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Bridge Scour and its Monitoring Using GSM Enabled Sensors – a Laboratory Study

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ABSTRACT: Local scouring around the bridge pier occurs because of flow separation and development of several vortexes around the bridge pier. Such scour can cause failure of the bridges especially during the river floods. This study presents an in-situ lab scour monitoring mechanism by using the Global System for Mobile (GSM) under clear water condition on cohesionless bed material. Circular pier with collar and another round nosed pier model at 5 different angles are considered for these experiments with GSM enabled sensors monitoring the scour. Scour failure occurs suddenly without prior warning or signs of distress in and around the bridge. However, there are many challenges to monitor the progress of scour, such as measuring equipments are essentially critical. Monitoring devices connected to GSM enabled sensors are installed near the bridge pier. Using the scour data provided by GSM unit, an alert is sounded for the local administration regarding the real time safety condition of the bridge.

Keywords: Pier, GSM enabled Sensors, Scour, Distress signal, Bridge stability.

1 INTRODUCTION

Bridges are designed to accommodate floods of certain magnitude without failure. But large proportion of bridges fail due to excessive scour around the bridge pier. So, an accurate estimation of likely scour depth considering safety and economy is a must. But this is where designers are lagging in the absence of single unifying theory of bridge scour depth. There are large numbers of literature published on the scour around the bridge pier in beds of cohesionless sediments. However, there are many challenges to monitor the depth of scouring at bridge pier. According to previous research, the fiber brag grating (FBG) sensors have been used for in-situ scour monitoring. Moreover, sonar and radar have also been used to estimate the local scour depth at bridge foundations. However, most of the proposed methodologies are complex and lost the cost effect. It is necessary to develop a real-time system to monitor the sour depth of bridge piers in the field.

In this paper, GSM enabled sensors approach by using open source hardware and software, to achieve the real-time bridge scouring safety monitoring is presented. Sensors can monitor the scouring depth at each point. Scouring depth or sedimentation depth of bridge piers can be identified by the time-history diagram. GSM-enabled sensors can report the rapid scouring depths in real-time, which can be used to evaluate the safety of the bridge.

2 LITERATURE REVIEW

A critical review of literature on model and field data was conducted by Breusers (1977), and the empirical data were compared with theoretical considerations. The final result was a set of design suggestions together with possibilities for protection against scour.

The relationship between scour depth at cylindrical bridge piers founded in cohesionless sediments, and mean approach flow velocity is defined for flows above the threshold of particle motion was presented Melville (1984) The work also concluded that contrary to previous findings, the maximum scour depth is found to occur at the transition flat bed condition in the case of ripple forming sands. For non ripple forming sediments, however, the maximum scour depth occurs at threshold condition.

Lagasse et al. (1998) conducted research to develop, test, and evaluate the fixed instrumentation that would be both technically and economically feasible for use in measuring maximum scour depth at bridge piers and abutments. A variety of scour measuring and scour-monitoring methods were tested in the laboratory and in the field, including sounding rods, driven-rod devices, sonic depth finders (fathometers), and buried devices. It was proved that with cooperative efforts with state highway agencies, both systems can be installed with equipment and technical skills normally available to district level department of transportation maintenance and inspection personnel. The report also showcased the installation, operation, and fabrication manuals for the low cost sonic instrument system and magnetic sliding-collar devices.

Kosnik and Steve (2010) investigated a development of a Tiltmeter-Based Bridge Scour Monitoring. Remote communication and robust Internet enabled display technology provided convenient access to both real-time and historical data, enabling quick comparison for decision-making.

Moustakidis et al. (2014) investigated on development of a system for continuous monitoring of scour around bridge piers and abutments using the Radio Frequency Identification (RFID) technology and examine its applicability for estimating scour around a pier or an existing bridge.

Yu-Ting Liu et al. (2010) investigated micro-electro-mechanical system (MEMS) pressure sensors which are integrated with the wireless Zigbee network on a sensor board for real-time bridge scour monitoring. A wireless MEMS scour monitoring system has been developed and tested in the laboratory. This system was used to measure the scouring/deposition process and the variations of water levels at a bridge pier.

3 EXPERIMENTAL DETAILS

The experiments were conducted in a re-circulating flume of 16.58 m length and 0.6 m width with sediment throughout the flume as shown in Figure 1. A pier fabricated from wood was installed 5.5 m off inlet and centrally across the flume. The ratio of the flume width to pier size is 12.76; far enough to avoid constriction scour. The sand used in all the tests was brought from west flowing river Netravati; had median size (d_{50}) = 0.6mm (< 0.7mm), hence falling under the category of ripple forming sand. Sediment layer thickness was 0.1 m throughout the flume. Height gauge manufactured by Mitutoyo Japan having accuracy of ±0.01 mm was used to measure scour depth along with GSM enabled sensors and NXL turbine flow meter to measure discharge. Calculations of hydraulic parameters (discharge, velocity, and slope) were based on the criteria of incipient motion condition so that clear water condition can be achieved in all tests throughout the test duration. The flow depth for all tests was twice the pier diameter to avoid the effect of flow depth on scour. For none of the test, time to equilibrium condition was defined and hence all tests were stopped after 24 hours.

Figure 1. Flume set up just before the experiment start

Figure 2. Photograph showing scour around the pier fitted with collar

In this paper, special focus on incorporating in global computing environments using small GSM enabled sensor devices, controlled by Short Message Service (SMS) were tested. SMS are traditionally used as means for controlling GSM-enabled devices and for logging data regarding their operation. A sensor specific proxy server collects client requests for information and submits them to the sensor. Then, it collects the specified information and makes it available in client-compatible format. The interaction between the proxy server and the mobile sensor is determined by the manufacturer's speciation regarding command sequences for initializing the sensor and for selecting amongst alternative delivery methods and data contents. The sensors and the open source hardware used for the work is shown in Figure 3. Schematic diagram of the setup with sliding pole / protective device is shown in Figure 4. The purpose of this project is to measure the scour depth using ultrasonic sensor and IR sensor. As an addition facility temperature and humidity sensors are also connected. This scour depth is processed by microcontroller and sent to the user over GSM mobile. Flowchart showing flow of data is shown using Figure 5.

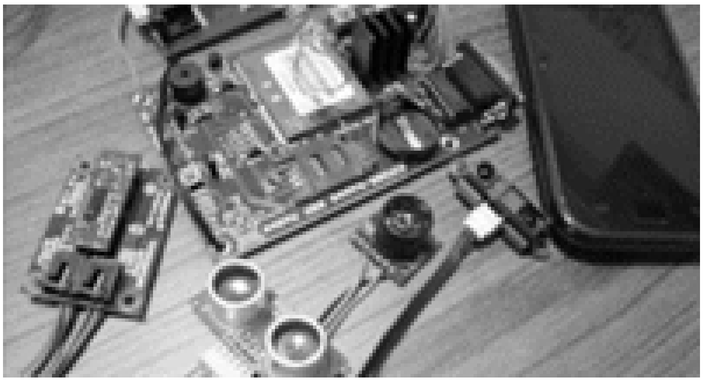

Figure 3. Microcontroller and sensors

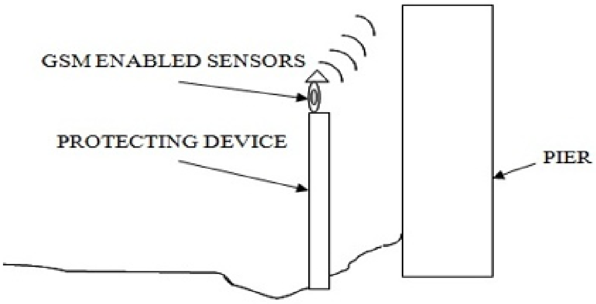

Figure 4. Schematic diagram of the setup with sliding pole / protective device

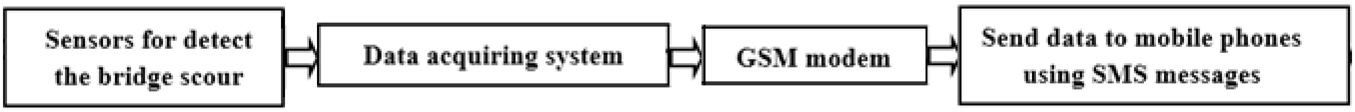

Figure 5. Flow of data

4 RESULTS AND DISCUSSION

A collar of three times the pier diameter was fixed to pier at bed level as shown in Figure 2. Scour in this case is initiated from downstream, slightly away from collar. It touched the collar in the next few minutes and gradually propagated towards upstream and beneath the pier. Even after 24 hrs, scour hole from either side was not able to meet the pier front nose nor able to touch the pier from any side and the maximum scouring in this case found to be 26.97 mm. Figure 6, shows the detailed scour development pattern. The scour development, was significant for initial few minutes. In 24 hrs period, the scour rate dropped from 171 mm/hr to 0.27 mm/hr. In this case, 60% of scour was observed in 16% of the time and 80% of scour in about 50% of the time. Collar reduced nearly half of the scour and complete protection at pier front face. The contour and 3D view of scour area in Figure 6 and Figure 7. shows the position of maximum scour and level surface beyond the scour hole. Similarly Figure 8 and Figure 9, show the scour development on the sides of pier in longitudinal and transverse directions. The maximum scour was exactly on the pier front nose in case of plain pier and that on the downstream side away from pier collar. This is the major advantage of collar. The GSM enabled sensors which continuously monitored the real time scour have clearly demonstrated that the river flow simulated for 24 hrs duration, is insufficient to develop maximum scour threating the bridge safety if 3D collar is fitted to the pier.

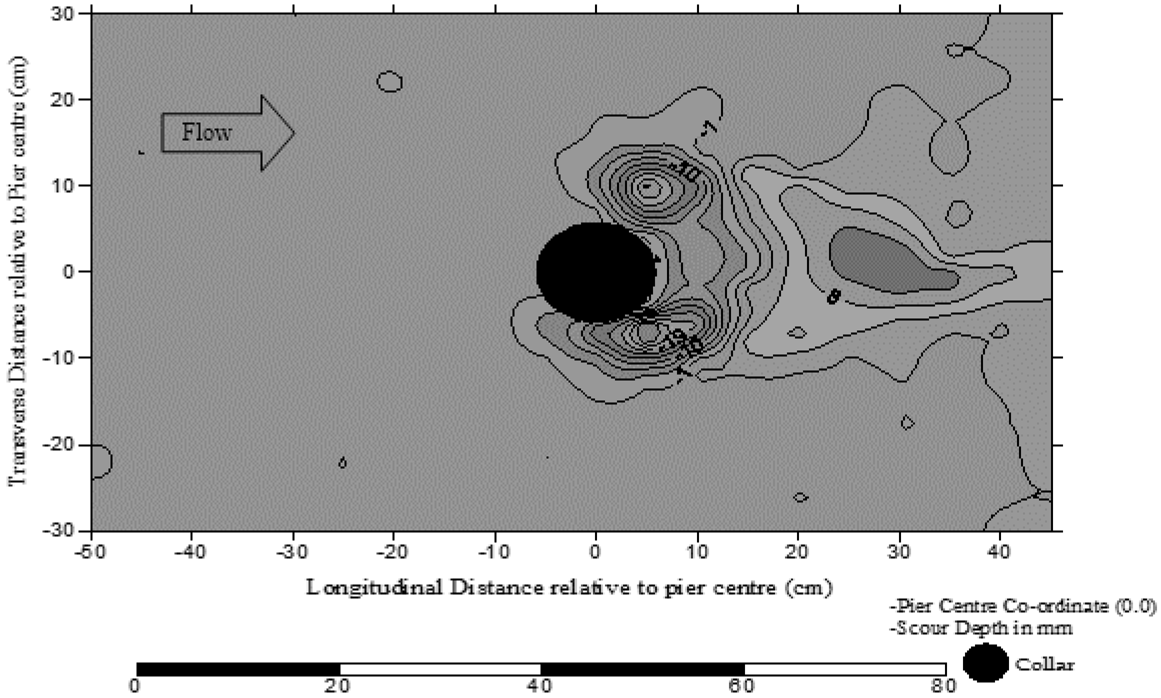

Figure 6. Contour view of scour and its surrounding area for a case of plain pier

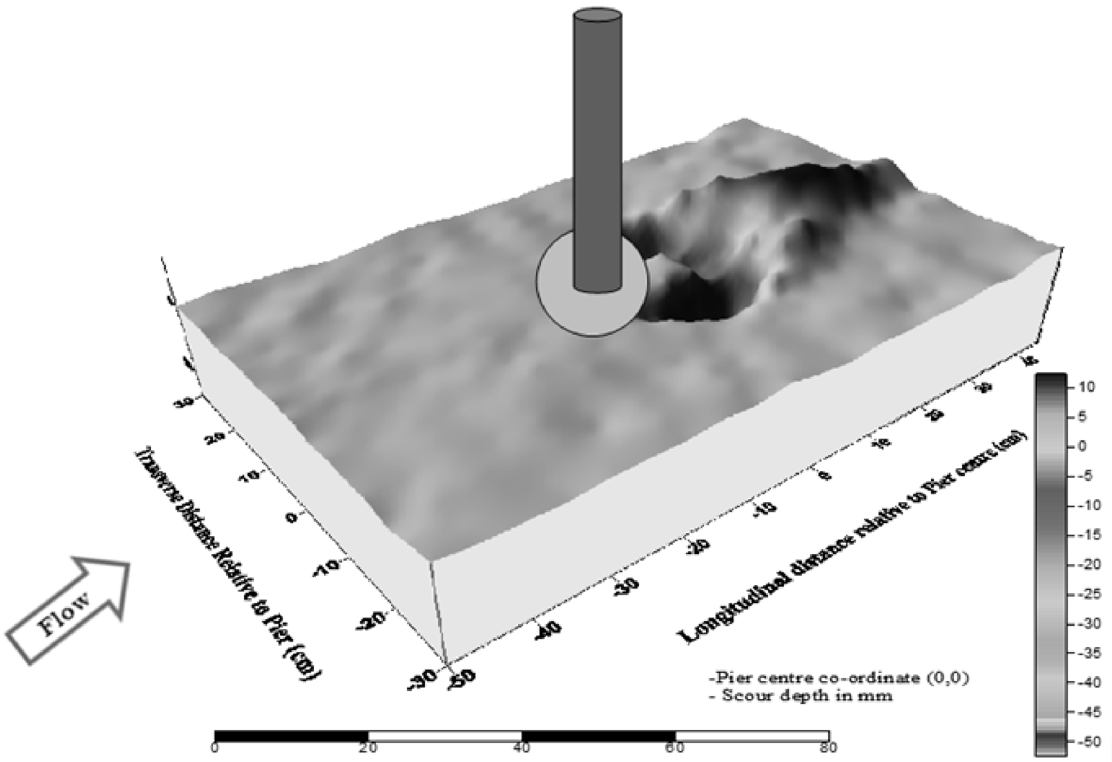

Figure 7. 3D view of scour and its surrounding area for a case of plain pier

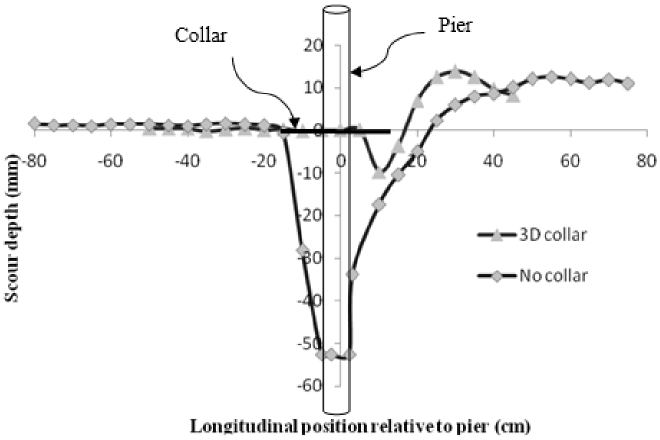

Figure 8. Longitudinal profile of scour hole

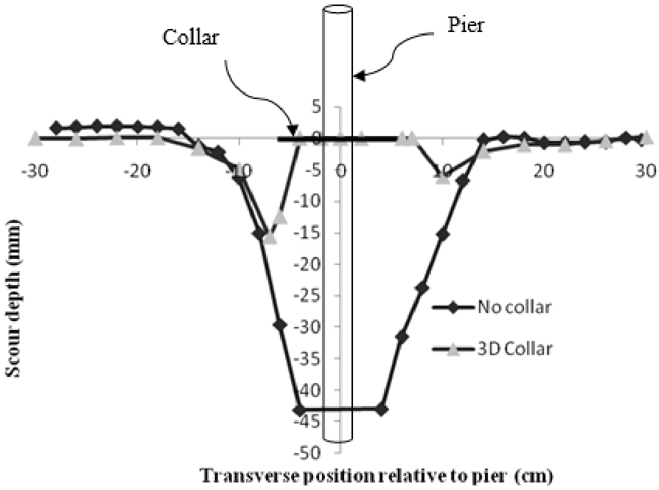

Figure 9. Transverse profile of scour hole

Figure 10. Photograph showing scour around round nosed pier

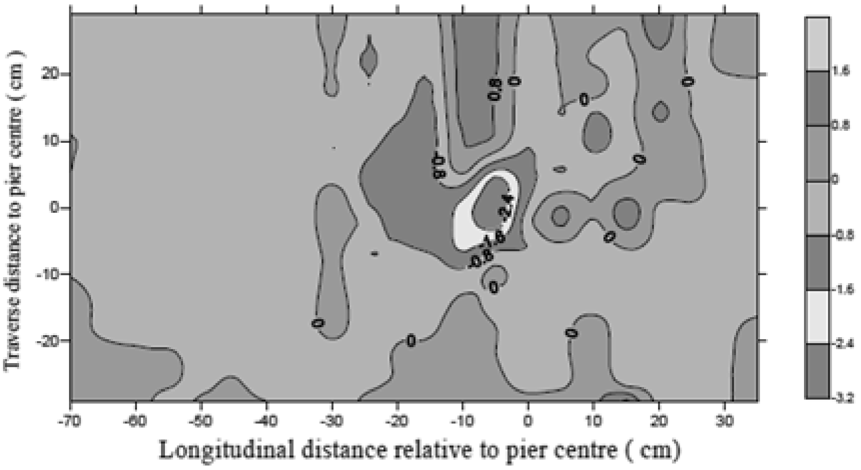

Figure 11. Contour view of scour and its surrounding area for a case of round nosed pier

The sliding pole / protective device with GSM monitoring unit is an useful instrument to measure the total scour depth at bridge pier when an submersible sensors is unavailable. As bridge scour monitoring system, GSM enable sensors has been successfully applied to measure the real time bridge scour in this study. After comparing the result using standard depth measuring hook gauge with GSM scour monitoring unit the maximum variation of scour was found 8 %. Typical photograph after 24 hrs of experimentation, contour and 3D view of scour and its surrounding area for a case of round nosed pier is shown in Figure 10, Figure 11 and Figure 12. The repeatability test conducted for different angle of attack for round nosed pier, demonstrated that highest maximum scour depth occurs for angle of attack of 75º and the lowest maximum scour depth occurs for the angle of attack of 0º.

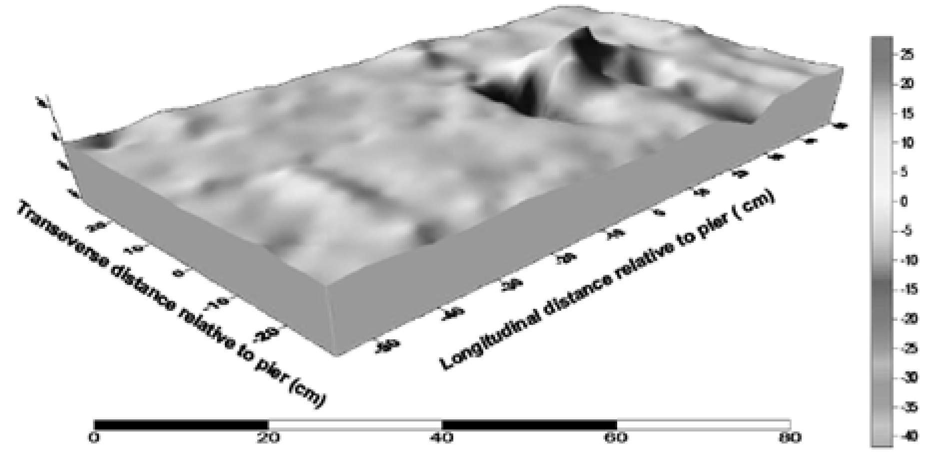

Figure 12. 3D view of scour and its surrounding area for a case of round nose pier

For angle of attack 0, 45º and 75º the maximum scour occurs on the downstream side and for 30º, 60º and 90º the maximum scour occurs on the upstream side. The GSM monitoring sensors can be quickly designed and installed and are cost-effective relative to other hydraulic and structural scour countermeasures. The GSM scour monitoring unit can be used for remote downloading of data and it reduces required field visits to the bridge. It also reduces the number of diving inspections and/or bathymetric surveys. The GSM sensors allows for the development of a prescribed plan of action to guide decision making during a flood event and is appropriate for large bridges and deep water conditions. Remote communication and GSM enabled display technology provide convenient access to both real-time and historical data, enabling quick comparison for decision- making. When the scour crosses a threshold limit the indicators alert the station and thus preventive measures can be taken at that point so as to avoid the catastrophe.

5 CONCLUSIONS

The GSM enabled sensors allow for continuous monitoring of stream bed elevations and scour conditions The GSM monitoring unit were placed at critical point where maximum scour is likely to occur. After comparing the result using GSM Scour monitoring unit with standard point gauge the maximum variation of scour was found to be around 8 %. The GSM based monitoring sensors can be quickly designed and installed and it is cost-effective system. When the scour crosses a threshold limit the indicators alert the station and thus preventive measures can be taken at that point so as to avoid catastrophe. The repeatability test conducted for different angle of attacks for round nosed pier concluded that the highest maximum scour depth occurs for angle of attack of 75ºand the lowest maximum scour depth occurs for the angle of attack of 0º. The advantages of 3D collar fitted on the pier for reducing the effects of local scour was successfully demonstrated by using open source hardware and software GSM enabled sensor fabricated for scour monitoring

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