

# Scour Monitoring Devices for Bridges

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## ABSTRACT

Research efforts have developed a large body of knowledge on bridge scour, mostly from laboratory model studies. However, field data and measurements of scour at bridges, necessary to better understand the problem of scour and to evaluate analytical methods for scour prediction, are extremely limited. This deficiency results largely from the difficulties of field data collection under flood flow conditions when scour conditions are typically most severe. These same adverse conditions have inhibited development of a reliable scour monitoring device that can automatically or even semi-automatically collect scour data.

This paper presents a status report on the ongoing National Cooperative Highway Research Program (NCHRP) study being conducted for the Transportation Research Board (TRB). The objective of this research study is to develop, test, and evaluate instrumentation that would be both technically and economically feasible for use in monitoring maximum scour depth at bridge piers and abutments. An Interim Report was submitted to the NCHRP panel and TRB in October 1990 providing identification of potential devices, evaluation of devices, and recommendations for the laboratory phase of the research.

## INTRODUCTION

Highway bridge failures cost millions of dollars each year as a result of both direct costs necessary to replace and restore bridges, and indirect costs related to disruption of transportation facilities. However, of even greater consequence is loss of life from bridge failures. Stream instability, long term stream aggradation or degradation, general scour, local scour and lateral scour or erosion cause most of these failures.

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Research efforts have developed a large body of knowledge on bridge scour, mostly from laboratory model studies. However, field data and measurements of scour at bridges, necessary to better understand the problem of scour and to evaluate analytical methods for scour prediction, are extremely limited. This deficiency results largely from the difficulties of field data collection under flood flow conditions when scour conditions are typically most severe. These same adverse conditions have inhibited development of a reliable scour monitoring device that can automatically or even semi-automatically collect scour data.

There are many scour vulnerable bridges on spread footings or shallow piles in the United States. With limited funds available, these bridges cannot all be replaced or repaired. Therefore, they must be monitored during and inspected following high flows. During a flood, scour is generally not visible and during the falling stage of a flood scour holes generally fill in. Therefore, visual monitoring during a flood and inspection after a flood cannot fully determine that a bridge is safe. A reliable device to measure maximum scour would resolve this uncertainty.

## RESEARCH OBJECTIVES

In December, 1989, Resource Consultants, Inc. (RCI) was selected by the National Cooperative Highway Research Program (NCHRP) to conduct Research Project 21-3. RCI is supported by Colorado State University (CSU) and Electronic Techniques, Inc. (ETI) on this research program. The objective of the research is to develop, test and evaluate instrumentation that would be both technically and economically feasible for use in monitoring maximum scour depth at bridge piers and abutments. The scour monitoring device(s) should be low cost, reliable, and capable of installation on or near a bridge pier or abutment.

Required criteria for the scour monitoring device(s) include:

- \* capability for installation on or near a bridge pier or abutment;
- \* ability to measure maximum scour depth within an accuracy of +/- 1 foot;
- \* ability to obtain scour depth readings from above the water or from a remote site; and
- \* operable during storm and flood conditions.

Desirable criteria for the device(s) are:

- \* capability to be installed on most existing bridges or during construction of new bridges;
- \* capability to operate in a range of flow conditions;
- \* capability to withstand ice and debris;
- \* relatively low cost;
- \* vandal resistant; and
- \* operable and maintainable by highway maintenance personnel.

By March 1991, the first phase of this 2-1/2 year study will have been completed and laboratory testing of selected devices will be underway. This paper summarizes (as of November 1990) the results of comprehensive literature search, identification of devices for consideration, and initial evaluation of devices. The recommendations of the Research Team to the NCHRP panel are also summarized.

## SCOUR MEASUREMENT - AN OVERVIEW

### Historical Background

#### *Early Observations*

The earliest observations of bridge scour probably were carried out by railroad engineers during the first half of the 19th century. By the turn of the century, hydraulic engineers were involved in laboratory model studies of pier scour, but the main responsibilities for design and field studies were borne largely by the railways. The tradition continues today. In the People's Republic of China, bridge scour studies are carried out by the Ministry of Communications and Academy of Railway Sciences; in India field observations apparently are carried out by the Ministry of Railways (1); and in the USSR, the Ministry of Transport Construction has these responsibilities (2).

Equipment used for scour observations was simple: sounding rods for shallow flows and lead sounding weights on a line for deeper flows. Both of these devices were developed to sound for navigation depths hundreds of years ago, and were adapted for depth soundings in connection with stream flow measurements during the 19th century. The main adaptations involved streamlining the sounding weights and using stay lines or vertically supported sounding rods so that the weights or rods would not be swept downstream in high velocities. Early streamflow measurements were often made at ferry crossings, and special supports were designed to mount on the ferry cable so that the sounding rod with the meter could be held vertically approximately three feet in front of the bow of the ferry. The history of these developments is not clear, but they were standard operations in stream gaging early in the 20th century (3). The earliest record we could find of a vertically supported sounding rod permanently mounted on a bridge pier to measure scour was one designed in 1921 by Thomas Maddock for a bridge in Arizona.

#### *Developments in the 1950's*

Major advances in instrumentation occurred during the Second World War. By the mid-1950's, many devices became commercially available and were introduced into scientific studies of rivers. The main advances were in sonar, sonic sounders, electronic positioning equipment, and radar. Very often, equipment developed for one special purpose was modified and adapted to studies in rivers. For example, the dual channel stream monitor described by Karaki and others (4) was an ultrasonic sounder that had its origins in a device designed for ultrasound imagery of the human body developed by the Colorado Medical School and used to measure the thickness of fat layers on cattle. This same device was used to study alluvial channel bed configurations and the scour and fill associated with migrating sand waves. The equipment was highly accurate, but could not operate in depths greater than about 6 or 8 feet. Richardson and others (5) developed a sonic sounder for use in the laboratory and in shallow flows in the field. The sounder would work in flows from 1 to 6 feet. It had a very narrow cone and in 2 feet of water would only sound an area of the bed of 1/4 inch in diameter.

Commercial sounders such as the Bludworth and Raetheon (use of trade names is for identification purposes only, and does not imply endorsement by the authors

or sponsors) became available in the 1950's and soon were used extensively in hydrographic surveys. These also were used extensively to monitor scour and fill associated with migrating sand waves (6). This equipment was fairly accurate and could cover a great range of depth, but it could not operate in depths below about 3 feet, so it did not find much application in laboratory studies or in studies in small shallow streams.

Much of the impetus for bridge scour studies in the United States came from the pioneering work of Emmett Laursen and his co-workers at the University of Iowa. One extremely important piece of equipment, a scour meter, was developed for the model-prototype studies of the Skunk River. It was mounted in the streambed upstream of the pier and could sense the water-sediment interface at the streambed. This device, which operated on the electrode-impedance principle, was developed and designed by Philip G. Hubbard, and was described by him in an appendix to the report on scour around bridge piers and abutments by Laursen and Toch (7). For field application, the electrodes were mounted at six-inch spacing in a one-foot square concrete pile that was driven into the streambed upstream of the pier.

### Current Practices

Current practices refer to those developed during the past 25 or 30 years and to techniques and equipment that are in use today (1990) in a variety of ongoing field studies. For these latter cases, not much information has been published, so we have drawn heavily on personal communications with individuals who are carrying out the studies.

There are no standard methods or equipment for collecting scour data in the United States. In part, this is because there has been no coordinated long-term effort to study scour processes. Also, most scour studies are site-specific and the equipment and techniques that are used have to be tailored to the geometry of the site and the peculiarities of the existing hydrology and hydraulic conditions. However, a few trends can be identified. First, sonic sounders are standard equipment in most scour studies, but in many cases they will not work and more traditional methods are employed. Second, mobile teams are generally more effective in collecting scour data than relying on fixed installations. Third, there is a growing interest in the use of fixed installations, largely because improvements in data loggers, data transmission, and computers allow the

collection and processing of large amounts of real time data.

Earlier models of sonic sounders were heavy, cumbersome to use, and not too reliable. Nonetheless, their potential was recognized, and a number of special investigations were undertaken to develop the equipment and techniques for scour studies (4) (8) (9) (10) (11). Fixed installations were tried in a number of instances, but these met with limited success because of ice, debris, and mechanical problems related to the installations (Norman, 1990, personal communication). Pandy (1) reported that scour measurements were made with a sounding weight on a line before and during construction of Mokameh bridge across the Ganges; after the bridge was completed, a depth sounder was mounted from a sounding weight on a short cable and later on an L-shaped bracket that could monitor scour depth at 16 points around the bridge pier. Later, this system was abandoned and data are now being collected from a boat.

Scour studies are currently carried out with a great variety of equipment and techniques. Since pier and abutment scour are major concerns for operation and maintenance, many bridges are now inspected on a regular basis. Techniques for determining the extent of local scour include the use of divers and visual inspection, direct measures of scour with mechanical and electronic devices and indirect observations using ground-penetrating radar and other geophysical techniques (12). Only a few of the techniques currently employed are suitable for applications in fixed installations.

### Selected Examples

Although sonic depth sounders are clearly the most versatile and widely used piece of equipment for detecting the water-sediment interface at the bed of a stream, there are some conditions under which they do not work. For example, along the Yellow River, sediment concentrations near the bed are so high that the standard sonic sounders cannot distinguish between the moving sediment and the non-moving bed (Long Yuqian, Chief Engineer, Yellow River Conservancy Commission, 1983, personal communication). At the Old River Control structure along the Mississippi River, scour measurements are made with a lead weight on a line because the highly turbulent flows entrain so much air that sonic devices will not work. In general, sonic devices do not perform satisfactorily if there are high sediment concentrations, debris, or air entrained

in the flow. For these kinds of flows, simple mechanical devices may still be the most satisfactory instruments for measuring local scour.

Vertically supported sounding rods have been used in depth soundings for decades and for measuring scour at bridge piers at least since 1921. They presently are being used to monitor scour depth at bridge piers at a number of locations. A telescoping rod was mounted on an experimental bridge pier in New Zealand about 1980, several simple devices have been mounted on bridge piers in Arkansas, and a commercially available device, the Brisco Monitor, is being used in the State of New York. So far as we can tell, all of these devices work satisfactorily although only recently, in Arkansas, have there been floods of any magnitude since installation of the sounding rods. There is no evidence that these have been used in sand bed streams or that they have been tested to determine if the base plate of the sounding rod resting on the stream bed introduces scour in addition to that caused by the presence of the pier.

During recent years, many scour studies have been undertaken in New Zealand. One of the developments now being used in the field to measure maximum scour depth at bridge piers is called the "Scuba Mouse." The device consists of a pipe mounted to the bridge pier around which is placed a horseshoe shaped collar that rests on the streambed and sinks to the bottom of the scour hole during the flood. On falling flood stages the collar is covered with sediments as the scour hole refills. Its position is determined by sending a detector down the inside of the pipe after the flood. Earlier models involved a metal detector inside a PVC pipe, but the pipe was sometimes damaged by debris, so the current models use a steel pipe, a radioactive collar, and a radiation detector inside the pipe. This device is operational and has been installed on several bridges in New Zealand (Robert Ettema, University of Iowa, 1989, personal communication) (13).

At present, the U. S. Geological Survey Hydrologic Instrumentation Facility (HIF) has made a small effort in developing equipment for bridge scour studies. They have designed several conductance probes. One was used about 15 years ago in Arizona, and a more recent model was used in Arkansas. These devices apparently worked, but there were difficulties in collecting ground truth, and installation of the meters was

difficult. HIF also has evaluated data loggers and developed the component circuitry so that signals from sounders could be entered directly to the loggers (James Ficken, USGS, 1990, personal communication).

One of the more ambitious and successful investigations using fixed installations is underway at a new bridge site on Federal Highway 101 across Alsea Bay near Walport, Oregon. Stage, velocity, and scour depth are monitored every fifteen minutes and stored in a data logger that can be accessed by phone to enter the data directly into a computer. Velocities are sensed with Marsh-McBurney and Montedoro-Whitney electromagnetic flow meters, and depth soundings are made using Lowrance and Eagle sounders. The transducers for sounding are mounted on angles attached to the piers and pointed out slightly to avoid interference from detecting the side of the pier. The system has worked well, but the installation is not subject to much debris, ice, or air entrainment from highly turbulent flows. (Milo D. Crumrine, USGS, 1990, personal communication)

The USGS, in a cooperative scour study with the New York State Department of Transportation, has installed Brisco Monitors and Datasonics sonar altimeters to measure scour (Gerard K. Butch, USGS, 1989, personal communication). In this USGS/NYS DOT study remote telemetry of data is also used. Also, the New York Thruway Authority has installed Brisco Monitors to monitor their scour critical bridges (Keith Giles, NYSTA, 1989, personal communication). In addition, the Virginia Transportation Research Council has plans to install Brisco Monitors and sonic devices on the I-95 bridge at the Virginia/North Carolina state line (Daniel D. McGeehan, Virginia Transportation Research Council, 1990, personal communication). These field investigations should provide valuable information on sonic sounders and the use of rods to measure scour or provide a warning when scour has occurred.

Equipment used in geophysical surveys is finding increased applications in scour studies (12). Impulse radar, lasers, and multi-channel sounders appear to be the most promising techniques, but these devices are expensive and often the results are difficult to interpret. It may be unlikely that they could be adapted to fixed installations within reasonable costs at this time, but such devices will be considered and evaluated.

## RESEARCH APPROACH

### Overview

The following sections provide a brief discussion of our planned approach for the performance of each task of the research work plan for NCHRP Project 21-3. These tasks are:

1. Comprehensive Information Gathering
2. Identification of Potentially Feasible Measurement Devices
3. Evaluation of Devices Identified
4. Preparation of Interim Report and Test Plan
5. Development of Prototype Devices
6. Testing and Evaluation of Prototype Devices
7. Cost Analysis of Each Prototype Device
8. Preparation of Final Report

#### Task 1: Comprehensive Information Gathering

The first requirement for the project was to complete comprehensive information gathering. Specifically, a review of all relevant domestic and foreign practice, performance data, and research findings directly related to field measurement of scour at bridge crossings, or indirectly related research that could be transferable to the highway industry, was completed. A survey of equipment that has been proposed previously for bridge scour monitoring was also completed.

Many of these activities will continue through the research project. Any information obtained through these activities will be used to update our annotated bibliography periodically. Appropriate findings are included in the Interim Report, Task 4, and will also be included in the Final Report, Task 8.

#### Task 2: Identification of Potentially Feasible Measurement Devices

Task 2 identified electrical, mechanical, or other devices that have been or could be adapted to measure maximum scour at bridge piers and abutments. The identification of potentially feasible measurement devices was completed based on the criteria of significance for the research project. Specifically, this analysis was completed without any evaluation of a given device's feasibility, to insure that no possible device was eliminated from consideration at this stage. With the rapid advances made in instrumentation technology in

recent years, a technique that as little as 6 months ago was not feasible, based on cost or other reasons, may now be a practical alternative.

During Task 1 it was found that the techniques and devices for measuring scour depth fall into three general categories: (1) direct soundings to determine the bed elevation; (2) devices attached to the piers or abutments that can indirectly sense the difference between flowing water and the non-moving sediment of the bed; and (3) various devices such as scour collars, buried chains, and tracers. A list of the more common devices and techniques and some of their advantages and disadvantages are given in Table 1.

Direct soundings can be made with mechanical devices, sounding rods and sounding weights on a line, or by acoustic devices, impulse radar, or pulsed laser. Sonic sounders are standard tools in scour studies today. Impulse radar is being investigated for applications in scour studies, and pulsed laser is developed for bathymetric surveys in fairly clear water to depths of about 50 m.

The various devices that indirectly sense the difference between flowing water and non-moving sediment are based on differences in conductance, heat dissipation, or light transmission. The common problems of these devices are how to install and secure them on existing piers and abutments, anticipating the expected depth of scour, and reliability under conditions encountered during a flood.

The use of scour collars, scour chains, and various tracers are generally limited because they have to be recovered after the flood. These are used mostly in arid regions where the stream beds are dry much of the time. However, miniature transmitters such as those used to track fish and game show considerable promise. For example, transmitters of various frequencies that are motion-activated could be buried in a grid around a bridge pier and detected by a downstream receiver when the depth of scour reaches them and they float out.

#### Task 3: Evaluation of Feasible Devices

The evaluation of feasible devices was based on a comprehensive analysis and screening program. For each device this analysis considered the advantages, limitations, purchase and installation costs, potential problems and failure modes, and other important features or considerations (see additional discussion under Task 5). Based on this evaluation, those devices that showed promise for

TABLE 1. SUMMARY OF SOME TECHNIQUES OR DEVICES FOR MEASURING LOCAL SCOUR AT PIERS AND ABUTMENTS

TECHNIQUE OR DEVICE	ADVANTAGES	DISADVANTAGES	REMARKS
<u>Direct Bed Elevation Soundings</u>			
<u>Mechanical</u>			
Sounding Rods	Inexpensive, simple, rugged, accurate	Cannot be used in debris-laden flow, great depths, high velocities	Could be used unattended by mounting in a pipe on the pier or abutment, lowering and raising with an electro-mechanical system, from the bridge deck or the bank. Need to develop a tensiometer to sense the contact with the bed, reversing switch method to measure distance traversed and to transmit this information to a remote location.
Sounding weight on a line	Same as sounding rod	Same as sounding rod	Probably cannot be used unattended except for almost-ideal conditions.
<u>Electrical</u>			
Acoustic	Inexpensive, accurate	Problems with debris, air entrainment under transducer, and extremely high sediment concentrations	This is standard equipment for most scour studies today. Most work is done from boats or the bridge deck. A complete system for this costs about \$700.00. Needs development for weatherproofing, transmitting signal to the bank or a remote site, etc.
Impulse Radar	Can "see" through air, ice, water, sediment	Expensive, cannot "see" through organic debris	USGS-FHWA are conducting research on applications of Ground-Penetrating Radar to bridge scour studies.
Pulsed Laser	Can "see" through air, water	Clay particles in water cause problems. Expensive.	Presently operational for airborne bathymetry to about 50 m. in coastal waters and clear rivers. Possible applications to scour studies have not been investigated.

TECHNIQUE OR DEVICE	ADVANTAGES	DISADVANTAGES	REMARKS
<u>Indirect Bed Elevation Determinations</u>			
<u>Conductivity</u>	Designed to operate unattended.	May be difficult to mount on existing bridges.	Field tested by University of Iowa in 1954.
<u>Heat Dissipation Gage</u>	Same as above	Same as above	Same preliminary design by Federal InterAgency Sedimentation project. May be possible to fabricate using casting resins.
<u>Photo-Electric Cells</u>	Unknown	Same as above	Photo-cells mounted in a plastic pipe have been driven into the stream bank and used to monitor bank erosion. Applications to scour studies have not been investigated.
<u>Pressure Transducers</u>	Unknown	Must move up and down with the stream bed	Can measure depth to plus or minus 2% with relatively inexpensive system.
<u>Tracers and Other Methods</u>			
<u>Scour Collars</u>	Simple, inexpensive	Must be installed and recovered	Have been used on small circular piers. These tend to induce some additional scour in sand-bed streams.
<u>Buried chains, tapes, etc.</u>	Same as above	Same as above	Have been used to obtain general scour in arid-region streams.
<u>Tracers</u>			
Colored, fluorescent	Same as above	Same as above	Have been used to a limited extent in arid regions.
Magnetic	Same as above	Same as above	Have been used to a limited extent. Can be detected through about 60 cm of sediment.
Radioactive	Easy to detect	Hazardous to use	Environmental concerns limit use today.
Miniature Radio Transmitters	Easy to detect	Expensive unless recovered	Can be designed to float out of or tumble into scour hole.

further development and testing were identified. The screening of equipment measures and procedures resulted in an identification matrix summarizing all pertinent information on each device and an evaluation matrix. It was recognized at the outset of this research that it is not likely that any single device will meet the development objectives on all bridges or under all hydraulic and geomorphic conditions.

#### Task 4: Preparation of Interim Report and Test Plan

Upon completion of Tasks 1-3, an Interim Report was prepared documenting the findings of these tasks and proposing a Test Plan for evaluation of those devices selected during Task 3. Pertinent information documenting results of Tasks 1-3 included complete identification of all sources of information and a detailed discussion of the evaluation process. These were provided so that NCHRP reviewers have adequate information to independently evaluate potentially feasible devices. A cost estimate for developing and testing identified devices was also provided.

Development of the test plan was centered around the Hydraulics Laboratory at Colorado State University, which can provide prototype testing under controlled laboratory conditions. The Task 6 discussion highlights the specific prototype test conditions possible at the Hydraulics Laboratory for the testing, including the range of approach depth, velocity, pier size, etc.

#### Task 5: Development of Prototype Devices

This task will not be initiated until NCHRP has reviewed and approved the Interim Report. Development of prototype devices will be a team effort, involving both river engineering expertise and instrumentation expertise. Development of prototype sensors/electronics will be based on information obtained from Tasks 1 through 4 - the review, identification, and evaluation of existing, proposed, or conceptual devices which meet certain criteria.

Throughout the development, design and fabrication, the following factors and criteria will be given strong consideration:

- \* Hydraulic factors, flow patterns and possible complications from turbulence generated by the device itself.

- \* Mounting arrangements that protect the device from debris, ice and vandals such that it is operable during storms and flooding conditions when scour is most likely to occur.
- \* Ability to measure maximum scour depth to +/- 1.0 ft. and to operate over a broad range of flow conditions. Measurement and readout electronics must ultimately provide these readings at a safe location, such as the bank or possibly a remote site.
- \* Installation on most existing bridges and during construction of new bridges.
- \* Long term reliability, low maintenance and serviceability by highway maintenance personnel.
- \* A design that produces a relatively uncomplicated device that is simple to build, low in cost, and easy to ship.

Given all these factors, it is important to recognize that there may not be one single device that applies to all bridges and/or stream conditions.

#### Task 6: Testing and Evaluation of Prototype Devices

##### *Laboratory Test Program*

Once the prototype scour measurement devices/instruments have been developed and fabricated, each device will be laboratory tested and its performance evaluated at the Hydraulics Laboratory of Colorado State University. The prototype devices will be tested in two stages using the following facilities:

1. The prototype scour measurement devices will first be tested using a 1:50 scale pier model. The model will be placed in a tilting recirculating flume with dimensions of 200 feet long, 8 feet wide and 4 feet deep. The pier will be placed in the simulated stream channel of erodible bed material in which scour depths of over 2 feet can potentially develop. The prototype device will be mounted to the model pier and activated. The flume is capable of flows of over 100 cfs at bed slopes of up to 2 percent. Each device will be tested in clear water under controlled laboratory conditions.

2. When the scour measurement device proves to be reliable in the first stage, the device will be tested near full scale, under prototype conditions. An existing concrete flume 180 feet long, 20 feet wide and 8-13 feet deep will be modified and a stream channel will be simulated. A pier will be constructed and installed in erodible bed material on the stream bottom. The facility is capable of discharging over 100 cfs resulting in average channel velocities of 6-9 fps. The test set-up will allow for scour depths around the pier of up to 5 feet. In addition, sediment and/or debris can be injected into the flow to evaluate how debris impact and debris buildup may potentially affect device durability and operation.

The laboratory testing program will allow the Research Team to redesign and/or refine each device based upon laboratory performance. The two-stage laboratory testing at near prototype conditions will allow for a thorough evaluation of each scour measurement device before conducting an expensive, time consuming comprehensive field testing program.

#### *Field Test Program*

Field evaluation of the installation and operational characteristics of the most promising device(s) would support the cost analysis (Task 7) and recommendations for the comprehensive field evaluation program (Task 8). A limited field evaluation would provide information not available from the laboratory study regarding operation in the field, installation problems, cost of installation, and practicality of using state or county personnel to accomplish installation. Consequently, a limited field evaluation program of the most promising device(s) applicable to the widest range of geometric and geomorphic conditions will be conducted.

An important element of such a pilot field program will be availability of a suitable bridge site subject to high discharges on a predictable basis, i.e., below a controlled release site. If such a site can be located, the field test could be accomplished during the eight months currently scheduled for Task 6.

#### **Task 7: Cost Analysis of Each Device Tested**

Cost will be an important factor in the ultimate selection of a scour measuring device, particularly if widespread implementation is to be possible. Cost analysis will include the cost of fabrication, installation, and delivery, as well as operation and maintenance costs. An estimate of costs and time for performing comprehensive field evaluations will be included in the final report (Task 8).

#### **Task 8: Final Report**

The Final Report (scheduled for January 1992) will document all research findings, including recommendations for a comprehensive field evaluation program for prototypes that show promise, and an estimate of the related time and cost requirements. As part of the Final Report for this project, it is expected that several prototype devices will be recommended for further comprehensive field studies and testing. For each recommended device, including its measurement, interrogation, and recording component, a summary of expected acceptable operating conditions (ranges) will be provided. This information will include, but not be limited to, the temperature range at which the device will operate properly, maximum sediment transport rate at which the device will provide accurate readings, vulnerability to debris loading and hydraulic forces, etc. These operating conditions/ranges will be considered and evaluated during Task 6 testing.

#### **Expected Results**

The results of this research will include a comprehensive survey and evaluation of possible devices for measuring maximum scour at bridge crossings. Detailed testing of the most feasible devices will be completed at near full scale, prototype conditions. Limited field testing of the most promising device(s) will also be conducted. Results will be presented in the final report, with appropriate data presented in graphical and tabular form. Plans and specifications will be included as appropriate. Laboratory testing will also include still photography and video of observed performance.

The research will rank the devices based on completed testing and provide detailed recommendations and criteria for

a comprehensive field evaluation program to include identification of potential sites (Task 8). It is anticipated that the final recommendation of the best device(s) for widespread implementation will incorporate the results of this research effort and the comprehensive field evaluation program. Completion of the comprehensive field evaluation is not part of the scope of work of this research effort; however, involvement of state representatives on the State Advisory Panel will provide the transition from this research program to a comprehensive field testing phase.

## EVALUATION OF FEASIBLE DEVICES

### Discussion

Devices considered feasible for scour measurement at bridge piers and abutments can be grouped into four broad categories: Sonar, Sounding Rods, Buried (Driven) Rods, and Other Buried Devices (see Table 2). The evaluations in Table 2 are qualitative - Good, Fair, Poor or Unknown. When one of the criteria is marked U (unknown), it generally means that there is insufficient information or that the device has never been used under circumstances to test and establish its performance for that criteria.

While Item 1 (mandatory) rates the capability for installation on or near a bridge pier or abutment, Item 5 (desirable) evaluates the ease of installation. A device may be capable of being installed and rate higher under Item 1, but if it would be difficult to install the device would rate low under Item 5. Moreover, a device that would be easy to install on both existing and new bridges would rate higher under Item 5 than one that could be easily installed on only a new bridge.

The appraisal of Item 8 (desirable) is arbitrary and is based on the estimated cost of procurement, but not installation costs. For purposes here, costs under \$2,000 are rated good and costs over about \$20,000 are rated poor. In practice, costs need to be evaluated relative to the cost of the structure or relative to the cost of failure of the structure.

A significant number of bridges exist in the United States for which bridge plans are not available, i.e., the foundation and soil properties are unknown. Item 12 (desirable) evaluates the ability of the device to perform successfully and provide scour data where foundation and soil conditions are unknown. Specifically, this criteria rates as less desirable those devices

requiring a particular pier or foundation geometry for installation or requiring detailed knowledge of soil and substrate conditions underlying the bridge. In addition, a device which would provide additional information on the below-ground structural foundation of the bridge would be desirable. Item 12 of the evaluation matrix rates such a device higher than one that provides no data on unknown foundation conditions.

### Sonar

The first category (see Table 2), Sonar, is a clear favorite for most scour studies, but it is also clear that it cannot operate under all conditions. For example, floods rising over dry beds in desert streams usually pile debris against a pier from the bed up, and it is unlikely that sonar would work under those conditions. Similar conditions might exist at bridge sites that are subjected to flooding from ice jams. Some problems remain to be resolved with sonar, but these relate mostly to the mechanics of mounting the transducer on the structure in such a way that it can be easily replaced during flooding conditions, and to problems associated with loss of signal in flows with very high sediment concentrations. This latter problem can be studied in the laboratory. Laboratory studies also need to evaluate what region(s) of a scour hole is detected with various cone angles and mounting angles.

### Sounding Rods

Vertically Supported Sounding Rods also rate fairly high in the evaluation matrix, but they clearly are not suitable for all rivers. For example, it would be very difficult to install a sounding rod for the great flow depth of the lower Mississippi River. A number of questions remain to be resolved regarding these devices: Do they induce scour around their baseplate when installed in sand-bed streams? Will the unsupported length of rod vibrate due to vortex shedding and induce additional scour? In flows with high sand concentration, can sediment entering between the rod and its vertical support members hinder the free sliding of the rod or cause it to bind? Some of these questions can be answered by laboratory testing. Cayuga Industries has provided the Research Team with a prototype of their patented Brisco Monitor for testing.

Table 2. Evaluation Matrix

Device	Mandatory Criteria				Desirable Criteria							
	1	2	3	4	5	6	7	8	9	10	11	12
	Install on Pier	Accuracy ± 1 foot	Read Above Water or Remote	Operate During Floods	Ease of Installation	Range of Discharge	Withstand Ice/Debris	Low Cost	Vandal Resistant	O & M	Reliability	Subsurface Detection
1. Sonar	G	G	G	G	G	G	G	G	G	F	G	G <sup>1</sup>
2. Sounding Rod	G	G	G	U	F	P	U	F	F	G	G	P
3. Buried Rod												
Conductance	G	G	G	U	P	G	G	U	G	U	P	P
Optical <sup>2</sup>	G	G	G	U	P	G	G	P	G	U	U	P
Motion Activated <sup>3</sup>	G	G	G	U	P	G	G	U	G	U	U	P
Mechanical <sup>4</sup>	G	G	P	U	P	G	G	U	G	G	G	P
4. Other Buried Devices <sup>5</sup>	G	G	G	G	P	G	G	F	G	P	U	P

Legend:

- G Good
- F Fair
- P Poor
- U Unknown

Notes:

- <sup>1</sup> Item 12 - Tuned transducer only (see Table 2).
- <sup>2</sup> e.g., Sanyo device
- <sup>3</sup> e.g., Wallingford type device, piezoelectric film or mechanical trip transducer
- <sup>4</sup> e.g., Scubamouse
- <sup>5</sup> e.g., Radio transmitters

### Buried (Driven) Rods

The next category of devices in the matrix is Buried (Driven) Rods. These are devices that need to be mounted or driven below the bed on the pier or abutment to the expected depth of scour. Conductance meters, mechanical meters, and optical meters all fall into this category. Due to the below grade installation requirements, all of these devices are rated poor for ease of installation, particularly at existing bridges. The USGS has provided the Research Team with the conductance meter that was installed last year in Arkansas, and some tests on this device in the outdoor flume are recommended. Mechanical devices are presently best illustrated by the New Zealand Scubamouse (see Selected Examples section); but for this particular device remote readout capability is not currently available. Environmental concerns relative to the use of a radioactive collar may also restrict the use of a Scubamouse type device in the United States. One of the problems with the optical device is determining the upper limits of sediment concentrations beyond which it does not function. The only available commercial device is too expensive (about \$10,000) to procure for this project, but if it were possible to obtain just the sensor, it could be tested in the laboratory to resolve the sediment concentration issue.

Motion activated sensors are generally described as those devices that have some type of motion sensor at various intervals along the rod, such that when unburied by scour the sensor is free to move and motion is detected. For +/- one foot accuracy, such devices would have sensors at one foot intervals. The Wallingford "Tell Tail" device, which has a patent pending, falls into this category. The Research Team has developed several alternate concepts for a motion detector device, which could be tested in the laboratory. These include a piezoelectric polymer film transducer and a mechanical trip switch probe. Concerns with such a device would include installation, adequate assurance of free motion once unburied, possible erratic indications due to turbulence in the scour hole, and operation under potentially high sediment concentrations.

### Other Buried Devices

The final category in Table 2 is "Other Buried Devices" which are considered to be those devices that either float out of a hole or drop into a scour hole. Such

devices could include radio transmitters, pressure transducers, or a tethered target. Devices that drop into the hole would likely have to be tethered at an upstream location. Questions about the use of such devices for scour monitoring relate primarily to the physical motion of the device and its interaction with the flow and stream bed. Limited model study testing on the mechanics of this physical motion, without regard to the type of device or detection scheme, would contribute to evaluation of the applicability of these devices as a scour monitoring device.

### RECOMMENDATIONS

The Research Team recommendation to the NCHRP Panel is that at least one device from each of the four categories of Table 2 be procured or developed under Task 5 and tested under Task 6. Testing would be done in two phases in either the indoor flume (pre-testing - Phase 1) or the outdoor flume (near-prototype testing - Phase 2) at the Hydraulics Laboratory at Colorado State University. The recommended objectives of the testing for each of the categories of devices are discussed below.

#### Sonar

Testing is not necessary to prove the technology employed in sonar devices. This has been established through numerous applications to the scour monitoring problem and through adaptation of sonar devices to such related activities as river and reservoir cross section and bottom profiling. Results and performance data are available in the literature and from active field installations for the bridge scour application. Testing of sonar should concentrate on:

- \* Effects of debris (or ice) on performance and accuracy.
- \* Effects of high sediment concentrations on performance and accuracy.
- \* Mechanics of mounting the transducer on the bridge structure (pier or abutment) so that it is accessible and easy to replace.
- \* Identifying effects of cone angle and mounting angle on the accuracy of the instrument (i.e., how does the device "see" the scour hole, and will it "see" the maximum depth of scour?)

## Sounding Rods

While field installations provide some performance data on vertically supported sounding rods, a number of questions regarding the interaction of the rod with the flow and with the stream bed remain. The Brisco Monitor, for example, has been installed on several bridge abutments and piers in New York, but the streams have been of coarser or cohesive bed material. Thus, these field installations have not provided data or experience on performance of a vertical rod on a sand bed stream. A prototype Brisco Monitor is available to the Research Team and should be included in both the pre-testing and near-prototype testing phases to determine:

- \* The interaction of the rod baseplate with a sand bed, i.e., does the baseplate itself induce scour?
- \* Will the unsupported length of rod vibrate due to vortex shedding and induce additional scour?
- \* Is the rod system mechanically reliable with high concentrations of sediment which could cause the rod to bind?

## Buried (Driven) Rods

Buried (driven) rods include conductance, optical, motion activated, and mechanical devices. It is recommended that up to three types of driven rods be tested during the near-prototype phase of laboratory testing.

- \* The USGS conductance probe that had been installed in the field in Arkansas (supplied by the USGS to the Research Team) should be tested to gain experience with a conductance type device, supplement data from the field installation with laboratory data under controlled conditions, and, if possible, determine why the device did not perform satisfactorily in the field.
- \* A motion activated buried rod device developed by the Research Team should be tested during the near-prototype phase. This could be a rod with either piezoelectric polymer film transducers or mechanical trip switch transducers. Test objectives would include evaluation of installation techniques, performance, reliability, and data acquisition techniques.

- \* One testing "slot" should be held open to conduct tests on a device to be developed by the Research Team or to be acquired from a manufacturer (e.g., optical sensor, or Wallingford "Tell Tail" device). This device will be selected after consultation between the NCHRP Panel and the Research Team.

## Other Buried Devices

Testing of the physical response of a typical buried device (e.g., radio transmitter, pressure transducer, or tethered target) should be conducted during the near-prototype phase with the following objectives:

- \* Evaluate the response and physical fate of a "dummy" buried device to ascertain the mechanics of physical motion and interaction of the device with the flow and with a scour hole as it develops.
- \* Testing of detection and data acquisition capabilities of buried type devices should be deferred until the mechanics of motion tests provide better data on the physical fate of these devices on or in the stream bed and scour hole.

## SUMMARY

As discussed in the Introduction, highway bridge failures caused by scour or erosion-related processes account for most of the bridge failures in this country, yet our knowledge of scour under field conditions is extremely limited. The hazards of data collection during flood events and the lack of automated instrumentation presently inhibit collection of field data. There are many scour vulnerable bridges on spread footings or shallow piles in the United States. With limited funds available, these bridges cannot all be replaced or repaired. Therefore, they must be monitored and inspected following high flows. During a flood, scour is generally not visible and during the falling stage of a flood scour holes generally fill in. Therefore, visual monitoring during a flood and inspection after a flood cannot fully determine that a bridge is safe. A reliable device to measure maximum scour would resolve this uncertainty.

The ability to measure scour in the field would allow monitoring scour critical bridges so that countermeasures

can be taken before the problem becomes severe, or could provide a possible long term alternative countermeasure for scour in some circumstances. These actions would increase the safety of the traveling public and would reduce the costs of bridge inspection, operation, and maintenance. Thus, the results of this research will be of immediate value to state highway departments, authorities, county and city roadway and street departments, and private bridge owners. In addition, several states have undertaken or will initiate cooperative scour research programs with the U. S. Geological Survey. Instrumentation to measure maximum scour depths at bridge piers and abutments would provide invaluable support to such cooperative research efforts.

The lack of field data on scour requires researchers investigating bridge scour, and those developing analytical tools to predict scour, to rely on laboratory data, usually collected from scale models. However, problems in scaling sediment sizes and erosional processes limit the value of laboratory data acquired from scale models and such data cannot provide reliable confirmation of analytical procedures. Therefore, there is real and immediate need for field measurement of scour and erosional processes at bridge crossings. The development of a reliable, cost effective device(s) for measurement of maximum scour would support efforts to acquire a field data base on scour that would be of great value in development of reliable analytical procedures for scour prediction. Such data would be welcomed by researchers worldwide. Finally, this research could lead to development of early warning systems for impending bridge failures. Such systems could contribute to reducing the tragic loss of life associated with catastrophic bridge failures.

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