Bridge Scour Monitoring using Fiber Bragg Grating Sensors

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ABSTRACT: Bridge scour has attracted enormous attention due to its catastrophic influence on bridge safety. In order to measure and monitor scour depth variations including deposition process, a scour monitoring system was developed. An instrument with fiber Bragg grating (FBG) sensors was designed together with a reliable sensor protection measure. After being tested in the laboratory, the proposed system was applied on a field bridge with a critical scour history. The measured sensor responses have verified the functionality and the estimated scour depths based on the sensor data until now match qualitatively well with the actual scour depths observed on the bridge site.

Test Structure and Measured Data

The studied bridge is located in Louisiana crossing over the Redwood Creek on LA Highway 67. This bridge, built in 1965 with a length of 91.44 m (300 ft), consists of twelve spans supported by concrete pile bents, as shown in Fig.1. The Redwood Creek in the vicinity of the bridge site is a medium (30 to 150m wide) sinuous stream with a perennial flow habit. The channel boundaries are alluvial, and the floodplain is wide (greater than ten times of the channel width). After the bridge was built, the time history of the ground line change was recorded based on the site visit as shown in Fig. 2. The record shows a general trend of channel degradation at Bents 2, 3, 4, and 5, and a general trend of channel aggradation at Bents 9, 10, and 11. The maximum scour of the bridge occurred at Bent 5, approximately 4.11 m (13.5 ft).

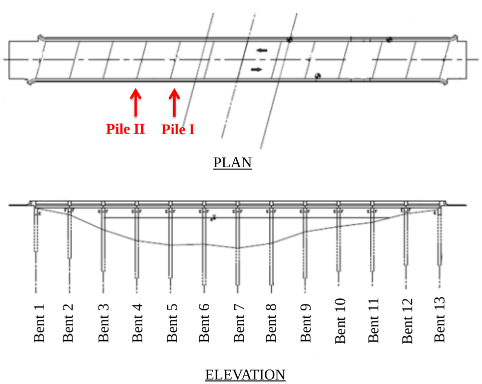

Fig. 1. Bridge layout

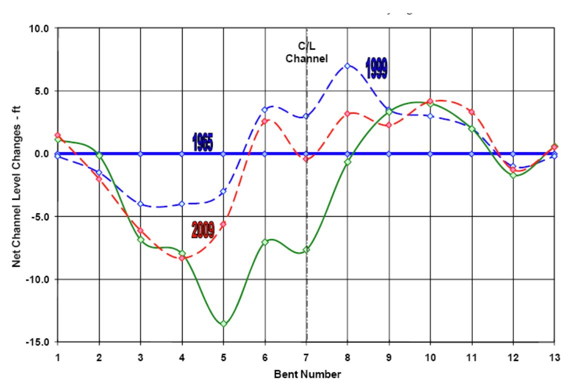

Fig. 2. Pattern of ground line change

SHM Methodology and Results

Although FBG sensors have already demonstrated their advantages and applicability in many studies, their application in scour monitoring is actually not well established. Designing an efficient and reliable scour monitoring system and instrumentation with FBG sensors is still a significant challenge in the practical application. The authors [1] have designed an innovative monitoring system not only to fully exploit the advantages of FBG sensors in the scour monitoring but also to protect FBG sensors in the field. The detail of this design is shown in Fig.1. Intuitively, we may take for granted that the responses of the sensors are not independent since they are on the same steel bar. Actually, that is not the case for a cantilever beam embedded in the ground in terms of the authors' study [2]. Fig. 4 shows the bending moments (equivalent to strain) at different positions of a cantilever pile versus the scour ratio. It is found that for any position of the pile, if it is buried deeply in the soil, its moment is not significant. Only if the scour depth approaches to that position, the moment becomes significant near the soil line. Therefore, the sensors on the steel bar can be used to independently identify the riverbed level.

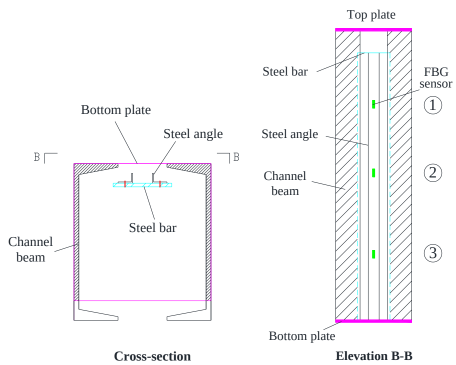

Fig. 3. Sketch of the monitoring system

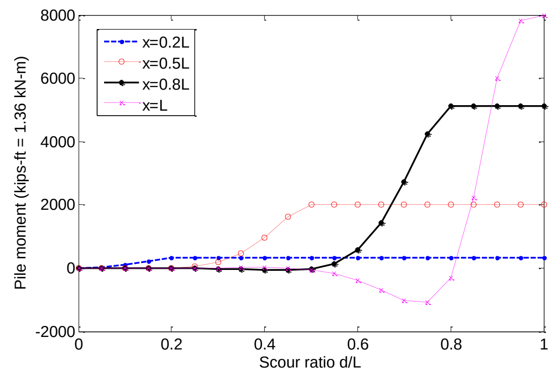

Fig. 4 Pile moments at different positions

A sample of the monitoring system was manufactured and tested in the flume. Fig. 5 shows the history of sensor responses of one test case, and it demonstrates the sequence of sensors starting to have significant responses as the scour depth increases. The strain profile of the steel bar was extracted and shown in Fig. 6. For example, at time t=67s, the strains of the three sensors are 0.5 (sensor 1), 5.5 (sensor 2), and 24 (sensor 3), respectively. The above observation is consistent with the finding above, namely, the maximum bending moment (strain) of the pile changes with the scour ratio, and its location is slightly below but close to the scour depth, i.e., the soil line.

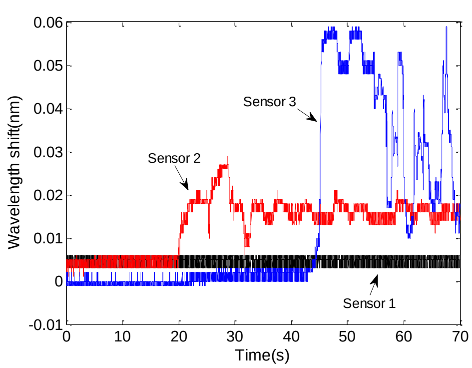

Fig. 5. Wavelength change of three sensors

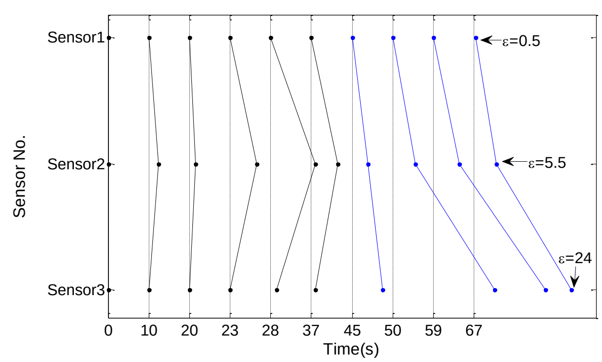

Fig. 6. Strain profile along the steel bar

Based on the scour history of the bridge, about 4 m depth below the riverbed needs to be monitored for the purpose of scour detection. It is inconvenient to build the instrument with the whole depth/length all at once. Therefore, the instrument is manufactured as several 3 ft-long segments; each segment is independent and has a complete scour monitoring system with FBG sensors. Such a way of manufacturing can greatly improve the stability and sensitivity of the system. Through connecting every segment, the monitoring instrument with any required depth/length can be easily achieved for various applications. Herein, six standard units (3 ft-long-segment) were used to assemble an instrument with 18 ft long. In total, two instruments were assembled, which are named as Pile I and Pile II as shown in Fig.7, and the locations are shown in Fig.1. The field test results at different dates as shown in Fig. 8 indicate that the sensor response can truly reflect the actual scour depth. For example, significant responses can be observed on sensors II-1 and II-2 in the top first segment, and sensors II-5 and II-6 in the second segment. It indicates that the first two segments are out of the river ground, which is consistent with the actual condition.

(a) Pile I in position (b) Pile II in position (c) River with flood and after flood

Fig. 7. In-situ installation of sensor instrumentation

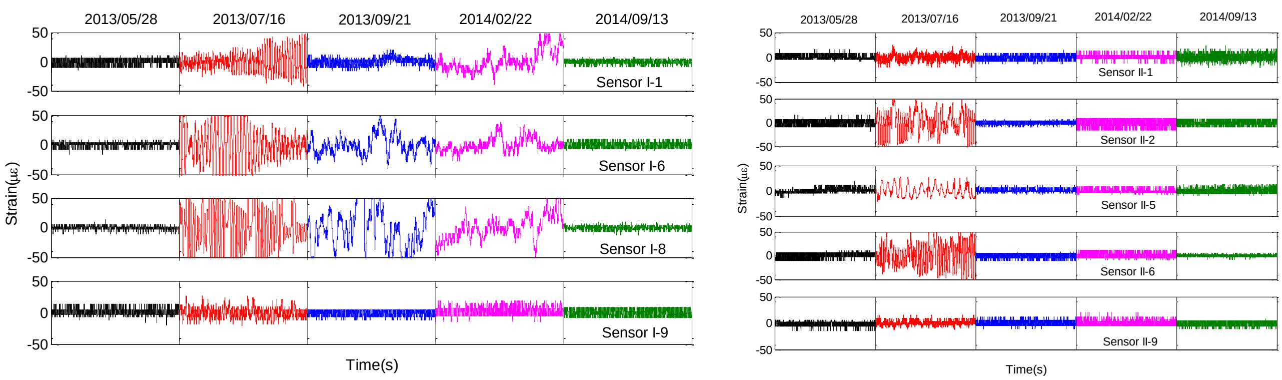

Fig. 8. Strain response of (a) Pile I sensors (b) Pile II sensors

Lessons Learned

The FBG sensors are very fragile and some of them were still broken during this process. Since the scour is a very long-time process and may need several years to see significant effects, the sensing system needs to be really stable and robust to last for many years.

Acknowledgements

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