An Information System for a Sensor-Based Bridge Health Monitoring System

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Abstract_ **Bridges are a critical component of the transportation infrastructure and are subjected to numerous load types with varying magnitudes leading to premature deterioration. Continuous monitoring of the performance of a bridge can assist in determining the deterioration rate and predicting the remaining service life. This paper describes an information system for health monitoring of a full-depth, precast concrete bridge deck for the Parkview Bridge in Kalamazoo, Michigan, USA. The system is composed of a remotely accessible on-site data acquisition system and a sensor network for monitoring stresses and temperature over the life-cycle of the bridge.**

Keywords_ **Bridge Health Monitoring, Bridge Condition Assessment, Sensor Networks.**

I. INTRODUCTION

The United States Federal Highway Administration (FHWA) statistics show that about 47% the U.S. bridges are either structurally deficient or functionally obsolete [1,2], resulting in a total of about 152,000 bridges requiring immediate repair or replacement. Routine inspection and maintenance are, therefore, essential in any bridge management program to ensure structural integrity, durability, and user safety. To assess the condition of a bridge, a few approaches are commonly used in practice. Visual inspection has been the main approach for assessing bridge condition and documenting signs of deterioration. However, assessing the extent of structural deficiency through visual inspection is usually unreliable [3]. Therefore, there is a need for bridge health monitoring technologies and information management to enable continuous monitoring and to facilitate effective and timely bridge management decisions.

This paper presents a sensor-based bridge health monitoring information system developed for the Parkview Bridge in Kalamazoo, Michigan, USA. Continuous bridge condition data are being collected in real time, archived in the laboratory computer workstation, and analyzed to assess the structural performance and integrity.

II. HEALTH MONITORING SYSTEM ARCHITECTURE

The Parkview Bridge is the first bridge in Michigan to take advantage of accelerated bridge construction techniques, particularly using prefabricated components. A sensor network was designed and deployed to provide an information system for monitoring the performance of the bridge superstructure, especially the structural integrity of the full-depth deck panels [4]. The bridge has four spans and three lanes, with all its major bridge concrete elements including piers, abutments, I-beam girders, and full-depth deck panels prefabricated off site, see Fig. 1. The health monitoring information system for the Parkview Bridge is composed of 184 vibrating-wire strain sensors (VWSG), with built-in thermocouples, installed in the bridge deck panels. Additionally, the system hardware includes 12 multiplexers, 2 data loggers, 2 modems, a remote computer workstation in a laboratory, and the necessary wiring for communication and data transfer.

Fig. 2 provides a schematic view of the designed system. To facilitate the effective monitoring of the bridge performance under varying load conditions, sensors were grouped into four performance categories:

- Group 1 – Longitudinal stresses and temperatures at mid spans and over the piers;
- Group 2 – Transverse stresses and temperatures at mid spans;
- Group 3 -- Stresses and temperatures at joints between panels; and
- Group 4 – Stresses and temperatures on both sides of the CIP grouted joint.

These sensors were used to capture data throughout the day in ten-minute increments to determine maximum and minimum values of stresses and temperatures recorded. In this project, all sensors were attached to the top reinforcement using zip ties with foam spacers to provide cover, see Fig. 3(a). Once the sensors were properly attached to rebar, the wires connecting them to multiplexers were loosely coiled around the reinforcement to allow concrete bonding between the wires and the reinforcement and to prevent any damage that might occur to the wire during the placement of concrete. The wires were run to a four-inch diameter PVC pull boxes to protect them from the concrete during the pour and to provide accessibility to the wires after the installation of the deck panels at the bridge site. Each wire was labeled to indicate the sensor location and orientation after casting. Fig. 3(b) shows a completed sensor network for a panel along with wire routing and pull box placement. Fig. 3(c) illustrates the exposed pull box underneath the deck panels for access and splicing. Sensor wires were spliced together and run through PVC conduits underneath the deck panels to the data logging equipment. The equipment was housed in three cabinets to protect against varying environmental conditions, see Fig. 3(d).

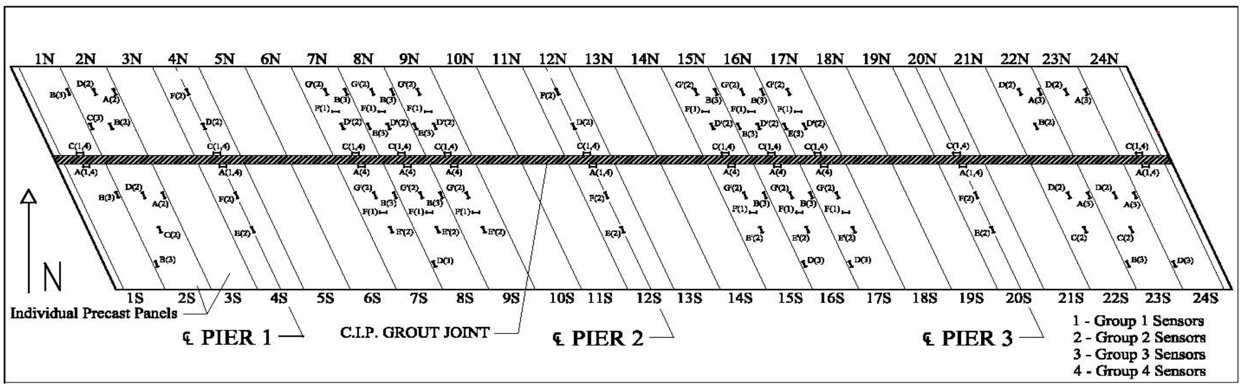


Fig. 1 Parkview Bridge deck layout.

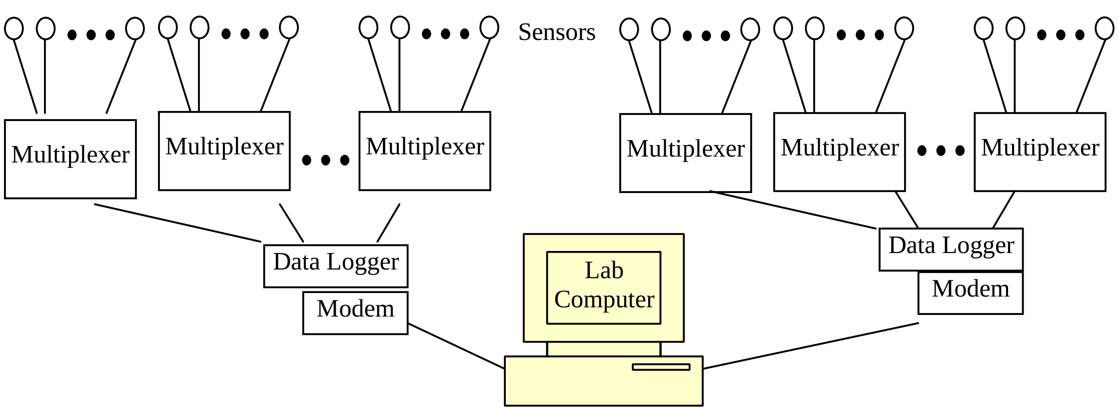
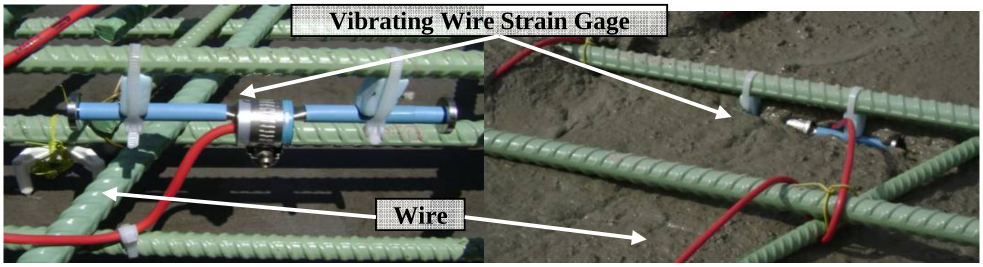
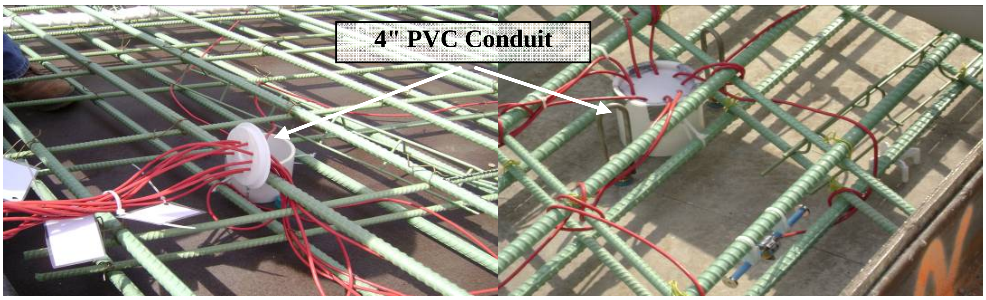


Fig. 2 Schematic view of the Parkview Bridge health monitoring system configuration.



(a) Properly secured sensor



(b) Conduit placement

(c) Exposed Conduit, Wire, and Splicing.

(d) Cabinets and data logging equipment.

Fig. 3 The components and wiring of the sensor network.

III. DATA ACQUISITION AND ANALYSIS

The health monitoring information system started to function in December 2008. Two examples of data analysis are presented below to illustrate how such data is processed and interpreted. Fig. 4 shows the longitudinal stress monitoring for the North panels of Span 2 (Group 1) in June 2009. Note that a negative stress value represents compression. Also, note that the bridge deck is designed to be in compression (deck panels are post tensioned) at all times and that the maximum compression allowed is -3600 psi (-24,821 kPa) and the maximum allowable tension is +537 psi

(+3702 kPa). The coinciding temperatures recorded are illustrated in Fig. 5. It is observed from this figure that the difference in magnitudes between sensors as well as the slope of the lines over similar time periods are fairly similar (almost identical) with respect to temperature, suggesting a uniform behavior. The trend patterns for each sensor in Fig. 4 demonstrate a uniform behavior as well. Since all deck panels are fully restrained between supports, examining Figs. 4 and 5 reveals that as temperature decreases, tension increases, reducing the total compression in the deck panels. It also reveals that as temperature increases, compression increases. The fluctuations between different locations are very minimal, indicating how little effect daily traffic has over the given time period and suggesting that temperature variation is the controlling factor in stress variation.

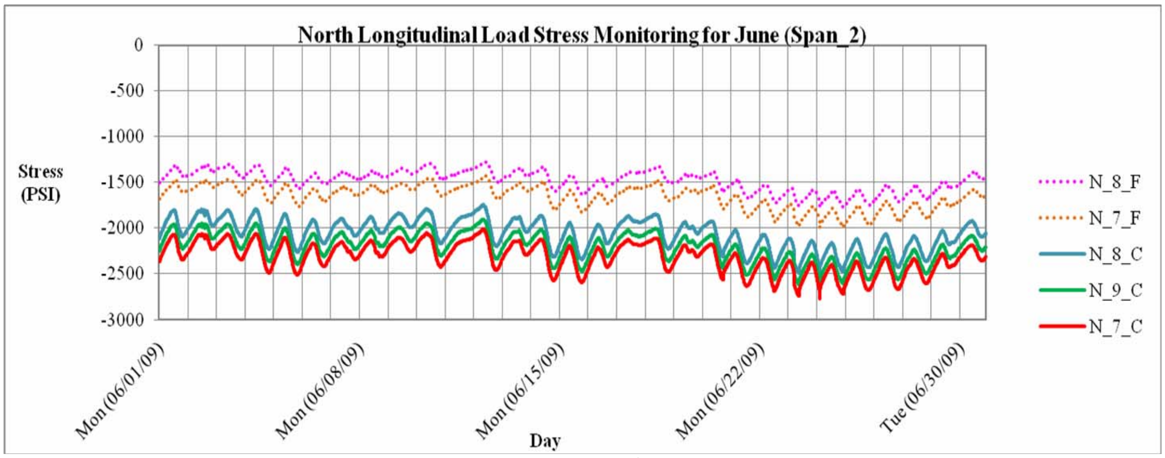


Fig. 4 Longitudinal load stress monitoring for span two (June 2009).

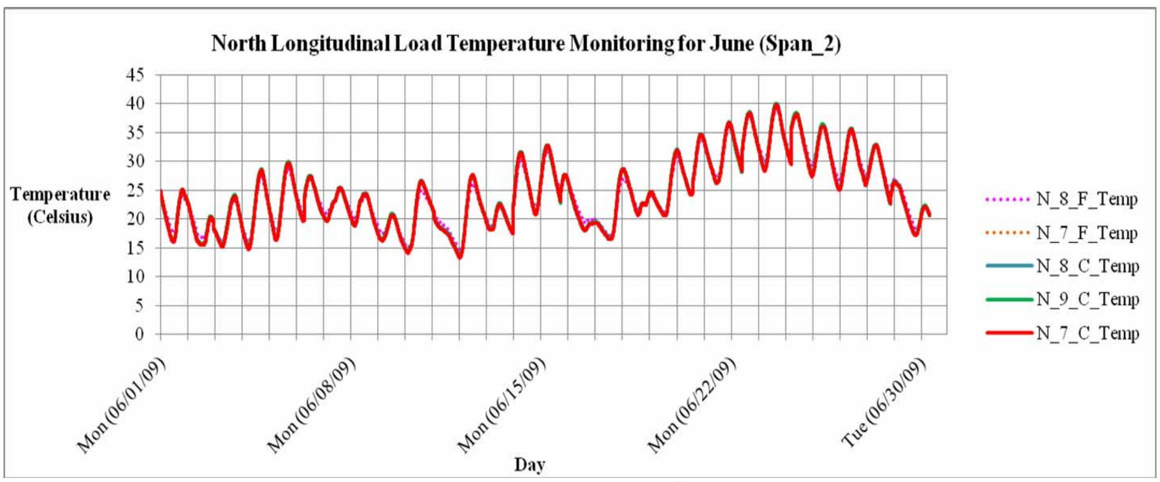


Fig. 5 Longitudinal load temperature monitoring for span two (June 2009).

The stresses at the joints between panels are also very important to monitor. Figs. 6 and 7 show the recorded values for June 2009 for the stresses and their pattern at the joint between North panels 8 and 9 (N-8-B and N-9-E sensors). These sensors should have similar stress patterns in normal condition, indicating an intact joint between the two adjacent panels. If stresses in the adjacent panels begin to show different patterns, then an analysis would be necessary to determine the causes for the change in pattern, which may include the development of cracks that are weakening the bond between the panels.

IV. CONCLUDING REMARKS

The Parkview Bridge sensor-based health monitoring information system is capable of providing continuous monitoring of the bridge deck to determine its condition and assess the impacts from environmental factors such as temperature. Even with limited preliminary data, meaningful observations regarding the bridge performance and the relationship between temperature and stress were obtained, leading to the conclusion that temperature seemed to be the controlling factor in stress variations for this full depth deck design. Data that cover a relatively long period of time, combined with the development of a bridge deterioration model, can help predict future bridge performance and allow for timely preventative maintenance.

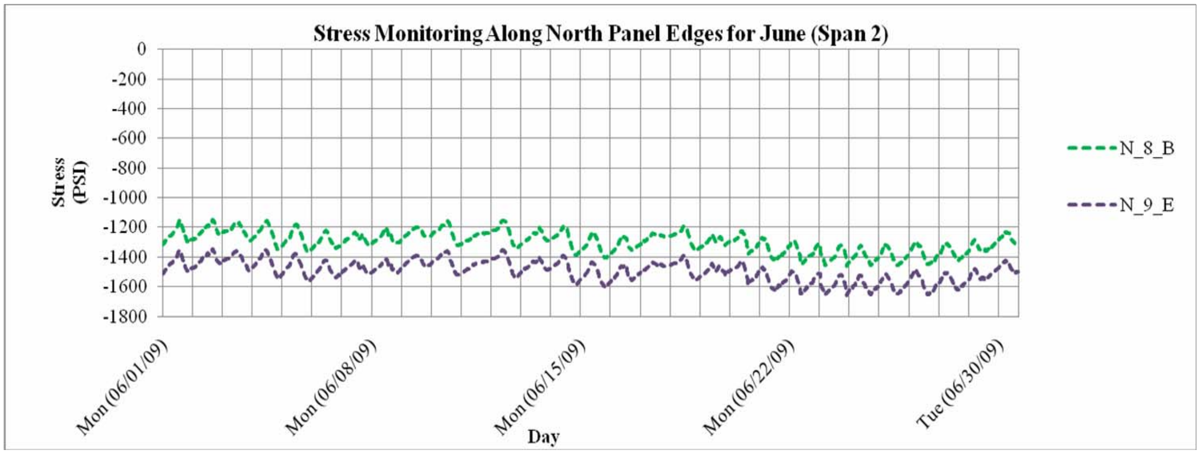


Fig. 6 Stress monitoring at north panel edge for span two (June 2009).

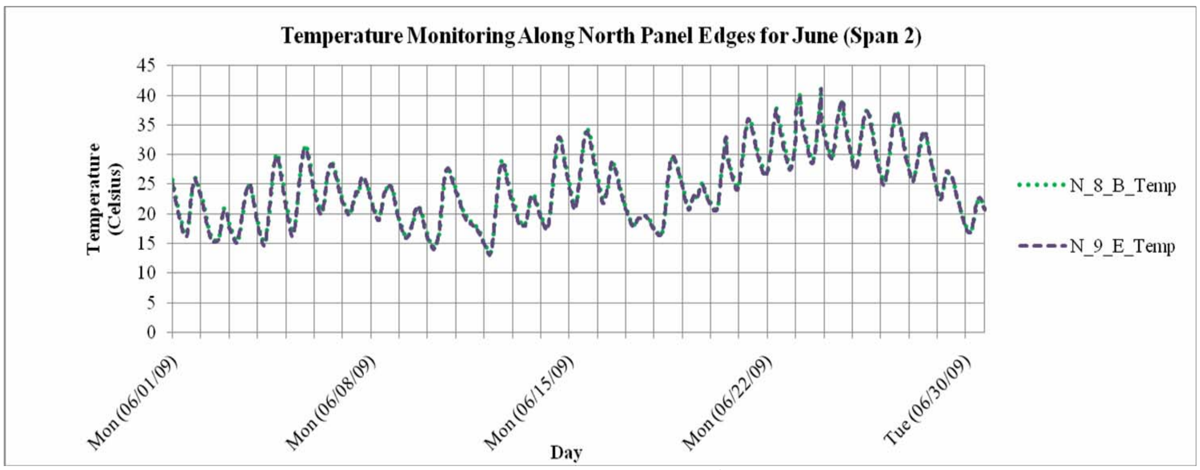


Fig. 7 Temperature monitoring at north panel edge for span two (June 2009).

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