2010-39TS
Published December 2010

RESEARCH SERVICES

OFFICE OF POLICY ANALYSIS, RESEARCH & INNOVATION

TECHNICAL SUMMARY

Technical Liaison:
Moises Dimaculangan, Mn/DOT
Moises.Dimaculangan@state.mn.us

Administrative Liaison:
Shirlee Sherkow, Mn/DOT
Shirlee.Sherkow@state.mn.us

Principal Investigator:
Arturo Schultz, University of Minnesota

PROJECT COST:
$85,000

Waterproof housings allow for on-site installation of electronics necessary to power the sensors and acquire data.

Development of an Advanced Structural Monitoring System for Fracture-Critical Steel Bridges

What Was the Need?

While not inherently unsafe, fracture-critical bridges have at least one nonredundant structural component whose failure would lead to collapse of the bridge. As they age, such bridges require more frequent on-site inspections than other types, and these inspections are costly. Advanced monitoring of bridges using on-site sensing systems has the potential to provide more information about a bridge's health more quickly and at a lower cost, ensuring safer bridges and saving dollars.

Researchers developed an advanced continuous monitoring system for steel bridges that would provide a distress warning of likely imminent collapse.

Following the collapse of the I-35W bridge in August 2007, Mn/DOT adopted the goal of developing technology that could be used to effectively monitor fracture-critical bridges. Current commercial technologies for distress warning are triggered by the collapse of the bridge being monitored. Bridge caretakers would much prefer a system that warns of imminent collapse or other serious circumstances that could be addressed by immediate repair and/or closing of the bridge to traffic.

To fill this gap, Mn/DOT has funded an ongoing research effort aimed at developing and deploying a structural monitoring system to provide advance warning of distress. (After this project began, the Minnesota Legislature also passed a law requiring that all fracture-critical bridges be monitored.) The Mn/DOT report "Bridge Health Monitoring and Inspection: A Survey of Methods" (2009-29) describes researchers' work with Mn/DOT bridge engineers to generate criteria for the evaluation and selection of bridge monitoring systems and technologies, and to develop a spreadsheet-based program to aid in assessing which commercially available systems best fit the monitoring requirements of a given site.

A research gap that still needed to be filled was monitoring specific to steel tied-arch bridges, a specific class of fracture-critical bridges that have a history of problems with cracking in the welds and joints.

What Was Our Goal?

The objective of this project was to develop a detailed design for a monitoring scheme of a selected tiered-arch bridge with at least 10 years of remaining service life. This would involve determining the most appropriate monitoring technology and producing cost estimates and overall specifications for placement of monitoring equipment.

What Did We Do?

In cooperation with the Mn/DOT bridge office, researchers selected the Cedar Avenue/MN 77 bridge for monitoring. The bridge is 30 years old and a major commuting thoroughfare in the Minneapolis-St. Paul area.

The designed system focused on monitoring vibrations from stress waves to detect the formation or growth of local fatigue cracks in the steel structural members: steel connections, box ties, floor beams and cables. The selection tool developed in 2009-29 was used to choose acoustic emission (AE) technology to monitor and analyze the development and propagation of fatigue cracks. AE sensors pick up vibrations in the material to which they are attached. These vibrations are characteristic of the underlying material

continued

"This research is part of Mn/DOT's ongoing effort to develop robust monitoring of fracture-critical bridges in Minnesota."

—Moises Dimaculangan,
Bridge Rating Engineer,
Mn/DOT Bridge Office

"One of the goals of advanced warning systems is to prevent the loss of life and property for both bridge users and bridge owners."

—Arturo Schultz,
Professor, University of
Minnesota Department of
Civil Engineering

Built about 30 years ago, the Cedar Avenue bridge carries MN 77 over the Minnesota River to connect Minneapolis to the southern suburbs. It is a steel tied-arch bridge that is considered fracture-critical: The design lacks redundancy such that failure of a structural member could lead to collapse. As such, it was selected for this project to develop advanced structural monitoring systems.

and structure, and computer analysis of the AE sensor output reveals these characteristics. AE sensors are permanent on-site devices that provide a continuous stream of monitoring information. Depending upon placement and position of the sensors, both local and global monitoring systems can be built.

In a local monitoring system, the sensors are placed at the location of known cracks and fractures. They can be used to monitor the growth of both surface and internal cracks, which would otherwise be missed by visual inspection. In a global monitoring system, the sensors are used to determine where cracks originate as well as to track how they propagate over time. In general, global monitoring systems require significantly more sensors and equipment, increasing their cost relative to local monitoring systems.

Researchers generated specifications for both the local and global systems using a finite-element model of the Cedar Avenue bridge. In the model, major structural components and connections of the bridge were included and the virtual bridge was then loaded and tested to identify locations of high-stress regions ("hot spots") optimal for sensor location.

Using these design specifications, researchers also developed an implementation plan for the monitoring system including pricing; an installation schedule and procedure; and plans for initial testing, verification and maintenance of the equipment.

What Did We Learn?

The components for both local and global bridge monitoring systems are commercially available, and the spreadsheet-based monitoring technology selection tool previously developed worked well. Ultimate evaluation of the capabilities of the monitoring system itself will occur after installation.

What's Next?

As part of a second phase of this study, researchers are currently deploying a reduced version of the local monitoring system developed in this project at the Cedar Avenue bridge. The goal of this second phase is to fine-tune the placement of the sensors in the complete system using data to be collected over a one-year period on the Cedar Avenue bridge.

Produced by CTC & Associates for:
Minnesota Department
of Transportation
Research Services Section
MS 330, First Floor
395 John Ireland Blvd.
St. Paul, MN 55155-1899
(651) 366-3780
www.research.dot.state.mn.us

This Technical Summary pertains to Report 2010-39, "Development of an Advanced Structural Monitoring System," published November 2010. The full report can be accessed at http://www.lrrb.org/PDF/201039.pdf. *This project uses the results of Report 2009-29, "Bridge Health Monitoring and Inspections—A Survey of Methods," which may be accessed at* http://www.lrrb.org/PDF/200929.pdf.