Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 80 (1999)

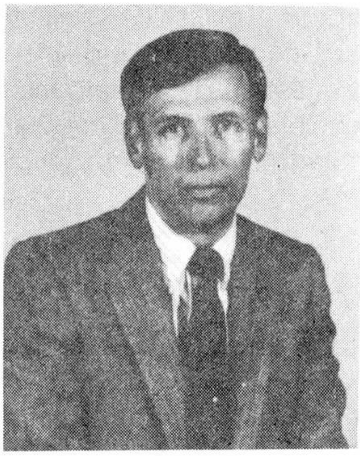
Artikel: Development and testing of instrumentation for monitoring scour at bridges

Autor: Lagasse, Peter F.

DOI: https://doi.org/10.5169/seals-60749

DEVELOPMENT AND TESTING OF INSTRUMENTATION FOR MONITORING SCOUR AT BRIDGES

Peter F. LAGASSE
Senior Vice President
Ayres Associates, Inc.
Fort Collins, CO USA



Peter Lagasse obtained his engineering degrees from U.S. Military Academy (BS), University of California, Berkeley (MS), and Colorado State University (PhD). After 20 years with the U.S. Army Corps of Engineers, he has been involved for the last 18 years in River Engineering Consulting, including stream stability and scour at bridges.

SUMMARY
This paper summarizes the results of research sponsored by the U.S. National Research Council, Transportation Research Board, to develop, test, and evaluate fixed instrumentation that would be both technically and economically feasible for use in monitoring maximum scour depth at bridge piers and abutments. A variety of scour measuring and monitoring methods were tested in the laboratory and in the field, including sounding rods, driven rod devices, sonic depth finders (fathometers), and buried devices. Two fixed instrument systems, a low-cost fathometer and a magnetic sliding collar device using a driven rod approach are described in detail. Cooperative efforts with state highway agencies proved that both systems can be installed with equipment and technical skills normally available to District level highway agency maintenance and inspection personnel. Installation, operation, and fabrication manuals for the low-cost sonic instrument system and magnetic sliding collar devices are referenced.

Co-Authors: Dr. L.W. Zevenbergen, Senior Hydraulic Engineer, Ayres Associates, Inc.
Dr. E.V. Richardson, Senior Associate, Ayres Associates, Inc.

1. INTRODUCTION

There are many scour susceptible bridges on spread footings or shallow piles in the United States and a large number of bridges with unknown foundation conditions [1]. 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. Visual monitoring during a flood and inspection after a flood cannot fully determine that a bridge is safe. A reliable device to measure or monitor maximum scour would resolve this uncertainty.

Recognizing this need, the Transportation Research Board (TRB) under the National Cooperative Highway Research Program (NCHRP) initiated NCHRP Project 21-3 "Instrumentation for Measuring Scour at Bridge Piers and Abutments" in 1989. The basic objective of this research was to develop, test, and evaluate fixed instrumentation that would be both technically and economically feasible for use in measuring or monitoring maximum scour depth at bridge piers and abutments [2]. The scour measuring or monitoring device(s) must meet the following mandatory criteria:

Mandatory Criteria

- Capability for installation on or near a bridge pier or abutment
- Ability to measure maximum scour depth within an accuracy of ± 0.3 m
- Ability to obtain scour depth readings from above the water or from a remote site
- Operable during storm and flood conditions

Since the mandatory criteria required that the instruments be capable of installation on or near a bridge pier or abutment, the research was limited to fixed instruments only. This paper summarizes the results of this research.

An initial literature search on scour instrumentation in 1990 revealed, and a resurvey of technology in 1994 confirmed, that fixed scour-measuring and -monitoring instruments can be grouped into four broad categories:

- Sounding rods - manual or mechanical device (rod) to probe streambed
- Buried or driven rods - device with sensors on a vertical support, placed or driven into streambed
- Fathometers - commercially available sonic depth finder
- Other Buried Devices - active or inert buried sensor (e.g., buried transmitter)

As a result of the literature review a laboratory testing program was designed to test at least one device from each category and to select devices for field testing that would have the greatest potential for meeting mandatory and desirable criteria.

2. FIELD TESTING OF INSTRUMENTS

The primary objectives of field testing of scour instrumentation were to test the adaptability of promising instruments to a wide range of bridge pier and abutment geometries and subject the instruments to a variety of geomorphic and environmental conditions. An additional significant objective was to gain experience in working with local State Highway Agency personnel who would ultimately be responsible for installation, maintenance, and collection of data from scour-monitoring devices.

2.1. Magnetic Sliding Collar Devices

Both simple (manually read) and automated readout magnetic sliding collar devices were installed and tested in a variety of locations in the field. Testing included pier installations of simple sliding collar instruments and pier and sloping abutment installations of automated magnetic sliding collar devices at riverine and tidal bridges.

Laboratory testing of a driven rod with an open architecture sliding collar with attached 152 mm magnets (see Figure 1) indicated that the sliding collar accurately tracked the progression of scour. Using this concept, a field prototype of a magnetic sliding collar was designed and fabricated. This instrument consisted of a 51-mm diameter stainless steel support pipe in 1.5-m sections. A magnetic collar, similar in design to the original collar used for laboratory testing, was fabricated to slide on the support pipe; however, the externally mounted magnetic switches tested in the laboratory were replaced by a much simpler approach to measuring scour. To determine the position of the collar, a sensor (probe) consisting of a magnetic switch attached to a battery and buzzer on a long graduated cable was fabricated. In operation, the probe is lowered through the annulus of the support pipe and the buzzer activates 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.

Following field testing of manual readout magnetic sliding collar devices at the Colorado and New Mexico test sites, it was apparent that the support pipe or extension conduit, which is normally fastened to the upstream face of a bridge pier, can be vulnerable to ice or debris impact. Development of an automated readout magnetic sliding collar device could reduce this vulnerability to debris and ice impact if only the head of the device protrudes from the streambed in front of a pier or adjacent to an abutment (Figure 1). A flexible conduit with the wiring for the automated readout could carry the signal by a less vulnerable route, such as along a pile cap or pier footer and up the downstream face of a pier to a datalogger.

In order to automate the operation of the magnetic sliding collar, a laboratory prototype electronic insert (probe) was developed. The insert consists of string of magnetically actuated reed switches located at 152-mm intervals along the length of a stainless steel support structure. Magnets on the sliding collar actuate the reed switch at a given position as it comes in proximity. A datalogger provides excitation voltage for a brief sampling period. The probe is encased with waterproof flexible tubing, and is then inserted into the stainless steel pipe section(s) that comprise the support rod for the instrument. Sensors at different levels are activated as the magnet on the sliding collar slides down the stainless steel pipe as scour develops.

2.2. Low-Cost Fathometer Instrument Systems

Field testing of sonic depth finders (fathometers) included pier installations at riverine and tidal bridges. A low-cost fathometer was also configured and installed on a sloping abutment.

Standard practice for installation of fathometers to monitor bridge scour has been to mount the sonic transducers into a small durable steel encasement which was then bolted to the pier of the bridge below water level. The NCHRP project developed an alternative which permits mounting the transducer so that it can be serviced from the bridge deck or above water. Either steel or PVC conduit is bracketed to the bridge substructure to "aim" the sonic transducer at the most likely location for scour. The transducer was encased in a PVC "probe," which was pushed down through a larger diameter steel or PVC conduit (Figure 2). The probe snapped into position so that it protruded through a fitting located below water at the bottom of the conduit. With this arrangement the transducer is serviceable from above water.

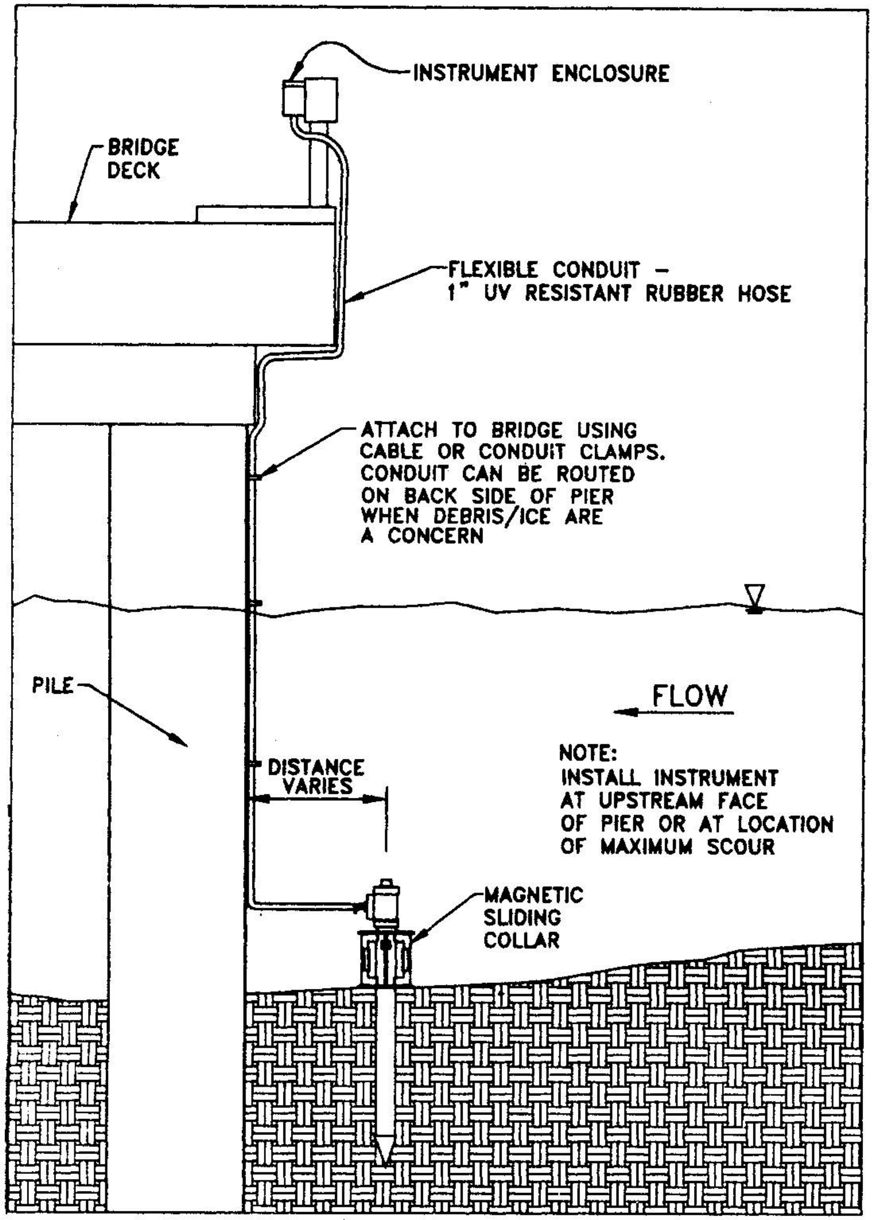


Figure 1. Automated read-out magnetic sliding collar device [3].

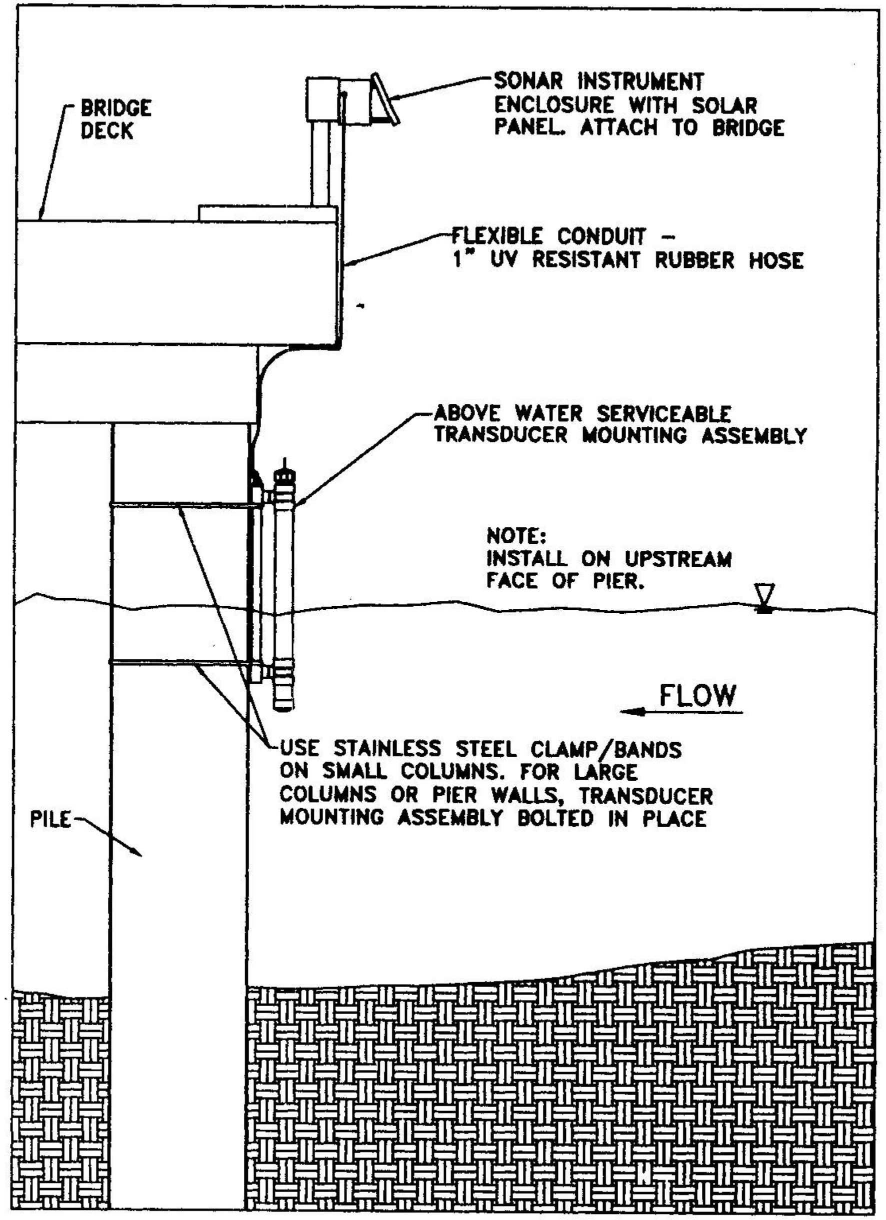


Figure 2. Above-water serviceable low-cost fathometer system [4].

2.3. Other Buried Devices

In late 1997 following completion of the NCHRP project, a buried transmitter "float out" device was developed for application on bridge piers over ephemeral stream systems. This device consists of a radio transmitter buried in the channel bed at a pre-determined depth. When the scour reaches that depth, the float-out device rises to the surface and begins transmitting a radio signal that is detected by a receiver in an instrument shelter on the bridge. Installation requires using a conventional drill rig with a hollow stem auger. 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.

The float out device can be monitored by the same type of instrument shelter/data logger currently being used to telemeter low-cost fathometer or automated sliding collar data. The instrument shelter contains the data logger, cell-phone telemetry, and a solar panel/gell-cell battery for power. The data logger monitors the sliding collar and sonar scour instruments, taking readings every hour and transmitting the data once per day to a computer at a central location (e.g., DOT District). A threshold elevation is defined that, when reached, initiates a phone call to a pager network. The bridge number is transmitted as a numeric page, allowing identification of the bridge where scour has occurred. The float out devices are monitored continuously, and if one of these devices floats to the surface, a similar call is automatically made to the pager network.

2.4. Instrument Costs

The "low-cost" sonic system as tested under NCHRP Project 21-3 will cost approximately $4,000 (U.S.). The cost of a magnetic sliding collar device will range from $2,500 for a simple manual-readout device to $4,000 for an automated system. Instrument system costs include the basic instrument and mounting hardware, as well as power supply, data logger, and instrument shelter/enclosure, where applicable. A cell-phone telemetry link will add approximately $3,000 to the system cost. A float-out buried transmitter can be fabricated for approximately $500, and monitored by the same data logger/cell-phone system installed for either a sonic system or automated sliding collar.

The installation costs for sliding collar and sonic devices can vary dramatically depending on the complexity of the installation. For large rivers where the installation must be conducted from the bridge deck, the level of effort required for installation of an instrument system can be 4-6 person days, plus the necessary equipment for installation.

3. RESEARCH FINDINGS

The two instruments developed under NCHRP Project 21-3, a low-cost sonic system and either a manual-readout or automated magnetic sliding collar device, have been tested extensively and are fully field-deployable. **Both instrument systems met all of the mandatory criteria and most of the desirable criteria established for this project**. Use of these instruments as scour monitoring countermeasures will provide State Highway Agencies with an essential element of their plans of action for many scour-critical, scour-susceptible, or unknown foundation bridges.

No single methodology or instrument can be utilized to solve the scour monitoring problems for all situations encountered in the field. Considering the wide range of operating conditions necessary, environmental hazards such as debris and ice, and the variety of stream types and bridge geometry's encountered in the field, it is obvious that several instrument systems using different approaches to detecting scour will be required.

The Installation, Operation, Fabrication Manuals for the low-cost sonic system and magnetic sliding collar devices [3] and [4] provide complete instrument documentation, including specifications and assembly drawings. That information, together with the findings, appraisal, and applications information of the final report [2], provide a potential user of a scour monitoring device complete guidance on selection, installation, operation, maintenance, and if desired, fabrication of two effective systems, one of which could meet the need for a fixed scour instrument at most sites in the field. In addition, a third instrument system consisting of float-out buried transmitters has been installed at several bridge sites on ephemeral streams, and at one site detected scour at 3.6 m below the streambed.

Of the devices tested extensively in the field, the low-cost sonic system and the manual-readout sliding collar device are both vulnerable to ice and debris; however, both proved to be surprisingly resistant to damage from debris or ice impact at field test sites. The sonic system can be rendered inoperative by the accumulation of debris, and presumably ice, between the transducer face and streambed. The manual-readout sliding collar requires an extension conduit, generally up the front face of a pier, which can be susceptible to debris or ice impact damage unless the extension can be firmly anchored to a substructure element. From this perspective, the automated sliding collar device has the distinct advantage of having a configuration which places most of the device below the streambed, and therefore, less vulnerable to ice or debris. The connecting cable from the device to a datalogger on the bridge deck can be routed through a buried conduit and up the downstream face of a bridge pier or abutment where it is much less vulnerable to damage.

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