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Technology at work:

Validating performance of new bridge materials and design methods

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The condition of the nation's infrastructure received a significant amount of attention in recent months generating serious debate about bridge safety. Although current bridge inspection and maintenance practices have served Iowa well and continue to be reliable, it is important to investigate the latest advances in structural monitoring technology.

The Iowa Department of Transportation's (Iowa DOT) Office of Bridges and Structures (Bridge Office) is responsible for the design and construction of Iowa's highway structures, and maintains roughly 4,000 bridges. In recent years, the Bridge Office has focused efforts on investigating the use of new high-performance materials, design and construction methods, and supplemental maintenance methods. These efforts are intended to increase the life span of bridges in meeting the objectives for building and maintaining cost-effective, safe bridges. Bridge testing and monitoring have also proven beneficial to determine Plans of Action (POAs) for Iowa's bridges. To help with these testing and monitoring efforts, the Iowa DOT enlisted Iowa State University's (ISU) Bridge Engineering Center.

The Iowa DOT uses bridge testing in numerous situations to supplement typical evaluation methods. The test concept involves taking field measurements—using various sensors and monitoring systems—on a bridge to identify the actual structural response (movement, forces, etc.) typically found under vehicle load conditions. Usually field data is compared with some design-based structural parameter to determine if the response is appropriate. The data may also be used to calibrate an analytical model to provide a more detailed structural assessment (e.g., a load rating to determine safe bridge capacity). Diagnostic testing can also be used to help identify deterioration and damage, or assess the integrity of an implemented repair or strengthening method. In cases where the Bridge Office investigated the use of innovative materials (e.g., high-performance steel [HPS], ultra-high performance concrete [UHPC] or fiber-reinforced polymers) and design/construction methods, testing was used as part of evaluating bridge performance.

Sensors and monitoring systems

One key component associated with testing is the use of sensors and monitoring or data collection systems. Each project has unique objectives, so sensor components and monitoring systems differed depending on specific test requirements. Most testing sensors are conventional electronic-based devices (Figure 1), such as displacement transducers, foil or vibrating wire-strain gauges, and accelerometers for monitoring vibration characteristics.

Figure 1 - *Conventional electronic-based displacement and foil-strain gauges used to evaluate structural connection response.*

For typical one-day tests, the Iowa DOT invested in a testing system that includes sensors, a monitoring and evaluation system (composed of hardware and software) from Bridge Diagnostics Inc. (BDI). This BDI system uses reusable electronic-based strain gauges (Figure 2). Innovative sensors and data-collection systems (fiber optic-based sensors use light wave mechanisms, unlike more typical electronic-based sensors) have also been used for monitoring several Iowa bridge projects. Fiber-optic sensors have been used for longer term, continuous monitoring (Figures 3 and 4).

Figure 2 - *Multiple BDI strain gauges placed on bridge girders for load rating test.*

Bridge monitoring, *continued on page 2*

Bridge monitoring, *continued from front page*

Figure 3 - *Uncoated fiber on hanger rod with sensor (in black package) bonded to the specimen; the actual fiber-optic sensor within the fiber is extremely small (designated by arrow pointing to blue region)*

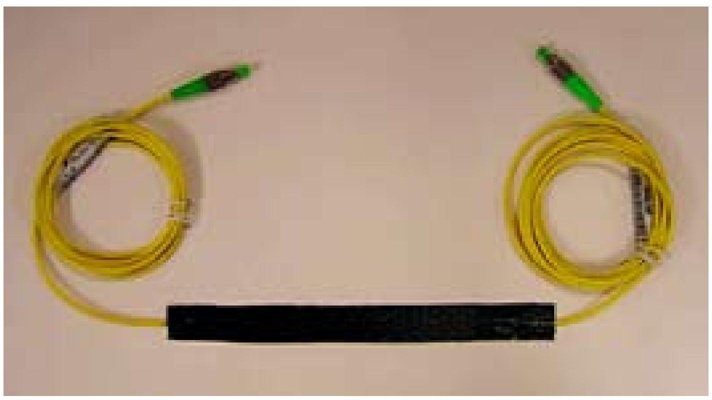

Figure 4 - *The coated fiber leads, on either end of a fiber-optic sensor, are contained within a larger (210 mm x 20 mm) carbon-fiber package and bonded directly to a bridge member.*

Brief project descriptions

Some typical Iowa projects utilizing bridge testing and monitoring illustrating the practical use of structural health monitoring (SHM) technology are:

• **I-235 pedestrian bridges -** The bridges at 40^{th} and 44^{th} streets in Des Moines (two of three pedestrian bridges) were monitored during construction to ensure hangar forces supporting the precast deck units were within specifications. During and after construction of the first pedestrian bridge near the Des Moines Botanical Center (Figure 5), there were indications the forces were not controlled to the desired degree. The Bridge Office decided that monitoring during and after construction of the bridges at 40^{th} and 44^{th} streets would provide better quality control.

Figure 5 - *The I-235 pedestrian bridge near the Des Moines Botanical Center is one of three pedestrian bridges in Des Moines.*

• **Bridge capacity for atypical vehicles -** Overweight and overdimentional permit-issued vehicles—often referred to as superloads—cross bridges on a regular basis. Before the permit is issued the Bridge Office must evaluate the bridge capacity for the atypical vehicle. When an evaluation does not indicate adequate bridge capacity, testing is performed to provide additional information.

Figure 6 - *A permitted vehicle crosses a bridge on U.S. 18 in Cerro Gordo County during bridge testing.*

On one occasion, using several representative Iowa DOT trucks, bridge testing and evaluation were conducted to supplement the typical bridge rating evaluation for the superload. The additional tests determined the permit could be approved. To further validate this decision, the bridge response was monitored during the superload's passage and response data confirmed the load test evaluation was valid (Figure 6).

• **SHM technology -** Several recent, continuous monitoring projects were conducted to develop SHM systems for identifying the potential development of bridge deterioration or damage. The SHM systems used fiber-optic strain sensors and wireless communication on a bridge over the Skunk River in Ames (Figure 7), the first such application of these sensors in the United States.

The first HPS bridge in Iowa was also monitored. The bridge is at East 12^{th} Street over I-235 in Des Moines and the SHM system collected structural performance data continuously from 2004-2006 with typical traffic. The data was processed at the data collection point on the bridge and sent via wireless communication to a Web site operational during the study. The temporary Web site was available through ISU's Bridge Engineering Center Web page and allowed visitors to view real-time data from each bridge sensor as traffic crossed the bridge, illustrating how structural performance monitoring could be observed and used.

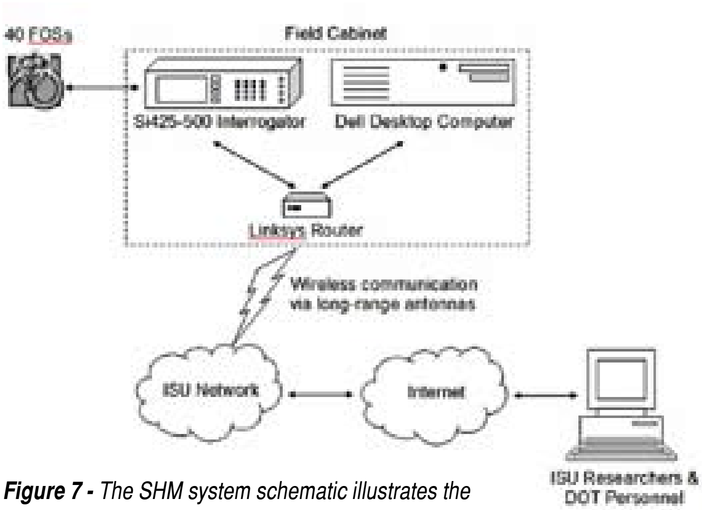

Figure 7 - *The SHM system schematic illustrates the fiber-optic sensors, data collection and processing system, and wireless communication on the U.S. 30 bridge over the Skunk River in Ames.*

Figure 8 - *A truss bridge on Hwy 926 in Fort Dodge that was load tested to validate load-rating results.*

Another application using SHM to supplement the typical rating process is the Iowa 926 bridge over the Des Moines River in Fort Dodge (Figure 8). After the collapse of the I-35W Mississippi River bridge in Minnesota, the Iowa DOT evaluated bridges with similar design details for structural capacity and safety. The Iowa 926 bridge was one of the bridges investigated. The Bridge Office utilized bridge testing to provide supplemental information for validation of its bridge rating evaluation.

Figure 9 - *Precast approach slab unit prior to placement in O'Brien County*

• **Accelerated bridge construction (ABC) -** The Bridge Office has been investigating the use of ABC to improve bridge durability and reduce construction time. This concept was used on new and existing bridges to address bridge approach slab problems (Figure 9), such as the bump at the end of a bridge due to settlement. The ABC method can alleviate traffic interruptions and delays and construction-zone safety concerns. ABC typically involves using large, precast concrete bridge components shipped to the bridge site and assembled.

The first step in implementing ABC is to develop reliable and effective design concepts, and the Iowa DOT has explored various concepts for bridge superstructures and substructures on several projects. To evaluate these concepts and provide improvements for future implementation, the Bridge Office has used monitoring and testing during and after construction. As a result of these demonstration projects, the Iowa DOT developed modified-design concepts for future projects. To advance this effort, the Iowa DOT is collaborating with the Federal Highway Administration (FHWA) to host a regional ABC workshop in August 2008.

• **UHPC projects -** The Iowa DOT has also investigated using UHPC for two bridge projects supported by FHWA funding through the Innovative Bridge Research and Construction (IBRC) Program. This program has provided funds for research and demonstration bridge construction to city, county and state agencies using new and innovative materials and methods since 1998. Testing and evaluation must be completed to verify the success of the UHPC applications. UHPC is very high strength, has low permeability and does not use typical structural steel reinforcing. It has the potential to provide more durable bridges with extended service.

The first bridge built in the United States using UHPC was in Wapello County, Iowa, in 2005. Engineers designed the bridge, monitored construction and evaluated utilization of this material (Figure 10). With no design specifications in existence for this material, the Bridge Office used laboratory and bridge testing to validate the bridge's design procedure and assess field performance.

Figure 10 - *The United States' first UHPC bridge was built in Wapello County (deck placement after UHPC I-shape girders placed).*

Bridge monitoring, *continued on back page*

Bridge monitoring, *continued from page 3*

The results will provide guidance on standardization of bridge design procedures and provide information for improving material application.

Currently, the Iowa DOT is working on the next generation UHPC girder-shape (Pi-shape) bridge in Buchanan County for a similar demonstration and testing. This bridge will once again put Iowa at the national forefront of bridge design and construction implementation using the UHPC shape (Figure 11).

Figure 11 - *The first bridge in the United States to use new generation Pi-shaped girders will be constructed in Buchanan County.*

The next step is a collaborative effort with Wapello County to advance the use of UHPC in bridge decks, where it is most beneficial. A waffle-shaped UHPC slab is proposed for a high-performance deck on a traditional beam bridge.

Summary

The Iowa DOT's Office of Bridges and Structures, in cooperation with the Bridge Engineering Center at ISU, utilizes some of the most technologically advanced health monitoring devices to test the safety of Iowa's bridges and validate the performance of new construction materials and bridge design methodology. For additional information on this technology, visit http://www.dot.state.ia.us/bridge/research.htm.

Bridge monitoring

About the authors

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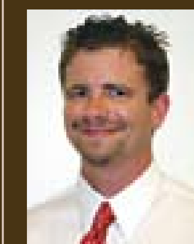

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The Iowa DOT's Research and Technology Bureau proudly announces the launch of a redesigned and updated Web site. The site has a wealth of transportation research information on Iowa's current research activities. Search for recent or past research studies, learn how to submit research ideas, find information about the Iowa Highway Research Board, and read *Research News*—the bureau's quarterly newsletter. Visit www.iowadot.gov/research for more information.

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