Establishment the Bridge Scour Safety Monitoring System by Using Fiber Bragg Grating Sensors

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Abstract

Taiwan is located in the rim of the Pacific Ocean. The activities of the earthquake happen frequently, which threaten the safety of the bridge in the Taiwan Island. Besides, the severe floods resulted from the typhoon or storm events can cause great damages due to the bridge scouring. The steep-sloped rivers and sand mining problems in Taiwan accelerate the degradation of the riverbed. Scouring at a bridge pier in the river can be caused by general scour, contraction scour or local scour. Among them, local scour is the most critical and generally caused by the interference of the structures with river flow. In the present study, it is shown that the FBG sensors have demonstrated the capability to measure the water level, scour depth and deposition height at the Dadu Bridge. The field results indicate that the real-time monitoring system using FBG sensors have the potential for real world applications.

Keywords: earthquake, bridge scour, monitor, fiber Bragg grating sensor.

Introduction

According to statistic data from the report of the Transportation Department, there are around 20,000 bridges built and operated in Taiwan. Due to lack of the sufficient budget, management and maintenance the existing bridges face extreme difficulties in scouring, overloading, aging, etc. There were 13 bridges inspected in dangerous conditions from a general safety survey in 1990. These bridges include Shan-yung, Peng-tang and Chung-zen bridges in the Keelung city; Kung-ming, Phone-hung and Lu-ching bridges in the Taichung county; Tung-hu and Min-chan bridges in the Hua-lan county; Tan-lu and Chu-Pha bridges in the Tainan city; Chi-shan-lu bridge in the Tainan county; Yang-lui bridge in the Shinchu county; and Chun-I bridge in the Taitang county.

The Transportation Department has inspected 7,580 bridges since the failure of the Kaopeng Bridge happened in 1990. It is well known that scour is one of the major causes for bridge failure[1-21]. When scouring occurs, the bed materials around the pier footing can be eroded, 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 serious problem also happens in many East-Asian countries such as Taiwan, Japan, Korea…etc., owing to the fact that these areas are subject to several typhoon and flood events each year during the summer and fall seasons. Scour failure tends to occur suddenly and without prior warning or sign of distress to the structures. The nature of the failure is usually defined as the complete collapse of an entire section of a bridge. Scouring at a bridge pier in the river can be caused by general scour, contraction scour or local scour. Among them, local scour is the most critical and 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 or abutments. A great deal of time, money and efforts have been dedicated to the development and evaluation of scour detection and instrumentation in order to obtain more accurate measurements. However, it is not easy to measure or monitor the depth variations of scouring at piers, especially in a flood.

Many methodologies and instruments have been carried out for measuring and monitoring, such as

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sonar, radar, and time-domain reflectometry (TDR) to estimate or predict the local scour depth at bridge foundations. However, most of these available techniques have limited applications. For example, both sonar and radar are easy to install, but the results are difficult to interpret, especially when the running water contains high concentration sediments, debris or rocks in a flooded river. In addition, the noise caused by the turbidity of the flow will make those systems unreliable for real-time monitoring of the scouring processes. Therefore, radar and sonar are usually good for applications after flood, and the data of scour depth measured can mainly indicate the final status of the degredation/aggregation surrounding the bridge pier. However, instead of the final scour depth after flood, the actual-deepest scour depth (ie. maximum scour depth during flood) is much more important to the safety of the bridge structure, which generally occurs near the peak flood discharge.

Therefore, the local scour depth monitoring system faces the challenge of developing a real-time, reliable and robust system, which can be installed in a river bed near the bridge pier or abutment. Moreover, it is well known that the established scour formula for estimating the maximum scour depth relate to the characteristics, including the flow depth, velocity and sediment size. In practice, the limitations of these scour formula should be addressed before one can apply them 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 channel bed variations. Besides, the scour process around the pier or abutment is essentially complex due to the three-dimensional flow patterns interacting with sediments. 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.

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. In order to fulfill the monitoring needs of a large structure, an optical fiber sensory system can provide many sensor locations together with minimum processing requirements. Civil structures must resist environmental and in-service loads such as wind, earthquake, traffic, thermal effects, etc. It has been demonstrated that an intelligent sensory system coping with optical fiber sensors is highly effective in monitoring the dynamic responses of structures under the abovementioned external loads.

Fiber Bragg Grating Sensor

Fiber Bragg grating (FBG) sensors are highly attractive since their inherent wavelength response and their multiplexing capability for the distributive sensing network. FBG sensors are absolute, linear in response, as well as interrupt immune and of low insertion loss so that they can be multiplexed in a series of arrays along a single optical fiber. Furthermore, FBG sensors are developed for quasi-distributed or multi-point strain monitoring in both surface mounted and embedded sensing applications to provide local damage detection.

As well known, the Bragg phase-matching condition[1] determines the Bragg wavelength, λ_B, of a fiber grating. The wavelength shift $\Delta\lambda_B$ of a fiber Bragg grating sensor subjected to physical disturbance can be expressed as

$$\frac{\Delta\lambda_B}{\lambda_B} = (1 - p_e)\varepsilon + (\alpha + \xi)\Delta\mathrm{T}$$

in which P_e, ε, α, ξ, and $\Delta\mathrm{T}$ is the effective photoelastic constant, axial strain, thermal expansion coefficient, thermal optic coefficient, and temperature shifts, respectively. These coefficients generally depend on the type of optical fibers and the wavelengths at which they are written and measured. However, in sensor applications, the wavelength shifts induced by the variations of the doped materials in optical fiber can be treated as constants, compared to structure strain, because the measurements of the fractional Bragg wavelength variation induced by the different doped materials is small.

Scour Monitoring for Da-Du Bridge in Aery Typhoon

Figure 1 shows the installation location of the FBG monitoring system in the Dadu Bridge. The distance between each sensor is one meter. The top sensor was installed one meter above the riverbed. The water flow condition in the Aery flood event is presented in Figure 2. The measured data of the scouring processes from FBG sensors are shown in the Figure 3. As shown in the Figure 7, there are two signals emerging to show the fluctuations.

The top signal presents the water flow impact on the sensor, and the second signal shows the scouring processes after the sensor emerges. Based on the data recorded in the second time-series data of the Figure 3, it indicates that there is about one meter scour-depth created in this flood event. After the Aery flood, as shown in Figure 4 debris is trapped in front of the bridge piers. It has been proven that the FBG monitoring system can function well through the severe flood.

Conclusions

Scouring at a bridge pier in the river can be caused by general scour, contraction scour or local scour. Among them, local scour is the most critical and generally caused by the interference of the structures with river flow, which is one of the major causes for bridge failure. Without prior warning or sign of distress to the structures, scour failure tends to occur suddenly. A great deal of efforts has been dedicated to the development and evaluation of scour detection and instrumentation in order to obtain more accurate measurements. Essentially, it is important to measure or monitor the depth variations of scouring at piers in a flood.

In the present study, it is shown that the FBG systems have demonstrated the capability to measure the water level, scour depth and deposition height. The field results indicate that the real-time monitoring system using FBG sensors has the potential for real world applications. However, to protect it from being damaged by the huge impact forces of the high-velocity flood with drifting debris and sediments, the installation procedures as well as the packaging of the FBG scour monitoring system require careful designs for more practical engineering purposes.

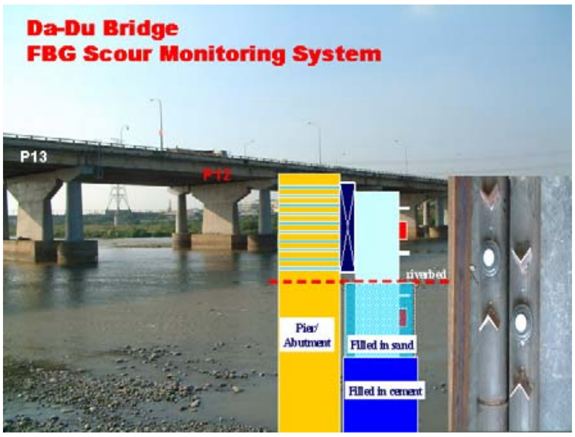

Figure 1 Installation of the FBG monitoring system in the Dadu Bridge

Figure 2 Water condition in the Aery flood

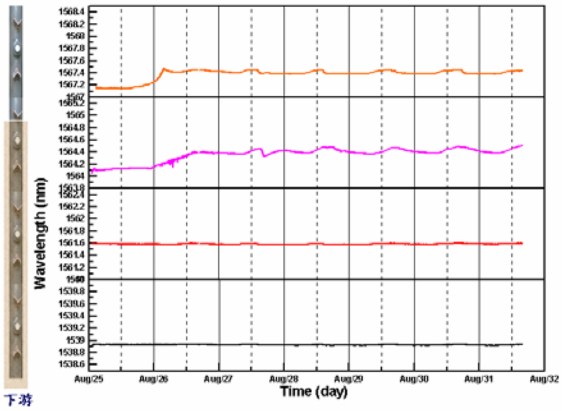

Figure 3 The measured data of the scouring processes from FBG sensors

Figure 4 Debris trapped in front of the bridge piers

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