

Remote Monitoring of Bridge Scour Using Echo Sounding Technology

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ABSTRACT

Bridge scour is one of the leading causes of bridge failure in the United States. To prevent this type of failure, it is necessary to closely monitor the scour and the mechanisms, which contribute to its development. To assist government agencies responsible for the safe operation of these bridges, a scour monitoring device using echo sounding technology has been developed.

Based on previous research, echo sounding was identified as a dependable method to measure scour. The newly developed unit incorporates the capability of multiple depth sensors, water temperature sensors, tide elevation gauges, and water velocity sensors. The unit may be programmed to obtain measurements at any interval and is able to store several months of collected data. Downloading of stored information is possible through a direct connection to a portable PC or via telephone (or cellular) communication. The data is stored in standard delimited format, which can be imported to any standard spreadsheet software for analysis.

A prototype unit was initially installed on one pier of a bridge identified by the Florida Department of Transportation as scour critical. An additional set of sensors was later installed to a second pier and connected to the unit. Upon establishing communication with the unit, the user may select each pier (set of sensors) separately for programming and downloading information.

This paper describes the equipment, installation and the initial performance of the scour-monitoring unit.

INTRODUCTION

Bridge scour is the leading cause of bridge failure in the United States (1). Exposure or undermining of pier and abutment foundations from the erosive action of flowing water can result in the structural failure of a bridge.

Scour is the void or cavity produced when sediment (sand and/or rock) is washed away from the bottom of a river or other body of water. Although scour may occur at any time, it is significantly more intense during floods and storms when stronger currents are generated, allowing more sediment to be carried downstream.

When the sediment or rock on which a bridge support rests is scoured by water, bearing support is lost, and the bridge becomes unable to carry the design loads. Partial or full exposure of the footers and/or piles can also adversely affect the safety of the structure

by causing sliding or lateral movement. This becomes more critical when vertical movement (settlement) is also present. The vertical or lateral movement of a pier or pile produces overdesign stresses, which may ultimately lead to full structural failure.

Following the collapse of the Schohaire Creek Bridge in New York State in 1987, the US Department of Transportation–Federal Highway Administration (FHWA) required every state to identify all highway bridges located over water by screening them into three categories: low risk, scour susceptible, and scour critical. After screening, the bridges identified as scour susceptible were re-evaluated based on office and field analysis to determine if re-classification as scour critical was necessary. Additional interest on scour research was generated following the 1993 flooding of the Mississippi River, which produced several scour related bridge structural failures.

At this time, scour research has concentrated on four important areas. These areas are: 1) Evaluation of scour measurements under flood and storm conditions; 2) development of scour equations and computer modeling; 3) identification of bridges sensitive to scour; and 4) development of monitoring systems and protection techniques for scour critical bridges.

Several measuring instruments have been developed to monitor scour on bridge structures. The Federal Highway Administration and other interested organizations have sponsored numerous research projects to identify the most accurate and dependable instruments for this purpose. In the “Participants Workbook” for Demonstration Project 97, FHWA describes the systems which appear to be the most adequate for this purpose. The equipment is grouped in two major categories: portable and fixed instruments. In most cases, the instruments and procedures identified in this report fulfill the requirements for each specific condition.

On bridges identified as scour critical, FHWA requires the development of a plan of action. This plan of action shall include countermeasures to address the scour deficiencies. Accurate monitoring of the scour development accompanied by an adequate emergency contingency plan is considered an acceptable countermeasure. Following the FHWA requirement, the Florida Department of Transportation (FDOT) incorporated into its bridge inspection program a more aggressive plan to identify these scour critical bridges. Research was conducted on fixed instrumentation for scour monitoring, on selected scour critical bridges, as part of this action plan.

After studying several scour-monitoring techniques, sonar was determined to be both accurate and dependable, and required the least maintenance. In addition, the installation of sonar systems with data storing capability allows for continuous monitoring during flood periods.

BACKGROUND

The first evaluation of an echo sounding scour measuring device on a Florida bridge was sponsored by the National Cooperative Highway Research Program (NCHRP) through FHWA (2). This device employed a commercially available recreational depth finder which was primarily manufactured for navigational use. Since the depth finder was intended for national and international markets, the water depth calculation parameters were factory preset to have an acceptable degree of accuracy under most conditions. The

depth finder was interfaced to a specially designed datalogger, which controlled the power supply for the depth finder and also recorded data transmitted by the depth finder. Power was provided to both units by a photovoltaic generator and a current storage cell.

Since the location of the datalogger was only accessible by boat, a communications cable was routed to a more accessible location on the bridge. Depth measuring intervals were programmed into the datalogger through a direct connection to a portable computer using the extended communications cable. Direct connection to a computer was also necessary to download the collected data.

After two years of field evaluation, a report was produced by NCHRP with favorable findings. The report concluded that "the system provided an excellent continuous record of seasonal scour and fill, and performed successfully under hurricane storm surge conditions" (2). FDOT bridge engineers evaluated the report and determined that the technology satisfied the basic requirements for adequate scour monitoring. However, certain modifications were considered necessary in order to adopt the technique as a scour countermeasure.

It was concluded that at a minimum, the monitoring unit should include the following:

1. In addition to standard AC electrical power operation, solar power operation capability needed to be provided to maintain full operation during severe weather conditions such as storms and/or hurricanes, which are common to the State of Florida and typically produce electrical power and telephone line interruptions.
2. The instrument needed to include temperature sensors, which measure the water temperature at the same intervals as the depth measurements and transmit the data to the datalogger for temperature corrections to the depth measurements as required.
3. The unit should contain sufficient memory to store several weeks of readings.
4. The Engineers should be able to communicate with the unit from the office via telemetry. This should include downloading of data, real time measurements, and programming of monitoring parameters.
5. The unit had to be able to measure the velocity of the water at the scour site as this was considered an important factor in understanding a site scour mechanism.
6. Since scour may occur at more than one place on the bridge, the datalogger should be capable of collecting and recording data sent from several sensors or set of sensors located at various locations on the bridge.
7. Telemetry should be accomplished via a standard telephone line or cellular transceiver as required based on specific needs for each site location.

IMPLEMENTATION

The scour-monitoring unit installed used a fathometer echo sounder to measure the distance to the bottom from a fixed point on the bridge. It also included transducers to measure water temperature and tide elevation. A transducer to measure water velocity was not initially installed but added at a later date.

The fathometer is composed of an acoustic narrow beam (6 degrees) - 200 kHz transducer attached to a fixed point below the water surface with an electronic processor,

which is installed above the water surface. The electronic components of the fathometer have an RS-485, 2-wire communications interface that transmits the measured data via cable to an IBM-AT compatible minicomputer also mounted on the structure above the water. The computer records and saves the received information on a PCMCIA memory card disk drive, and can monitor up to eight sites on a bridge. MS DOS 6.0 is configured into the computer as the disk operating system such that additional programming could be added for on-site data processing, analyzing, and remote communications. The 2-wire RS-485 interface allows multiple echo sounders to be connected to the system.

The computer has two RS232C serial I/O ports and connects to a 14.4 kb fax and data modem, which transmits the requested information via standard telephone line or a cellular transceiver. Upon connection, the unit can upload the collected data or it can be programmed to send a graphical or text fax printout to a specified fax machine number. Downloading of data and setting of measurement parameters on site is also possible via direct connection to another computer (laptop) through a standard Null Modem cable. Since the collected data is stored in a removable card drive, a third method of data transfer is by removing and replacing the PCMCIA card. Data can then be transferred from the removed card drive to any computer with a PCMCIA type 2 compliant card slot or adapter.

A photovoltaic generator and a current storage cell (battery) power the transducers, computer, and cellular transceiver. It also has the capability of operation using AC electricity and a backup battery. Local or remote communication with the data logger computer is established using any standard communications software. Once the communication connection is established, the unit transmits a menu from which the user selects the desired function.

EVALUATION

A prototype unit was installed at the St. John Pass Bridge in St. Petersburg, Florida. The bridge spans an inlet, which connects the Gulf Intracoastal Waterway and the Gulf of Mexico. The first echo transducer was attached to a concrete drilled shaft on Pier 4 which serves as support to a post construction crutch bent that was installed after severe scour problems were detected. The datalogger and the cellular transceiver were attached to a support column directly above the shaft (Figure 1). The unit was powered by a solar panel that was installed on top of the bridge and connected to a charge regulator and battery via a No. 8 AWG dual conductor cable.

The sensors were attached to the bottom of a 20-ft-long fiberglass square pipe, which was then secured to the drilled shaft using stainless steel bolts and anchors. The pipe was bolted to the drilled shaft at several locations above the water level. This pipe was later replaced with a 4-inch diameter, double wall PVC pipe with the sensor wires routed inside the pipe to the fathometer unit.

Immediately after installation, divers working for the FDOT physically measured the water depth from the transducer to the inlet bottom. In addition, the divers verified that no physical obstructions were present on the beam path. It was also observed that the sound reflection point at the bottom was a cavity of conical shape apparently produced by water movement. The distance measured by the divers was 32.9 feet, while the distance recorded by the datalogger was 32.4 feet. The difference in measurements was attributed

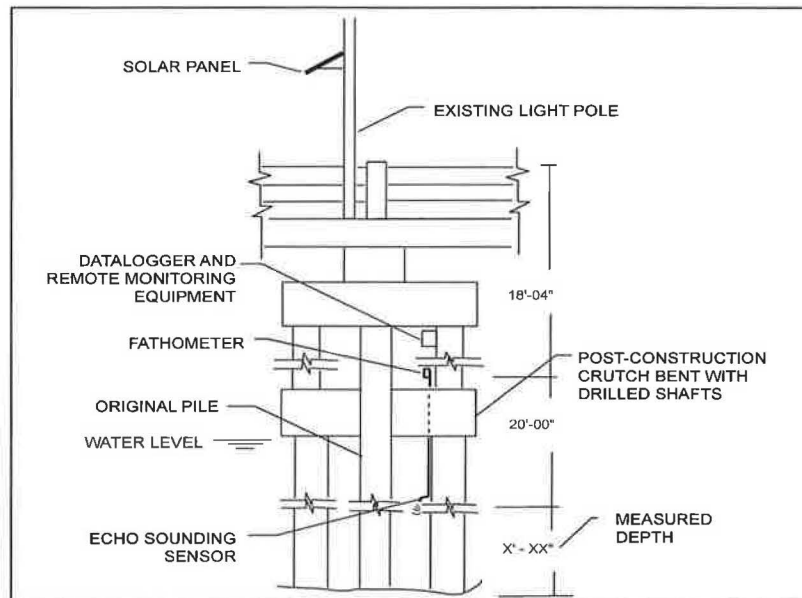


Figure 1: Schematic of initial scour monitor installation at Pier 4 powered by a photovoltaic generator.

to the geometry of the echo reflection point area (because of its conical shape). The physical measurement was obtained at the center of the scoured cavity. At this point it was decided not to redirect the beam since the development of the scoured cavity as a hole was of interest to the engineers.

The unit was programmed to obtain a set of readings (depth, water temperature, and tide elevation) at one-hour intervals. During the first week after installation, the unit was called through the telemetry system daily to download data and confirm operation. Once the system was determined as operating properly, the downloading schedule was adjusted to once a week. Upon telemetry connection using the cellular transceiver, the collected data was downloaded to an office computer and imported to a standard spreadsheet used to analyze and produce graphical representations of the measurements. During the telemetry connection periods, it was observed that downloading data at high speed (9600 baud or higher) introduced a significant amount of errors and sometimes allowed abrupt communication interruptions; however, downloads at 2400 baud appeared to be very accurate. When downloading at high speed using a direct connection to a portable computer (laptop), the data transfer did not show any errors. This suggested that the cellular connection rather than the monitoring unit introduced the high-speed data transfer errors.

The system continuously collected data for approximately 45 days at which time some modifications were made to the sensor support bracket. During the first 15 days the daily average depths measured ranged from 33.4 to 32.4 feet with a maximum daily change of 0.3 feet. On day 17, a more significant change was detected. The average depth for the day was 1.0 foot less than that of the previous day. The fill development peaked at day 18 with a measured fill of 1.9 feet above the bottom depth measured on day 16. The additional fill material was gradually washed away. By day 21, the measured depth was back at 32.7 feet, which appears to be the normal depth (Figure 2).

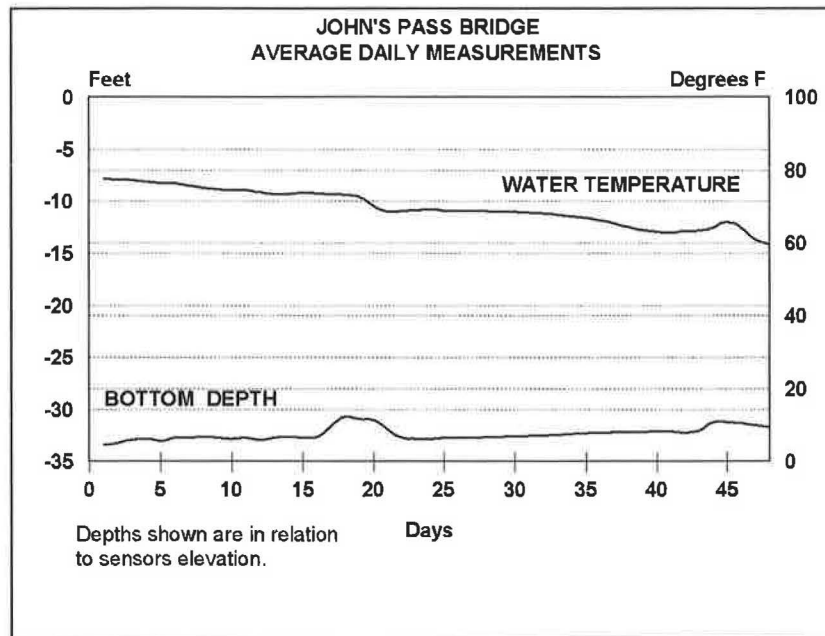


Figure 2: Water temperature and scour activity around Pile "C" of Pier 4 for a period of 47 days. Values are daily average of measurements obtained at one hour intervals.

Tides elevation and water temperature were also measured. The daily averaged water temperature measurements showed a gradual daily decline, which was considered normal for the months of October and November. The temperatures measured ranged from 77.7 to 62.4 degrees F. After analyzing the fathometer data, it appeared that the changes in water temperature observed to this date do not significantly affect the depth measurements obtained by the fathometer.

After evaluation of the hourly measured data, the routine normal depth variations of the bottom were clearly identified. As expected, it was noticed that most of the depth changes were occurring between the times of slack tides (Figure 3). This is considered normal since at this particular location, extremely strong currents are produced during the periods of tide change.

The tide (measured in feet of water above the sensor) elevation measurements were plotted and compared to standard tide charts. Although the exact times of low and high tides did not always concur with the times of the standard charts, for the most part, they were very accurate in determining actual times of water movement. This discrepancy was expected since the standard charts only offer tide elevation changes under normal conditions and do not consider winds and other factors. The tide elevation was determined by mathematical process with the location of the sensor estimated at an elevation of -10 ft.

After ninety days of operation another set of sensors was added to the system. The new sensors consisted of depth and water velocity transducers, and monitored the scour and water velocity around a similar drilled shaft on Pier 5. The new scour sensor was similar to the one installed at Pier 4 and the water velocity sensor was of mechanical type (paddle wheel with transducer). Each set of sensors had its own digital address and was

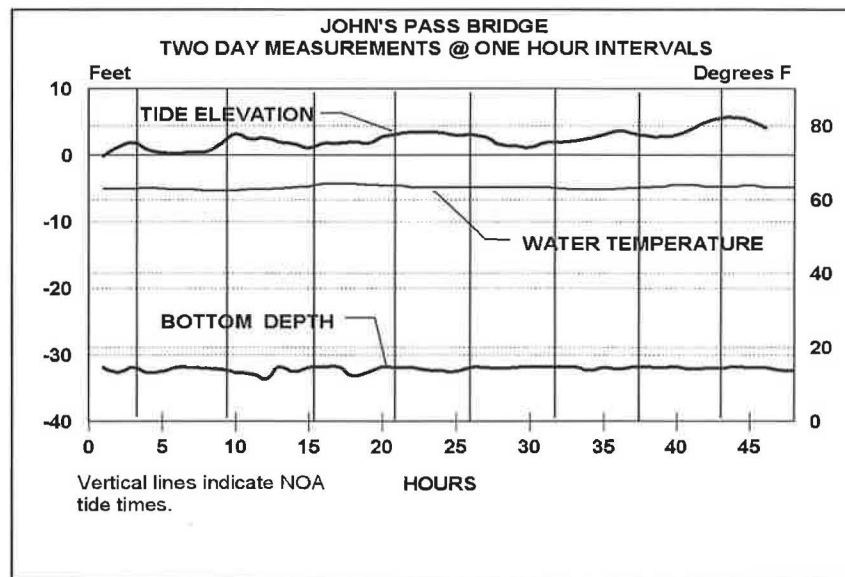


Figure 3: Two day measurements of depth, tide, and temperature. Vertical lines indicate NOAA tide times for comparison to sensor tide measurements.

connected to the main unit in a daisy chain mode. Like on Pier 4, the sensors at Pier 5 were installed at an elevation of -10 feet and the measured bottom had a conical cavity similar to that at Pier 4. The main unit (datalogger computer) was relocated and, for testing purposes, disconnected from the photovoltaic generator and connected to an AC power source with backup battery. A standard telephone line was also installed to improve the accuracy of data transmissions at high speed.

To separate the data obtained from each set of sensors, the first set of sensor (Pier 4) was identified as Unit 1 on the data logger software with the second set (Pier 5) identified as Unit 2. Upon establishing connection with the data logger, the software requests the user to enter a code to identify which unit to communicate with (Unit 1 or Unit 2).

When re-activating the unit in its new setup, it was again programmed to obtain measurements at hour intervals on both piers. The scour sensor at Pier 5 performed similar to that of Pier 4 (previously described). The initial daily hourly readings on Pier 5 typically ranged from 42.5 to 43.1 feet. At approximately 65 days of service, a slow accumulation of soil on the bottom was observed. During the following 100 days, the bottom around the shaft on Pier 5 gradually rose approximately 3 feet (Figure 4). Three physical measurements were performed during this time to verify the sonar measurements. As previously on Pier 4, the physical measurements showed a discrepancy with the sonar measurements ranging from 0.1 to 0.6 feet. Similar temporary fill deposits were observed around Pier 4 although, not during the same period as Pier 5.

Occasionally, the unit recorded erroneous readings indicating changes ranging from 10 to 100 feet. Typically, the erroneous readings appeared at different times and days, and were not consecutive. Data for these readings were discarded and the cause has not yet been certainly determined; however, it is suspected that these were produced as a result of moving debris, introduction of noise, or movement of the sensors (with the last one considered the most probable).

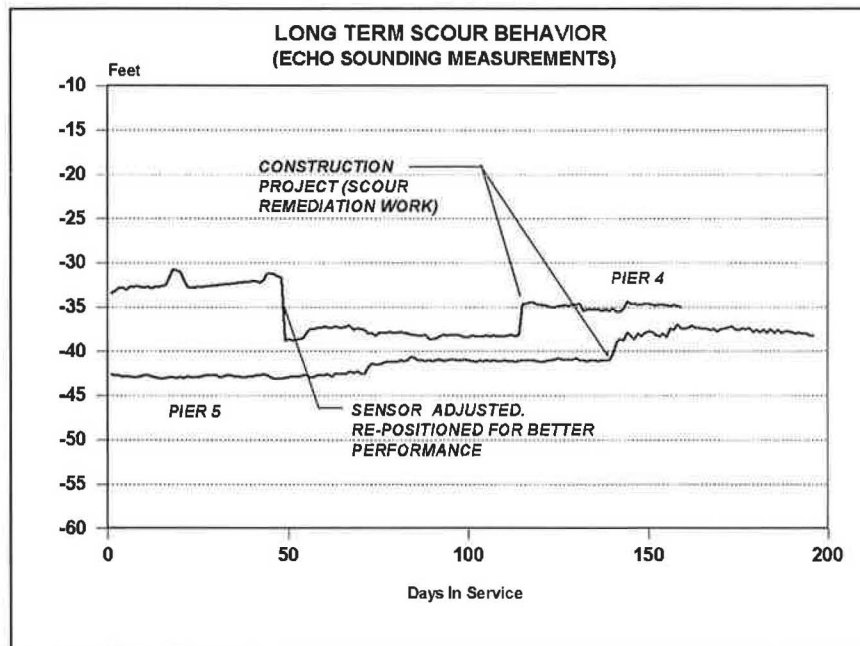


Figure 4: Average daily depth measurements of Pier 4 and Pier 5. As noted, graph shows elevation adjustments made to sensors.

Water velocity measurements were never satisfactorily obtained. The velocity sensor was removed for maintenance and/or repair on two occasions. Although the sensor (paddle wheel and transducer) tested in good operating condition while removed, it appears that when installed (at 10 feet below water) the water did not move the sensor paddle wheel sufficiently. Acoustic velocity water sensors were considered but rejected based on cost.

After approximately 120 days of operation, the evaluation was temporarily interrupted, first on Pier 4 and following on Pier 5. The interruption occurred when the sensors were accidentally released from the mounting brackets due to a scour correction work, which consisted of placing large rocks around the piers. The sensors remained in place supported only by the connection wires. The users easily recognized the problem since the unit began recording consecutive readings in excess of 100 feet. When the sensor units were removed for repairs, it was also observed that a large amount of marine growth had accumulated on the mounting bracket and around the sensors even though an antifouling coat had been applied to all areas. However, this appeared not to significantly affect the depth readings.

CONCLUSIONS

1. Depth measurements obtained using echo-sounding devices were sufficiently accurate to define the scour movement near the bridge supports. Gradual bottom changes as well as abrupt changes were recognized from the obtained data. However, detailed engineering and installation of the sensors fixed support are necessary to avoid any movement of the sensors which may result in erroneous readings.

2. Based on the calibration data (physical measurements vs. unit measurements) the accuracy of the evaluated system is satisfactory with a resolution of plus or minus 6 inches at a measuring distance between 30 and 40 feet. Accuracy of the measurements could be increased by reducing the measured depth to a distance between 5 and 10 feet or as considered reasonable for the specific site.

3. The telemetry system using analog cellular communication limited the data transmission speed to 2400 baud. This limitation does not affect the monitoring process, and affects only slightly the download process since the normal amount of weekly data to be transferred does not exceed 50 k bytes. Digital cellular technology may increase the transmission speed. However, this service is not available at many locations.

4. The use of continuous monitoring allows for the positive identification of scour movements as soil is removed and re-deposited around the bridge supports (footers or piles). Recognizing the depth of re-deposited soil is of great importance when determining actual load bearing characteristics.

5. Because of the tidal location of the test site, and the marine growth accumulated around the sensors, it appears that periodic maintenance of the sensors will be required. At this time, it is estimated that the sensors will require cleaning and re-coating on a two to three year basis. Extended maintenance periods may be possible based on the quality of the water at individual installation sites.

6. Research to identify an economically feasible and compatible water velocity sensor will continue as this data is considered very important for predicting future scour development. In addition, other types of sensors such as strain and movement gauges, and embedded concrete temperature sensors, could be added to the system to provide continuous bridge condition assessments.

REFERENCES

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