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FIELD IMPLEMENTATION AND EVALUATION OF THE SIMPLE COST-EFFECTIVE SCOUR SENSOR

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A report of the findings of
ICT-R27-71
Field Implementation and Evaluation of the Simple Cost-Effective Scour Sensor

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16. Abstract

Bridge scour, the erosion of stream bed materials around the bridge foundation, endangers many of the bridges that cross over water. Over the years, a number of scour sensors have been developed to determine the extent of scour, especially following major floods. Many of these systems are either too complicated, expensive, or not efficient. However, it is important to ascertain the safety of bridges after major floods in an expeditious manner. Therefore, in a previous ICT study (R27-35), researchers developed a simple and highly accurate scour sensor. That initial study encompassed laboratory proof of concept tests and small scale field trials.

The objective of the research outlined in this report is to implement the scour sensor in a multi-span scour critical bridge. The scope of the project included selection of the bridge; design and fabrication of the field sensors; installation of the sensors, interrogation unit, multiplexer, and remote computer for real time data acquisition; installation of a wireless internet system for remote desktop monitoring of scour; and development of software for automated calibration and user-friendly remote data acquisition; and archiving of scour history for the bridge.

This report includes background information about scour in bridges and existing scour monitoring technologies. Additionally, a short summary of ICT's earlier study to develop and experiment with the simple scour sensor concept is provided for the sake of continuity. The primary sections of the report encompass the implementation of the new scour sensing technology in a multi-span bridge in northern Illinois. This work introduces a simple concept with the potential to provide means for rapid and widespread installation of scour sensors in scour critical bridges.

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Members of the Technical Review Panel are the following:

Dave Copenbarger (Chair)
Sarah Wilson
Dave Greifzu
Matt O'Connor

The research team is indebted to the technical advice and cooperation of the Technical Review Panel leader, Mr. Dave Copenbarger, for moving this project forward. Support from IDOT District 1 was essential for the success of this project. The research team is grateful for the cooperation they received from Ms. Sarah Wilson and her crew in District 1.

EXECUTIVE SUMMARY

Bridge scour, the erosion of stream bed materials around the bridge foundation, endangers many of the bridges that cross over water. Over the years, a number of scour sensors have been developed to determine the extent of scour, especially following major floods. Many of these systems are either too complicated, expensive, or not efficient. However, it is important to ascertain the safety of bridges after major floods in an expeditious manner. Therefore, in a previous ICT study (R27-35), researchers developed a simple and highly accurate scour sensor. That initial study encompassed laboratory proof of concept tests and small scale field trials.

The objective of the research outlined in this report is to implement the scour sensor in a multi-span scour critical bridge. The scope of the project included selection of the bridge; design and fabrication of the field sensors; installation of the sensors, interrogation unit, multiplexer, and remote computer for real time data acquisition; installation of a wireless internet system for remote desktop monitoring of scour; and development of software for automated calibration and user-friendly remote data acquisition; and archiving of scour history for the bridge.

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TABLE OF CONTENTS

1. BACKGROUND

Scour is considered one of the major causes of highway bridge failures in the United States. It is especially prevalent during floods and periods of rapid river flow activities. During floods, erosion of the foundation materials below the bridge piers causes structural instability. This process is dynamic, where erosion takes place near the peak flow rates, and deposition of sediments occur during the descending stages of the flood. If local scour is not identified in time, the structural integrity of the foundation progressively deteriorates and leads to severe damage and collapse of the bridge. According to the data from the National Bridge Inventory (NBI), 484,546 highway bridges out of an inventory of 590,000 in the United States cross over waterways. Sixty percent of these bridges have been declared scour critical (Hunt and Price, 2003; Gee, 2003). The 1987 catastrophic collapse of the Schoharie Creek Bridge in New York State due to scour was one of the most severe bridge failures in the United States. Considering the consequences of scour damage, the Federal Highway Administration (FHWA) issued a Technical Advisory in 1988 revising the National Bridge Inspection Standards (NBIS) to require evaluation of all bridges for susceptibility to damage resulting from scour. This issue is not only confined to the U.S. boundaries, and local scour was identified as a high priority research need for infrastructure by the North American Euro Pacific Workshop for Sensing Issues in Civil Structural Health Monitoring (Ansari, 2004). Participants of this workshop included government highway agency engineers and researchers from academia and industry from the U.S. and other countries. Development of a simple, reliable, and cost-effective scour monitoring system that is easily mass produced will have a tremendous impact on the state of health of our bridges. The sensor will help highway officials schedule periodical maintenance programs and help circumvent costly repairs and bridge replacements as well as emergency road closures.

Local scour is caused by the interference of bridge piers with flow and is characterized by the formation of scour holes resulting from clear-water scour or live-bed scour. Clear-water scour occurs when the bed materials upstream of the scour area are at rest. The maximum local scour depth is reached when the flow can no longer remove bed material from the scour area. Live-bed scour occurs when general sediment is transported by the river.

A great amount of effort has been expended for the research and development of scour monitoring sensors and systems. Applicability of the existing methodologies; however, has been limited considering issues pertaining to the complexity and cost effectiveness, resolution, capability for providing repeated and reliable information, installation, and rigor in data retrieval and processing. A wide array of methodologies have been used in attempts to develop scour monitoring sensors including sonar (Mason et al., 1994; Hays et al., 1995), time domain reflectometry or TDR (Dowding et al., 1994; Yankielun, et al., 1999), sliding collar (Lagasse et al., 1997; Richardson et al., 1994), radar (Gorin, et al., 1989), piezoelectric (Lagasse et al., 1997), and the seismic transducer techniques (Zabilansky, 1996).

Radar and sonar based techniques have been successful in monitoring the scour depth after a flood. However, their applicability for monitoring the scour event in real time has been limited, and both techniques involve rigorous data processing and interpretation schemes. The information provided by battery operated devices including those based on neutral buoyancy of seismic transducers are crude and in general these devices have limited active lives. Buried mechanical devices such as magnetic collars are comparatively inexpensive. However, it is not possible to reset these devices for reuse, and issues pertaining to binding and installations have hindered their usage. Techniques based on TDR either use sacrificial sensors that break off during scouring events or solely depend on the impedance mismatch and are not practical for real applications involving various types of sedimentations. Attenuation and pulse dispersion errors due to length of electrical cables as well as probe length limitations are among the other deficiencies of these systems. Sensors based on spatial positioning of PZT or fiber optic sensors (Bin et al., 2006) on a rod that can be driven into the sediment provide only incremental resolution. Moreover, these multi-sensor arrangements are expensive since they require sophisticated multi-channel data acquisition and interpretation techniques. The currently available scour monitoring techniques do not possess the necessary attributes for widespread deployment in scour critical bridges. Therefore, the objective of the previous ICT study was to develop a practical scour sensor with the following attributes:

- accurate
- simple in principle
- easy to install and operate
- simple to calibrate
- cost effective
- reliable

2. GENERAL DESCRIPTION OF THE PROPOSED SCOUR SENSOR

The work described here pertains to the development of a scour sensor capable of monitoring the scour depth. The system includes a single sensor element based on any of the sensing mechanisms including but not limited to: fiber optics, electrical strain gages, accelerometers, PZT sensors, wireless sensors, etc. The sensor element is attached to a rod cantilevered into the river bed. As the scour initiates and develops, it changes the dynamic characteristics of the rod, which is measured from the sensor attached to the rod. The fundamental dynamic characteristics of the rod are independent of the flow rate and they are directly related to the scour depth through the calibration process. The sensor element employed in the present study consists of an optical fiber Bragg grating sensor (FBG).

Fiber Bragg Gratings (FBG) sensors are commercially available, and they are manufactured by inducing gratings with specific pitch in the core of the optical fibers. The gratings are designed to reflect a specific wavelength of light, and grating pitch variations due to strain are proportional to changes in the reflected wavelength changes. The FBG sensors are calibrated precisely to relate the change in the wavelength to strains. Each FBG sensor in a system can be tagged with a specific wavelength during the manufacturing process to serve as the reference wavelength λ_B.

3. SUMMARY OF PREVIOUS STUDY ACTIVITIES

3.1 LABORATORY PROOF OF CONCEPT TESTS

The previous work involved two activities, namely laboratory proof of concept tests to validate the hypothesis and preliminary field tests to evaluate the scour detection capability under turbulent flow. The laboratory experimental setup involved using a hydraulic pump and the discharge unit to create a closed-loop flow through a water tank with siliceous sediments. A scour sensor was fabricated and inserted into the sediment. No efforts were made to create any river flow simulations. The idea was to examine the viability of the concept and to correlate the frequency response to scour depth. Experiments were performed by embedding a graduated ruler inside the sand and through manual removal as well as re-deposition of sand to simulate scour. The physical measurements by the ruler were calibrated against the frequency changes. Experimental results indicated direct correlation between the fundamental frequency of the sensor and the scour depth.

3.2 PRELIMINARY FIELD TESTS

The field sensor design and dimensions were based on the prevailing flow rate loading on the sensor at the particular bridge site. The bridge on Toughy Ave over North Branch of Chicago River was selected for the preliminary field experiments and field proof of concept experiments. Considering the behavior of a rod driven inside the river bed, it was decided to design the sensor as a friction pile in order to evaluate the response and the stability of the sensor. AASHTO specifications were used for the sensor design.

The scour sensor design pertains to the condition when the sensor is completely submerged inside the river water. In such a case it is possible to establish a reference calibration factor based on the fully submerged state of the sensor. For the field proof of concept tests, the sensor design involved a 6 foot aluminum rod with 0.5 in diameter. The sensor rod was embedded 3 feet within the river-bed soil. Evaluation of the sensors' responses was carried out by several different tests on different dates. A graduated ruler was employed as a depth gauge to measure the scour depth in the river. Typical results comparing the two methods of measurements, namely the scour sensor and ruler readings, are shown in Tables 1 and 2.

Table 1. Comparison of Ruler Measured and Scour Sensor Measured Values

Sensor 3		
Frequency (Hz)	Measured Scour Depth by Ruler Depth Gauge(in)	Scour Depth by the scour sensor computations(in)
10.2094	0	-0.2674924
9.3	1.2	1.5022
8.35	2.7	3.3509
8.11	3.7	3.81794

Table 2. Comparison of Measured and the Sensor Measured Response

Sensor 1		
Frequency (Hz)	Measured Scour Depth by Ruler Depth Gage (in)	Scour Depth by the scour sensor (in)
12.13	0	-0.33485
10.93	1.3	1.27915
10.14	2.7	2.3417

4. CURRENT STUDY

4.1 PERMANENT FIELD INSTALLATIONS AND REMOTE FIELD MONITORING

This section of the report pertains to the work performed during 2009-2010. The primary objective of this project was to install a permanent scour monitoring system in a scour critical bridge with capability for real time monitoring of the bridge scour. The specific objectives of the project included selection of the bridge; design and fabrication of the field sensors; installation of the sensors, interrogation unit, multiplexer, and remote computer for real time data acquisition; installation of wireless internet system for remote desktop monitoring of scour; and development of software for automated calibration and user-friendly remote data acquisition and archiving of scour history for the bridge.

The project commenced with a meeting at IDOT headquarters in Springfield, Illinois. The meeting participants included the technical review panel members and the principal investigator. Decisions were made regarding assistance from IDOT's district 1 personnel in selection and access to a scour critical bridge in the Chicago area, purchase of the instrumentation, and other logistical issues including running of the powerline to the bridge for the sensor instrumentation. The following sections describe the instrumentation installed at the bridge site and the processing of the sensor data.

4.2 REMOTE MONITORING INSTRUMENTATION

The sensing system consists of four different parts as follows:

- sensors
- multiplexer
- interrogator module
- processing module

Each component of the remote real time monitoring system has its own responsibilities in various stages for monitoring the scour at the sensor locations. The interaction among the various components of the monitoring system is schematically shown in Figure 1.

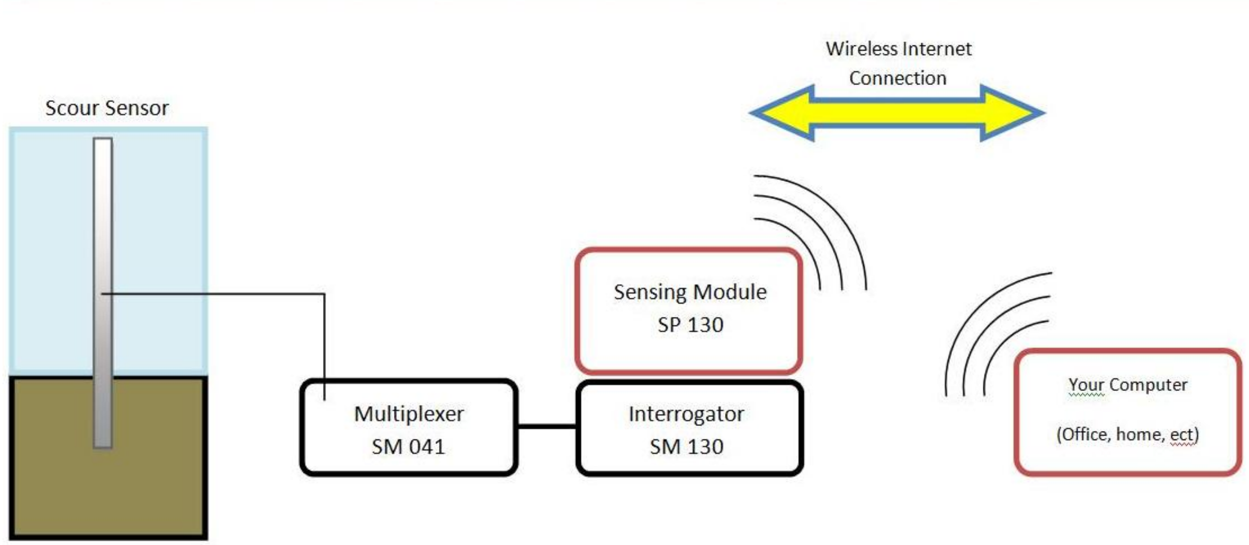


Figure 1. Schematics representative of the entire scour monitoring system.

4.2.1 Scour Sensors

The operational principles and fabrication of the scour sensors were described earlier in this report. Each sensor rod has an FBG sensor with an 18-20 foot fiber optic cable extension (Figure 2). These cables are armored for protection against damage by rodents and impacts. This design was conceived to facilitate sensor replacement in future operations in case of damage, or design changes without further need for additional wirings. The sensors are connected to the interrogation unit for conversion of optical signals from the sensors to meaningful strain signals. However, the sensor signals are routed through a multiplexer first. Multiplexers allow for connection of the interrogation unit to many sensors.

4.2.2 Multiplexer device SM041

The sm041 Sensor Multiplexer is commercially available and manufactured by Micron Optics, Inc. It is a compact, field proven, industrial grade multiplexer module that economically adds measurement channels and fiber connections to an interrogator device. This multiplexer was employed for installation in the field. The device is depicted in Figure 3 and, as shown, it has capability for connection to 16 optical cables.

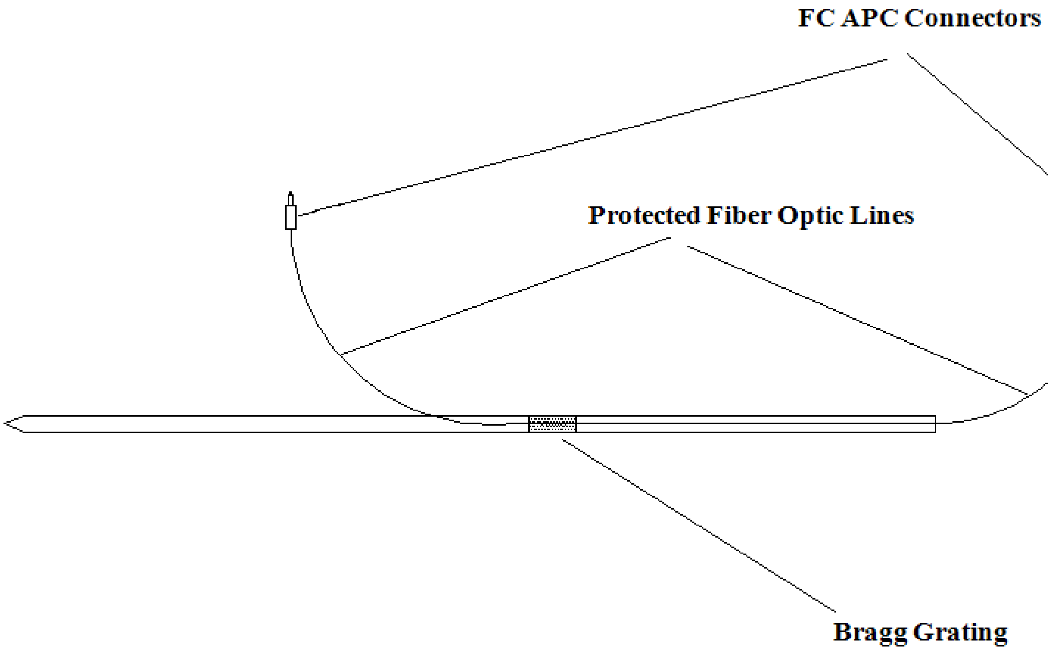


Figure 2. Schematics of a typical scour sensor rod.

Figure 3. SM041 Multiplexer device (source: Micron Optic's web site).

The multiplexer is based upon a network of fused wide band fiber optic couplers and shares a common optical spectrum simultaneously among multiple output ports. The multiplexer is designed to withstand demanding requirements of continuous operation without wear-out, longevity without fail, and live operation under vibration and shock. This device expands interrogator's 4 channels to 16 sub-channels to accommodate enough dynamic sensors. Technical specification of the 16 sub-channeled sm041 multiplexer device is summarized in Table 3.

Table 3. Technical Specification of the sm041 (Source: Micron Optic's web site)

Specifications	sm041-008	sm041-016	sm041-408	
Number of Optical Channels	4 In / 8 Out	4 In / 16 Out	4 In / 8 Out	4 In / 16 Out
Multiplexer Type	Coupler	Coupler	Switch	Switch
Wavelength Range		Same as Host Instrument		
Scan Frequency		0.25 Hz to 2KHz		
Insertion Loss (2-way)	8 dB	16 dB	3 dB	4 dB
Optical Connectors		FC/APC		

4.2.3 Optical Sensing Interrogator SM130

The sm130 Optical Sensing Interrogator is also a compact, industrial grade dynamic sensor interrogation module designed for robust, reliable, long term field operations. The Optical encompasses a high power, high speed swept wavelength laser. It is a high speed measurement system, optimized for rapid data acquisition of many simultaneous FBG sensors. It provides measurements with high acquisition rates, moderate dynamic range, and continuous lifetime on-board referencing. It is capable for simultaneous monitoring of dynamic sensors and measures static sensors with ultra-high resolution. The interrogator shown in Figure 4 possesses capability for direct connection to a microprocessor computer unit for data acquisition and remote interface via hardwire internet or wireless data transfer.

Figure 4. SM130 sensing processor unit.

The interrogator system responds directly to the user commands of the optical interrogator core and outputs sensor wavelength data via Ethernet port and custom protocol. All module settings, sensor calculations, data visualization, storage, and alarming tasks are run on external pc or sensor processor modules. A summary of the interrogator specifications is shown in Table 4.

Table 4. Summary Data Sheet of the Sm130 Device (source: Micron Optic's web site)

Specifications	sm130-200	sm130-500	
Number of Optical Channels	1 (up to 16)	4 (up to 16)	4 (up to 16)
Scan Frequency	100 Hz	500 Hz	1 KHz
Wavelength Range		1510-1590 nm	
Wavelength Stability		2 pm typ, 5 pm max	
Wavelength Repeatability		1 pm, 0.05 pm with 1,000 averages	
Dynamic Range		25 dB with user-selectable gain	
Max FBGs per Channel		80 (up to 160 with expanded λ range)	
Internal Peak Detection	Included	Included	Included
Spectral Diagnostic View	Optional	Included	Included
Optical Connectors		FC/APC	

4.2.4 Sensing Processor Module SP130

The system computer and processing system sp130 is an industrial grade, high performance sensing processor module for use with Micron Optics sm130 Optical Sensing Interrogators. The sp130 is built on a fan-less industrial PC and facilitates communication and power control to the sm130 module. Custom software development and application management is included with the sp130 module. The data processing environment enables one to measure the optical domain and report those results in the appropriate engineering units of strain, temperature, pressure, acceleration, and in this case, scour. Data can be saved locally to an on-board compact flash card or hard drive. The computer is shown in Figure 5.

Figure 5. Sensing processor module.

Raw or processed data can also be exported to other processors via Ethernet, 3G wireless, which is the case here, or Serial and USB ports, etc. For some remote applications, power management is critical. This processor provides power management through wake-on-LAN and wake-on-clock functions. Furthermore, it can support remote data transmission through most PC compatible protocols like TCP/IP, RS-232/422/485, Modbus, wireless LAN, etc. Specifications for the processor are listed in Table 5.

Table 5. Specifications for the Sensing processor module (Source: Micron Optic's web site)

Specifications	sp130-500
Operating System	Windows XP Professional
Processor Type	Low Voltage Pentium
Processor Speed	1.4 GHz
Memory	512 MB DDR
Storage Media	100 GB 2.5" HDD

5. REMOTE MONITORING SITE – BRIDGE OVER SALT CREEK

In cooperation with IDOT's District 1 personnel, a number of candidate scour critical bridges were visited; they were all located in the vicinity of Chicago metropolitan area. Eventually, the bridge over Salt Creek on State Route 83 at the intersection with Saint Charles Road in Elmhurst Illinois was selected for installation of scour sensors. This bridge will be referred to as Salt Creek Bridge for the remainder of this report. A photo of the bridge showing the pier segments in the upstream section is included as Figure 20. The bridge consists of three spans resting on two abutments and two piers. A schematic drawing of the bridge is also shown as Figure 6. The abutments and piers of the Salt Creek Bridge face the upstream flow at an angle which increases the severity of scour during floods.

Figure 6. Upstream section of the Salt Creek Bridge.

In general, faces of the piers and abutments which are subjected to upstream current are more vulnerable to the scour than those in downstream sections of the bridge. In addition, following preliminary site investigation, it was clear that the scour holes at the head of the piers in the upstream sections were much deeper than holes at the downstream locations. It was also understood, that in certain occasions, the scour materials from the pier heads accumulate along the pier walls as they travel downstream (Figure 7).

Figure 7. Accumulation of sediments along the abutment wall due to upstream scour.

Considering all the potential scour activities, the sensor layout plan shown in Figure 8 was selected in order to capture the scour effects in the upstream and downstream sections as well as along the pier walls. This layout allows evaluation of the scour sensors for performance under various conditions including sediment removals and accumulations. This plan called for a total of 14 scour sensors.

As shown in Figure 8, six sensors were placed at the upstream sections of the bridge, one for each abutment and two for each pier. Six more sensors were placed along the abutment and pier walls halfway between the upstream and downstream ends of the bridge. In addition, two sensors were placed downstream at the pier ends. Altogether, a total of 14 sensors were installed at the Salt Creek Bridge site.

5.1 FIBER OPTIC WIRING AND INSTRUMENT ENCLOSURES

The wiring plan is also shown in Figure 8.

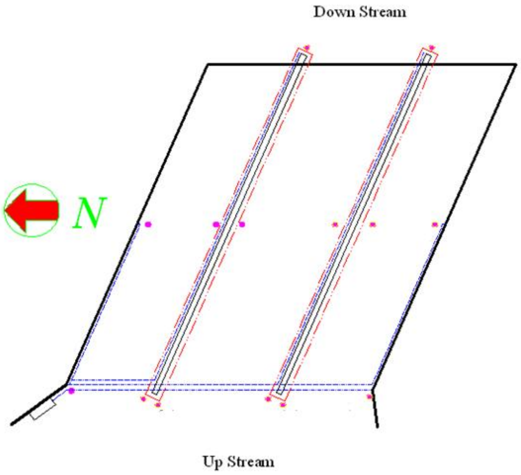


Figure 8. Sensor plan layout.

The Nema enclosure box was installed at the north end corner of the abutment on the upstream side of the bridge. This enclosure unit was provided with electrical power, several outlets, a fan, heater and thermostat (Figure 9). The interrogation unit, multiplexer and the computer/processor systems were housed in the Nema enclosure. The fiber optic lead line wiring plan was designed in such a way to produce redundancy. This would allow for future replacement of individual sensors in case of damage without interrupting the entire wiring system. To achieve this effectively, junction boxes were installed at the sensor locations, on top of the piers and abutments. The junction boxes provide for sensor lead input and lead out for routing to the Nema enclosure. This allows for direct connectivity of individual sensors to the interrogation unit. Typical junction box installations on the piers and abutments are shown in Figures 10 and 11.

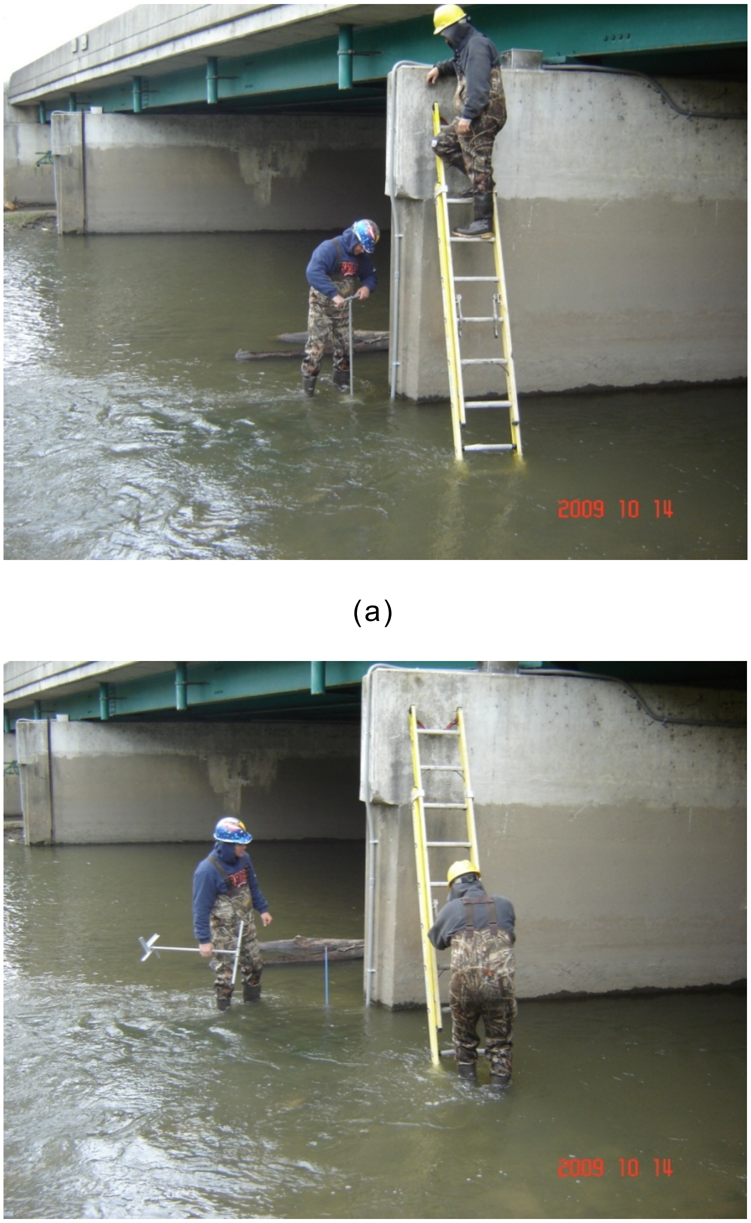
Figure 9. Nema enclosure box to house the instrumentation.

Figure 10. Typical junction boxes on the bridge piers with conduit lines to sensors.

Figure 11. Typical junction box on the abutment.

5.1.1 Sensor Placement

The scour sensors developed in this project are in general small in diameter and can be easily pushed into the sediments. Therefore, it is possible to insert them into the sediments by using a hammer. However, they have to be embedded to precise lengths for calibration and establishment of reference of zero scour. Although the present study sensor installation operations took place when the water levels were low; it is desired to be able to install the sensors at any time, even during the high water seasons from a boat for instance. For this reason, a simple gadget was designed that consisted of a hollow tube with a stop and latch mechanism. The stop mechanism assures the correct sensor height for embedment within the sediment. Because the installer is not able to observe the operations below the water surface, the four arm base of the sensor insertion gadget prevents the tube from penetrating into the sediment. It signals to the operator that the sensor is embedded to the exact height. The operator uses the handle to twist the sensor in place, and the twisting action also releases the hatch. These operations are shown in Figure 12. This device can simplify the operations during the installations of the sensors while the crews are on a boat.



(a)

(b)

Figure 12. (a) Sensor installation; (b) sensor in river bed right after installation.

5.1.2 Sensor Protection

Two types of floating objects interfere and affect the performance of the sensors: leaves and large tree branches and trunks. The tree leaves influence the vibration of the rod by clinging to the rod that in turn results in an increase in the resultant frequency of the sensors. On the other hand, large tree trunks damage the sensor.

The impact of tree trunks and accumulations of the leaves occur when the sensor is above the water line or when it is only slightly submerged. During the floods, the water level is very high and the tree trunks and the leaves move closer to the surface and will not influence the sensor because the sensors are in general very short, i.e. 2 feet high. Nevertheless, it is irrational to assume that the water level remains high, and preventive measures have to be taken. A logical approach involved using large diameter steel tubes to deflect the impact of the trees. While this method was tried and proved to be successful, it was considered an “over kill”. Another approach that proved to be very successful was to use a fence slightly taller than the sensor. The fence consisted of two 1.5 inch diameter steel rods for stiffness, and flexible soft material 1 inch gratings. This system was useful to deflect the trees and to catch the leaves. The fence was placed two feet ahead of the sensor to allow for the river flow to reach the sensor. The system is shown in Figure 13. To date, it has collected all the leaves and has allowed for interruption-free operation of the sensor. However, it won’t be tested for use against the tree trunks until spring.

Figure 13. The protective fence system.

5.2 REMOTE MONITORING

The goal of the project was to enable IDOT personnel to remotely monitor the state of the scour in real time, acquire archival data, i.e. scour history over different time periods, and generate reports. The processor at the bridge site is connected to the internet via a 3-G wireless connection through a subscription with Verizon Wireless. The following sections provide information about connecting to the site via remote computer, i.e. from an office or home, user friendly software, procedures for calibration of the sensors, and archiving for generation of reports.

5.2.1 Salt Creek Scour Sensor Numbering System

The interrogation unit has four operating channels to accept sensor input. As discussed earlier, because the Salt Creek Bridge was instrumented with 14 sensors, a multiplexer was employed for accommodating all 14 channels. In general, multiplexers could handle up to 16 channels of data. The interrogator/multiplexer design allows for the all the sensor channels, in this case 14 of them, to be analyzed by the four channel interrogator system. Therefore, in assigning the 14 sensors to the four channels of the interrogator, more than one sensor is assigned to an individual channel. To assure matching the sensor locations to the channel readouts in the computer, the two digit sensor numbering system shown in Figure 14 was adopted for this project.

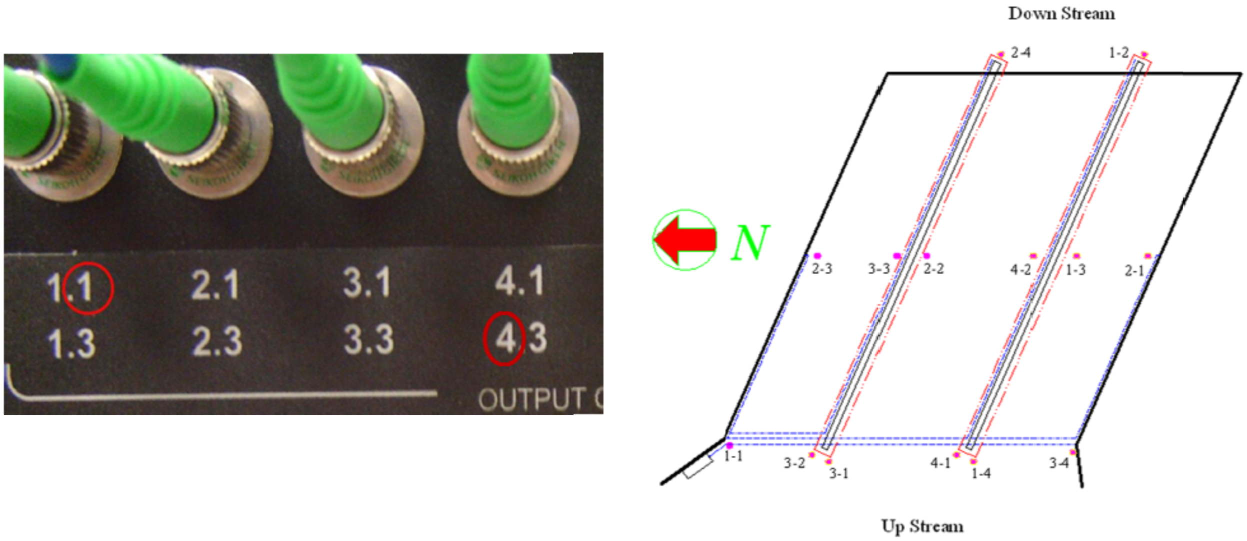


Figure 14. Matching the two-digit scour sensor numbers at the bridge site to the interrogator channels.

The first digit in each sensor number points to one of the four channels, 1 through 4, of the interrogation unit. The second digit is the assigned sensor number. For example sensor 4.1 is the sensor at the upstream pier head, and it is one of the sensors in channel 4. Later in the remote software program, one could select and monitor this sensor's scour activity by inserting 4 for the channel number and 1 for the sensor number. Similarly 2.3 refers to sensor number 3, which is at the north abutment wall, and it is analyzed by channel 2, and so on.

5.3 REAL TIME SCOUR MONITORING PROGRAM

Throughout the project period, various programs where written to access the remote scour data. The original versions of the program required access to several programs by the user including Labview and Matlab. However, once the sensor installation activities were completed, it was possible to further enhance the software. The current version is the new version of the remote software for real time monitoring of scour at Salt Creek Bridge. Users should discard any previous instructions and use the instructions provided here for remote access, monitoring, and reporting. The advantage of this new version is that all the activities are combined into one program. Following successful connection to the remote computer via the "remote Desktop" application described here, users only need to use the "Labview" software for all the activities previously accomplished by three programs. Moreover, this new version is user-friendly.

5.3.1 Remote Access to the Computer

A remote desktop connection enables one to connect to the other computers over the internet. This program is available on all windows based systems. This program was used to connect to the Salt Creek monitoring computer. The instructions are as follows:

1. Click on the Start => All Programs => Accessories => Remote desktop control. A window similar to that depicted in the Fig. 15 will appear.

Computer: 166.156.100.48

User name: SP130\sp130demo

You will be asked for credentials when you connect.

Figure 15. Remote desktop connection.

2. In the blank space in front of the Computer, enter the machine's IP address.
3. After successful connection, the program will ask you the username and password for this machine.

If connected properly to this device, a user will see the Salt Creek computer desktop. Once connected to the remote computer, the RTSM program can be started by double clicking the icon shown in Figure16.

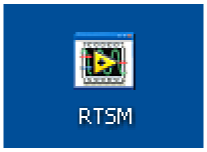
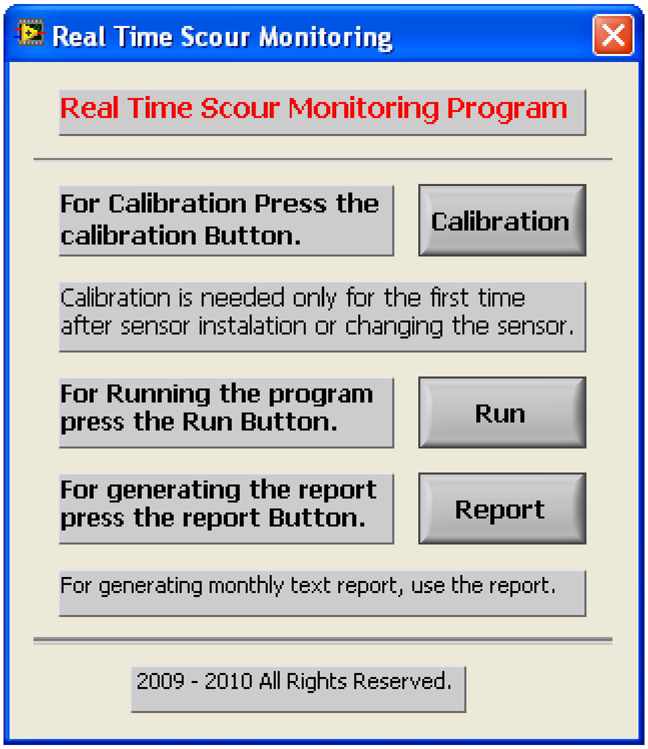


Figure 16. RTSM program icon.

The program will run once double clicked. After running the program, the main panel for the scour monitoring program will be opened. The program will provide the user with three options for calibration; real time monitoring (Run); or for generating reports for the archived data (Figure 17).



Real Time Scour Monitoring Program

For Calibration Press the calibration Button.

Calibration is needed only for the first time after sensor instalation or changing the sensor.

For Running the program press the Run Button.

For generating the report press the report Button.

For generating monthly text report, use the report.

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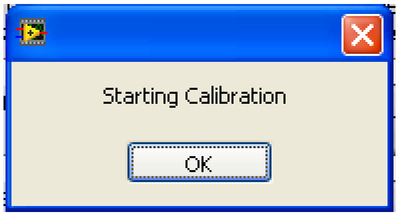
Figure 17. Program main screen.

1. To calibrate the sensors for the first time, or change the calibration factor for the new sensor, select and click the “Calibration” button.
2. For real time scour monitoring of the bridge, select and click the “Run” button.
3. Selecting the “Report” button will generate a scour report based on the period of time selected by the user.

These segments will be described in the following sections

5.3.2 Calibration

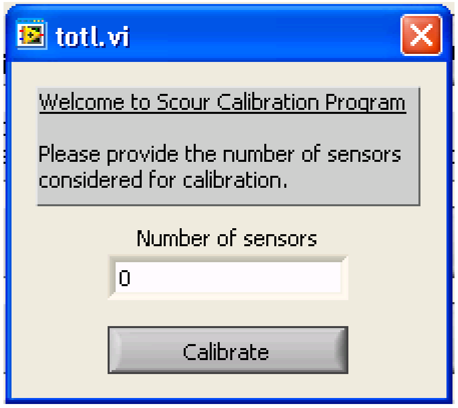
After selecting the “Calibration” button, if it is the first time the program is run for the calibration of the sensors, a window, as presented in Figure 18, will be displayed on the screen. Click on the “OK” button to proceed to the next step.



Starting Calibration

Figure 18. Starting calibration.

The program prompts the user to insert the total number of sensors for calibration. Input the total number of the sensors that you wish to calibrate, and click the “Calibration” button. This window is presented in Figure 19.



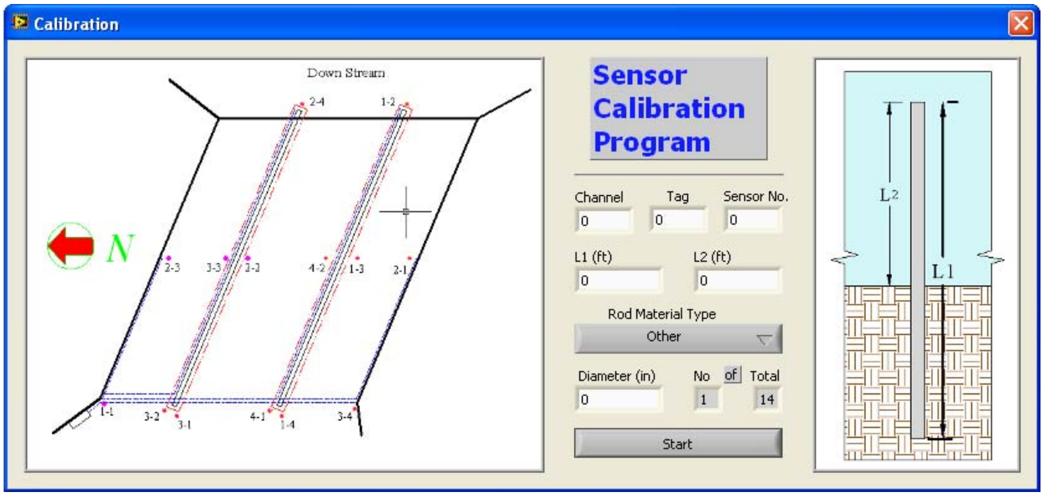
Welcome to Scour Calibration Program

Please provide the number of sensors considered for calibration.

Number of sensors: 0

Figure 19. Total number of the sensors.

In the next window, the calibration panel will open.



Sensor Calibration Program

Channel: 0

Tag: 0

Sensor No.: 0

L1 (ft): 0

L2 (ft): 0

Rod Material Type: Other

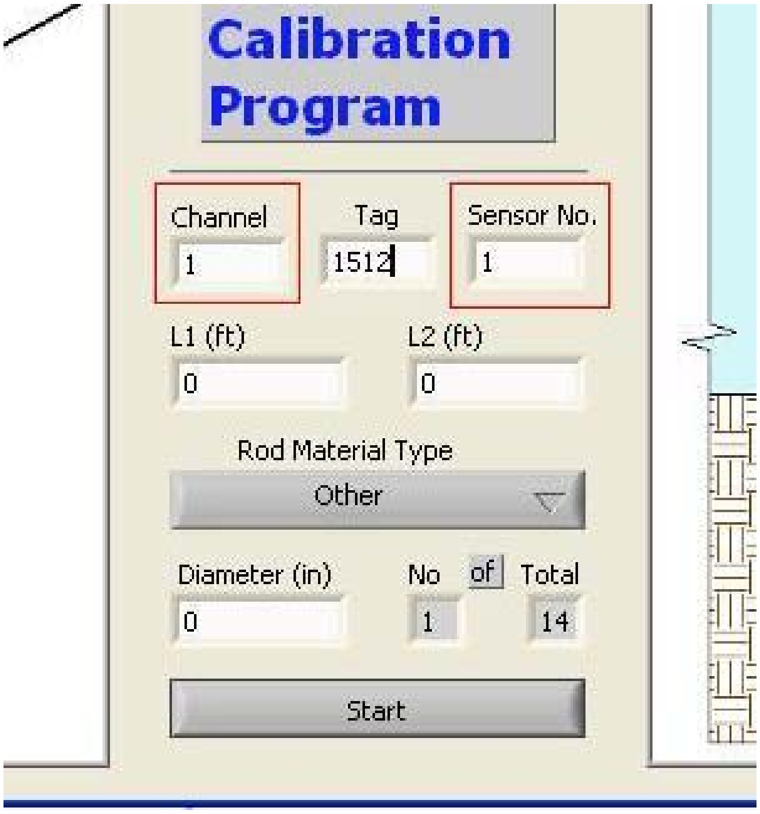
Diameter (in): 0

No 1 of Total 14

Figure 20. Calibration panel.

The sensor locations at the Salt Creek Bridge are shown on the plan view of the bridge substructure. The plan view is used as a guide to locate the sensors. For use of this software with other bridges, the bridge plan could be directly loaded into the program by placing the plan of the bridge named “pic.PNG” into the following folder at the remote computer site: C:\Documents and Settings\sp130demo\My Documents\data

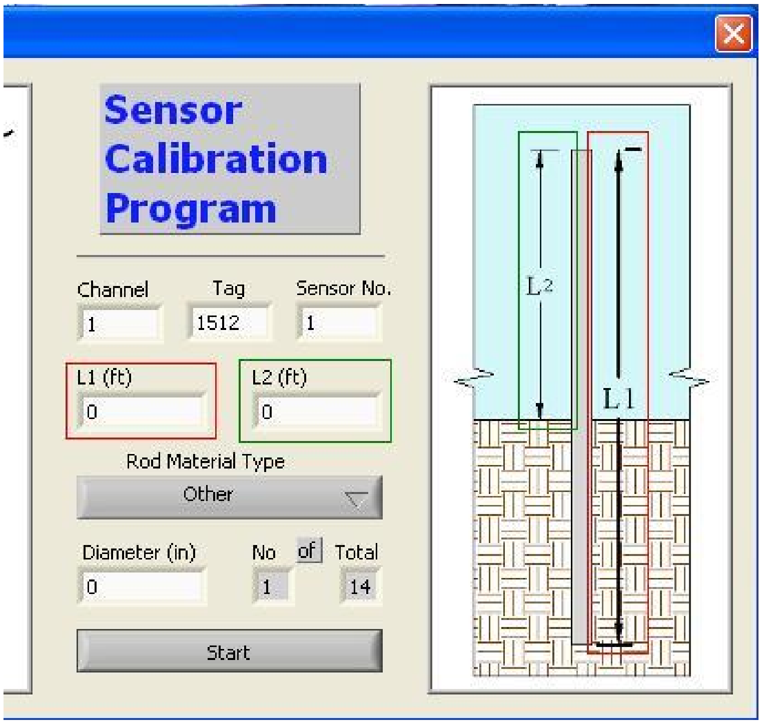
For calibration, a user must input the channel and sensor numbers, respectively as shown in Figures 20 and 21. As noted the sensors are identified by two digits, in X.X format. The first digit corresponds to the channel number, and the second digit is the sensor number. For example, sensor 2.1 points to the first sensor in the second channel.



Channel: 1
Tag: 1512
Sensor No.: 1
L1 (ft): 0
L2 (ft): 0
Rod Material Type: Other
Diameter (in): 0
No 1 of Total 14

Figure 21. Sensor and channel number.

To identify sensors prior to field installation, each sensor is identified by a tag that corresponds to the wavelength of the optical fiber used for the manufacturing of the sensor. The identification tags are provided with the sensors. At this point, it is necessary to insert the wavelength of the sensor which is being calibrated in the tag box. Two other boxes are provided for the user to input the total length of the sensor (L_1), and the length of the sensor exposed to the river flow (L_2). As shown in Figure 22, L_1 is the total length of the sensor rod, and L_2 pertains to the length out of the soil segment (exposed length to the water flow), both in feet.

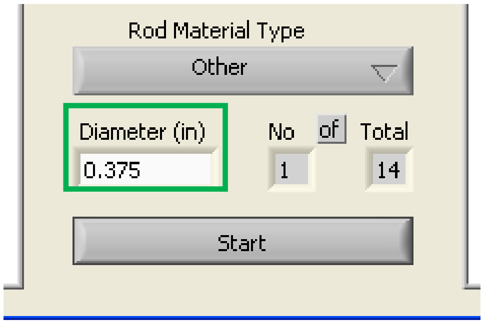


Channel: 1
Tag: 1512
Sensor No.: 1
L1 (ft): 0
L2 (ft): 0
Rod Material Type: Other
Diameter (in): 0
No 1 of Total 14

Figure 22. L1 and L2 definition.

The material type of the sensor rod can be chosen from the drop down menu. Aluminum and steel are considered standard, and their mechanical properties have already been considered by the program. For other sensor materials, i.e. FRP, the user could specify and input the material properties manually. In these cases, for other types of materials select the “other” button.

The diameter of the sensor rod must be inserted in the specified box as it is shown in Figure 23. The program will also remind you about the number of sensors calibrated up to this step. Once all the required sensor parameters have been entered, the calibration process for the sensor under consideration begins by clicking on the “Start” button.

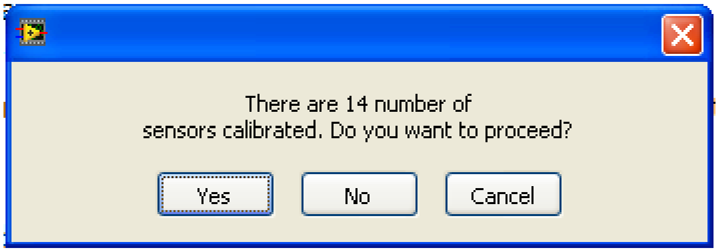


Rod Material Type: Other
Diameter (in): 0.375
No 1 of Total 14

Figure 23. Diameter box.

Note that the IP address of the device must be the same as the default number. After a while, the program reverts back to the calibration panel. Repeat this procedure until all of the sensors are calibrated.

In some cases, the user may wish to re-calibrate one or more of the sensors, i.e. when a sensor is replaced and the new sensor needs to be calibrated. To recalibrate, the “Calibration” button on the main screen can be selected again. Another window will pop up and will state the number of already calibrated sensors in the system (Figure 24). If the user clicks on the “Yes” button, the program will proceed to the calibration window, where the user is prompted to select the sensors for the re-calibration. If the user wants to add new sensors to the current configuration, in the recalibration phase, the total number of new sensors must be entered.

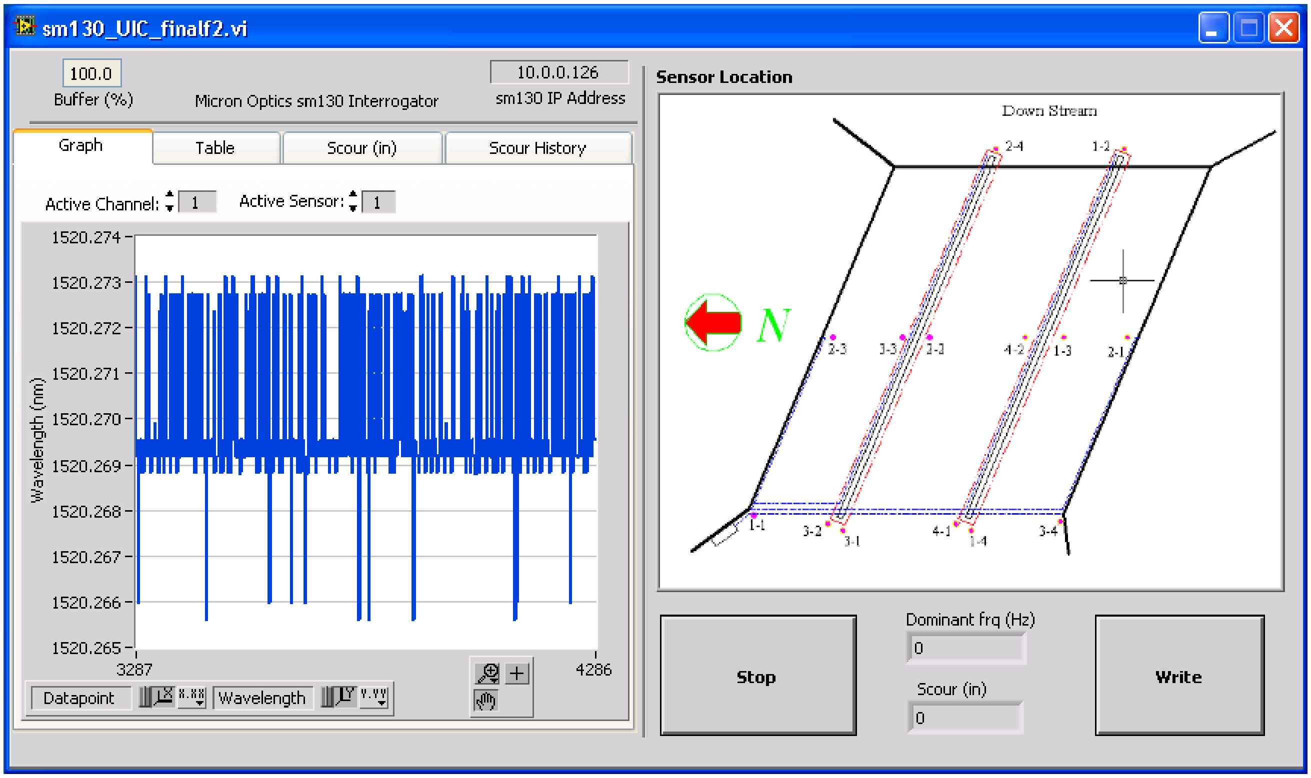


There are 14 number of
sensors calibrated. Do you want to proceed?

Figure 24. Calibrating existing system.

5.3.3 Real Time Monitoring

To start real time scour monitoring, the user must click on the “Run” button on the main screen (Figure 3); it will start the monitoring program shown in Figure 25. All of the sensor locations are presented in the plan view of the bridge substructure at the right side of the monitoring panel. On the left side of the panel, the user could utilize four distinct tabs.



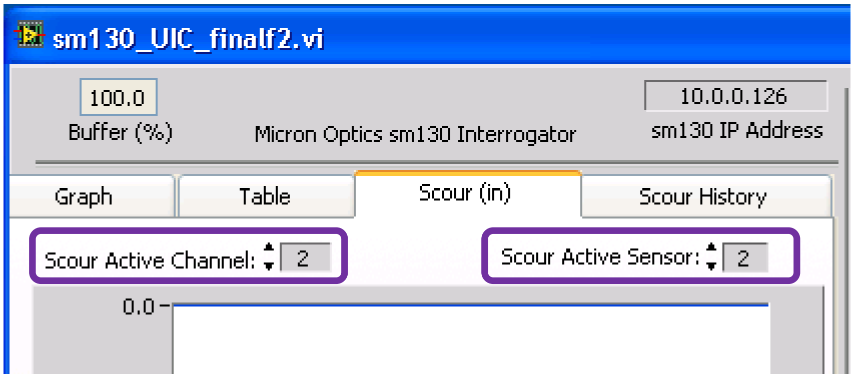
Buffer (%): 100.0
sm130 IP Address: 10.0.0.126
Active Channel: 1
Active Sensor: 1
Dominant frq (Hz): 0
Scour (in): 0

Figure.25. Scour real time monitoring.

1. Graph Tab: In this tab, the user could select the channel number and sensor number (active channel and active sensor) and monitor the real time raw data (wavelength in nanometers). While this information does not have much engineering context, lack of sensor activity will alert the user that the particular sensor is damaged.

2. Table Tab: The current wavelength of each sensor is represented on this tab, categorized by the channel number. In this table, each column represents a channel, numbered from 1 to 4 and each row represents a sensor. Row number and sensor number are the same. For example, a sensor in the second column and third row portrays the third sensor in the second channel, or simply, sensor 2.3. Although this tab might not have any engineering information, it serves to indicate the number of active sensors, wavelength changes for the optical fiber which is necessary for debugging the system if necessary.

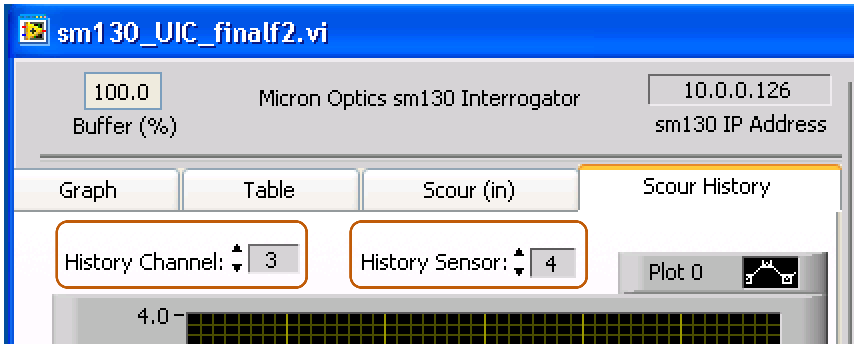
3. Scour Tab: The scour tab presents the real time scour in inches for the selected channel and sensor number. The channel and sensor number selection are highlighted in the Figure 26.



Buffer (%): 100.0
sm130 IP Address: 10.0.0.126
Scour Active Channel: 2
Scour Active Sensor: 2

Figure 26. Scour channel and sensor number selection.

4. Scour History Tab: In this tab, average hourly scour magnitude is plotted versus time. Vertical axis displays the scour in inches, and horizontal axis presents time in terms of hours. The user could choose or change the specific sensor by means of selecting channel and sensor number as presented in Figure 27. Positive values indicate scour (depth of removed sediments), and negative values indicate accumulation of sediments.
5.

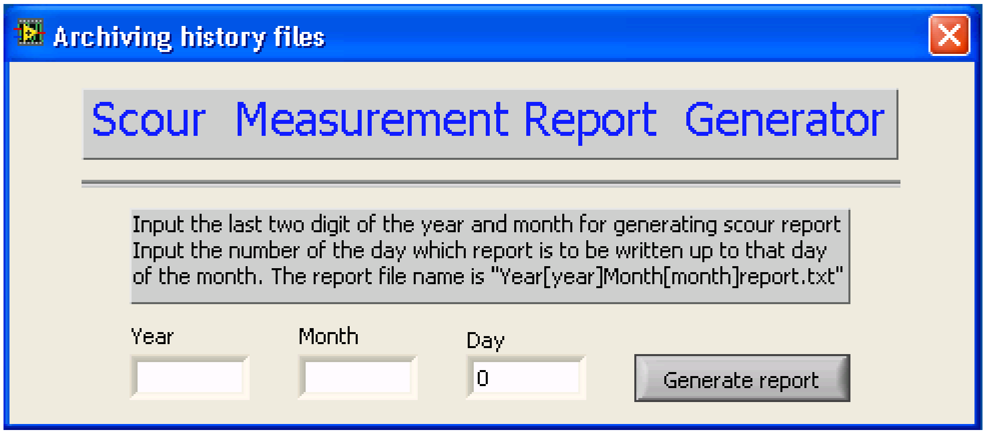


Buffer (%): 100.0
sm130 IP Address: 10.0.0.126
History Channel: 3
History Sensor: 4

Figure 27. Scour history channel and sensor selection.

5.3.4 Report Generation

This program automatically records the state of scour for all of the sensors. To reduce the volume of generated data, the frequency of data collection for each sensor is four times daily: at midnight, 4 a.m., noon, and 4 p.m. The data is utilized for preparation of monthly or month to date text report files. To generate the report file, a user must click on the “Report” button on the program main panel (Figure 17). This opens up the “Archiving history files” window. Text report files are easy to handle, and it is possible to import them to other platforms like spreadsheets. For the purpose of report generation, the user must input the time period for which the report needs to be generated. As it is shown in Figure 28, it prompts the user to input the last two digits of the year, (i.e. for the year 2010 input 10 in the year box) and the two digits of the month. For the monthly report, the user must input the number of days in the month. Moreover, for month to specific date reports, the user must input the desired day in the day box.



Input the last two digit of the year and month for generating scour report
Input the number of the day which report is to be written up to that day
of the month. The report file name is "Year[year]Month[month]report.txt"

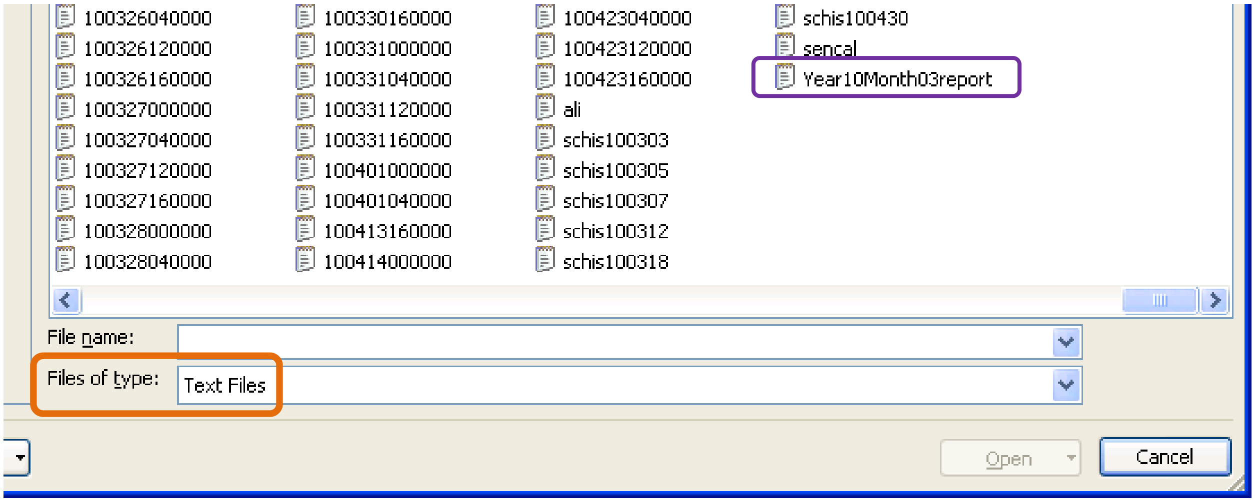
Year:
Month:
Day: 0

Figure 28. Archiving window.

The program develops a report file with a unique name for the report file. This file is stored in the following path in the remote computer:
C:\Documents and Settings\sp130demo\My Documents\data

For instance, for the year 2010 and month of February, program will develop a text file named: Year10Month02report.txt.

To open the file, select the “Text” type file, and open the appropriate report file (Figure 29).

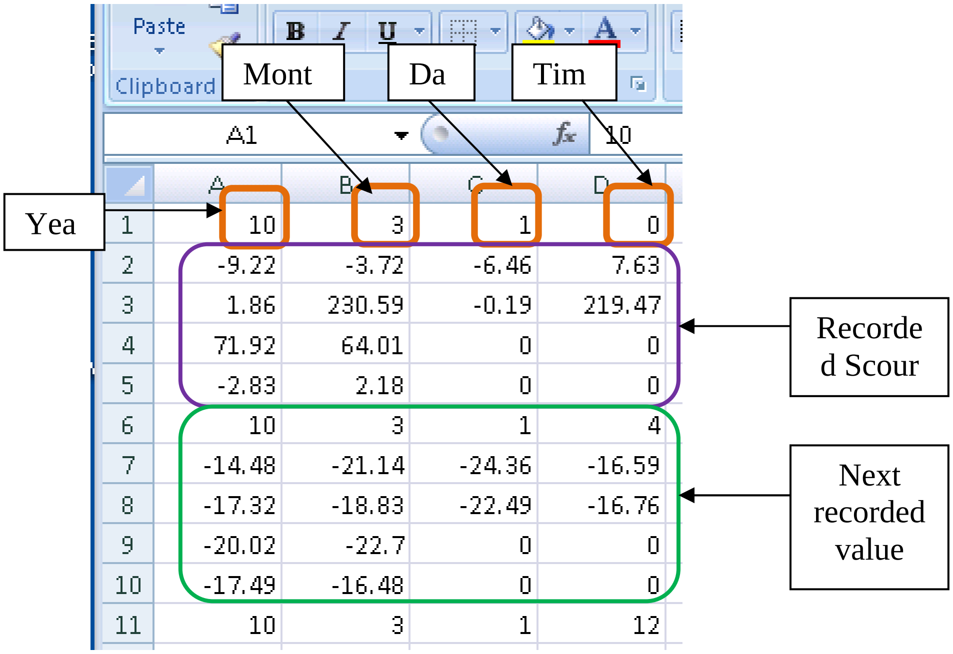


100326040000
100326120000
100326160000
100327000000
100327040000
100327120000
100327160000
100328000000
100328040000
100330160000
100331000000
100331040000
100331120000
100331160000
100401000000
100401040000
100413160000
100414000000
100423040000
100423120000
100423160000
ali
schis100303
schis100305
schis100307
schis100312
schis100318
schis100430
sencal
Year10Month03report

File name:
Files of type: Text Files

Figure 29. Report file selection.

The program will show the contents of the file as depicted in Figure 30. As shown in the figure, recorded scour values are presented for each reading of the day. For example, in this figure, recorded values at 12:00 a.m. (time: 0 in 24 hour format), first day (Day: 1) of the month of March (Month: 3) year 2010 (Year: 10) are depicted (first row). In this table, each column represents a channel, (A for channel 1, B for 2, C for 3, and D for channel 4) and each row represents a sensor. For example, a sensor in the second column and third row portrays the third sensor in the second channel, or simply, sensor 2.3. (Note: Scour values in this figure are randomly generated and do not present real values). The next values would be for the same day, at 4 a.m., 12 p.m. and 4 p.m. respectively.



	A	B	C	D
1	10	3	1	0
2	-9.22	-3.72	-6.46	7.63
3	1.86	230.59	-0.19	219.47
4	71.92	64.01	0	0
5	-2.83	2.18	0	0
6	10	3	1	4
7	-14.48	-21.14	-24.36	-16.59
8	-17.32	-18.83	-22.49	-16.76
9	-20.02	-22.7	0	0
10	-17.49	-16.48	0	0
11	10	3	1	12

Figure 30. Report file content.

6. CONCLUSIONS

This research involved installing scour sensors for remote and real time monitoring of scour. This report details the field installation procedures, calibrations, fiber optic wiring, sensor embedment in the sediments, instrumentation, junction boxes, enclosures, software development, and instructions for remote monitoring of data and generation of archival data. The remote monitoring site is currently operational and the sensors are producing data. This data is automatically stored for archiving. IDOT personnel have access to the remote site via personal computers.

One of the objectives of the research was to develop a cost-effective sensor. While this objective was achieved in terms of the sensor and instrumentation itself, the issue of wiring posed additional costs and delays. Moreover, the current system requires delivery of electrical power to the site. For the future, it is important to develop a sustainable system using solar panels and wireless sensor technologies to alleviate cost and installation delay issues.

REFERENCES

Annandale, G.W. (2006), *Scour Technology.* Mechanics and Engineering Practice. McGraw-Hill.

Ansari, F. (2004), "North American Euro-Pacific Workshop for Sensing Issues in Civil Structural Health Monitoring, NSF Final Report, CMS-0438151, 16 p. (http://cshm.cme.uic.edu)

Ansari, F., Ed. (1998a), "Fiber Optic Sensors for Construction Materials and Bridges," Technomic (CRC) Publishing Co., Lancaster, PA, 1998, 368 p.

Bin, L. Y.**,** J. S. Lai, K. C. Chang, and L. S. Li, "Flood Scour Monitoring system using Fiber Bragg Grating Sensors," *Smart Materials and Structures,* December 2006, 15 (6), pp. 1950-1959.

Dowding, C. H., and C. E. Pierce, (1994), ''Use of Time Domain Reflectometry to Detect Bridge Scour and Monitor Pier Movement.'' Proc., Symp. and Workshop on Time Domain Reflectometry in Envir., Infrastruct. and Mining Applications, Northwestern University, Evanston, IL, 579-587.

Gee K. W. (2003), Action: compliance with the national bridge inspection standards—plan of action for scour critical bridges, FHWA Bridge Technology Memorandum. http://www.fhwa.dot.gov/engineering/hydraulics/policymemo/072403.cfm

Gorin, S. R., and F. P. Haeni (1989), ''Use of Surface-geophysical Methods to Assess Riverbed Scour at Bridge Piers.'' *Water Resources.* Investigations Rep. No. 88-4212, U.S. Geological Survey, Hartford, Conn.

Hayes, D. C., and F. E. Drummond, (1995), ''Use of fathometers and electrical-conductivity probes to monitor riverbed scour at bridges and piers.'' *Water Resources.* Investigations Rep. No. 94-4164, U.S. Geological Survey, Hartford, Conn.

Hunt, B. E. and G. R. Price (2003), Scour and Monitoring—Lessons Learned Keynotes of the 2nd Int. Conf. on Scour and Erosion (Singapore).

Lagasse, P. F.,E. V. Richardson, J. D. Schall, and G. R. Price (1997), Instrumentation for Measuring Scour at Bridge Piers and Abutments, Transportation Research Board, Rept. 396, National Academy Press, Washington, D. C.

Lyn, D. A., E. Neseem, A. Ramachandra Rao, and A. G. Altschaeffl (2000), A Laboratory Sensitivity Study of Hydraulic Parameters Important in the Deployment of Fixed-in-Place Scour-monitoring Devices. FHWA/IN/JTRP-2000/12. Final Report.

Mathworks Inc, MATLAB Product site. http://www.mathworks.com/products/matlab/

Mason, R. R., and D. M. Shepard, (1994). ''Field Performance of an Acoustic Scour-depth Monitoring System.'' Proc., Fundamentals and Advancements in Hydr. Measurements and Experimentation, ASCE, New York, 366-375.

Melville, B. W. and S. E. Coleman (2000), Bridge Scour. Water Resources Publications, LLC, Colorado, USA.

Melville, B. W. and A. J. Sutherland (1988), Design Method for Local Scour at Bridge Piers, J. Hydraulic Eng., 114, No. 10, October, pp. 1210-1226.

Micron Optic Inc, product specification data sheet, http://www.micronoptics.com/sensing_instruments.php

Priestly, M. J. N., F. Seible, and G. M. Calvi (1996), *Seismic Design and Retrofit of Bridges*. John Wiley and Sons.

Raudkivi, A. J. (1990), Loose Boundary Hydraulics, Pergamon Press, Oxford.

Richardson, E. V., and P. F. Lagasse, (1994), ''Instrumentation for Measuring Bridge Scour at Bridge Piers and Abutments.'' Phase II Final Rep., Nat. Cooperative Hwy. Res. Program, Transp. Res. Board, National Research Council, Washington, D.C.

Richardson, E. V., D. B. Simon, and P. Y. Julien (1990), Highways in the River Environment, Publication no. FHWA–IP–90–016, U. S. Dept. of Transportation, Federal Highway Administration, Washington, D. C.

Richardson, E. V., L. J. Harrison, and S. R. Davis (1991), Evaluating Scour at Bridges, Publication No. FHWA–IP–90–017, Hydraulic Engineering Circular No. 18, U. S. Dept. of Transportation, Federal Highway Administration, Washington, D. C.

Yang, B. (2005), Stress, Strain and Structural Dynamics, Elsevier Academic Press.

Yankielun, N. E. and L. Zabilansky (1999), Laboratory Investigation of Time-domain Reflectometry System for Monitoring Bridge Scour. *Journal of Hydraulic Engineering*, 1279-1284.

Zabilansky, L. J. (1996). ‘‘Ice Force and Scour Instrumentation for the White River, Vermont,’’ Special Rep. 96-6 U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, N.H.

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