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Monitoring Bridge Scour Using Fiber Optic Sensors

INTRODUCTION

It is well known that scour is one of the major causes of bridge failures. In the last 30 years, more than 1,000 bridges collapsed in the US and about 60% of the failures are related to the scour of bridge's foundations. Due to the difficulty in inspecting bridge scour, scour-induced failures tend to occur suddenly without prior warning or signs of distress to the structures. Owing to the threat of hurricane-induced flooding and the fact that there are a significant number of coastal and river/bayou bridges in Louisiana, a more reliable inspection and monitoring procedure for bridge scour is needed.

Fiber Optic Sensors (FOSs) have become increasingly popular in long-term monitoring of structures, especially in harsh environments. The FOSs' major unique benefits related to this project are: corrosion-resistant and long-term stability that make it possible to be embedded in soil/foundations and submerged in water; distributed sensing and multiplexing capabilities that make it possible to install a series of sensors along a single cable to collect information along the depth of the foundation; small size and light weight with little disturbance to the structure and soil; immunity to electromagnetic/radio frequency interference, etc. FOS system, particularly fiber Bragg Grating (FBG) sensors, has been explored for this application by using it to measure strain and other related information so that the scour situation of bridges can be either directly monitored or derived.

This project will help Louisiana develop the required expertise for the field applications of fiber optic sensors. The success of this research project will reap great economic benefits and may largely impact the practice of bridge maintenance in Louisiana. There is also potential for this project to develop and test equipment that can be used for future scour monitoring. The ultimate objective will be to develop more efficient strategies to mitigate the deficiencies of bridges.

OBJECTIVE

The proposed research aims to develop a scour monitoring system for bridges using fiber optic sensors and to verify the concept in laboratory and field tests. The system may be used for existing or newly constructed bridges. The existing equations and methods for bridge scour predictions are based primarily on laboratory research and have not adequately been verified with field data. The developed system will be potentially used to collect field data that can be used to verify the applicability and accuracy of the various design procedures for the range of soil conditions, stream flow conditions, and bridge designs in Louisiana and eventually to result in improving existing scour prediction methods.

SCOPE

The scope of this work included theoretical and numerical studies, scour monitoring instrumentation designs and verification by laboratory tests, field installation and tests, and long-term scour monitoring. The scour monitoring system adopted the FBG fiber optic sensors and the field bridge was provided by DOTD to the research team. The scope of this research was achieved through:

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Theoretical and numerical study – The scour effect on a single pile foundation was studied theoretically and verified by numerical examples. Based on that, a few scour detection mechanisms were proposed and tested in-laboratory.

Instrument design and laboratory test – Three scour monitoring systems were designed and the third one recommended based on their performance comparisons. A sample of the recommended designed was then fabricated in the laboratory and tested in a flume at LSU.

Installation and field test – Two scour monitoring piles with FBG sensors were fabricated and driven besides the pile foundations of the selected field bridge. The original data was recorded for further comparisons.

Field long-term monitoring – Since the bridge foundation scour is a long-term procedure, a long-term scour monitoring strategy was developed for this specific bridge, from which the long-term scour performance of bridges can be monitored.

METHODOLOGY

To achieve the research objective, the research work was classified into four parts. The first part studied the scour mechanism from theoretical and numerical analyses and proposed three possible methods for monitoring foundation scour. The second part was to test the proposed monitoring methods using FBG fiber optic sensors. The third part was to design a monitoring instrument for field application and verify it with a laboratory experiment. The final part was to fabricate two test piles with FBG sensors, install them on the field bridge, and implement long-term monitoring for the field bridge.

CONCLUSIONS

This proposed study has developed bridge scour monitoring techniques using fiber optic sensors. Based on theoretical and numerical studies, laboratory verifications, and field tests, the following conclusions can be drawn:

1. The bending test of the GFRP pipe buried in sand with different heights has verified the numerical observations; that is, the position of the maximum moment in the pile is close to the interface of the sand and water. It has also confirmed the feasibility of the scour monitoring method based on the bending moment profile.
2. In order to measure and monitor the scour depth variations in real time, including soil deposition (refilling) process, three designs for a scour monitoring system using FBG sensors were discussed in the present study; the third one is highly recommended for field applications. A verification test using a flume was carried out in the laboratory and it demonstrated the applicability of the recommended scour monitoring system. The advantages over other conventional scour monitoring systems have been proven.
3. The field monitoring has shown that significant responses can be observed on sensors I-1, I-3, I-6, and I-8 and slight response on I-10, which indicates the soil level is already to the position of sensor 8. The top three segments of the test pile I are already exposed out of the riverbed.

RECOMMENDATIONS

Based on the initial results obtained from this research program, the following recommendations are made:

- Periodic visual inspection of the water and riverbed level should be carried out.
- Long-term scour monitoring should be ensured by periodically taking measurements from the permanently installed monitoring plies with FBG sensors.
- Currently, measurements are carried out by field trips, and it is very difficult to know in advance if a high water and scour event occurs. For practical applications, on-line monitoring technology using fiber optic sensors should be developed, which can continuously monitor the scour process.

Figure 1
Installed monitoring piles in the field