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by
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ABSTRACT

Field and laboratory research sponsored by the Federal Highway Administration, State DOT's and the Transportation Research Board has developed a toolbox of fixed and portable instruments for measuring and monitoring scour depths at bridges. Fixed measuring instruments are magnetic sliding collar, Low-cost sonar and float-out cylinders. Portable are physical probing rods and weights on cable, low-cost sonar, and geophysical. A toolbox of instruments is needed in-order-to select the appropriate instrument for the many varied bridge, stream and environmental conditions. These instruments have satisfactory operated in this varied environment. They have significantly improved the scour database, methods of predicting scour depths, bridge scour monitoring and to bridge safety.

INTRODUCTION

In the United States, as of April 2002, there are 26,149 scour critical bridges, 20,353 scour susceptible and 88,912 with unknown foundations These statistics come from an on going screening and evaluation program of the 484,286 bridges over water in the United States. With limited funds available, these bridges cannot all be replaced or repaired. Also, during a flood, scour is generally not visible and on the falling stage of a flood, scour holes generally fill in. Therefore, scour depths of scour critical, and scour susceptible bridges and bridges with unknown foundations must be monitored during high flows. This monitoring with a suitable plan of action (for example close the bridge when scour reaches a given depth) is considered to be an adequate scour countermeasure for these bridges. In addition, every bridge in the U. S must be inspected every two years. If the foundations cannot be inspected during the two-year inspection, an underwater inspection is required every 5 years. These inspections require that a profile of the elevation of the streambed at the bridge be taken. Thirdly, the development and/or improvement of equations to determine bridge scour depths require field measurements of scour depths along with the corresponding hydraulic conditions. For these reasons, two basic categories of instruments, portable or fixed, have been developed in the United States.

Whether to use fixed or portable instruments in a scour monitoring or measurement program depends on many different factors. Unfortunately, there is not one type of instrument that works in every situation encountered in the field. Each instrument has advantages and limitations that influence when and where they should be used. The idea of a toolbox, with various instruments that can be used under specific conditions, best illustrates the strategy to use in selecting instrumentation for a scour-measuring/monitoring program. Specific factors to consider include the frequency of

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data collection, the physical conditions at the bridge and stream channel, and traffic safety issues.

Fixed instrumentation is used when frequent measurements or regular, ongoing measurements (e.g., weekly, daily, or continuous) are required. Portable instruments would be preferred when only occasional measurements are required, such as for the inspection program, or during a major flood. The physical conditions at the bridge, such as height off the water and type of superstructure, can influence the decision to use fixed or portable equipment. For example, bridges that are very high off the water, or that have large deck overhang or projecting geometry's, would complicate portable measurements from the bridge deck. Making portable measurements from a boat assumes that a boat ramp is located near the bridge, there is sufficient clearance under the bridge for safe passage of a boat and the turbulence and velocity of the flow allow the boat to get near the foundations. . Bridges with large spread footings or pile caps or those in very deep water can complicate the installation of some types of fixed instruments. Stream channel characteristics include sediment and debris loading, air entrainment, ice accumulation, or high velocity flow, all of which can adversely influence various measurement sensors used in fixed or portable instruments. Traffic safety issues include the need for traffic control or lane closures when either installing or servicing fixed instruments, or attempting to make a portable measurement from the bridge deck.

Therefore, it is apparent that the selection of the instrument category (fixed or portable) and the specific instrument types to be used in a measurement/monitoring plan is not always straightforward. In some situations there is no clearly definable plan that will be successful, and the plan is developed knowing that the equipment may not always work as well as might be desired. Ultimately, the selection of any type of instrumentation must be based on a clear understanding of its advantages and limitations, in consideration of the conditions that exist at the bridge and in the channel and the objectives of the monitoring/measuring program.

To improve the state-of-practice the National Academy of Science's Transportation Research Board (TRB) under the National Cooperative Highway Research Program (NCHRP) funded research programs to develop fixed and portable instruments to measure scour depths. In addition, to facilitate the technology transfer of instrumentation-related research to the highway industry, the Federal Highway Administration (FHWA)(1998) developed a Demonstration Project (DP97) on scour monitoring and instrumentation. The purpose of the Demonstration Project was to promote the use of new and innovative equipment, both fixed and portable, to measure scour, monitor changes in scour over time, detect the extent of past scour, and serve as countermeasures. This paper provides information on the development and use of portable and fixed instrumentation. The experience of several State Highway Agencies with the use scour depth instrumentation is also included.

FIXED SCOUR MEASURING INSTRUMENTATION

A review of the literature (Lagasse, et al, 1997 and 2001) determined that fixed scour-measuring and -monitoring instruments could be grouped into four broad categories:

1. Sounding rods - manual or mechanical device (rod) to probe streambed

2. Buried or driven rods - device with sensors placed vertically into streambed
3. Fathometers - commercially available sonic depth finder
4. Other Buried Devices - active or inert buried sensor (e.g., buried transmitter)

Sounding Rods

Laboratory and field testing of sounding rod devices, determined that 1) binding of the rod in its supporting enclosure (pipe) could be a factor for large scour depth; 2) in sand bed streams, sand deposited between the rod and its supporting enclosure also would bind it up; and 3) in sand- and noncohesive bed materials the rod would penetration into the bed a significant and indeterminate amount. However, successful installations have been reported on coarse-bed streams by the manufacturer (Cayuga Industries) and USGS (Lagasse, et al, 1997).

Buried or Driven Rods

Buried/Driven rods includes all sensors and instruments supported by a vertical support member such as a pipe, rail or column placed vertically in the bed, at the location where scour would be expected to occur. Installation of the support column is either by driving, jetting, augering, or excavation and burying. Examples of buried/driven rods include Hubbard's electrode-empedence (Laursen and Toch, 1956), New Zealand's "Scubamouse" (Melville, et al, 1989), Wallingford's "Tell-Tail" (Waters, 1994) and Transportation Research Board's (TRB) "Magnetic Sliding Collar" (Lagasse et al, 1997, 1998, 2001) The following discussion will focus on magnetic sliding collar devices.

<u>Magnetic Sliding Collar</u>. Both simple (manually read) and automated readout magnetic sliding collar were developed in the TRB project. Plans are given in NCHRP Report 397 B (Schall, et al 1997)

The instrument consists of a 51-mm (2-inch) diameter stainless steel support pipe in 1.5-m (5-foot) sections, which is buried in the bed of the stream. . A magnetic collar slides on the support pipe, (Figure 1 and 2). To determine the position of the collar, in the manually read device, a sensor consisting of a magnetic switch attached to a battery and buzzer on a long graduated cable is lowered through the annulus of the support pipe. The buzzer is activated when the sensor reaches the magnetic collar. Collar position is determined by using the graduated cable to determine the distance from an established datum near the top of the support pipe to the magnetic collar.

The automated readout magnetic sliding collar consists of string of magnetically actuated reed switches located at pre-selected intervals (152-mm (6-inch), 304.8-mm (1 ft), and etc) along the length of a waterproof flexible tubing, which is inserted in the support pipe. Magnets on the sliding collar actuate the reed switch as it is lowered by scour. A data logger provides excitation voltage for the reed switches and records the elevation of the scour depth. The data logger can be down loaded periodically into a portable computer or accessed by phone (landline or satellite). Power can be provided locally or by solar panels (see Figure 2 and 4).

Thirty-six manually read or automated sliding collar devices have been installed in eleven States. They were successfully installed and operated on tidal estuaries, and ephemeral and perennial rivers (Lagasse, et al, 2001, Price, 2002).

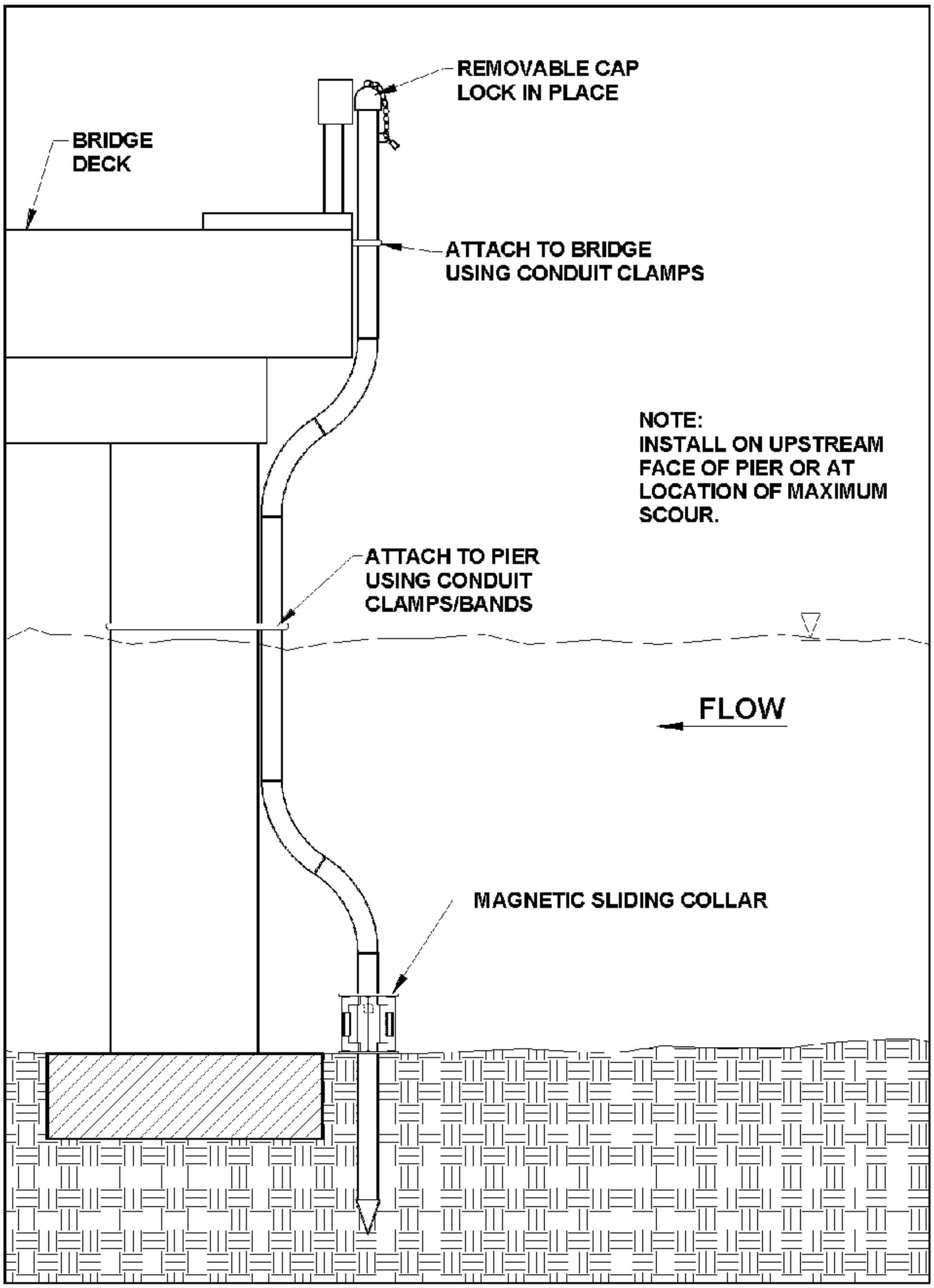

Figure 1. Manual read out magnetic sliding collar device (Schall, et al, 1997B).

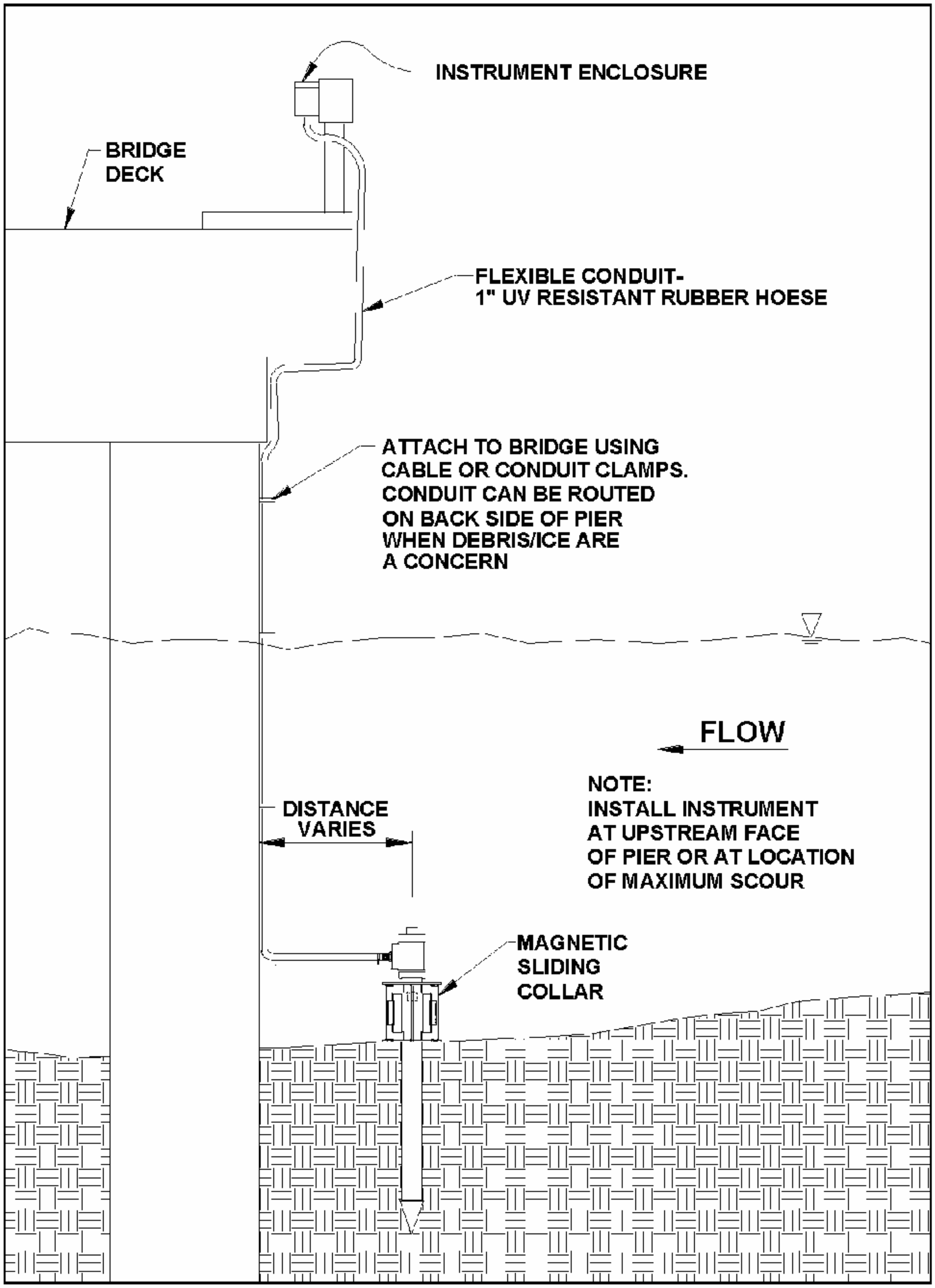

Figure 2. Automated read out magnetic sliding collar system (Schall, et al, 1997B).

Fathometers

Fathometers, a sonar instrument or sonic sounder, which measures distance based on the travel time of a sound wave through water. Fathometers consists of the electronics (black box) for generating and receiving the sound pulse and converting it to distance. And a transducer, which is in the water, transmits and receives the sound wave to and from the bed. Transducer frequency (typically around 200 kHz) and beam width are important considerations in the use of sonar for scour monitoring work. There are several fathometers available commercially, which are relatively expensive instruments for a scour-monitoring-measuring function. Research conducted by the NCHRP project determined that low-cost fathometers (recreational-type sonar fish-finders) could be used for measuring scour (Lagasse, et al, 1997).

The low-cost fathometers would determine the scour depth plus or minus 0.3 m (1 ft), which is acceptable for field scour measurements. Such devices are readily available from several manufacturers. These commercially available fishfinders do not have corrections for temperature and salinity effects on the speed of sound. However, studies found that there should not be a concern for most installations, with the limits of ± 0.3 m [± 1.0 ft] accuracy and for the depth and temperature ranges expected at most riverine and tidal bridge sites. If necessary, the corrections for temperature and salinity can be made as a post-processing step.

Low-cost fathometers scour measuring/monitoring instruments consists of a fishfinder, its transducer, an above water serviceable transducer mounting, data logger, power source and read out device (Schall et al, 1997A, Lagasse et al, 2001). The power source can be solar panel or power line. Read out can be by down loading to a computer or telemetry. Generally telemetry is by phone, either landline or cellar. Transducers need to be cleaned periodically. This is made easy by installing a conduit to the pier and sliding the transducer on a pipe inside the conduit for easy removable and bridge service. The master instrument can be configured to service many transducers (Price, 2002).

Fathometers are mounted so the transducer is aimed at the location where maximum scour will occur. The sonar signal must be unobscured by debris or ice. Loss of signal can occur with air entrainment or very high sediment concentrations. However, normally these are not of major concern for most applications. The fathometers have operated successfully in concentrations of sand as large as 50,000 ppm and silts and clays as large as 100,000 ppm.

Sixty-three low-cost fathometers have been installed in 11 States and the District of Columbia. They were successfully installed and operated on tidal estuaries, and ephemeral and perennial rivers (Lagasse, et al, 2001, Price, 2002). Six transducers are successfully monitoring the scour at six piers on the I-95 (Woodrow Wilson) bridge over the Potomac River estuary downstream from Washington, D. C., (Price, 2002) One master instrument (fish-finder sonar, data logger, solar panel, battery, and landline phone) services the six transducers.

Other Buried Devices

Other Buried Devices includes sensors, which could be buried in the bed of a river at various elevations. When scour exposes these instruments they would float out of the scour hole. These float-out devices could be either untethered or tethered to the pier or abutment. Obtaining scour data from a tethered device could be as simple as visually inspecting which tethered devices have been removed from the hole by scour. Untethered devices would most likely incorporate a motion-activated transmitter, with a receiver on the bridge or stream bank sensing when a transmitter has been moved and activated (Winter, 1995, Price, 2002).

Float-out Cylinder As a monitoring device, to protect scour susceptible bridges on ephemeral stream, a buried transmitter "float-out" device was developed for application on bridge piers (Price, 2002). This device consists of a 6 x by 11-inch cylinder with a radio transmitter buried in the channel bed at a pre-determined depth. When the scour reaches that depth, the float-out cylinder rises to the surface and begins transmitting a radio signal to a receiver in an instrument shelter on the bridge. The receiver transmits the information to a central location by telemetry. Normally by Landline or cell phone. The battery in the cylinder lasts 8 to 10 years. Installation requires using a conventional drill rig with a hollow stem auger (Figure 3). After the auger reaches the desired depth, the float out transmitter is dropped down the center of the auger. Substrate material refills the hole as the auger is withdrawn. Two cylinders are often placed in the auger hole. The first to alert that scour is approaching a problem and the second at the critical depth where action needs to be taken.

Figure 3. Hollow stem auger and installation of a float-out cylinder. (Lagasse et al, 2001)

The float-out devices can be monitored by the same type of master instrument shelter/data logger currently being used to telemeter low-cost fathometer or automated sliding collar data. A master instrument shelter serves all devices. It contains the data logger, phone telemetry, and a solar panel/gell-cell battery for power, (Figure 4).

One hundred and twenty nine float-out devices have been installed at bridges in Alabama, Arizona, California, and Nevada (Lagasse et al, 2001, Price, 2002). Most devices were installed at various levels below the streambed as described above. However, several devices at bridges in Nevada were buried in riprap at the base of bridge piers to monitor riprap stability, (Figure 5). At several of the bridges sliding-collar or low-cost sonar instruments were installed.

One of the bridges experienced several scour events that triggered threshold warnings during February 1998. In one case the automated sliding collar dropped 1.5 m (5 ft) causing a pager call-out. Portable sonar measurements confirmed the scour recorded by the sliding collar. Several days later, another pager call-out occurred from a float-out device buried about 4 m (13 ft) below the streambed. In both cases, the critical scour depth was about 6 m (20 ft) below the streambed and no emergency action was called for to insure public and/or bridge safety.

PORTABLE SCOUR MEASURING EQUIPMENT

A wide variety of instruments have been used for making portable scour measurements. In general, the methods for making a portable scour measurement can be classified as:

1. Physical probing
2. Fathometers (Sonar)
3. Geophysical

Physical Probes

Sounding poles and sounding weights on a cable are the most common physical probes. Sounding poles are long poles used to probe the bottom, (Figure 6). Sounding weights, sometimes referred to as lead lines, are typically a torpedo shaped weight suspended by a measurement cable, (Figure 7). Sound weights typically range from 3.7 to 75 kg (10 to 200 lbs). The lighter weights can be used with a hand line. Whereas, the heavier weights use a crane and reel. They can be used from the bridge or from a boat. Physical probes collect discrete data and can be limited by large depth and velocity (e.g., during flood flow condition) or debris and/or ice accumulation. Advantages of physical probing include not being affected by air entrainment or high sediment loads, and it can be effective in fast, shallow water.

Fathometers

Fathometers or acoustic depth sounders, as described in the fixed instrument section are widely used for portable scour measurements. Fish finders and precision survey-grade hydrographic survey fathometers are used. However, low-cost fish-finder type sonar instruments have been widely used for bridge scour investigations. When the measurements are made from the bridge, transducers are attached to a pole (Figure 8), hand-line, tethered float, or attached to a boom. Tethered float platforms include kneeboards, (Figure 9) and pontoon-style floats, (Figure 10). The size of the float is important for stability in fast moving, turbulent water.

Figure 4. Typical instrument shelter with data logger, cell-phone telemetry, and a solar panel/gel-cell for power. (Lagasse et al, 2001)

Figure 5. Installation of a float-out device to monitor riprap stability. (Lagasse et al, 2001)

Floating or non-floating systems can be deployed from a bridge inspection truck. This is particularly useful when the bridge is high off the water. For example, bridges that are greater than 15 m (50 ft) off the water are typically not accessible from the bridge deck without using this approach.

An articulated arm to position a sonar transducer was developed under an FHWA research project (Bath, 1999). The system was mounted on a trailer and could be used on bridge decks from 5-15 m (16-50 ft) above the water surface. An onboard computer calculated the position of the transducer, relative to a known position on the bridge deck, based on the angle of the boom and the distance between the boom pivot and transducer. A NCHRP project is developing a truck mounted articulated arm to position a sonar transducer using the same concepts, (Figure 11) (Shall, 2002)

A Sonar Scour Vision system was developed by American Inland Divers, Inc (AIDI) using a rotating, and sweeping 675 Khz high resolution sonar (Barksdale, 1994). The transducer is mounted in a relatively large hydrodynamic submersible, or fish, that creates a downward force adequate to submerge the transducer in velocities exceeding 6 m/s (20 ft/s). Given the forces created, the fish must be suspended from a crane or boom truck on the bridge. From a single point of survey, the system can survey up to 100 m (328 ft) radially. Data collected along the face of the bridge can be merged into a real-time 3-dimensional image with a range of 90 m (295 ft) both upstream and downstream of the bridge.

Manned boats are used as a platform for scour measurements. They generally require adequate clearance under the bridge and nearby launch facilities. This can be a problem at flood conditions when the river stage may approach or submerge the bridge low chord, and/or boat ramps may be underwater. Normally a fathometer is used for depth measurements and GPS systems for location.

The safety, launching and clearance issues have led to the development of a prototype unmanned boat. It uses a small flat bottom jon boat, an 8 hp outboard motor, fathometer and GPS with remote controls. It was successfully tested during six flood events (Mueller and Landers, 1999).

The advantage of GPS over traditional land-based surveying techniques is that line-of-sight between control points is not necessary. GPS also works at night and during inclement weather, which could be a real advantage for scour monitoring during flood conditions. The disadvantage of GPS is the inability to get a measurement in locations where overhead obstructions exist, such as tree canopy or bridge decks. However, GPS measurements up to the bridge face, without venturing under the bridge, have been successful.

Figure 6. Sounding pole measurement.

Figure 7.   Lead-line sounding weight with truck mounted crane.

Figure 8. Portable sonar in use. Transducer on tip of rod.

Figure 9. Kneeboard float with transducer.

Figure 10. Pontoon float, note the transducer.

Figure 11. Truck mounted articulated arm with sonic transducer, fathometer, and computer.

Geophysical

Geophysical instruments, based on wave propagation and reflection measurements, determine the interfaces between materials with different physical properties. A primary difference between sonar and geophysical techniques is that geophysical methods provide sub-bottom information, while sonar can only "see" the water-soil interface and is not able to penetrate the sediment layer. The main difference between different geophysical techniques are the types of signals transmitted and the physical property changes that cause reflections. A seismic instrument uses acoustic signals, similar to sonar, but at a lower frequency (typically 2-16 kHz). Like sonar, seismic signals can be scattered by air bubbles and high sediment concentrations. A ground penetrating radar (GPR) instrument uses electromagnetic signals (typically 60-300 mHz), and reflections are caused by interfaces between materials with different electrical properties. In general, GPR will penetrate resistive materials and not conductive materials. Therefore, it does not work well in dense, moist clays, or saltwater conditions.

The best application of geophysical technology is to determine scour depth after a flood during lower flow conditions in areas of infilling. In general, the cost and complexity of the equipment and interpretation of the data are limiting factors for widespread use and application as a portable scour monitoring device. These issues have moderated as newer, lower cost GPR devices with computerized data processing capabilities have been developed. However, GPR may still be limited by cost and complexity, and often the need for bore hole data and accurate bridge plan information to properly calibrate and interpret the results.

SUMMARY

Fixed scour depth measuring/monitoring equipment has been successfully used under many different bridge, stream and climate environmental conditions. Their success has required a toolbox approach. The instruments in the toolbox are magnetic sliding collar, low-cost sonar and float-out cylinders. The have been installed in remote locations with solar panels for power and telemetry for instant access to scour depth information.

Portable scour measuring instruments are physical probing with rod or weights, sonar and geophysical. Physical probing and sonar are useful for real-time measuring scour during a flood and for routine measurements of bridge cross-sections. Geophysical instruments are better used for scour determination after the flood and scour holes have filled in.

The development of these fixed and portable scour measuring instruments, along with GPS, remote controlled boats, instrumented trucks, and awareness of the need to measure and monitor scour at bridges have significantly improved the scour data base, methods of predicting scour depths, monitoring bridges for scour and to bridge safety.

REFERENCES

Barksdale, G. 1994, "Bridge Scour During the 1993 Floods in the Upper Mississippi River Basin," ASCE Compendium on Stream Stability and Scour at Bridges, Richardson, E.V. and Lagasse, P.F. (eds.), Reston, VA. p 551.

Bath, W.R., 1999, "Remote Methods of Underwater Inspection of Bridge Structures," FHWA Report RD-99-100, Turner-Fairbank Highway Research Center, McLean, VA.

Federal Highway Administration, 1998, "Scour Monitoring and Instrumentation," Demonstration Project 97 Participants Workbook, FHWA-SA-96-036, Office of Technology Applications, Washington, D.C.

Lagasse, P.F., E.V. Richardson, J. D. Schall, G.R. Price, 1997, "Instrumentation for Measuring Scour at Bridge Piers and Abutments," NCHRP Report 396, Transportation Research Board, NRC, National Academy Press, Washington, D.C., 110 pp.

Lagasse, P.F., E.V. Richardson, J. D. Schall, J. R. Richardson, and G.R. Price, 1998, "Fixed Instrumentation for Monitoring Scour at Bridges," ASCE Compendium on Stream Stability and Scour at Bridges, Richardson, E.V. and Lagasse, P.F. (eds.), Reston, VA. p 505.

Lagasse, P.F., L.W. Zevenbergen, J.D. Schall, and P. E. Clopper, 2001, "Bridge Scour And Stream Stability Countermeasures," Hydraulic Engineering Circular 23, Second Edition, FHWA NHI 01-003, Federal Highway Administration, Washington, D.C.

Laursen, E. M. and Toch A., 1956, "Scour Around Bridge Piers and Abutments," Bull No. 4, Iowa Highway Research Board, Iowa Institute of Hydr. Research, Iowa City, IA, 60 pp.

Melville B.W., Ettma, R., and Jain, S.C., 1989 "Measurement of Bridge Scour," Bridge Scour Symposium, Turner-Fairbank Highway Research Center, cosponsored by Federal Highway Administration and Subcommittee of Sedimentation, Interagency Advisory Committee on Water Data, OWDC, USGS, McLean, VA, pp. 183-194.

Mueller, D.S. and M.N. Landers, 1999, "Portable Instrumentation for Real-Time Measurement of Scour at Bridges," Federal Highway Administration Publication No. FHWA-RD-99-085 (FHWA approval pending), Turner-Fairbank Highway Research Center, McLean, VA.

Price, G. R., 2002, "Personnel Communication," Instrument Systems, Inc., 1317 Webster Ave., Ft. Collins, CO, 80524

Schall, J.D., G.R. Price, G.A. Fisher, P.F. Lagasse, and E.V. Richardson, 1997a, "Magnetic Sliding Collar Scour Monitor-Installation, Operation, and Fabrication Manual," NCHRP Report 397B, Transportation Research Board, NRC, National Academy Press, Washington, D.C.

Schall, J.D., G.R. Price, G.A. Fisher, P.F. Lagasse, and E.V. Richardson, 1997b, "Sonar Scour Monitor-Installation, Operation, and Fabrication Manual," NCHRP Report 397A, Transportation Research Board, NRC, National Academy Press, Washington, D.C.

Schall, J.D., 2002, "Personnel Communication," Ayres Associates, P. O. Box 270460, Ft. Collins, CO, 80527

Waters, C.R., 1994, "The HR Wallingford Scour Monitoring System," 1994 Centenary Year Bridge Conference, Cardiff, United Kingdom pp. 323-328.

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