use by field crews for surveying suspect bridges during flood conditions. It will be deployed from the deck and is ideally suited for use by bridge maintenance and inspection crews. A more elaborate portable package will utilize a radio-controlled boat to deploy sounding devices. The boat will be equipped with a fathometer, pitch gauge, data telemetry apparatus, and automatic position system, all capable of decimeter accuracy. This rig will be capable of detailed bathometric, subbottom surveys up and down stream of the bridge, and will not be confined to measurements from the deck, pier, or abutment.

There are drawbacks to portable methods. It is difficult to mobilize a crew and get to the site before the flood passes. In some cases, roads may be impassable or access to the bridge or launch site may be restricted. Crews must be trained and properly equipped. Traffic control is often required and safety is always a concern. Yet, these are procedures of opportunity having the greatest potential for collecting large amounts of scour data during floods.

Fixed Methods — In-situ measurements depend on installation of instrumentation at preselected bridge sites in anticipation of a flood event or flow that would cause scour. These methods are well suited for monitoring scour around piers and abutments at scour vulnerable and scour critical bridges. The methods are designed to detect and document the maximum scour that occurs and, depending on the technology employed, some can record the time-progression of scour during a flood. Generally, in-situ methods measure local scour or bottom depths only in the vicinity of the area targeted by the detector. These devices may be particularly attractive for monitoring the condition of riprap or other scour protection measures on degrading or unstable stream beds. Field crews are not required for the equipment to function or record scour depths.

An AASHTO-sponsored study to develop scour monitoring devices that can be permanently mounted to bridge piers or abutments is being conducted for the Transportation Research Board by Resources Consultants, Inc. (RCI). A summary of interim results from that study is available in the literature (Lagasse, 1991) and the final report (Richardson, 1992) presents a comprehensive report on this class of instrumentation. The study identified and evaluated devices in the following categories: *sounding rods, sonar, buried/driven rods, and other types of buried devices*. One or more devices from each category show promise for use to measure or monitor the maximum depth of scour in various environments and conditions. Selected devices will receive further development and prototype field testing in a second phase study to begin in 1992.

Sounding Rods - A falling rod confined by guides or a housing attached to piers has been used to monitor local scour on several bridges. The foot of the rod follows the scour and the amount of fall is a measure of the maximum scour. Conditions for use and installation include: the foot of the rod must be large enough to resist settlement in sand bed rivers; the length of the rod has practical limits; rods should be mounted in a near vertical orientation and must extend beyond the footing; the installation could be vulnerable to damage by debris and ice forces (Richardson, 1992). The Brisco Monitor™ (use of trade names is for identification purposes only and does not represent endorsement) is being manufactured for installation on bridge piers and is representative of falling rod devices. Further field tests are underway and performance of existing installations will help in development of this type of device.

Sonar — Use of permanently mounted sonic fathometers or echo sounders on piers and abutments to detect scour has been implemented on several bridges in the past. Cost and configuration of the equipment package can be tailored to suit individual bridge site characteristics and special needs for monitoring. Various combinations of transducers, data loggers, power supplies, data transmission methods, and alert/alarm strategies have been tried and tested in recent years by the USGS and others. Moderate cost, temperature compensated fathometers are well suited for use in monitoring scour depths at bridge foundations for certain classes of site conditions.

Buried/Driven Rod — Devices that depend on buried or driven rods to support or enclose sensors are as diverse as the sensor or transducer technology employed. Sensor technologies include mechanical trip switches, motion detectors, electronic conductance and capacitance, thermal conductivity, acoustic transducers, magnetic sensors. Typically, sensors are embedded in rods at intervals dictated by the accuracy desired. Rods are jetted, drilled and/or driven into the river bottom alongside the foundation to a depth beyond the expected or critical scour. Data transmission from the rod to the deck is usually through cables attached to the bridge though romote telemetry could also be employed. RCI has researched, evaluated, developed, and/or reported on advantages and disadvantages and logistic and installation problems of several variations of buried rods (Richardson, 1992). Research focused on the use of mercury trip switches held in place by soil and activated when exposed by scour; magnetic sensors detect the position of metal collar(s) which slide down the rod into the scour hole; and a very promising technology using piezoelectric film as a sensor. The piezoelectric film is bonded to flexible vanes protruding from the buried rod. When the vanes are exposed to flow they flutter. The piezoelectric film produces a small voltage when flexed; hence, scour depths can be detected.

Other systems have been proposed. The USGS is working on a rod using capacitance to define the soil/water interface. A report to the National Science Foundation (NSF) documents another concept using a low frequency acoustic pulse, triggered in the water column, with tethered receivers buried in the river bed (Davies, 1991). This technology can detect interfaces of refilled scour holes in addition to real-time scour depths. Furthermore, the signal is not influenced by debris in the water column.

Other Buried Devices — This class of sensor consists of devices buried in the river bed at various elevations and positions. When scour exposes these devices, they would activate by being rolled or moved into or out of the scour hole, or dislodged and floated to the surface. Devices can be either tethered or untethered and can incorporate a range of sensor technologies. The key to measurement is detecting the condition of the device; miniature radio transmitters embedded in a weighted or buoyant container are an example of techniques being investigated. Measuring scour might be as simple as visually observing if tethered floats have been dislodged from the riverbank or riverbed. Untethered radio transmitters could be activated by motion to initiate transmission or to change its frequency of transmission (Carlson, 1991). These devices are best used where dry installations are possible, e.g., to detect local scour on ephemeral streams or floodplains and lateral migration of riverbanks. Benefits and problems of this class of monitor are discussed in the NCHRP final report.

Post-Flood Scour Measurements

Measurements of scour during low flow, after the flood, or even as the flood is receding are not an adequate alternative to measuring scour at the flood peak. Field data show that the bed load on alluvial channels is redeposited shortly after the peak and long before the flood has receded (Trent, 1991). At that point, local scour holes are promptly refilled and any residual scour holes are likely to be remnants of the original. This process is less typical of rivers with cobbles or boulders or cohesive bed materials.

Special methods are necessary to measure scour after scour holes have refilled. Post-flood scour measurements can be attempted through a variety of techniques. These include direct visual observations and measurements, and higher order surface geophysical techniques.

Direct Measurements — Post-flood measurements of the river bottom by direct soundings cannot be regarded as quantitative measurements of scour, unless it can be determined that scour holes formed during flood events have not refilled after the flood. The technology for visual observation and direct measurement has been in use for many years.

Visual Detection — Under clear water scour conditions, visual post-flood inspection of foundations on the floodplain can be a useful scour monitoring technique, but only where it is clearly evident that sediments could not have refilled scour holes. The condition of rock riprap at abutments or piers will be visible, and in some instances vegetation and ground condition around unprotected foundations will provide evidence of no or little disturbance.

Sonar and Sounding Weights — Sonar or fishfinders, sounding weights, divers, poles and probes, and other direct methods are sometimes used for checking for scour at suspect bridges immediately after the flood. The same procedures are regularly employed as a part of scheduled underwater bridge inspections. Inspections are normally conducted during low flow conditions and results must be used with caution on alluvial streams — remnant scour holes that have refilled will not be detected and results may be misleading and even dangerous.

Subbottom Sampling — Certain invasive methods like subbottom sampling or coring can be used to confirm whether scour holes have refilled. Coring can also be used as ground-truth for helping to interpret results of geophysical surveys and verify the performance of fixed instrumentation.

Surface Geophysical Techniques — Surface geophysical methods are rather like forensic investigative tools; they can assist in the assessment of historical local scour and infilling processes where sediments have refilled the scour holes. Geophysicists use remote sensing techniques to explore and evaluate the nature and condition of subsurface geology and to map subsurface stratigraphy. These techniques depend on sensing the differential reflection of surface-transmitted signals (e.g., seismic or electromagnetic) at interfaces of sediments, soils, and rock types of different densities and character. Field surveys using geophysical techniques result in continuous graphical and tape records that can be replayed and reprocessed in the laboratory for further analysis. Interpretation of graphical output requires training and experience. Calibration and interpretation of results to the on-site conditions benefits from coring records of sediments and bed materials.

Ground Penetrating Radar (GPR) — GPR uses low frequency electromagnetic signals transmitted and received by one or a pair of antennae. Antennae are usually floated along side of the survey boat for water applications or pulled across the ground for land applications and makes a continuous record of strata. GPR is not suited for use in conductive materials (e.g., salt water and clays). It does not work well in deep (>20 ft) fresh water since the signal attenuates rapidly in the water column. Signal scatter over rocks and cobbles can make interpretation of the subbottom stratigraphy difficult.

Seismic Transducer — High frequency continuous seismic equipment operates in the 3 to 20 Khz frequency range, or roughly equivalent to low frequency sonar; typical fish finder, sonar-type devices operate above 100 Khz and do not penetrate the subbottom. Commercial fishfinders (like the *Color Video Echo Sounder* used by Haeni, 1989) sometimes have dual frequencies where lower frequencies in the 20 Khz range can penetrate in up to 20 ft of sediments. Data Sonics™ produces a *Swept Frequency Acoustic Profiler* that combines improved penetration of lower frequencies with high resolution of higher frequencies, and promises to be a useful technique for mapping the depth and extent of refilled scour holes and channels. Seismic and sonar devices operationally are dependent on working in the water column; in fact air entrained in the water or sediments attenuates the signal. The practical limit to penetration of subbottom sediments is about 20 ft. Similar to GPR, cobbles and boulders scatter the signal and make interpretation difficult.

Conclusions

For a wide range of bridge and fluvial conditions, instrumentation and equipment systems for measuring scour and sedimentation processes, both during and after the flood, are being developed through a coordinated program of research. New and evolving technologies are being incorporated in portable and fixed instrumentation, and forensic evaluation methods to meet the needs of a range of applications, including scour inspection, monitoring of scour critical bridges, and description of the scour and sedimentation processes at highway stream crossings. This collection of instrumentation systems and methods will become the foundation of a vastly improved understanding of scour and sedimentation processes, and will lead to improved analytical models and more scour resistant bridges and highway stream encroachments.

Appendix

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