Monitoring 'work horse' bridges
Structural health monitoring system with more than 200 sensors is tested on a smaller, non-signature bridge.

By Leonard Dzengelewski, P.E.

The Vernon Avenue Bridge in Barre, Mass., is one of the first "work horse" bridge projects in the country to implement a structural health monitoring system, incorporating more than 200 sensors.

During a time of aging bridge infrastructure and limited funds for improvements, pressure is mounting to make costly repairs in a timely, efficient fashion. Fortunately, technologies are emerging that help ensure our nation's bridges will have a longer service life and that users will have safe passage.

**Research team**

- Masoud Sanayei, Ph.D., professor, Department of Civil and Environmental Engineering, Tufts University, served as principal investigator (PI).
- Erin Santini Bell, Ph.D., associate professor of civil engineering, University of New Hampshire, served as the co-PI.
- Brian Brenner, vice president at Fay Spofford and Thordike and a Professor of the Practice at Tufts, also contributed as a co-PI for the project.
- Allen Marr, Ph.D., P.E., president and CEO, Geocomp Corporation, served as the main partner for instrumentation and data acquisition.
- Graduate students at Tufts University and the University of New Hampshire played a major role in instrumentation, data acquisition, and analysis of the Vernon Avenue Bridge using the measured nondestructive test data.

One such technology is structural health monitoring (SHM), a concept that centers around the idea that a bridge can provide engineers with important information about the strains and stresses associated with everyday usage. SHM, which is utilized as a complementary approach to traditional visual inspections, can provide structural condition assessment and performance evaluation information that's both reliable and objective.

In the past, SHM instrumentation took place on existing structures. However, a recent bridge project in a small central Massachusetts town is helping to change this approach. The construction process for the Vernon Avenue Bridge in the town of Barre, Mass., involved implementing a SHM system, thus making it one of the first "work horse" bridge projects in the country to do so. Some larger signature bridges have SHM systems, but the Vernon Avenue Bridge is not a signature bridge. As a smaller bridge spanning a river, it may not draw national attention, but its continued operation is vital to the community it serves.

**Project's origins**

The research project's roots go back to January 2008, when the National Science Foundation-Partnership for Innovations (NSF-PFI) selected a team from Fay Spofford & Thordike (FST), Tufts University, the University of New Hampshire, and Geocomp Corporation to participate in a collaborative partnership titled, "Whatever Happened to Long-Term Bridge Design?" The partnership sought to evaluate bridge design procedures to facilitate long-term monitoring, as well as develop protocol...
As part of the work, the partnership designed and installed an instrumentation system. The bridge's system of more than 200 sensors provides the partnership's researchers with a great opportunity to observe many different types of bridge behavior.

In support of the NSF project, the central Massachusetts town of Barre, in coordination with the Massachusetts Department of Transportation, granted the research team access to the construction of the Vernon Avenue Bridge. The research team's involvement centered on developing structural baseline analytical models of the bridge, an instrumentation plan, and protocol to help compare predicted behavior.

Concrete thermistors were tied to reinforcing bars prior to the placing the bridge deck. Data was collected throughout the construction process, including during the concrete deck pour.

Strain gauges and thermistors were installed on the steel girders at the steel fabrication yard prior to delivery to the construction site.
Two structural models
Prior to SHM instrumentation, the research team created two structural models (fine and course) with Computers & Structures Inc.'s SAP 2000 software. The fine model used solid and shell elements; the coarse model utilized Bridge Modeler with shell and frame elements. Using these models, an instrumentation plan was designed that featured more than 200 sensors, including strain gauges, tiltmeters, accelerometers, and temperature gauges.

The Vernon Avenue Bridge – which opened to traffic in September 2009 – is a three-span, continuous steel girder bridge with a composite reinforced concrete deck. The structure's specifications are as follows:

- The bridge measures 47 meters long with a 23.5-meter center span and two 11.75-meter secondary spans.
- The south and center spans are 12.7 meters wide and widen to approximately 19 meters at the north abutment to accommodate the intersection with state highway MA-122.
- Six main girders run the length of the bridge, evenly spaced at 2.25 meters apart.
- There are seven diaphragms along the length of the bridge and a Barre water line running underneath the deck.

The research team's instrumentation plan featured:

- One-hundred strain gauges, 36 steel thermistors, 30 concrete thermistors, 16 bi-axial tiltmeters, and 16 uniaxial accelerometers at 13 stations along the length of the bridge. Data from these sensors are collected continuously using iSite data acquisition boxes provided by Geocomp Corporation.
- Strain sensors and thermistors distributed along the length of each girder on both sides of the web with the exception of the exterior girders, which only have instrumentation on the interior face. Each girder was fabricated in two parts with a splice located just off the north pier. All iSite data acquisition boxes were placed on the south end of the girders for ease of access to a power supply and communication source.
- Two pressure plates were installed on the approach span to capture the vehicle weights of the ambient traffic.

Wires were wrapped for transportation; each gauge was environmentally protected. Meanwhile, concrete thermistors were tied to reinforcing bars prior to the deck pour. Tiltmeters and accelerometers were installed at the bridge site after girder erection and deck casting, but prior to commissioning. Data was collected throughout the construction process, including during the concrete deck pour and a load test, which took place after completion of the bridge.

This element of the Vernon Avenue Bridge project allowed the research and construction teams to work together closely. Instrumentation and data acquisition never impeded on the construction schedule. Project costs were not adversely impacted as well. Overall, the construction and project teams' cooperation and commitment was paramount to making this unique project a success.

Bridge load rating using nondestructive test data
Some bridges in the U.S. interstate highway system are load posted because of structural deficiencies. However, these bridges may have additional load-carrying capacity that is not accounted for in the traditional load rating analysis approach, which is based on elemental as opposed to 3D system behavior. The American Association of State Highway and Transportation Officials allows for the use of nondestructive test data for capturing the 3D system behavior of the bridge, which may lead to determination of a higher load-carrying capacity.

Using the nondestructive static and dynamic test data, 3D computer models of the Vernon Avenue Bridge were calibrated. Calculations from the calibrated models showed some additional load-carrying capacity in comparison with the traditional analysis approach.

A controlled load test is the ideal way to obtain a known response for a monitored bridge. However, if temperature loadings cause a similar response to that of a load test, the natural cyclic temperature loadings on a bridge may be used instead of a load test or to supplement it for model calibration and successful performance of a SHM system. Successful application of temperature effects in this way would greatly improve the feasibility and use of SHM to assist bridge monitoring and maintenance, particularly since load tests can be expensive and disruptive.

This year, the Vernon Avenue Bridge research team focused on calibrating structural models by temperature response. This approach has proved to be more challenging than the static and dynamic response from the controlled load tests. Weights and positions of trucks can be accurately determined. However, measuring and analyzing temperature response of a structure is more difficult.

Transforming bridge design and management
SHM is emerging as an important element for the sustainable management of public works infrastructure systems. Regular and effective use of SHM for bridges can provide more objective data and lead to improved maintenance and a more efficient use of resources. Simply put, this technology has great promise at a time of aging infrastructure and limited funds.
The Vernon Avenue Bridge project demonstrated that SHM instrumentation can be achieved successfully during the construction process. Also, the project proved that such instrumentation can be done while significantly reducing installation costs and increasing the benefits of the gathered data.

Acknowledgements
The project was supported by a grant from the National Science Foundation-Partnership for Innovations Program (Number 0650258) with assistance from the National Science Foundation CAREER Program (Number 0644683). The town of Barre, owner of the bridge, provided access and ongoing help with coordination for all phases of the project. Likewise, the Massachusetts Department of Transportation provided coordination and assistance. The bridge constructor, E.T. & L. Corporation, and its steel fabricator, High Steel Inc., provided access, assistance, and coordination during bridge construction.

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