SCOUR MONITORING – LESSONS LEARNED

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In the United States over 60 percent of bridge failures occur due to scour. The number of bridges declared "scour critical" total over 26,472. Scour monitoring is an efficient, cost-effective countermeasure alternative. The use of scour monitoring technology in the United States (U.S.) led to the development of several fixed instruments suitable for different types of sites and structures. Developed in the late 1990s, the instruments are now in use throughout the U.S. The focus of this paper is the lessons learned in the establishment of a scour monitoring program. The program comprises fixed scour monitors, data collection, data analysis, and the establishment of a prescribed set of emergency procedures to follow in case a "scour event" has occurred. The basic parts of a scour monitoring program consist of a theoretical analysis of bridge scour susceptibility, a substructure stability analysis, the determination of scour critical depths, an analysis of various scour countermeasure alternatives, the design and installation of a data collection and retrieval system, and a plan of action should any of a number of prescribed "trigger points" be met.

1 Introduction

1.1. *U.S. Guidelines for Scour at Bridges*

The Federal Highway Administration (FHWA) reports there are approximately 590,000 highway bridges in the U.S. National Bridge Inventory. Of these, about 484,546 bridges are over water (Gee, 2003); with over 26,472 of them having been declared scour critical. A bridge is considered scour critical when its foundations have been determined to be unstable for the calculated or observed scour condition.

Three FHWA Hydraulic Engineering Circulars (HEC) are the guidelines for bridge scour, stream stability, and scour countermeasures: HEC-18, *Evaluating Scour at Bridges* (Richardson and Davis, 2001) provides guidance for the design, evaluation, and inspection of bridges for scour; HEC-20, *Stream Stability at Highway Bridges* (Lagasse, et. al., 2001) provides instruction on the identification of stream instability problems at highway stream crossings; and HEC-23, *Bridge Scour and Stream Instability Countermeasures – Experience,* *Selection, and Design Guidance* (Lagasse, et. al., 2001) provides guidelines for the various types of scour countermeasures. For conducting new or rehabilitation designs for bridges, both HEC-18 and HEC-20 are used. Countermeasure solutions may be developed when there are concerns with regard to scour or stream stability.

1.2. *Scour Critical Bridges*

The FHWA National Bridge Scour Evaluation Program started in 1988. The program consists of screening all bridges over water to determine their scour vulnerability, and setting priorities for their evaluation. The program categorizes existing bridges, placing each into one of the following: (1) low risk, (2) scour susceptible, (3) unknown foundation, or (4) scour critical. An evaluation conducted by an interdisciplinary team of hydraulic, geotechnical, and structural engineers leads to the necessary engineering judgments to determine the vulnerability of a bridge to scour. Each state Department of Transportation structures its own evaluation program using these guidelines furnished by FHWA. A “scour susceptible bridge” is one that is awaiting evaluation by its owner to determine its scour vulnerability. An “unknown foundation bridge” is an existing bridge lacking information regarding its foundation type and/or depth. A “scour critical bridge” has foundations that have been determined to be unstable for the calculated or observed scour condition. The most recent FHWA memorandum on this subject (Gee, 2003) reports that as of April 2003, 93 percent of the nation’s bridges have been evaluated for scour. The following summarizes the status of the FHWA program for the evaluations of the 484,546 existing bridges over water:

- 351,538 – low risk
- 19,333 – scour susceptible
- 86,133 – unknown foundations
- 26,472 – *scour critical*

The FHWA has mandated the establishment of a plan of action for all scour critical bridges. Due to both financial and time restraints, it is not possible to replace all the scour critical bridges in the near future. In addition, it may be more efficient in terms of cost and/or time to rehabilitate some bridges using scour countermeasures. In many instances, scour countermeasures have been evaluated and used successfully to extend the life of a scour critical bridge, and at the same time protect the safety of the traveling public using that bridge.

1.3 *Types of Scour Countermeasures*

Scour countermeasures, as defined in HEC-23, are “measures incorporated into a highway-stream crossing system to monitor, control, inhibit, change, delay, or minimize stream instability and bridge scour problems.”

Based on their functionality, scour countermeasures can be divided into three general categories – hydraulic, structural, and monitoring. Hydraulic countermeasures include both river training structures that modify the flow and also armoring countermeasures that resist erosive flow. Structural countermeasures consist of modifications of the bridge foundation. Monitoring countermeasures may be fixed instrumentation, portable instrumentation, or visual monitoring.

1.4 *The Scour Monitoring Alternative*

HEC-23 contains the most recent information on scour monitoring, and defines scour monitoring as “activities used to facilitate early identification of potential scour problems. Monitoring could also serve as a continuous survey of the scour progress around the bridge foundations.” There are limited funds to replace or repair all the scour critical and unknown foundation bridges, therefore HEC-23 states that an alternative solution is to monitor and inspect the bridges following high flows and storms. A well-designed monitoring program provides an efficient and cost-effective scour countermeasure.

Recommended in HEC-23 are three types of scour monitoring: fixed instrumentation, portable instrumentation, and visual monitoring. Fixed monitors are placed on a bridge structure. The recommended fixed monitors include magnetic sliding collars, sonar monitors, float out devices, and tilt and vibration sensors. Portable instrumentation monitoring devices can be manually carried, used along a bridge, and transported from one bridge to another. Portable instruments are more cost-effective in monitoring an entire bridge or multiple bridges than fixed instruments; however, they do not offer a continuous watch over the structures. It is often dangerous for individuals to take measurements during a storm event. The allowable level of risk affects the frequency of data collection using portable instruments. Examples of portable instruments are sounding rods, sonars on floating boards, scour boats, and scour trucks. Visual inspection monitoring may be performed at standard regular intervals, and may include increased monitoring during high flow events (flood watch), land monitoring, and/or underwater inspections. The scour hole that forms during a high-flow event is often infilled during the receding stage as the stream flow returns to normal. This “scour-and-infill” cycle is neither detected using portable devices nor during measurements taken by divers after a storm.

A bridge may have one or more types of scour monitoring techniques that also can be used in combination with other hydraulic or structural scour countermeasures. Scour monitoring may be a permanent or temporary interim countermeasure.

1.5 *Fixed Instrumentation and Scour Monitoring*

According to the FHWA guidelines, existing bridges found to be vulnerable to scour, should be monitored and/or have scour countermeasures installed. FHWA's HEC-18 (Richardson and Davis, 2001) first recommended the use of fixed instrumentation and sonic fathometers as scour monitoring countermeasures in their Second Edition (1993). The sonar scour monitors used in the case study in this paper were developed under the Transportation Research Board National Cooperative Highway Research Program, Project 21-3, *Instrumentation for Measuring Scour at Bridge Piers and Abutments* (Lagasse et al. 1997). The purpose was to study devices that measure and monitor maximum scour at bridges. The project developed, tested, and evaluated methods both in the laboratory and in the field. The NCHRP project extensively tested and recommended two systems – the sonic fathometer and the magnetic sliding collar devices. Each of these fixed instruments measures and monitors scour.

The sonar scour monitors are mounted onto the pier or abutment face to take streambed measurements, and each is connected to a data logger. The sonar instrument measures distance based on the travel time of a sound wave through water. The data logger controls the sonar system operation and data collection functions. The data logger is programmed to take measurements at prescribed intervals. These instruments can track both the scour and refill processes. The case study projects in this paper took the research recommendations—custom-designed sonar systems that met difficult site-specific requirements—and developed programs for the monitoring of these bridges that satisfied FHWA criteria.

Magnetic sliding collars are rods that are attached to the face of a pier or abutment. The rods have a collar that is placed on the streambed, and if the streambed erodes, the collar moves down into the scour hole. The depth of the collar provides information on the scour that has occurred at that particular location. Sonar scour monitors may be used to provide a timeline of scour, whereas magnetic sliding collars can only be used to monitor the maximum scour depth.

Subsequent to the NCHRP project, two additional fixed monitors were developed and installed – float out devices, and tilt and vibration sensors. Float out devices are buried at particular locations near the bridge's substructure. If scour develops, the devices float up and each transmits a signal, only measuring the particular depth where each was buried. These are particularly easy to install in dry riverbeds, during the installation of an armoring countermeasure such as riprap, and during the construction of a new bridge. Tilt and vibration sensors measure movements of the bridge.

Data from any of these fixed instruments may be downloaded manually at the sight, or may be telemetered to another location. A scour monitoring system at a bridge may use one of these devices, or include a combination of two or more of these fixed instruments all transmitting data to a central control center. These four types of scour monitors are being used in a wide variety of climates and temperatures, and in a host of bridge and channel types throughout the United States. Fixed scour monitors are in use from Florida to Maine and from Alaska to Hawaii.

2 Case Study: Scour Monitoring of Three Long Island Bridges

A partial bridge pier failure due to scour resulted in the investigation of the cause, the design of repairs, and the preparation of a plan of action. This event led to the development of a scour monitoring program that uses sonar scour monitors to ensure stability of the bridge and the safety of the traveling public. Twenty-seven sonar scour monitors were installed at three bridges to provide a continuous ongoing record of streambed elevations. The monitors were designed and installed quickly, and were relatively inexpensive compared to other types of scour countermeasures.

In 1998, a pier failure at Wantagh Parkway over Goose Creek in Nassau County, New York, initiated the emergency investigation of the cause and the subsequent design repairs for the bridge. This was a 28.3m (93-foot) bascule bridge with concrete pile bent approach piers and 15 spans. The streambed at one pier was found to have had experienced approximately 8.8m (29 feet) of localized scour since it was built in 1929. The scour was not the result of a single storm event, but rather the erosion from various events over the years and the degradation caused by the daily tidal action at Goose Creek. This resulted in the downward movement of two piles and the fracturing of the pile cap above them. The outermost pile of this bent was left with only 0.37m (1.2 feet) of embedment in the sand. The owner, the New York State Department of Transportation (NYSDOT) decided to replace the bridge approach spans immediately, but the bascule piers would remain in service for about seven years. In order to ensure that these bascule piers were safe, several countermeasure options were investigated, and a scour monitoring system and program was designed for the bridge.

Due to the situation of the Wantagh Parkway over Goose Creek, a bridge just south of it, the Wantagh Parkway over Sloop Channel, was also examined. Built at the same time with similar pile depths, the Sloop Channel crossing had higher flow rates. This fixed concrete pile bent bridge was 175.6m (576 feet) long. It was found to have similar problems with respect to scour of the piers. As a result, four scour monitors were installed at the bascule piers of Goose Creek, and ten monitors were installed at Sloop Channel. In addition, a water stage sensor was installed at each bridge.

The sonar scour monitors were installed on either side of each bascule pier at Goose Creek. There were numerous piers with scour at Sloop Channel. A study of the historic diving inspections and fathometer surveys, the history of the riprap placement at the piers, the as-built pile tip elevations, and the most recent emergency diving inspection were used to determine which pier locations were most critical. The scour monitors, approved by NYSDOT within one week of the failure, were designed, custom-built, and delivered to the site ten weeks later. A temporary bridge was erected at Sloop Channel one year after the monitors were installed. The monitors were salvaged from Sloop Channel and placed in storage, serving as spare, repair parts for Goose Creek or available to be used in rebuilding monitors for other bridges in the region should they require sonar scour monitors.

A scour monitoring program and manual was developed for the two, Wantagh Parkway Bridges. This was the first procedural manual ever to be developed for scour monitors. The manual provides various options available for pursuit should these bridges continue to experience scour. Pier stability analyses were conducted for the bridges to determine scour cautionary and critical depths. The manual included cautionary and critical streambed elevations for each pier; procedures for normal and emergency situations; a plan of action should certain scour elevations be reached; and troubleshooting, maintenance, servicing and inspection instructions. An effective communication system for all responsible parties was established.

The 2001 installation of sonar scour monitors at Robert Moses Causeway over Fire Island Inlet in Suffolk County, New York, is a long-term solution to the scour problems at that bridge. The bridge is a 326m (1,068-foot), tied arch flanked by 24 approach spans for a total length of 1,290m (4,232 feet). Built in 1966, it has extremely high flow rates. For the 100-year storm, the flow rate is over 13,932cms (492,000cfs). Riprap scour protection had been placed at some piers over the years, and according to the HEC-23, riprap should be monitored when used as a countermeasure at piers. Sonar scour monitors were placed at thirteen piers, a water stage was installed, and the Long Island scour monitoring manual was revised to include this system. To establish critical depths, a pier stability analysis was conducted using the Florida Pier Analysis software for the piers that were considered to be the most likely candidates to experience potential scour failure. These piers were selected based on several factors including their location in the inlet, height, history of scour, and superstructure loadings. A scour analysis study was simultaneously conducted for a group of bridges on the South Shore of Long Island. The computed potential scour was used in the selection of the pier locations to be monitored. This was an extremely complex design and installation due to the proximity of the bridge to the Atlantic Ocean, the deep-water conditions, the pier configurations, and the high flow rates.

The scour monitoring systems at Goose Creek and Fire Island have been in operation for six and three years, respectively. The scour monitoring program includes the daily routine monitoring of these bridges, including data acquisition and analysis; round-the-clock monitoring during scour critical events; the preparation of weekly graphs of the streambed elevations and tide gauge data; periodic data reduction analyses and graphs; and routine maintenance, inspection, and repairs. In 2004, a complete refurbishment of the Goose Creek system was completed. This included the installation of the latest operating system software and a new bracket for the sonar transducer at one monitor location. An underwater contractor installed the new bracket and also strengthened the scour monitor mountings at the other three pier locations. The condition of the scour monitors and the accuracy of their streambed elevation readings are checked during the regularly scheduled diving inspections at each bridge. Also, all debris and/or marine growth on the underwater components are cleared away during these inspections.

3 Development of Scour Monitoring Program

The development of a scour monitoring program for these bridges incorporated the guidance from the FHWA for scour at bridges, resulting in a solution to fulfill these requirements. An interdisciplinary team of hydraulic, geotechnical, structural, and electrical engineers designed the scour monitoring programs. There are several steps in the development and implementation of the scour monitoring program. There may be some variation in the order in which these steps are completed, depending on the work previously done, the available information, and the emergency nature of the installation.

3.1 *Review of Available Data*

A review of all available data to assess the historic, current, and potential scour conditions should be undertaken. This data includes aerial photographs; bridge plans; diving and structural inspection reports; fathometer surveys; topographic maps; Federal Emergency Management Association (FEMA) Flood Insurance Studies; details on any scour countermeasure installations; soils data and boring reports; bridge scour evaluations; observations from those familiar with the site including bridge maintenance engineers, county officials, and local residents; and scour information on any nearby bridges.

3.2 *Hydraulic, Scour and Stability Analyses of the Bridge*

The hydraulic engineer would conduct a hydraulic analysis, compute the potential scour, and evaluate the observed scour conditions. If these results indicate that the bridge is scour critical, the stability of the bridge would need to be evaluated. A geotechnical engineer would conduct the pier and/or abutment stability analyses for the substructure units that are scour critical. This would provide information as to whether the foundation is stable under the observed or potential scour conditions. This analysis would be conducted to determine the critical depth for a bridge failure, as well as investigate potential failure mechanisms. It would also provide guidance to establish a second scour depth to be used as the trigger (cautionary) elevation. If this elevation is reached, certain prescribed actions would be taken in order to prevent further scour (i.e. the installation of hydraulic or structural countermeasures), or to protect the traveling public (i.e. closure of the bridge or increased visual monitoring).

3.3 *Evaluation of Scour Countermeasure Alternatives*

Scour monitoring is often the preferred alternative for a variety of reasons. For bridges that are scheduled to be replaced, scour monitors may be selected because they may be less expensive than traditional structural or hydraulic countermeasures. In addition, armoring of the channel bottom may interfere with the construction of the new bridge. The placement of armoring in a waterway may also result in environmental concerns and complicated permitting issues.

The selection, location, and design are dependent on cost, environmental, construction, and maintenance considerations. Some advantages include:

- Continuous monitoring of streambed elevations and scour conditions
- Quick design and installation
- A cost-effective system relative to other scour countermeasures
- Data gathered is useful for replacement bridges
- Reduction in the number of required diving inspections due to the information provided by the monitors
- Capability of measuring both scour and the refill processes
- Development of a prescribed plan of action to guide decision-making during an event

Scour monitors may be used in conjunction with other types of scour countermeasures such as riprap, to confirm that they are functioning to protect the bridge. They may also be installed as an interim countermeasure, prior to the installation of other hydraulic or structural countermeasures that may take longer to design and install.

3.4 *Design of the Scour Monitoring System*

The scour monitoring program is custom designed for each bridge site. The type of monitoring instrument employed depends on the geometry of the bridge substructure and on the channel characteristics. Guidance on the selection of a scour monitoring system is provided in HEC 23. Factors such as the depth of the water, the size of the bridge, the geometry of the substructure unit, the frequency with which readings will be taken, and the extent of debris, ice, air entrainment and/or turbidity in the channel need to be considered in the selection of a scour monitoring system.

The location of the monitors on the substructure units is selected in consideration of accessibility, protection against vandalism, and any potential ice or debris forces. The heightened security at the bridges in the past few years has made accessibility a major issue. Traffic safety, lane closures, and traffic detours for servicing the monitors also need to be considered.

The location and number of the monitors will vary depending on the extent of the existing and potential scour problem, the amount of risk the owner is willing to take, and the funding available for the scour monitors. The monitors are placed in the locations where maximum scour is expected to occur.

Accessibility is important to ensure access to the monitoring system when maintenance is required. It is necessary for servicing the system, for inspection, and repairs. The daily data record produced by the system also provides information on the health and operational status of the scour system. There are instances, however, where the data appears reasonable, yet one of the sensors is not functioning properly. Regularly scheduled routine maintenance and inspections help to ensure that the system is functioning properly and the streambed readings are accurate.

The design of the monitoring instrument and the method with which it is attached to the substructure is site-specific. As-built plans and diving inspections may provide information on the geometry of the underwater portion of the pier or abutment. When there are uncertainties regarding dimensions and clearances, adjustable arms should be designed for the sonar mounting bracket. During installation, the contractor can then adjust the bracket so that the sonar projects out sufficiently to clear the footing and take streambed readings. Once the location of the device and the spot to be monitored are selected, the hydraulic engineer should work with the structural and electrical engineers to detail the mounting and the conduits for the bridge. Items such as material types, types of bolts and their embedment depths, and conduit routing and attachments are best detailed by these specialists. Using more robust, though often more expensive materials and methodologies will most likely result in improved sensor integrity as well as significant savings in future repair costs, especially on bridges over deep waters. This is due to the high costs associated with underwater installations.

Severe environmental conditions that may interfere with the functioning of the monitors, such as ice and tidal waters, need to be considered when choosing the materials and type of mountings for the fixed instruments. These fixed monitors will not operate under frozen water conditions. Due to the cold weather and tidal waterways in the Long Island, New York installations, ASTM Grade 316 stainless steel was used. A lower grade of stainless steel (ASTM Grade 304) was employed during an emergency installation, and a few years later the mountings had extensive corrosion. On an Alaska bridge installation there were instances where floating debris ripped the sonar sensor from the substructure. Under development is a "retractable arm" which lowers the sonar into the water at designated times to take readings, and then retracts back to a designated location under the bridge.

The power source will vary depending on what is available at the site. The monitoring system may be solar powered or connected to electrical power at the bridge, if available. The monitoring systems require low power; therefore, solar power is adequate and preferred. Initially there was concern regarding the use of solar panels due to potential vandalism. Numerous panels have been installed when there was no other power source, and these have performed better than the locations using traditional electrical power. The locations powered by alternating current have required replacement float chargers, most likely due to power surges.

Remote monitoring has been installed using cellular telephone, telephone landline, or satellite technology. The telephone lines have proved to be the most reliable. They do not require power and are continuously available. Cellular telephones are also reliable, but they are not continuous, and need to be turned on and off at regular intervals using solar panels. Satellite service has been used when the other two options were not available. Satellite service, although less expensive than cellular systems, has a disadvantage – it can provide only one-way communication from the bridge. The system can send data from the bridge, however incoming commands to examine, modify, or repair the system cannot be transmitted to the bridge, as is done with the other methods.

The mechanism for the design and installation of the scour monitoring instrumentation and the program may be accomplished under numerous types of contracts. The plans and specifications may be developed as part of a larger bridge rehabilitation program. In this case, careful attention is required for the timing of the installation of the scour monitors, as well as the protection of the monitors during the construction. The scour monitors may be installed as a stand-alone contract, accomplished under emergency conditions, or implemented if funding is available for this type of system.

The data from the monitors may be taken at programmed intervals and downloaded at any time. The data can also automatically alert the owner of emergency situations. The system can provide round-the-clock monitoring, even during storms; scour data for bridge scour research, velocity, and water stage records; and the integration of the newest scour prediction techniques with physical data collection. The system helps to ensure the safety of the traveling public, and utilizing conventional technology, it is a cost-efficient solution to a potentially costly remediation.

3.5 *Installation of the Monitoring System*

Scour monitoring systems are relatively new products. Electrical and underwater contractors usually install the system. It should be noted that on larger bridges in deep waters in the U.S., the contractor installation costs often equal or exceed the cost of the manufacture of the scour monitoring system. Most likely, the contractor has not performed this type of work, so the plans and specifications should be detailed. The inclusion of good details can aide in keeping the bid prices reasonable. It is also advisable to have one of the designers of the monitoring system "on-site" or in close contact with the contractor throughout the installation. There are often many unknowns both in the underwater conditions and in the as-built geometry of the substructure unit. Having the system designer available during the installation ensures the proper changes are made.

One note: If the underwater contractor is not receiving lump sum payment, but the work is based on the time to install, the designer should specify which type of drill the contractor must use to install the underwater components. In the U.S., a pneumatic drill has been used effectively for the installation of anchor bolts into concrete substructure units. There could be extensive time delays when the contractor uses drills that are not appropriate for underwater construction.

Since the construction inspector cannot view the underwater component, it is advisable to have this component of the installation inspected by an independent contractor. This will ensure that all bolts and attachments are in place, and that the mounting is properly secured to the substructure unit.

In smaller waterways and in areas of installation that are less complicated, there have been cases where the DOT maintenance group or others have installed the scour monitoring system. Here also, it is recommended that a member of the monitoring design team work with these groups.

As with all bridge reconstruction projects, it is good practice to develop a set of as-built plans following the installation of the system. This is particularly true for the underwater components of the system. This will aid in future maintenance and inspections, and repairs to the system.

3.6 *Implementation of the Scour Monitoring Program*

FHWA HEC-23 recommends to bridge owners that a plan of action be developed for scour critical bridges. The two primary components of the plan of action are instructions regarding the type and frequency of inspections to be made at the bridge, and a schedule for the timely design and construction of scour countermeasures. A plan of action includes the following: (1) management strategies, (2) inspection strategies, (3) bridge closure instructions, (4) countermeasure alternatives and schedule, and (5) miscellaneous information. Scour monitoring programs are often part of a plan of action.

The implementation of the scour monitoring program is a critical aspect of the program. Due to the interdisciplinary nature of scour monitoring, and perhaps due in part to the newness of the FHWA scour program and of these devices, it is not always obvious which division(s) of the owner is(are) responsible for the scour monitoring program. It is important during the design process for the owner to identify the group(s) that will be responsible for the scour monitoring program. This could be the owner or it may be outsourced. This would include the design of the system; routine and emergency monitoring; analysis of the data and determination of the safety of the bridge; the chain of command to make decisions during an emergency situation; maintenance, inspection and repairs to the system; and the funding for the continued operation of the scour monitors. This information should be documented in the scour monitoring program manual and plan of action for the bridge. The manual needs to be updated on a regular basis to reflect any changes in the program. The responsibility for the monitoring system has been the most difficult aspect in the implementation of the scour monitoring programs in the U.S.

If a clear protocol detailing responsibilities is in place, this can help to provide proper maintenance to prevent a sensor or system failure. If the person(s) responsible for monitoring are transferred to other positions, or if they retire, new person(s) need to be given the responsibility and training for the system. There have been instances where the telephone service has been interrupted due to non-payment of the telephone bill. This was due to job transfers, and in one case, the invoice was being sent to someone not involved in the scour program. In one situation, the area code in a city changed and the data could not be accessed because the new area code needed to be programmed into the new system.

3.6.1 *Routine and emergency monitoring and data analysis*

The development of a clear set of detailed instructions for those responsible for the routine and emergency monitoring of the bridge is essential. There should be a chain of command so that responsibility is transferred when those who are responsible are on vacation, sick, unable to monitor, or are no longer in their particular position. The routine and emergency procedures are very site specific. Often an owner will start with a conservative program with high frequencies for routine and emergency monitoring. After a period, the records will be reviewed and the frequency of monitoring adjusted.

A clear chain of command of those responsible for emergency situations needs to be in place. Those responsible for analyzing the data should have instructions as to who they should contact "round-the-clock" should the scour readings indicate a problem. The plan of action would indicate possible procedures to follow, which may include closure of the bridge, land monitoring, underwater inspections, the emergency installation of contingency countermeasures such as riprap, etc.

The scour monitoring systems that are continuous are capable of producing a large amount of data. Consideration needs to be given to the intervals at which the data should be recorded and collected. Data reduction methods using computer spreadsheet programs provide valuable assistance for analyzing and storing the data. They help identify trends, and may be useful when comparing data with other bridge sites.

Changes in the watershed may also affect the data. Those responsible for analyzing and interpreting the data should keep informed as to new developments, construction, mining, or other situations that might cause scour or siltation at the bridge.

3.6.2 *Maintenance, inspection and repairs*

It is important to develop a regular maintenance and inspection program. The maintenance crews for the owner may be responsible for routine, above water maintenance. The frequency of underwater and structural inspections and fathometer surveys at each bridge will vary. The owner should add inspection and maintenance requirements for the monitoring system to the underwater and structural inspection contracts. This should include detailed checklists and sketches to guide the inspectors, and to ensure that the scour monitoring system is examined periodically. Provisions may be made in these contracts for minor repairs as well. During the inspections, it is advisable that a member of the scour monitoring team coordinate with the inspection crew to ensure that all important components are inspected, and to help interpret their findings. If possible, this person would be on-site. The streambed elevations recorded during diving inspections and fathometer surveys may also be used as ground truth measurements to check the accuracy of the scour monitoring devices.

3.7 *Conclusions*

A scour monitoring program can be an efficient, cost-effective alternative or complement to traditional scour countermeasures. The system and program are custom designed for each bridge and site. There have been many innovations in scour monitoring technology and this paper outlines some of the lessons learned in installations in a wide variety of locations. A thorough and systematic plan developed prior to the installation of the scour monitoring system will result in a program that is successful to ensure the safety of the bridge and of the traveling public.

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