4th International Conference on
Structural Health Monitoring on Intelligent Infrastructure (SHMII-4) 2009
22-24 July 2009, Zurich, Switzerland

Abstract of Paper No: XXX

Structural Health Monitoring System for the new I-35W St Anthony Falls Bridge

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The collapse of the I35W Bridge in Minneapolis shook the confidence of the public in the safety of the infrastructure that we use every day. The Design Build team realized the construction of the replacement bridge must help rebuild this confidence, by demonstrating that a safe, reliable bridge can be attained starting at construction and maintained throughout the projected 100-year life-span of the bridge. One of the central factors contributing to this is the design and installation of a comprehensive structural health monitoring system, which incorporates many different types of sensors measuring parameters related to the bridge performance and ageing behavior. This system continuously gathers data and allows through appropriate analysis to obtain actionable data on the bridge performance and health evolution. The data provided will be used for operational functions as well as for the management of ongoing bridge maintenance, complementing and targeting the information gathered with routine inspections.

The main targets of the SHM system are to support the construction process, record the structural behavior of the bridge, and contribute to the bridge security. The design of the system was an integral part of the overall bridge design process allowing the SHM system to both receive and provide useful information about the bridge performance, behavior and expected lifetime evolution. Finally, collected information may allow designers to refine specifications for future concrete box girder bridges.

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Structural Health Monitoring System for the new I-35W St Anthony Falls Bridge

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ABSTRACT: The collapse of the I35W Bridge in Minneapolis shook the confidence of the public in the safety of the infrastructure that we use every day. The Design Build team realized the construction of the replacement bridge must help rebuild this confidence, by demonstrating that a safe, reliable bridge can be attained starting at construction and maintained throughout the projected 100-year life-span of the bridge. One of the central factors contributing to this is the design and installation of a comprehensive structural health monitoring system, which incorporates many different types of sensors measuring parameters related to the bridge performance and ageing behavior. This system continuously gathers data and allows through appropriate analysis to obtain actionable data on the bridge performance and health evolution. The data provided will be used for operational functions as well as for the management of ongoing bridge maintenance, complementing and targeting the information gathered with routine inspections.

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Monitoring instruments on the new St Anthony Falls Bridge measure dynamic and static parameters to enable close behavioral monitoring during the bridge's life span. Hence this bridge will be considered to be one of the first 'smart' bridges of this scale to be built in the United States. The SHM system includes a range of sensors which are capable of measuring various parameters to enable the behavior and condition of the bridge to be monitored: vibrating wire strain gauges, thermistors, linear potentiometers, accelerometers, concrete corrosion and humidity sensors and SOFO long-gauge fiber optic deformation sensors. The sensors are located throughout both the northbound and southbound bridges, and are present in all spans. A denser instrumentation is utilized for the southbound bridge to validate load distribution and design methodology. In addition, it allows correlation and comparison between different methods of measuring. Finally, collected information may allow designers to refine specifications for future concrete box girder bridges.

1 INTRODUCTION

The new I-35W Bridge Design Build project, designed by FIGG Engineering Group (see Figure 1), was awarded in October 2007 following the tragic collapse of the original bridge on August 1, 2007. The proposal for the new bridge included a state-of-the-art Structural Health Monitoring (SHM) system that will allow for easier and more comprehensive monitoring throughout the bridge's lifetime (Del Grosso and Inaudi, 2004).

Figure 1: View of the completed I-35W St. Anthony Falls Bridge (courtesy of Minnesota Department of Transportation)

The Roctest Group, including Roctest and SMARTEC and MNME were awarded by the Flatiron Constructors/Manson Construction Company of Minneapolis (Flatiron-Manson JV), principal contractors for the I-35W Minnesota Bridge construction, the contract to support the design, supply and install the main part of this SHM system. Roctest Group worked in close relationship with Minnesota DOT and the University of Minnesota in finalizing the optimal instrumentation solution for the bridge (Russel 2008).

The targets of the SHM system are the following:

- Support construction processes
- Record of structural behavior (structure monitoring)
- Bridge security

The design of the SHM system was an integral part of the overall bridge design process allowing the SHM system to both receive and provide useful information about the bridge performance, behavior and expected lifetime evolution.

2 SHM SYSTEM DESIGN

The monitoring instruments on the I-35W Bridge will measure dynamic and static parameter points to enable close behavioral monitoring for the bridge's life span. This bridge will be considered one of the first Smart Bridges of this scale to be constructed in the United States.
The system includes a range of sensors which are capable of measuring various parameters to enable the behavior of the bridge to be monitored. Strain gauges measure local static strain, local curvature and concrete creep and shrinkage, thermistors measure temperature, temperature gradient and thermal strain, while linear potentiometers measure joint movements. At the mid-spans, accelerometers are incorporated to measure traffic-induced vibrations and modal frequencies (Eigen frequencies). Corrosion sensors are installed to measure the concrete resistivity and corrosion current.
Meanwhile there are long-gauge SOFO fiber optic sensors which measure a wide range of parameters, such as average strains, strain distribution along the main span, average curvature, deformed shape, dynamic strains, dynamic deformed shape, vertical mode shapes and dynamic damping – they also detect crack formation. An additional set of accelerometers was installed in the fiber monitored span.

The sensors are located throughout the two bridges, the northbound and southbound lanes, and are in all spans. However, a denser instrumentation is installed in the southbound main span over the Mississippi river, as depicted in Figure 2.

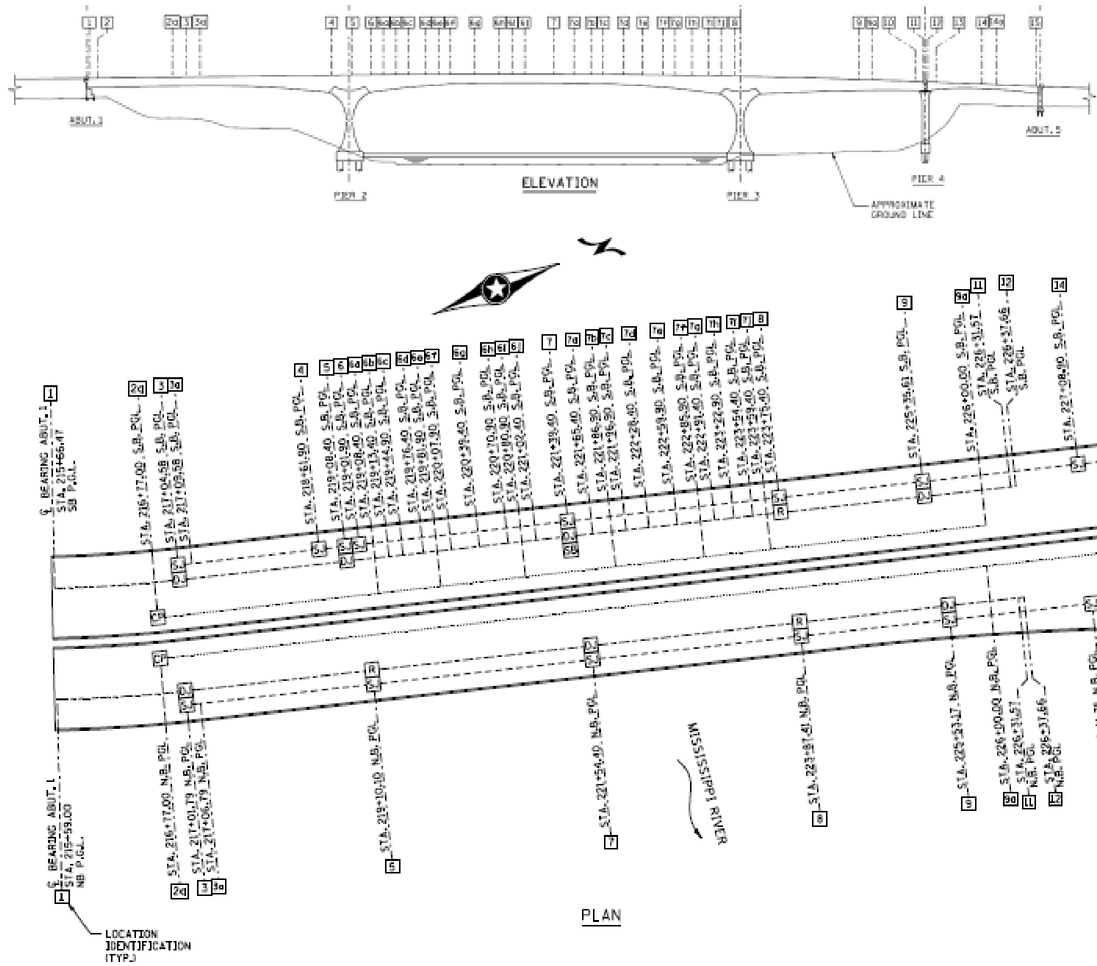


Figure 2: Global overview of the I-35W Bridge health monitoring system (courtesy of Flatiron Mason)

In this project, fiber optic has been selected as a complementary solution to vibrating wire strain gauges (Glisic and Inaudi 2007). This project is also one of the first to combine very diverse technologies, including vibrating wire sensors, fiber optic sensors, corrosion sensors and concrete humidity sensors into a seamless system and a single database and user interface.

Table 1 summarizes the installed instrumentation and the monitoring purpose of each of them.

Sensor Type	**Purpose**	**Addressed risk / uncertainty**
Vibrating-wire strain gauges	Local static strain	Concrete shrinkage and creep. Correspondence with FEM
	Local curvature	Loss of pre-stress, creep
Thermistors	Temperature	Temperature induced deformations
	Temperature gradient	Temperature induced strain
Linear Potentiometers	Joint movements	Stuck joints Anomalous global movements
Accelerometers	Traffic induced vibrations	Excessive vibrations Dynamic amplification
	Modal Frequencies	Correspondence with FEM
	Dynamic damping	Stuck joints Anomalous global behavior
Corrosion Sensors	Concrete resistivity	Water exchange in concrete deck
	Corrosion current	Corrosion of concrete deck rebars
Long-gauge fiber optic sensors	Average strains	Detection of Cracks Correspondence with FEM
	Strain distribution	Temperature induced deformations Correspondence with FEM
	Average Curvature Deformed Shape	Loss of pre-stress, creep Correspondence with FEM
	Dynamic Strains, dynamic deformations, mode shapes	Anomalous global behavior

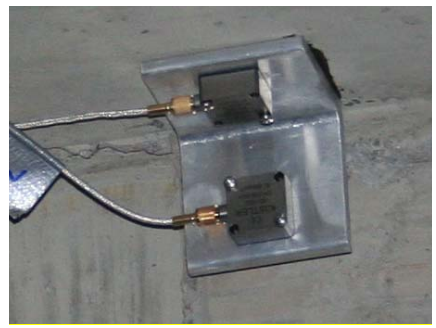
Table 1: Sensor types, purpose and addressed risk or uncertainty for the I35W Bridge

Figure 3 provides an overview of the different types of sensors and data acquisition systems installed in the I35W Bridge.

Long-gauge SOFO fiber optic sensor

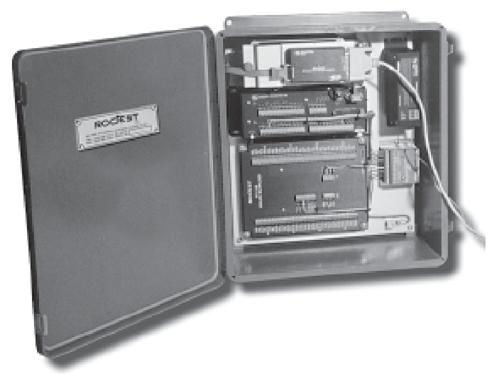
Vibrating Wire Strain Gauge

Concrete corrosion and Humidity sensors



Accelerometer

SOFO Fiber Optic Sensor Datalogger



Vibrating wire and temperature sensors datalogger

Figure 3: Overview of sensors and data acquisition systems installed in the I35W Bridge

Figure 4 shows a simulation of the user interface implemented to display the data. The software is capable of displaying real-time information and to color-code the measurements according to pre-defined warning levels.

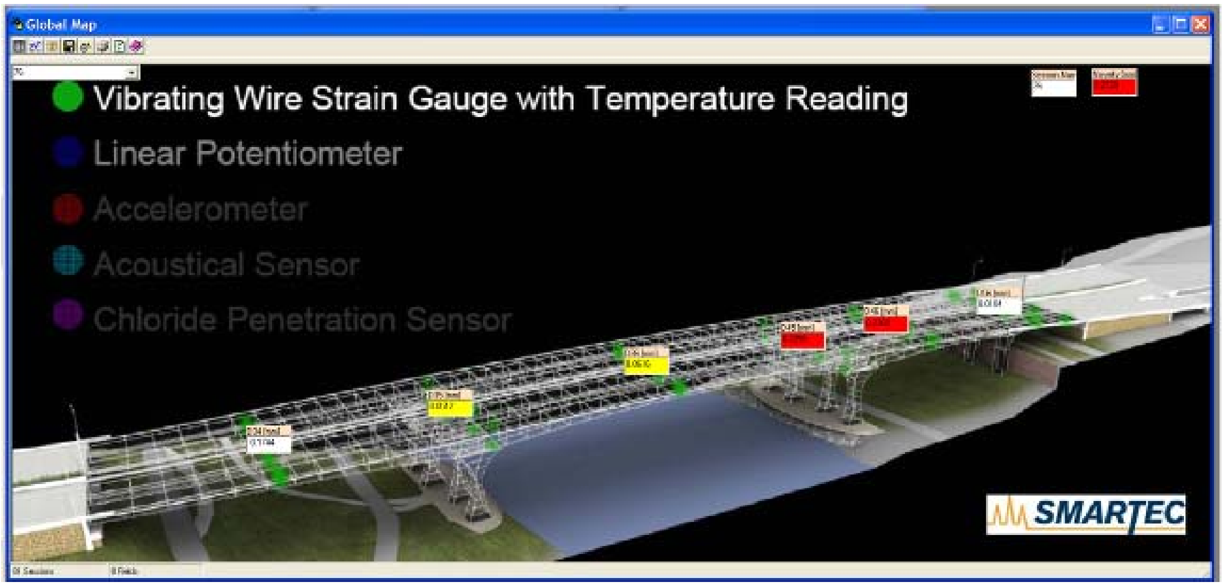


Figure 4: SDB View Software interface (simulation)

3 PROGRESS AND RESULTS

All sensors and dataloggers have been installed and commissioned in the bridge. The SHM monitoring system is currently gathering data from the sensors, complementing the manual reading that were taken during construction. This data is currently being analyzed, but we will provide a few early results form the monitoring system.

Figure 5 shows the measurements from the fiber optic sensors over a period of one week. The daily cycles due to the bridge expansion and contraction due to temperature changes are clearly visible.

A load test was performed on the bridge prior to its opening on September 18, 2008. Figure 6 shows an example of the deformations recorded by the fiber optic sensors during one of the tests.

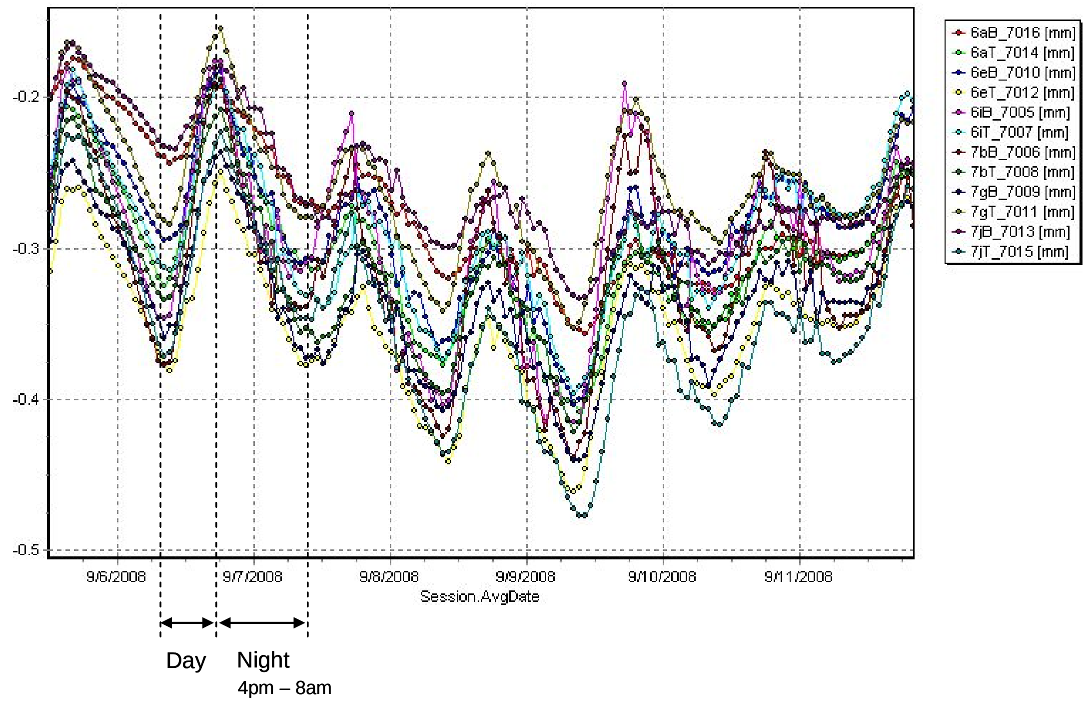


Figure 5: Example of fiber optic sensor data acquired over a period of 7 days.

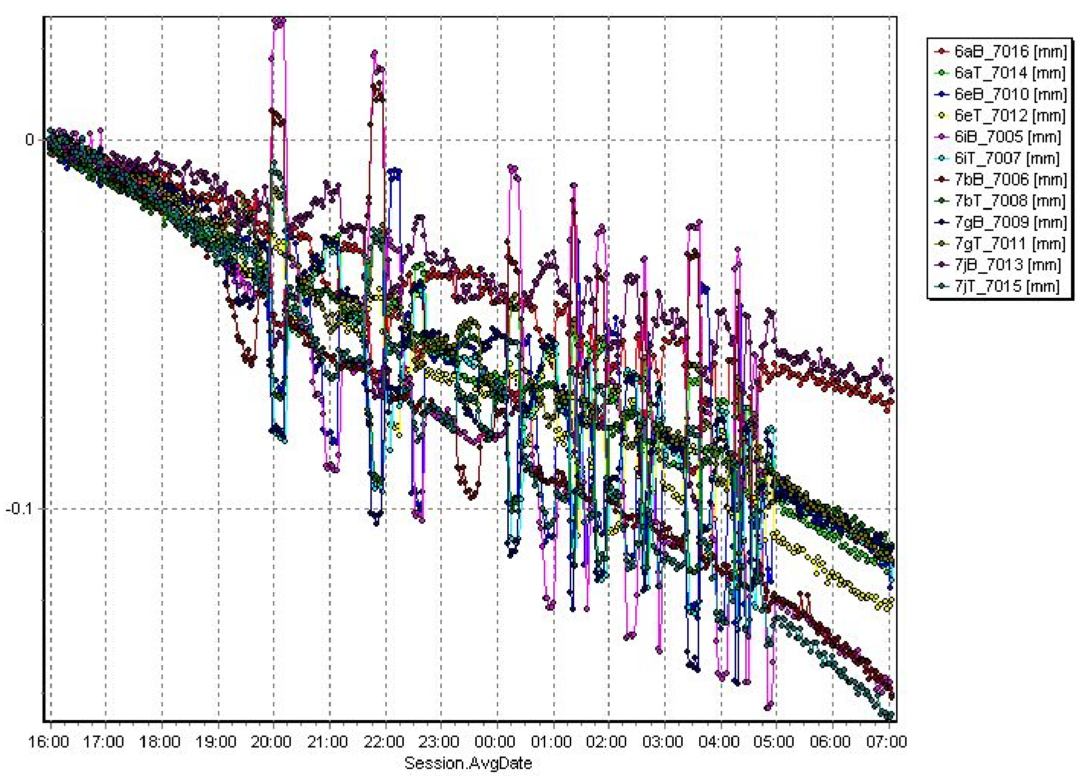


Figure 6: Raw data acquired on the SOFO strain sensors during the test.

4 CONCLUSIONS

The collapse of the I35 Bridge has affected the confidence of public in the safety of the infrastructure we use every day. It was therefore necessary to regain that confidence by building a new bridge with enhanced safety, but it is also necessary to demonstrate that this high level of safety is attained during construction and maintained throughout the projected 100 years lifespan of the bridge. A comprehensive Structural Health Monitoring system, including many different types of sensors measuring parameters related to the bridge performance and ageing behavior was therefore designed and installed in the bridge. This system will continuously gather data and allow through appropriate analysis to obtain actionable data on the bridge performance and health evolution. The provided data will be used for both operational functions as well as for the management of the bridge maintenance, complementing and targeting the information gathered with routine inspections.

This project will be remembered as a landmark in bridge history, not only because of the tragic events that lead to his construction, but also for being the first Smart Bridge of this scale constructed in the United States.

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