Fiber Bragg Grating Sensing for Structural Health Monitoring of Civil Structures

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ABSTRACT

Structural Health Monitoring (SHM) is fast becoming a highlight of both research and applications in civil engineering. One key driver is the ever-improving function and cost of fiber-optic sensing (FOS) systems. To date, FOS have been used on hundreds of civil structures around the world. This paper focuses on two initiatives that rely on FOS. Researchers from Iowa State University's Bridge Engineering Center demonstrate a novel approach to SHM data management, analysis and presentation. Preliminary results are shown and links to live data are provided. At the Harbin Institute of Technology, civil engineers are studying local damage on large-span bridges. Current work focuses on solving key practical challenges for several existing and new large spans.

KEYWORDS

Bragg grating, fiber optic sensors, structural health monitoring, civil structures, bridge.

HIGH PERFOMANCE STEEL BRIDGE

In early 2004, the Iowa Department of Transportation (DOT) completed construction of Iowa's first High Performance Steel (HPS) bridge (Figure 1) through the Federal Highway Administration's (FHWA) Innovative Bridge Research and Construction (IBRC) program. When compared with conventional steels, HPS has improved weldability, weathering capabilities, and fracture toughness.

Figure 1. Photograph of Iowa HPS Bridge obtained from SHM Network Camera

In cooperation with the Office of Bridges and Structures at the Iowa DOT, the Bridge Engineering Center at Iowa State University has developed a continuous Structural Health-Monitoring (SHM) system to monitor and record the performance of the HPS bridge for a two-year period. With this system, the bridge performance can be evaluated at any point in time as well as with respect to time.

OBJECTIVES

The main objectives of the monitoring and evaluation portion of the HPS bridge include:

- Continuously evaluate local and global bridge structural performance
- Monitor the bridge over time to develop a baseline record for identifying structural performance changes
- Conduct a detailed fatigue evaluation

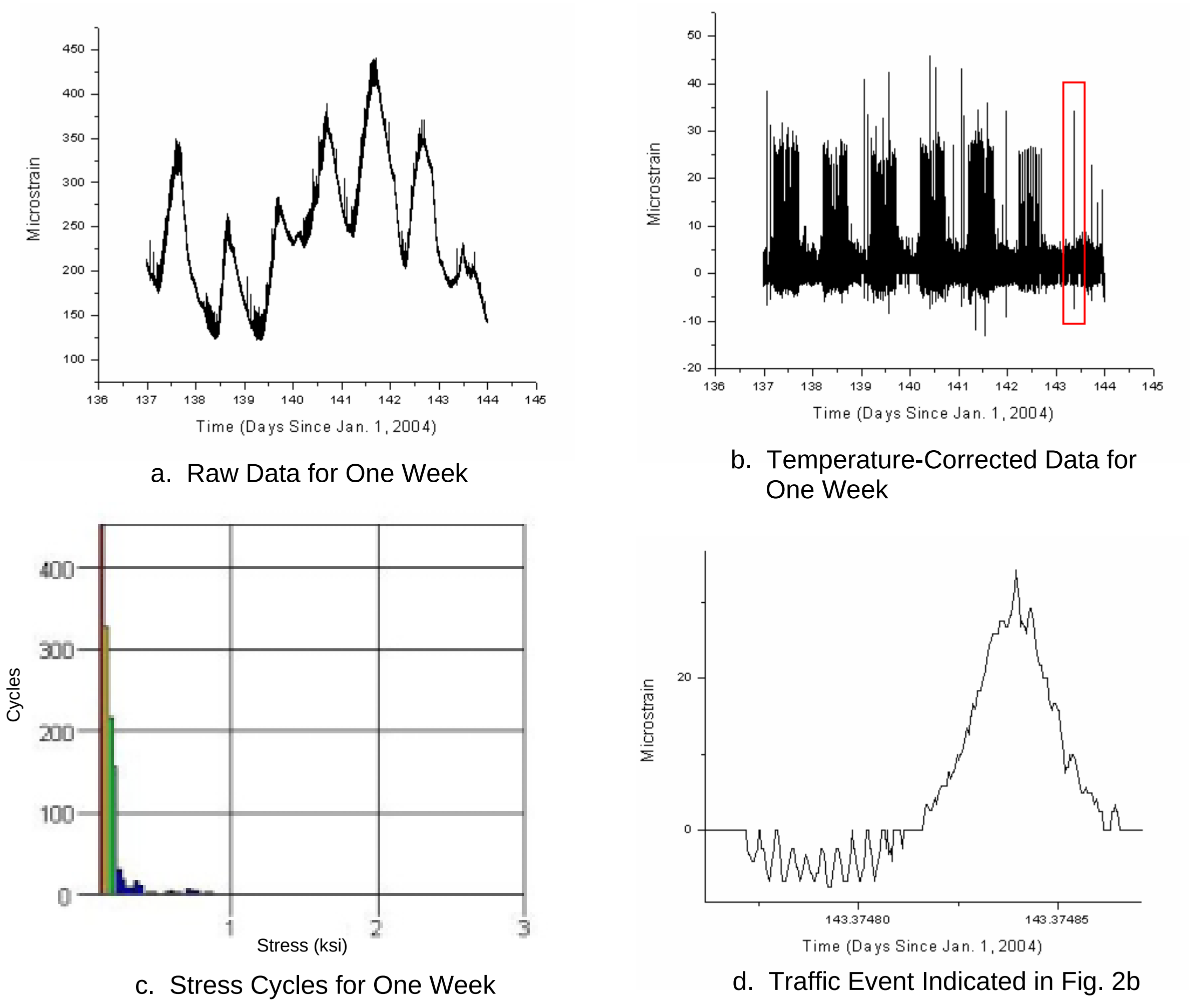
By using the SHM system to continuously monitor local and global bridge behavior, at any point in time the overall condition of the bridge can be evaluated. Moreover, the technology configured in this project could provide the required information to predict bridge deterioration over time, and thus, provide an opportunity to predict the remaining life of a structure by knowing current characteristics of the bridge. Finally, the long-term performance of several typical and atypical fatigue sensitive details is being evaluated.

SHM SYSTEM CONFIGURATION AND DATA

The HPS bridge SHM system consists of components developed from several different manufacturers. When possible, standard off-the-shelf components were utilized to maintain minimum cost for the system. The primary components of the SHM system are as follows:

- Strain sensing equipment: si425-500 Interrogator, by Micron Optics, Inc.
- Strain sensors: 30 Fiber Bragg Grating (FBG) Sensors
- Video equipment, networking components, and three computers for web service, data collection and data storage

The SHM system collects strain information at critical bridge locations, uploads the strain data to the internet where it can be viewed from anywhere in the world in real time (http://www.ctre.iastate.edu/bec/structural_health/hps/index.htm), and automatically transfers the data to the Bridge Engineering Center at Iowa State University for analysis. Typical data is presented in Figure 2.



a. Raw Data for One Week

b. Temperature-Corrected Data for One Week

c. Stress Cycles for One Week

d. Traffic Event Indicated in Fig. 2b

Figure 2. Typical Collected Strain Data – Bottom Flange of Girder

A method for summarizing the daily, weekly, and monthly performance of the bridge is also being developed. These brief reports will be automatically generated to give the bridge owner an overview of the bridge condition and performance.

LARGE-SPAN BRIDGES

In China, FBG sensors are being accepted more and more for deployment in the field. In provinces like Shandong, bridges are a crucial element of the regional transportation system. Many lots of large-span bridges are under construction in developing countries as well as China. As more SHM systems are deployed, many bridge owners are realizing the importance of adding SHM systems to the bridges while under construction. For such grand spans, civil engineers are using FOS SHM data to reduce the risk of catastrophic failure. And as in Iowa, the data will be used to track day-to-day usage of the spans.

Ou (2003) has developed several SHM systems based on FBG sensors for several large-span bridges (Figures 3-6) to monitor the performance of the bridges under construction and in service. Clearly, FOS systems can gather detailed information about a span, but making effective use of the data poses somewhat of a challenge.

Figure 3. Binzhou Yellow River Bridge in Shandong Province

Figure 4. Dongying Yellow River Bridge in Shandong Province

In particular, engineers need to be able to detect and analyze damage at specific locations. This local damage monitoring is paramount. Generally speaking, local damage appears as crack, fatigue, slip, delamination, stiffness loss, effective force-resistance area loss, and so on. Strain is an alternative parameter which can be used to describe deformation, study a crack opening and even detect the slip and bonding, so high-quality strain sensing has always been pursued by the structural researchers.

Figure 5. Songhuajiang River Bridge in Heilongjiang Province

Figure 6. Maocaojie Bridge in Hunan Province

CHALLENGES

Bragg grating and other fiber-optic sensors are still very new to most civil engineers and construction firms. Special training for these parties is a necessary element of any FOS deployment. Currently, for the new bridges in China, programs are being developed. Training will focus on the following issues:

1) How to provide adequate temperature compensation for FBG strain sensors;
2) How to optimize the FOS system to best balance of number of FBG sensors with the practical considerations of routing the optical fiber and maximizing the capabilities of the interrogation instrumentation.
3) How to protect FBG sensors and cables during installation and bridge construction;
4) How to verify the gage factor for packaged FBG strain sensors to ensure accurate readings;
5) How to improve the FBG monitoring systems such that they become accepted as a standard civil engineering tool.

CONCLUSIONS

With the SHM system in place on the East 12th St. Bridge over I-235 in Des Moines, IA, a significant step has been made in the ability to effectively (both in terms of information collected and cost) monitor and evaluate structures continuously from a remote location. The system allows the client to view real-time video of traffic crossing the bridge and the corresponding real-time strain data at various bridge locations.

The stakes may be even higher on several major spans in China. Practical challenges must be overcome in the installation of FBG sensors to make these SHM installations a clear success. Both installation and data analysis techniques need to be refined to make best use of the information supplied by the FOS system. Even with the challenges noted, the value of fiber-optic sensing systems for long-term SHM installations is clear, and governments in China and elsewhere are making FOS-based SHM systems mandatory on major structures.