4th International Conference on Structural Health Monitoring of Intelligent Infrastructure (SHMII-4) 2009

22-24 July 2009, Zurich, Switzerland

Novel structural monitoring system for the Chiapas bridge

Roberto Gómez-Martínez[1], David Murià-Vila[1], Miguel A. Mendoza-García[1], Alexis Méndez[2], Keith Chandler[3], Roberto Sánchez-Ramírez[1], J. A. Escobar Sánchez[1], Andrei Csipkes[4]

[1] Institute of Engineering, Universidad Nacional Autónoma de México, Mexico City, Mexico
[2] MCH Engineering LLC, San Francisco, USA
[3] Chandler Monitoring Systems, Inc., Atlanta, USA
[4] Micron Optics Inc., Atlanta, USA

ABSTRACT: This paper describes the methodology and on-line equipment used for the Structural Health Monitoring (SHM) of the Chiapas Bridge. This installation represents the first SHM instrumented bridge in Mexico using optical fiber sensors and SHM techniques. The bridge was open to traffic in 2003 and is the most important structure of an entire highway going through the state of Chiapas in Southwest Mexico and part of the Transamerican highway system. The superstructure is a continuous grade 50 steel orthotropic box of constant height comprising 8 spans, with a total length of 1208m. Pier heights range from 27 to 89 m measured from the bottom of the dam. Steel jackets of the offshore type were used as the main elements of the piers. During construction of the superstructure, a basic monitoring system was initially implemented to monitor and assess the structural behavior of the bridge. However, advances in SHM techniques and the importance of the Chiapas Bridge in the region prompted the need for a new and advanced instrumentation system. The new solution is based on a multi-point, multi-sensor monitoring system based on optical fiber Bragg grating sensors and opto-electronic interrrogators. The self contained system works as stand-alone equipment and allows for the in-situ, real-time monitoring of the bridge as well as its long-term condition. A total of 82 fiber optic strain and temperature sensors were installed in key bridge locations. An environmental control cabinet is provided to maintain adequate temperature and humidity levels for all the electronic instrumentation. Local electric power is supplied by a solar panel system.

1 INTRODUCTION

The superstructure of the Chiapas Bridge is a continuous grade 50 steel orthotropic box of constant height comprising 8 spans with a total length of 1208m. Pier heights range from 27 to 89 m measured from the bottom of the dam. Jackets of the offshore types were used as the main elements of the piers. During construction of the superstructure, a monitoring system was implemented, so that the structural behavior of the bridge could be monitored and assessed [Gomez et al. (2004)].

Recent advances in SHM techniques and the importance of the Chiapas bridge prompted the need for a new and novel instrumentation system. The new system chosen is based on a multi-point, multi-sensor monitoring system with optical fiber Bragg grating sensors and opto-electronic interrogators. The self contained system works as stand-alone equipment and allows for the in-situ real-time monitoring as well as its long-term condition. An environmental control cabinet is used to maintain the instruments at adequate temperature and humidity levels.

In this paper, the installation of the SHM system is described in a preliminary phase based on fiber optic sensors, and the first results of the long-term monitoring of strain and temperature values at 16 different sections along the total span of the bridge are presented. Moreover, results from the first ambient vibration test are indicated and used to identify main structural frequencies. In addition, data obtained from the same set of sensors can also be used to monitor possible sloping of the steel girder bridge box as well as to determine strain variations, structural vibrations and expansion effects as a function of time of day, seasons and traffic.

After a brief description of the instrumentation, system installation and some preliminary measurements results are discussed in the following sections.

2 LONG TERM INSTRUMENTATION

Recording points of strains along the bridge were defined based on zones of expected maximum stress levels. Key sections are located at pier supports and mid span sections (Figure 1). At each selected location, four strain sensors and two temperature sensors were placed along the superstructure (Figure 2). A total of 82 optical fiber Bragg grating (FBG) sensors—64 Micron Optics os3100 spot-weld strain gages and 18 Micron Optics os4100 temperature compensating sensors—(Figure 3) were installed. The FBG sensors were spliced and pre-assembled together into 16 different arrays, cut to length for each bridge segment and then packaged for shipment. Once on-site, the arrays were unpacked and spot welded on the steel bridge flanges.

An 18 fiber count, optical fiber breakout cable was used as the main signal bus. The cable runs along the total length of the superstructure and terminates at the control cabinet, where the electronic equipment is housed. Along the cable's length, individual fibers branch off from each of the 16 measuring sections where they are connected to the respective sensor arrays (Figure 4). At the control box, each of the 16 fibers is connected to a separate channel of an optical 16x4 fiber multiplexer, which itself is linked to the FBG sensor interrogation unit. From this device, the data acquisition software allows end users to transmit data via satellite or directly by being plugged into a computer and extract data.

All hardware and sensors were previously shipped to Mexico City and then trucked to the bridge site. Access to the inside of the bridge is via an external access ladder.

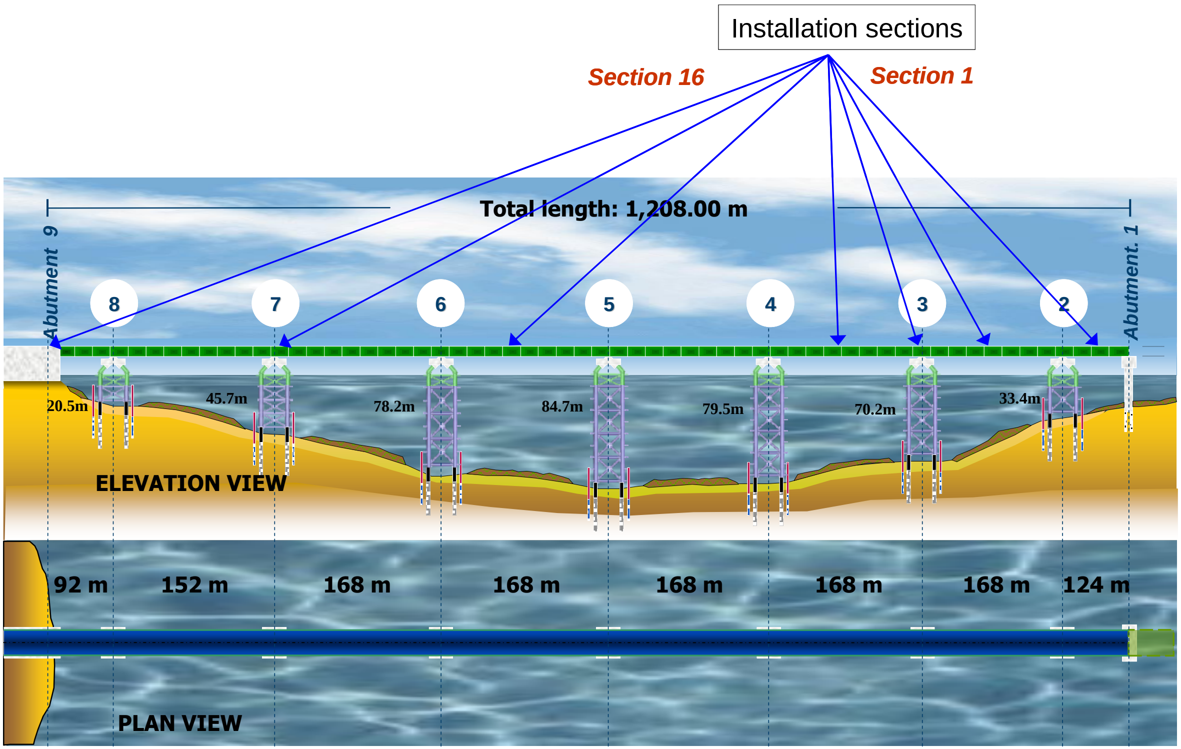


Figure 1. Elevation and plan view of the Chiapas Bridge with instrumented sections.

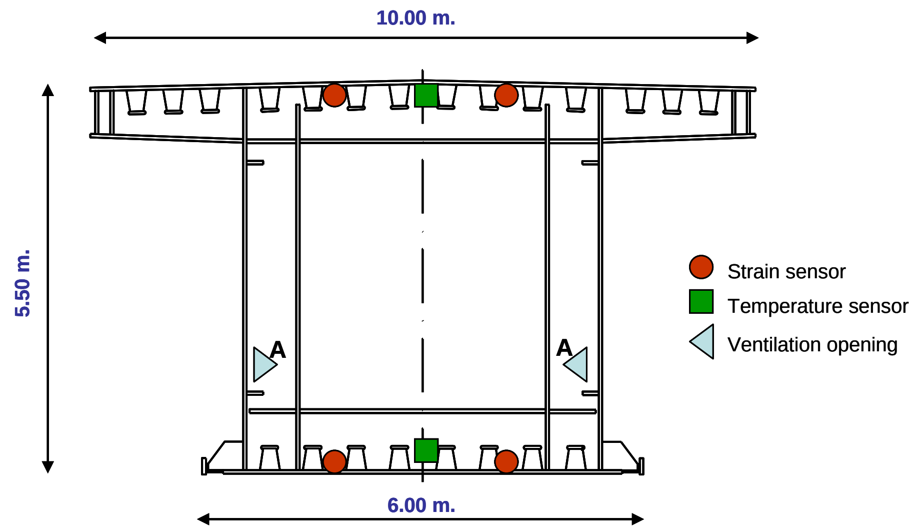


Figure 2. Chiapas bridge cross-section and sensor locations.

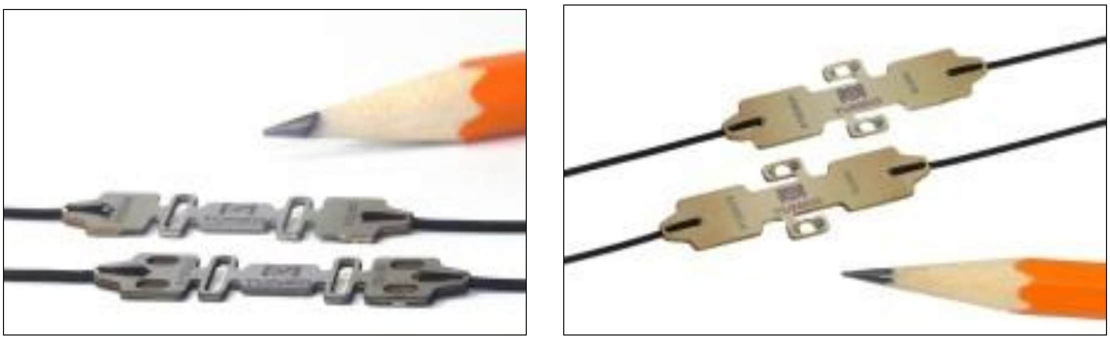


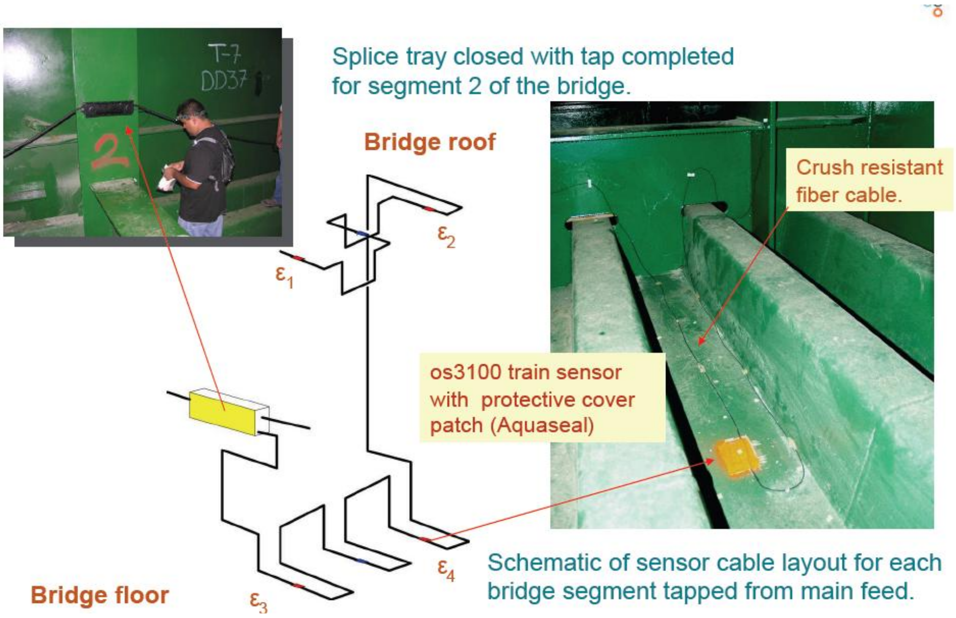
Figure 3. Photos FBG strain (right) and temperature (left) sensors used.

3 SYSTEM CONFIGURATION

The monitoring system instrumentation is composed of a single optical interrogator (Micron Optics model sm130-500) with 4 optical channels, scanning at 1khz; a 4x16 channel sensor multiplexer (model sm041-416) and a sp130 controller and data acquisition module (Figure 5). The system can be configured to record data at any specific interval and to any threshold level.

The optical system is housed inside an NEMA type box with controlled temperature and humidity. Because of the remote location of the bridge, local electric power is provided by a custom-made solar panel system.

The software provided with the sm130 optical interrogator, incorporates capabilities to ease the integration of the optical measurement sensor system and facilitate many of the common features needed in these kinds of SHM systems. Consequently, each monitoring task with optical sensor systems share many operational characteristics with conventional electronic sensor systems. Instructions such as configuration of channels, real time signal visualization, average values for defined intervals, a specific warning configuration and message generation when any signal is out of the indicated threshold are considered in the software provided. Optical sensors, however, have special properties outside the scope of traditional sensor software that require attention, management and control such as spectral calibration and conversion from spectral shifts to physical units of strain or temperature.



Splice tray closed with tap completed for segment 2 of the bridge.

Crush resistant fiber cable.

os3100 train sensor with protective cover patch (Aquaseal)

Schematic of sensor cable layout for each bridge segment tapped from main feed.

Figure 4. Aspect and topology of the installed sensor network inside the bridge. Left photo shows the main fiber optic data cable. Right photo depicts a strain sensor mounted on the bottom flange.

Controler and data storage

Main sensor interrogator

sensor multiplexer

Figure 5. Monitoring system main instrument components.

Given the straight forward, bus-type signal cable architecture of the system and standardized wavelength allocation of the FBG sensors, the installation process was simplified and future upgrades will be easy to make, allowing for the possibility to add and retrofit sensors by simply inserting them as part of the existing arrays.

4 RESULTS AND ANALYSIS

Data from static and dynamic load experiments have been recorded. Examples of time-windows of recorded signals from dynamic tests are presented in Figure 6, where the vertical axes represent measured strains produced by live loads. These four graphs were obtained at the mid central sections of the four longest spans (168 m) of the bridge. Two plots are included in each graph: one corresponding to a sensor located on the top flange and the other to a sensor located on the same position but on the opposite bottom flange. Hence, the strain sensor pairs have similar absolute magnitudes and strain profiles, but opposite signs (one is in tension and the other in compression). Other specific behaviors can be observed, such as the passing of a moving load from pier 1 to abutment 9. The number of peaks, maximum amplitude and periods are an indication of the type of load or vehicle moving along the bridge. Another important feature of the records is their similarity, since they correspond to the same excitation in load and time. From these types of records, maximum values of longitudinal stresses of the superstructure produced by on site temperature and current traffic loads could be readily extracted.

Similar plots are presented in Figure 7 but associated to sensors located on top of the piers. Basically, the same comments of the former figure can be assumed

So far, within this project only the response of the superstructure to very simple load scenarios has been carried out. Neither extreme static nor dynamic loads have been registered yet.

On the other hand, using the analysis of acceleration records—obtained during the first stage of ambient vibration tests carried out in November 2008—the most significant frequencies of the superstructure have been identified and listed in Table 1. These values will be used as reference in the next stages of planned experimental work.

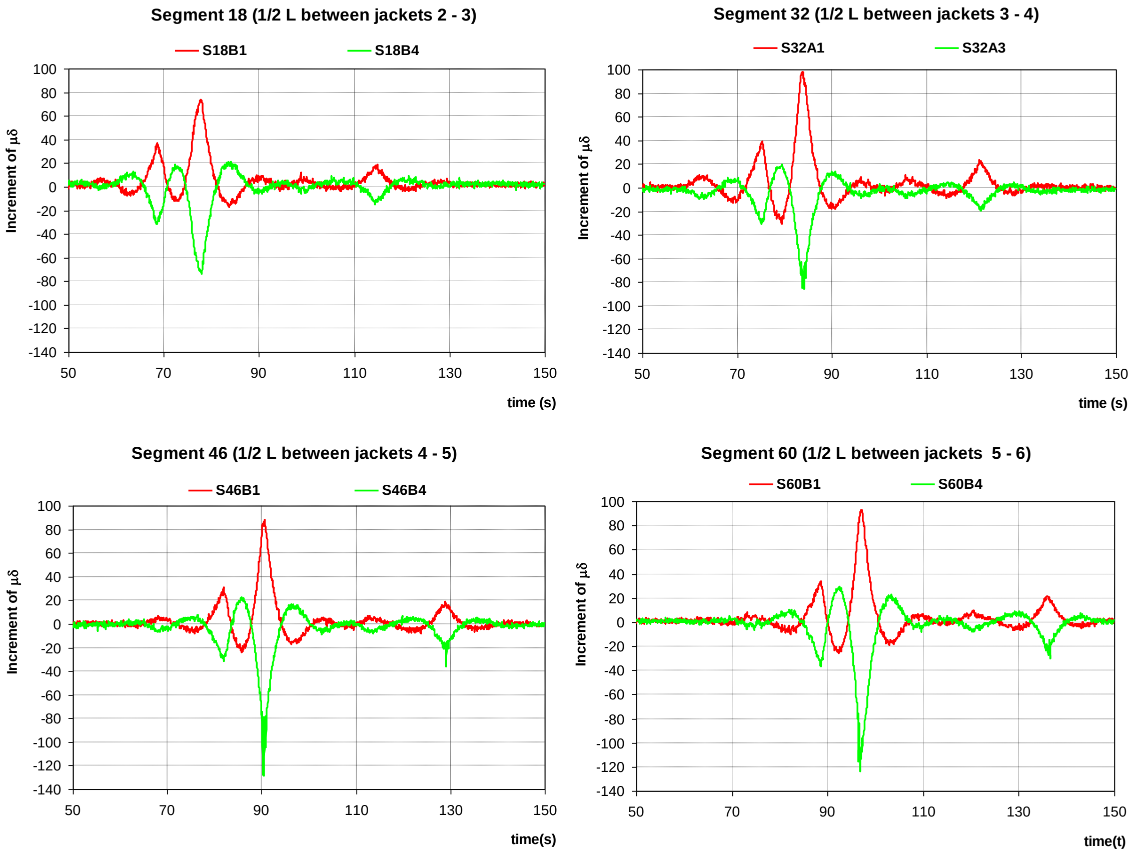


Figure 6. Time histories of strains for bridge section spans 2-3, 3-4, 4-5 and 5-6.

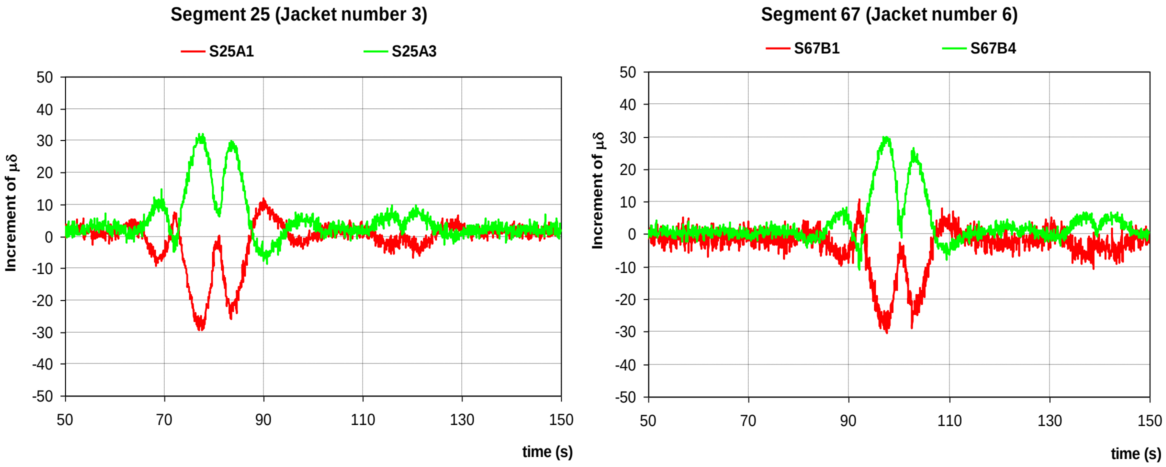
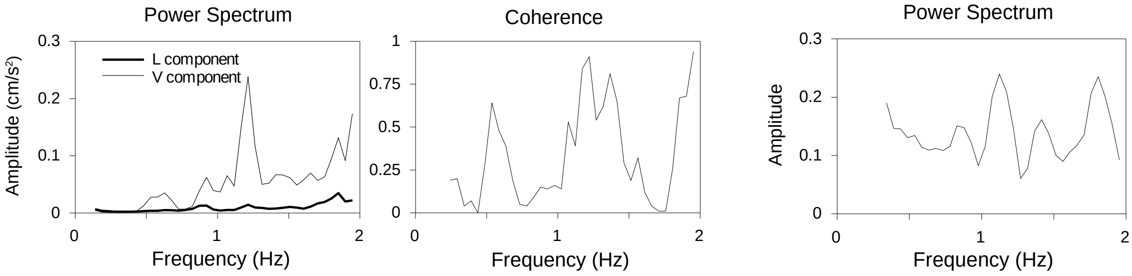


Figure 7. Time histories of strains; segments on piers 3 and 6.

Table 1. Vibration frequencies (in Hz) identified for some spans of the Chiapas bridge.

Span	Transverse direction	Vertical direction
2-3	0.59	1.22-1.32
3-4	0.54	0.93-1.07
4-5	0.54	1.07-1.22
5-6	0.54	1.22
6-7	0.63-0.78	1.22
7-8	0.83	1.07-1.22

So far, the correlation of longitudinal strains and vertical accelerations has been evaluated in order to determine the possibility of estimating vibration frequencies from the vertical vibration component of the deck. Evidence from the results have proven that this assumption is feasible since in all cases an acceptable level of coherence for the two directions was observed, as shown in Figure 8a for span 5-6. This fact suggests that longitudinal strain records could be used to estimate such frequencies, as found in some dynamic tests (figure 8b).



(a) (b)

Figure 8. Power spectrum and coherence functions, obtained from acceleration records, span 5-6 (a), and power spectrum obtained from fiber optic sensors (b).

5 FINAL COMMENTS

At present, the SHM system is operational and the Chiapas bridge is fully monitored. So far, it has been shown that records from FBG sensors are reliable. The work presented enabled the identification of the main structural parameters of the bridge. Some new experimental tasks are underway which may, eventually help to fully calibrate and give more insight on continuous and long term monitoring tasks. Tentatively, additional accelerometers and tiltmeters are planned to be installed in the course of 2009.

In a companion paper, although different in technology, another long term monitoring project is presented. These two experimental projects are the most important in the history of SHM systems in Mexico [Gómez et al. (2008)].

6 REFERENCES

Gómez, R., Murià-Vila D., Sánchez R., Escobar J.A., Muñoz D., and Vera R., 2004, *Construction of the Chiapas bridge superstructure, Mexico*, International Symposium on Steel Bridges, Millau France, 23-25.

Gómez, R., Murià-Vila D., Sánchez R., Escobar J.A., Rodríguez-Gutiérrez, G. Mendoza-García, M. 2008, *An account of structural health monitoring and related problems of bridge structures in Mexico: case studies*, The Monitor, ISHMII, March: 11-34.

7 ACKNOWLEDGMENTS

This study was carried out under an agreement funded and commissioned by the Ministry of Communications and Transportation (SCT) of Mexico. The authors gratefully acknowledge the assistance provided by Gerardo Rodríguez-Gutiérrez, Israel I. León-García and José Camargo-Pérez.