Experimental Study on an Innovative Bridge Monitoring System

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ABSTRACT

It is essentially important to prevent bridge damages from natural disasters such as typhoon flood, earthquake, etc. Accordingly, the attention on hydraulic caused bridge failure has been received due to scour problems. However, in-situ bridge scour monitoring is still one of the rugged works for researchers in their field applications. It is necessary to ensure that the bridge monitoring system under natural disasters is able to function well. By sending warning signals, the real-time information can provide engineers to make right decision and take appropriate actions in time while the bridge damage happens. This study applied the innovative scour monitoring techniques which have been designed and developed in the laboratory, and been installed and tested in the field. An innovative wireless sensor networks was also employed to construct the bridge monitoring system with varied sensors, including fiber optic sensors and electric sensing units. These sensors were integrated to obtain the information of vibration of the superstructure and scouring at the bridge foundation in this paper. Furthermore, four kinds of scour sensing units were developed and tested in the laboratory for the monitoring of water level and scour depth during typhoon flood. With the monitoring system proposed in this study, the measured data and the related evaluation can be provided to enhance the field bridge safety.

Key words: scour measurement, wireless sensor network, bridge monitoring system

1 BACKGROUND

Due to the distinctive climate and the geographical features in Taiwan, the bridge encounters many problems such as the erosion, overloading, aging, deterioration, so that the structural strength of the bridge may be decreasing gradually. Consequently, the probability of bridge damage is increasing especial in the event of typhoons, earthquakes or floods during large-scale natural disasters which happen more and more often with the global climate change in recent years. In order to maintain the safety of bridges and prevent structural deterioration, for examples, the effect of the river erosion, heavy vehicle overloading, earthquakes and other external forces to the bridge have to be considered with the reliable measured information. This is the main reason why developing a reliable monitoring and warning system for long term monitoring and structural analysis for bridges is very important.

In this study, an integrated monitoring system was developed and installed in the field for verification and test. The field monitoring system can provide the information helping site engineering department to maintain long-term safety and the durability of roads and bridges, assuring the functionality of the transport system during typhoons, floods and earthquakes. By applying wireless sensor network on the monitoring system for the prevention and the mitigation of multiple disasters such as bridge scour and earthquake is an innovative method with high feasibility. The main purpose of this study is to verify the laboratory research result and obtain the feedback from field application. The system proposed in this paper has been installed on in-situ bridges and ready for presently application research. With the experience of the success of this system settled in field, further study could be conducted with acquired field data for scour condition interpretation. More appropriate countermeasures could be carried out to protect the bridge foundation and reduce scour effect.

2 SCOUR MONITORING ISSUES

The accuracy of current calculation of bridge scour evaluation is not enough for reality engineering use. In the general processes for over water bridge design, the cross section of the river at the bridge site does not be measured, and the designer uses high water level evaluated near the construction site as the design cross section, and the maximum discharge per unit width is used as the design basis. Bridge erosion can be divided into two cases: one is the erosion under clear water condition which means the flow velocity near river bed must be less than the threshold velocity of the sediment of the river as the scour depth increased. The other case is the erosion containing the sediment comes from upstream site, which might reduce the scour depth, and the sediment could balance the sediment carried away by flowing water.

Once the bridge foundation scouring effect is getting worse, the flood cross section of the river might be unsatisfied according to the flood control standard and affect the safety of bridge traffic function. The local scour effect is the especially attention problem which will cause the insufficient of bridge foundation depth and endanger the structural safety.

Referring to the mechanism of the scour effect near the bridge foundation, the development of the scouring flow begins on the both sides of the pier then is quickly formed at the upstream along the cylinder with the flow structure intersection in front of the cylindrical pier. Generally, the maximum scour depth occurs in front of the pier and the spiral flow effect with the horseshoe vortex is speeded up due to the downward jet flow, which disturbs the bed material and forms the scour hole. (Fig. 1)

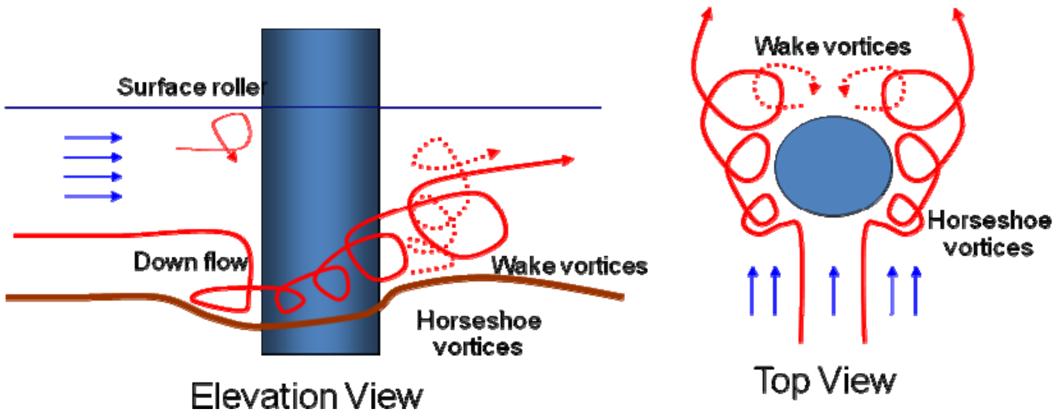

Fig. 1 Scour mechanism near the pier foundation

In general, the reliability and the stability of the bridge long-term safety monitoring and warning system involves the following issues: (1) The selection of sensing units of the monitoring system; (2) The objective of the monitoring parameters; (3) The benchmark study of data analysis algorithm; (4) The hardware installation, sensor calibration and the maintenance work; (5) The interpretation of the measured physical information.

3 PROPOSED MEASURMENT TECHNOLOGIES

With the development trend of wireless technologies, integrating the smart network system and the related hardware on a single silicon chip with varied functions such as sensing, data processing by using wireless communication module is feasible. A bridge monitoring system applying different sensing units to construct wireless personal area network and collect the field data is developed in this study. The operating concept of the system proposed is shown in Figure 2. The real-time scour monitoring system developed with sensing units and the wireless system are introduced separately in the following sections.

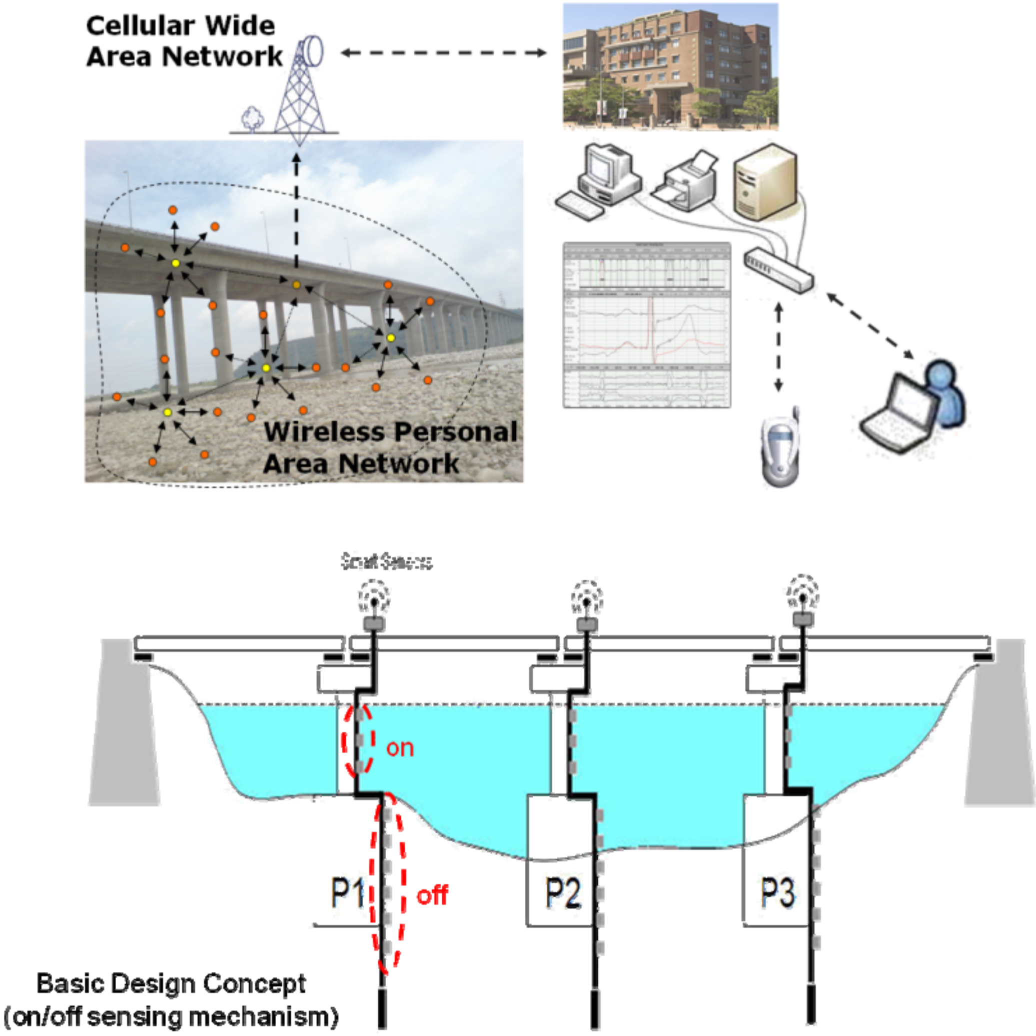

Fig. 2 Schematic diagram and basic concepts of monitoring networks

3.1 Fiber Brag Grating (FBG) sensing technology

An optical fiber sensory system, specifically fiber Bragg grating (FBG) sensors, has been developed and proven to have excellent long-term stability and a high reliability in strain and temperature measurements. According to previous experimental studies by several researchers, it has been demonstrated that the shift of the Bragg wavelength has a linear relationship to the applied strain in the axial direction. However, since only one sensing parameter, wavelength shift, is required in the sensor application, temperature and strain cannot be measured simultaneously with one single grating. To separate the strain signal from the temperature signal, different compensation methods of temperature effects have been reported in the literature.

3.2 Wireless Sensor Network (WSN) technology

The monitoring system introduced in this paper applied the wireless technology named ZigBee to build the sensing network system can be summarized with the following main features: (1) the hardware is easy to install, which can significantly reduce the installation cost generally; (2) high security and reliability of data communication; (3) low hardware cost; (4) low power consumption; (5) high network capacity.

3.3 Commercial Micro Electro Mechanical System (MEMS) sensors

MEMS is defined as an intelligent miniaturized system, including sensing, processing or actuation functions Simply speaking, MEMS-based sensors are composed of both mechanical devices and electrical devices. They are made in wafer fabrication facilities similar to semiconductor foundries. Low-cost, high sensitivity, durability, miniaturization of device and suitability to wireless system are powerful advantages of MEMS technology.

4 DEVELOPED MONITORING SYSTEM

The innovative scour monitoring technology developed in this study combines different sensing mechanisms with varied type sensors, which are MEMS-based pressure sensor and optical FBG strain sensor, integrated into practical sensing unit individually and mounted in the designed robust steel pipe and installed alongside the bridge foundation with the certain monitoring range together. Deploying sensing units at different level along with the bridge caisson or foundation piles, we can expect these sensing units to provide the scour information of each known level. The different sensing units used were described as follows.

4.1 FBG scour sensing units (Fig. 3a)

Comparing to conventional strain resistance gauges, optical fiber sensors have immunity from electromagnetic interference. Besides, FBG sensors are small, lightweight, flexible, stable, and durable in harsh environments and have high temperature tolerance. Field application of bridge scour monitoring by using FBG sensors have been successfully proved feasible. Previous study plastered the FBG strain sensors in the sensing unit based on the concept of piston-button mechanism. This study used a similar mechanism but made the modification on sensing capacity.

4.2 MEMS pressure sensors (Fig. 3b)

MEMS are integrated with mechanical elements, sensors, actuators, and electronics on a common substrate through the utilization of micro fabrication technology. This study also takes the FBG scour sensing units as the frame of reference to apply the MEMS-based pressure sensor. The water level can be measured by MEMS pressure sensors installed in the water. The total pressure measured contains the information of the static water pressure, dynamic water pressure and the soil pressure applied by deposited river sand. Since sensors were buried in the soil and not affected by the dynamic water pressure, the deposition depth can be obtained immediately by real-time water pressure and the lateral soil pressure.

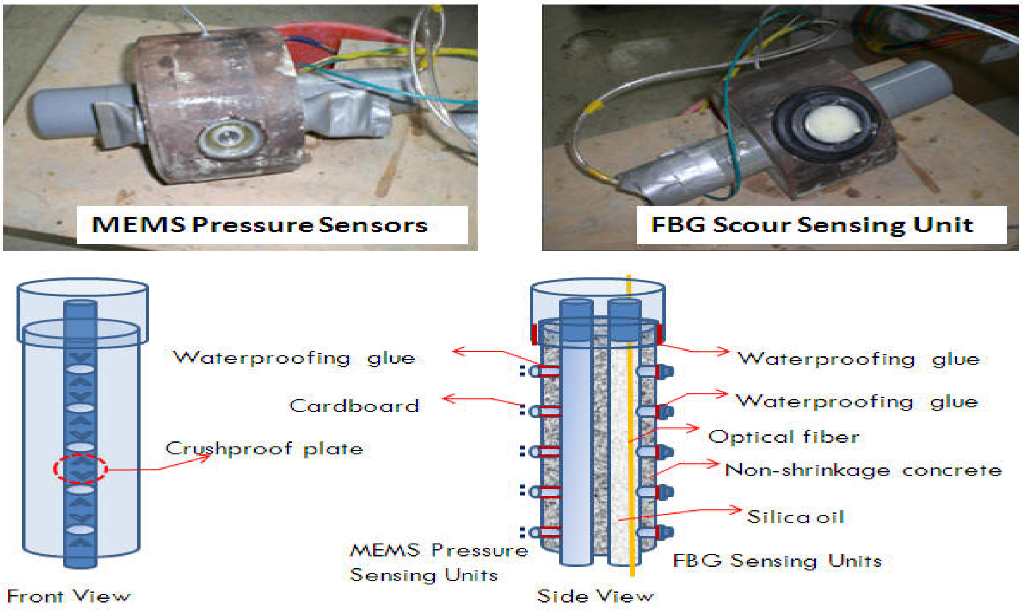

Fig. 3 (a) MEMS pressure sensors (b) FBG scour sensing unit

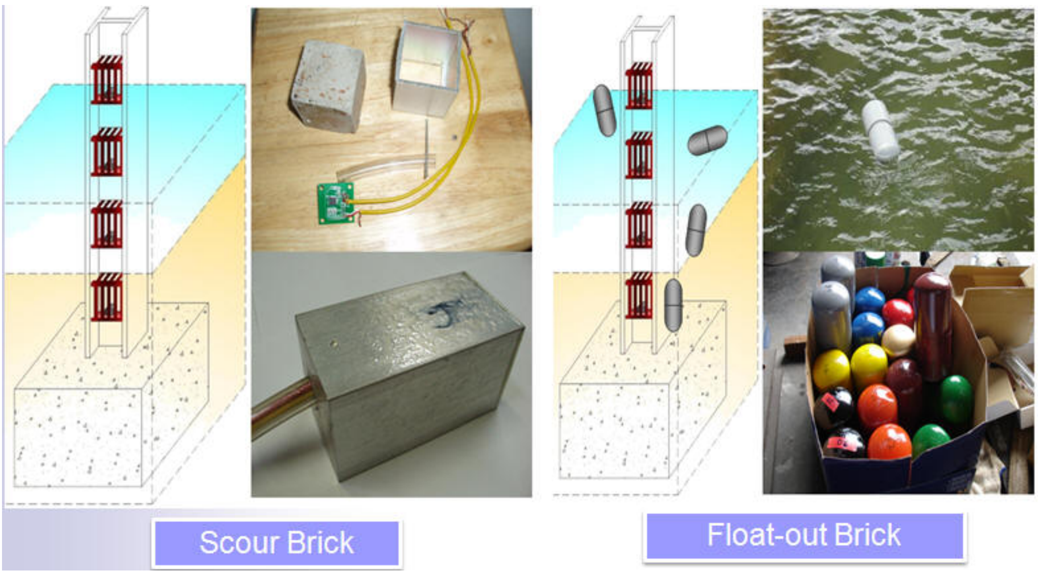

Fig. 4 (a) Scour brick (b) Floating brick

4.3 Wireless scouring bricks (Fig. 4a)

Wireless scouring brick integrated the MEMS accelerometers which is low cost and small in size as the sensing block. When the bricks are scoured out, the accelerometer can measure the vibration generated by flowing water and send the signal back to the monitoring center through the wireless network.

4.4 Wireless floating bricks (Fig. 4b)

Wireless floating brick is an improved RF component, which is a small signal detecting device with radio transmit function. By burying the floating brick near the bridge foundation, no signal will be sent as the brick is at the rest position. The built-in mechanism triggers the body transmitter system and sends the radio packet signals to the receiver while the brick is floating out by scour effect. This method can obtains the scour depth at each section during the time of flood stuck but the floating brick is disposable sensor could be used only one time after the installation.

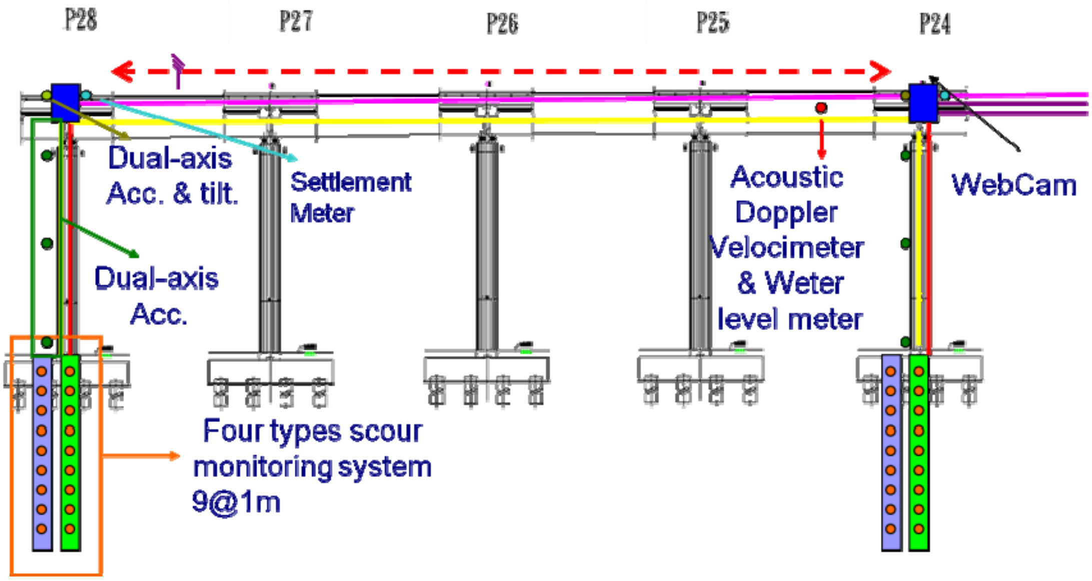

Fig. 5 Bridge monitoring system introduced in this paper

Fig. 6 Regular field maintenance work

The monitoring system with the wireless sensor network technology which integrates a variety of traditional bridge structural sensing equipments was introduced and shown in Figure 5. Moreover, the photos of the regular field maintenance work were showed in Figure 6. The purpose of installing the accelerometer at top, middle and bottom of the pier is to measure the vibration signal as the database for the system identification of the structure and the analysis for the relationship between the vibration of the bridge and the scour depth under certain flow condition. The tilt meters and the settlement gauges were used to monitor the structural state of the bridge, expecting to detect the unstable phenomenon and the status of structure before bridge collapse. The flow meter and the water level gauge were also included in the monitoring system introduced. The data measured can be regarded as the feedback from the field application to verify the hydraulic model. Moreover, the night-type camera installed can take the picture and the video of river bed conditions and the changes of water level.

5 CONCLUSIONS

Monitoring bridge scour is absolutely crucial for prior warning or signs of distress of bridge structures. However, bridge scour monitoring is still one of the rugged works in-situ application for researchers. This study applied the innovative scour monitoring techniques which have been designed and developed in laboratory as well as field bridge sites. To ensure the bridge structural function and reduce the probability of bridge collapse during the heavy rain or flood events are the main objectives in this study. In order to measure the real-time scour depth near bridge foundation, this paper introduced various kinds of scour sensing units including the optical fiber sensor, the MEMS pressure sensor, the wireless scouring brick and the wireless floating brick. Sensing units at different level along with the bridge caisson or foundation piles are installed to provide the scour information at each known level. Moreover, potential problems would be faced in-situ application and should be overcome in the ongoing studies, such as the installation methods, machines and procedures used in field, the long-term durability of sensing units, the signal interpretation of field data and the stability of the data transmit system. With the experience of the success of this system settled in field, further study could be conducted with acquired field data for scour condition interpretation. More appropriate countermeasures to protect the bridge foundation and reduce scour effect could be drawn up as well.

REFERENCES

1. Bruce, W. M., and Stephen, E. C., (2000), Bridge Scour, Water Resource Publications, LLC., U.S.A.
2. Chang, W. Y., Lai, J. S. and Yen, C. L., (2004), “Evolution of scour depth at circular bridge piers”, Journal of hydraulic engineering, Vol. 130, No. 9, 905-913.
3. Daugherty, R. L., Franzini, J. B. and Finnemore, E. J., (1989). Fluid mechanics with engineering application, McGraw-Hill Book Co., Singapore.
4. Falco, F. D. and Mele, R., (2002), “The monitoring of bridge for scour by sonar and

sedimetri”, NDT&E International, Vol. 35, 117-123.

5. Lin, Y. B., Chen, C. C., Chang, K. C., Chern, J. C. and Lai, J. S., 2005, Real-time monitoring of local scour by using fiber bragg grating sensors, Smart Materials and Structures, 14, 664-670.
6. Lin, Y.B., Lai, J. S., Chang, K. C. and Li, L.S., 2006, Flood scour monitoring system using fiber brag optical fiber sensors, Smart Material and Structures, 15, 1950-1959.
7. Mia, M. F. and Nago, H., (2003), “Design method of time-dependent local scour at circular bridge pier”, Journal of hydraulic engineering, Vol. 129, No. 6, 420-426.
8. Millard, S. G.., Bungey, J. H., Thomas, C., Soutsos, M. N., Shaw, M. R. and Patterson, A., (1998), “Assessing bridge pier scour by radar”, NDT & E International, Vol. 31, No. 4, 251-258.
9. Oliveto, G. and Hanger, W. H., (2002), “Temporal evolution of clear-water pier and abutment scour”, Journal of hydraulic engineering, Vol. 128, No. 9, 811-820.
10. Reddy, D. R., (2006), “Bridge scour detection”, Proceedings of National Conference on Advanced in Bridge Engineering (ABE), March 24-25.
11. W. Y. Chang, J. S. Lai and C. L. Yen, “Evolution of scour depth at circular bridge piers”, Journal of Hydraulic Engineering, v 130, n 9 (2004) 905-913
12. Yankielun, N. E. and Zabilansky, L., (1999), “Laboratory investigation of time-domain reflectometry system for monitoring bridge scour”, Journal of hydraulic engineering, Vol. 125, No. 12, 1279-1284.