Applications of Optical Fiber Sensor on Local Scour Monitoring

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Abstract

Scour is one of the major causes for bridge failure. A real-time optical fiber sensory system for bridge scour, using fiber Bragg grating (FBG) sensors, has been developed and tested. These optical fiber sensors, especially the FBG scour-monitoring system, can measure both the process of scouring and the variation of water level change. Several test runs have been conducted in the laboratory and in-site bridge to demonstrate the applicability of the FBG system. The results have shown that the system has the potential to be applied in the field to a real-time monitoring application for bridge scouring.

Keywords

FBG, scour, bridge, monitor

1. INTRODUCTION

It is well known that scour is one of the major causes for bridge failure[1-21]. When scouring occurs, the foundation material below the pier footing erodes, leaving the infrastructure such as bridge piers and abutments in an unsafe condition, and in danger of collapse, with the distinct possibility for loss of life. More than 1000 bridges have collapsed over the past 30 years in the U.S.A., with 60% of the failures due to scour[1]. This problem also represents a serious burden for East-Asian countries such as Taiwan, Japan, Korea…etc., owing to the fact that the area is subject to many typhoons and floods each year during the summer and fall season. Scour failures tend to occur suddenly and without prior warning or sign of distress to the structures. The nature of the failure is often the complete collapse of an entire section of a bridge. There were 68 bridges damaged due to scour damage in Taiwan, from 1996 to 2001[2]. Scour to a bridge crossing a river can be caused by general scour, contraction scour, or local scour. Among these, local scour is the more critical, and is generally caused by the interference of piers and abutments with the flow of the river, and is characterized by the formation of scour holes at bridge piers or abutments. Much time, money and efforts has been dedicated to the development and evaluation of scour detection and instrumentation to measure it. However, the depth of scouring at piers is not that easy to measure or monitor, especially, during a flood.

There are many equations and methods for measuring and monitoring, such as sonar, radar, and time-domain reflectometry (TDR) to estimate or predict the local scour depth of bridge foundations[3-21]. However, most of these available techniques have only a limited application. For example, both sonar and radar are easy to install, but the results are difficult to interpret, especially when the water flow is full of mud and debris or rocks during a flood. In addition, the noise caused by the turbidity of the flow will make these systems unusable for real-time monitoring of local scouring during a flood. Radar and sonar are usually applied after the scouring event, and only indicate the final status of the sedimentation surrounding a pier[3-5]. However, the actual scouring depth that occurred during a flood is much more important to the safety of the bridge. The TDR technique operates by generating an electromagnetic pulse and coupling it to a transmission line or cable[6-7]. The response signal changes if there is any variation in the current or potential. However, as the cables are often several hundreds of meters in length, attenuation and pulse disperses the TDR signal. This drawback reduces the ability to detect subtle scour changes. In addition, the electromagnetic environment also affects the results. A piezoelectric sensor, consisting of a series of spatially separated piezo films provides incremental spatial resolution to track the entire scour cycle[8]. However, this is a delicate set-up, and susceptible to damage by the muddy waters, and the debris in the flood waters.

The scour depth monitoring system therefore faces the challenge of developing a real-time, reliable and robust system, that can be installed in a riverbed during a flood. Moreover, the use of any scour formula must ensure that the expressions are relevant to the characteristics of the location involved, including the flows, the channel parameters of the river, and the sediment of the site. The limits of use, assumptions, and inadequacies of the formula should be established prior to the estimation equations being applied. The recognition of any possible aggradation and degradation of the riverbed level in response to a disturbance to the channels is important in the prediction of channel changes.

In this paper, novel FBG monitoring system is developed and utilized to real-time measure the process of the scour. The laboratory demonstrations of flow level, scouring depth and the deposited height of the sediment are presented in this study.

2. EXPERIMENTAL SETUP AND TEST RESULTS

Two local scour monitoring systems were developed in this study. The FBG monitoring system of model I, as shown in Fig. 1, uses the cantilever mechanism to measure the local scour depth incurred during a flood. Three FBG sensors, each with a different wavelength, are surface mounted on a cantilevered beam,and in this test are arranged in series along a single optical fiber. Similar to model I, FBG sensors are also arranged in series along a single optical fiber in Model II, but the FBG sensors are mounted on cantilevered plates like a flag inside a hollow chamber which are located at a different depth along a steel pile that can be fixed to the pier or the abutment as shown in Fig. 2. It must be noted that all the FBG sensors of model I and model II are carefully packaged to protect the sensors from any flow damage during the test. Three items are tested, the current level of the flow, the local scour depth, and the height of the riverbed sediment after a flood. When the current flows towards the cantilevered beam in Model I, a deformation strain will be generated by the bending moment, and this strain will be detected directly by the FBG sensors, as shown in Fig.1, when the FBG sensor emerges from the sediment during the flood erosion. The scour depth will be obtained directly from the responses of the different FBG wavelengths.

From the test results of model I, the local scour depth can be observed directly from the maximum strain of its corresponding FBG sensors. For example, as shown in Fig. 3, the FBG_1 has the largest bending moment strain among the FBG sensors, since only FBG_1 emerges from the sediment. It is obvious that the scour depth is the greatest at the location of FBG_1. As the current flow continues its erosion, the strain of FBG_2 and FBG_3 will gradually emerge in turns and show the maximum response, as illustrated in figures 4 and 5. Note that the response of the scour depth is real-time monitored by the FBG sensors in this test. During the test sine-wave-like noises were detected that were induced by the vibration of the cantilever. This vibration correlated with the variation in characteristics of the fluid, which was depending upon the presence of suspended soil particles, air bubbles and fluid turbulence and/or the eddying current.

The scour monitoring system, Model II, is settled in the sink to measure the flow levels, sediment situation, and scour depth. When the water flows towards the cantilevered plate, the FBG sensor will make contact and respond first to the water temperature, as shown in Fig. 6. The water temperature measures 0.025nm, which corresponds to about 2^{o}C difference from the ambient temperature[2]. The wavelength then shifts to the impact of the running water with the cantilevered plate which forces the plate to bend, which in turn will generate a bending strain. The flow level of running water can be obtained directly from the wavelength shifts of the FBG sensor as shown in Fig. 6. As is well known, the friction of the particles in the basin affects the current velocity of the running water. Fig. 7 not only reveals the levels of running water in real-time but it also shows the effects of the friction and the response of the current flow velocity at each current layer. These results regarding the velocity and the acting strain correlate with the fluctuating flow rate and can be useful for real-time calibration and to evaluate the flooding potential in a flood.

For the scouring test, the FBG sensor is affected by, and responds first to the temperature of the water as mentioned earlier. The response to the temperature of the water shifts the wavelength of the FBG sensor approximate 0.02 nm ,which corresponds to $1\sim2^{o}$C , as shown in Fig 8. As the flow gradually submerges and impacts upon the FBG sensor element. In case_1, the bending moment of the cantilevered plate will be induced by the current flow and indicate the height of the flow as shown in Fig. 8. At about the 150th second in the time line of the test, to simulate the riverbed sediment process, fine sand is poured in the path of the sink in case_2 and case_3. In this study, in case_2, vibration–noise-like signals are induced by the muddy drift, and turbulence of the fluid, as mentioned in model I. It is also observed that the friction reaction of the flow increases with the response of the wavelength shifts as the sediment rises. The steady-state flow force acting on the cantilevered plate decreases as the sand is being poured continuously into the sink. With the sand continuously being poured into the sink and settling, the cantilevered plate will be covered since no other forces are acting on the unit, as shown in case_3 of Fig. 8. This then indicates the deposited height of the sediment after a flood. Case_4 simulates and shows the scouring process during a flood as illustrated in Fig. 8. The signal resembles the process of flow level measurement as in case_1, since the cantilevered plate will emerge from the deposited sediment and reveal the scouring depth during a flood.

For field test, FBG scour monitoring system is installed on the Da-Du bridge, Taithung, Taiwan (Fig. 9). I-Li typhoon attacked Taiwan from August 24 to 31, 2004. Fig. 10 shows real time flow level attacked the bridge during the flood. The real time scour depth is also obtained as shown in Fig. 11.

3. DISCUSSION AND SUMMARY

Scour is one of the major causes for bridge failure. Scour failures tend to occur suddenly and without prior warning or sign of distress to the structures. Moreover, the pits created by the erosion tend to fill as soon as the flood begins to decrease, and the following inspections and measurements in the periods of dry weather or after a flood, are unable to furnish indications on the real and maximum scour depths created by the erosion during a flood. The nature of the failure is mostly a catastrophic one, a complete collapse of the entire bridge. The scour problem presents a particularly serious problem for Taiwan since the island is subject to typhoons and floods during most of the summer and fall months

The real-time monitoring systems for bridge scour, using fiber Bragg grating (FBG) sensors, have been developed and tested. This novel FBG scour-monitoring system can measure both the process of scouring and the variation in water level. Several testing runs in the laboratory and field bridge were conducted to demonstrate the applicability of the FBG system. The results have shown that the system has the potential to be applied in the field to a real-time monitoring application for bridge scouring. However, the installation procedures, as well as the packaging of the FBG scour monitoring system, to protect it from being damaged by the huge impact forces of the water flow during a flood, usually filled with drift, stones and various debris, requires further improvement and study.

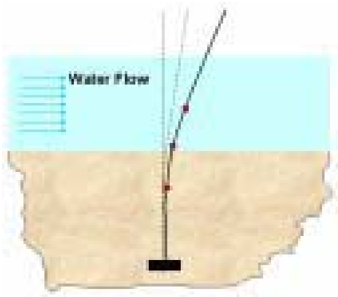

Fig. 1 The FBG scour monitoring system --Model I

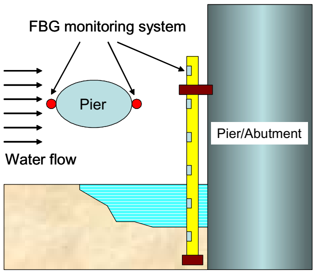

Fig. 2 The FBG scour monitoring system --Model II

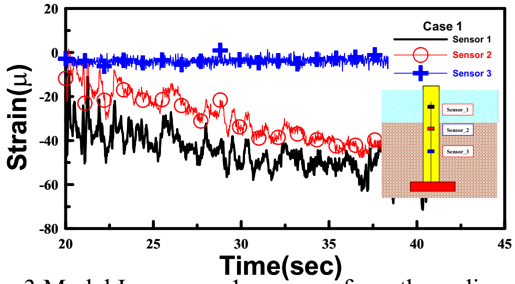

Fig. 3 Model I-- sensor_1 emerges from the sediment

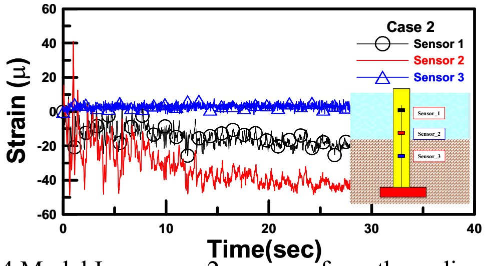

Fig. 4 Model I-- sensor_2 emerges from the sediment

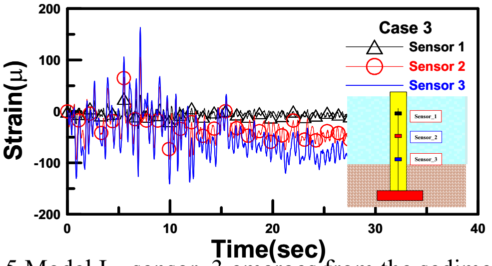

Fig. 5 Model I-- sensor_3 emerges from the sediment

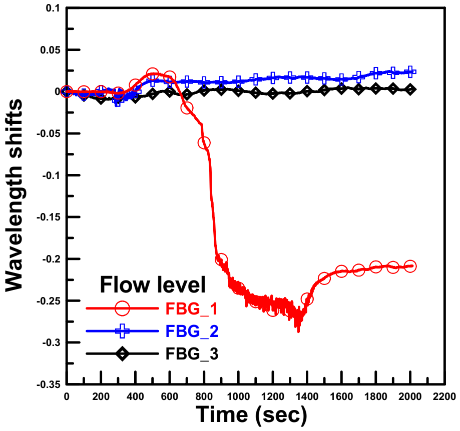

Fig.6 Test results of flow level __Model-II

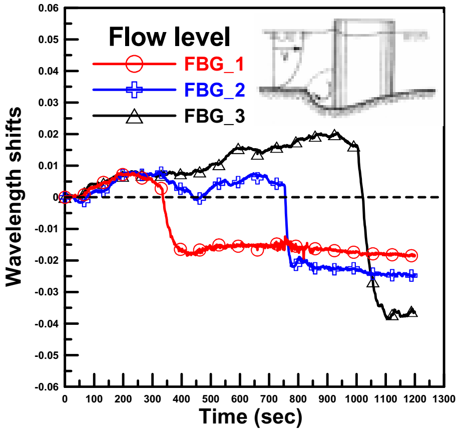

Fig.7 Test results of flow level __Model-II-case2

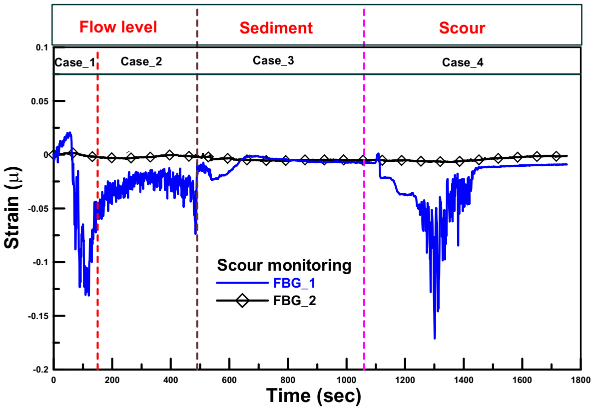

Fig. 8 Scouring test of Model II

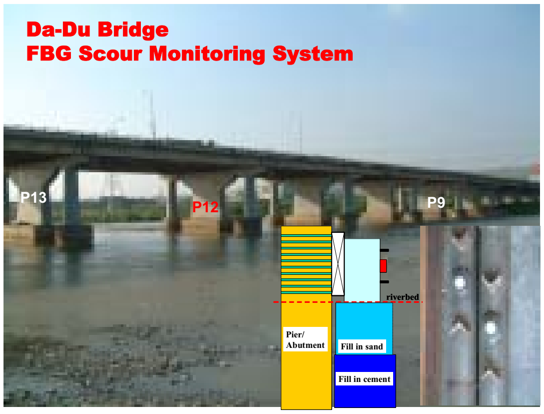

Fig. 9 Installation of in-site bridge scour monitoring

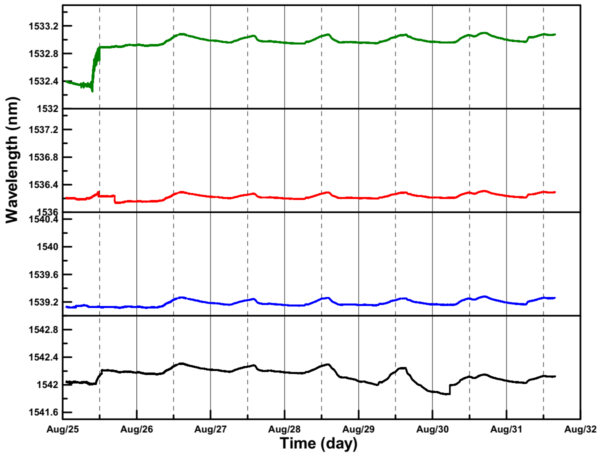

Fig.10 Flow level monitoring during I-Li typhoon flood

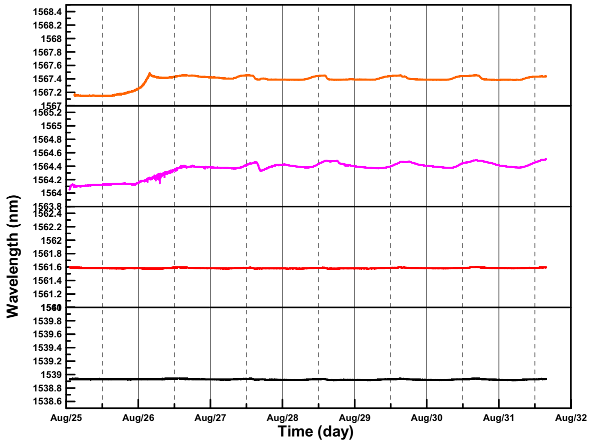

Fig. 11 Scour monitoring during I-Li typhoon flood

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