Monitoring Scour Depth at Bridge Pier by Using MEMS Sensor

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Scour failures tend to occur suddenly without prior warning to the bridge structure. Bridges subject to periods of flood flow require monitoring during those times in order to protect the traveling public. The micro-electro-mechanical systems (MEMS) pressure sensor is integrated with wireless sensor network for monitoring real-time bridge scour depth. The wireless sensors network has been widely used in many fields. A wireless MEMS sensor scour monitoring system has been developed and tested in the laboratory. This scour monitoring system can measure both the processes of scouring and deposition. Experiments have been conducted in the flume to demonstrate the applicability of the system. The study results indicate that this real-time scour monitoring system has the potential for further applications in the field.

Key Words : *MEMS, wireless sensor network, bridge, scour*

1. INTRODUCTION

Scour occurs when the bed materials around the pier footing is eroded, leaving the bridge piers and abutments in an unsafe situation or even in danger of collapse for loss of life. It is well known that scour is one of the major causes for bridge failure. In many East-Asian countries such as Taiwan, Japan, Korea,…etc., serious problems of bridge failure happen due to the fact that these areas are subject to several typhoon flood events each year during the wet seasons. Scour failure tends to occur suddenly and without prior warning or sign of distress to the structures. According to the survey from 1996 to 2001 in Taiwan, there were 68 bridges damaged due to scour damage (Lin et al., 2006). Bridge scour in the river can be caused by general scour, contraction scour or local scour. General scour may occur in a river far from the local structures. It basically occurs due to the entrainment of sediment from the bed. Local scour is generally caused by the interference of the structures with river flow, and it is characterized by the formation of the scour hole at bridge piers. The contraction scour can be caused by a narrowing of the stream channel. Although many studies on local scour around bridge piers have been reported, the measurements of in-situ scour-depth variations during floods are rather limited. A great deal of effort has been dedicated to develop and evaluate scour detection and instrumentation in order to obtain more accurate measurements, especially in-situ data. However, it is not easy to measure or monitor the scour-depth variations at piers in a flood.

A scour-depth monitoring system faces the challenge of establishing a real-time, reliable and robust system, which can be installed in a river bed near the bridge pier. Moreover, it is well known that the established scour formula for estimating the maximum scour depth relates to the flow depth, velocity intensity and sediment size. In practice, the limitations of these scour formula are derived from laboratory data instead of field data. Therefore, this should be addressed before one can apply them to practical design adequately. The recognition of any possible aggradation and degradation of the river-bed level in response to a channel disturbance is important for the prediction of bed variations as the total scour. Besides, the scour process around the pier or abutment is complex due to the three-dimensional flow patterns interacting with sediments (Chang et al., 2004; Oliveto et al., 2005). However, most of the data obtained to develop the scour formula are collected from the laboratory instead of from the field. Thus, it is necessary to develop a real-time system for monitoring and measuring the scour depth in the field. A scour monitoring system at a bridge pier has to face the challenge of complicated and severe flow environments, typically in floods. At bridge piers, scour-depth measurements in the field represent the values of the total scour depth.

In recent years, the wireless sensor networks has developed and emerged with growing interest in civil engineering and industrial applications. The wireless networked sensors can collect and process a vast amount of data for monitoring and control of designed systems. In the present study, wireless MEMS sensors integrated with the Zigbee network are developed and utilized to the real-time measurements in the scour process at a bridge pier in the laboratory. The laboratory data of the water level and scour-depth variations are herein collected and analyzed.

2. MEMS PRESSURE SENSOR

The micro-electro-mechanical system (MEMS) sensor industry has continuously made progress in the past two decade. MEMS devices have been used in a number of commercial applications such as the measurements of pressure and acceleration, projection displays, etc. New applications based on the existing technology of MEMS are promising to improve the flexibility and capability comparing with the conventional devices (Chintalapudi et al., 2006; Wheeler, 2007).

MEMS sensors offer high accuracy at relatively low cost and provide an interface between the mechanical system and the electrical system. In the present study, MEMS pressure sensor was fabricated using a 4 inch double side polished P(100) wafer. The sensor die consists of a thin Si diaphragm fabricated by bulk micromachining. Prior to the micromachining, piezoresistors are patterned across the edges of the diaphragm region using standard IC processing techniques. Etching the substrate to create a diaphragm, the sensor die is bonded to a Pyrex glass substrate to realize a sealed vacuum cavity underneath the diaphragm. The die is used to be mounted on a package such that the top side of the diaphragm is exposed to the environment through a port. The house of the pressure sensor die is filled with silicon oil. To prevent from corrosion or conduction, an indirect stainless foil bonding approach with different thickness is applied to weld onto the bottom of the sensor house using in the fluid field. This pressure sensor is integrated into the Zigbee sensor board for test.

A wireless monitoring system should provide relevant data from the observed structure without the requirement to inspect. The wireless monitoring system with MEMS sensors could reduce system cost and time consume. The data has to be transmitted in a sufficient way to the users. An on-site central unit for data collection and storage in a data log and further to analyze the data from sensor node is needed. The central unit also should allow a calibration and a wireless reprogramming of the sensor nodes to keep the whole system flexible. Choosing the right network topology that best suits the application is an important decision. When data reliability is crucial, mesh architectures provide the best shield against signal degradation and loss of data. Zigbee is a wireless standard based on 802.15.4 that was developed by the Zigbee Alliance. Zigbee supports star, mesh, and cluster-tree network topologies, which uses robust routing algorithm to obtain the best possible route for data transmission from one node to another and remember them.

3. EXPERIMENT AND RESULT

Absolute fluid pressure is measured directly by using MEMS pressure sensor. The MEMS sensor scour monitoring system is developed in the present study to measure total pressure including hydrostatic and dynamic pressures. Test cases include the calibration of the sensors under various pressures, the response under upraised and downfallen water levels, and deposition and scouring processes. When the running water flows towards the pier, pressure will be detected immediately by the sensor.

To measure the water level, two MEMS sensors, namely S1 and S2, are individually mounted in 10 cm interval on the pier in the flume. Another sensor named S3 is installed without influence by sand feeding to measure water level alone. These sensors are connected directly to the Zigbee sensor board to wireless send all the real time measured data to the coordinator for further analysis. The calibration results of establishing the relation of water level and pressure are shown in Figure 1. To mimic the variations of flood stages in the river, rising and falling water levels are controlled by changing the inflow discharge and adjusting the downstream tailgate in the flume. Employing the calibrated relations presented in Figure 1 for sensors S1 (in red) and S2 (in blue), the measured results of the water level variations are plotted in Figure 2 to show the real-time responses.

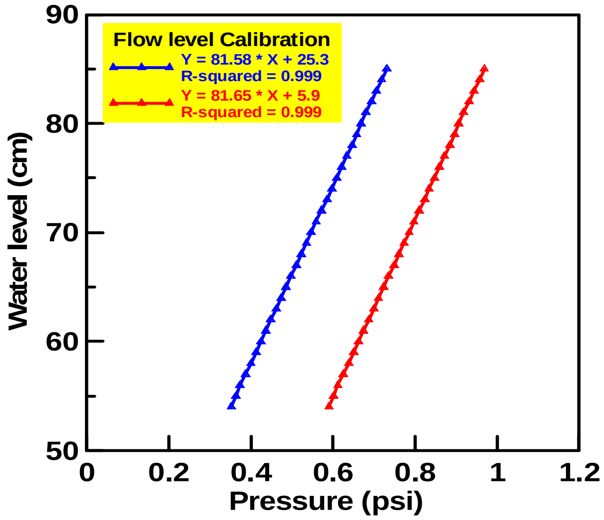

Fig. 1 Calibrated relations of water level and pressure for two MEMS sensors.

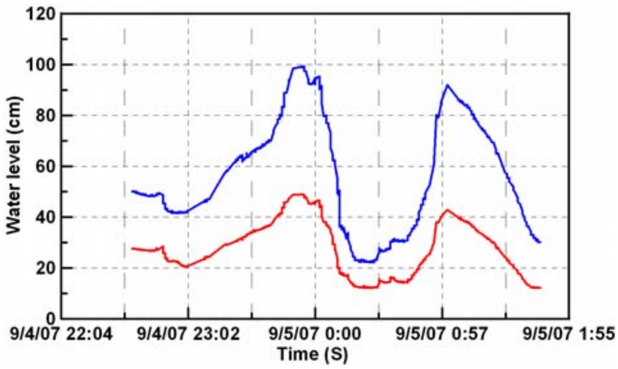

Fig. 2 Measurements of the water level variations displaying real-time responses.

For testing the applicability of the sensors, experiment was conducted in a 12 m-long, 1 m-wide and 1.2 m-deep flume with glass sidewalls at the Hydrotech Research Institute of National Taiwan University, Taipei, Taiwan. The pier was fastened within a recess located at the middle of the flume. The prescribed discharge and its corresponding water depth in the experiment were controlled by adjusting the inlet valve and tailgate. To simulate scouring and deposition of the river bed, sand feeding was operated upstream of the pier in the experimental setup. To start the experiment, the inflow discharge was released upstream of the flume. The real-time records of water level and pressure for sensors S1, S2 and S3 are presented against time in Figures 3 and 4.

When the rushing water reaches the sensor shown in Figure 3, sensor S1 almost immediately responds to the pressure variations. At T1 as recorded in Figures 3 and 4, sensors S1 and S3 have similar trends of responses. At that moment, the flow drops inside the recess and impacts on them directly to create strong fluctuations. After T1, water level reaches sensor S2 and therefore the reading goes up and the water level gradually increases until T2. The trend of rising pressure indicated by sensors S1~S3 shows a similar pattern of water level variations for the period between T1 and T2. By feeding sand at the water surface upstream of the recess in the flume at time T2, the test run tries to mimic the depositional processes. In Figure 3, the noise-like signals from readings of dynamic pressure may be induced by sediment particle movement under flow turbulence condition. During the sand feeding period from T2 to T3, the dynamic pressure values fluctuate but maintain their rising trend. At the end of the sand feeding at T3, accumulative sand deposits have buried sensor S2. From the experimental results, it indicates that the real-time monitoring system presents capable potential for further applications.

4. SUMMARY AND CONCLUSION

The wireless MEMS scour monitoring system using Zigbee sensor network has been developed and tested herein. It is evident that results from the system is much convenient and innovated for real-time scour monitoring. Moreover, this monitoring system not only useful for scouring safety of a bridge, but it also beneficial to integrate the accelerometers onto the single sensor board for bridge health diagnosis. The resistant performance characters under torrential flood on a pier or abutment can be monitored at real-time and at anytime while the event happens. The experimental results indicate that the proposed real-time monitoring system has the potential for further applications in the field.

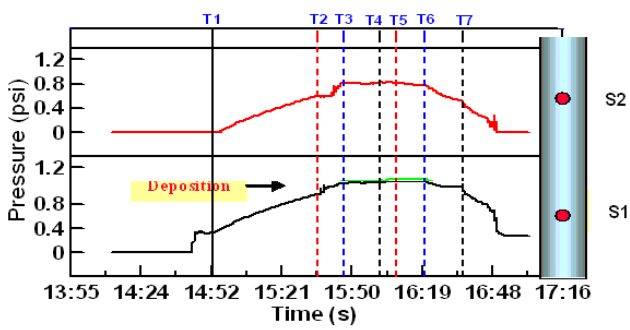

Fig. 3 Real-time responses for the scour and deposition processes by sensors S1 and S2.

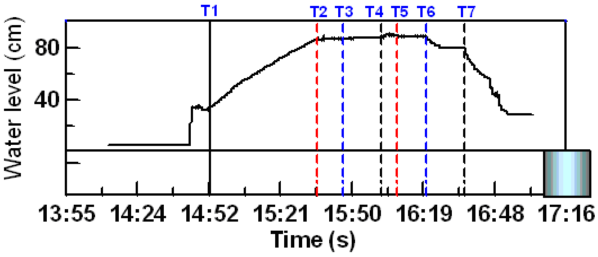

Fig. 4 Real-time responses for water level variations by sensor S3.

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