

STRUCTURAL FORENSICS

investigating structures and their components



The Vernon Avenue Bridge in Barre, Mass., was one of the first “work horse” bridge projects in the U.S. to involve implementing a structural health monitoring system.

A unique project in Barre, Mass., is helping to transform the way bridges are designed, constructed, and managed. With support from the National Science Foundation, the construction process for the Vernon Avenue Bridge involved implementing a structural health monitoring (SHM) system, 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.

The Vernon Avenue Bridge, which spans the Ware River, is a three-span, continuous, steel girder bridge with a composite reinforced concrete deck. The bridge measures 47 meters long (154 feet) with a 23.5-meter center span (77-foot) and two 11.75-meter secondary spans (38.5-foot). There are six main girders, evenly spaced at 2.25 meters (7.4 feet) apart, which run the length of the bridge.

The research project’s roots go back to January of 2008, when the National Science Foundation-Partnership for Innovations (NSF-PFI) selected a team of researchers from Fay Spofford & Thorndike (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 for a structural health monitoring system.

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

Vernon Avenue Bridge

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The bridge construction crew conducts the pour.





Three of the steel girders at the steel fabrication plant in Lancaster, Penn.

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 measured with predicted behavior.

How It Works

Prior to SHM instrumentation, the research team created two structural models (fine and coarse) with SAP 2000®. 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.

This particular aspect of SHM instrumentation features its own set of challenges. SHM is based on the concept that a bridge can provide data regarding its own strains and stresses under various loading conditions. This is accomplished by determining specific locations for the various types of sensors and monitors used. Also, placement of the sensors and monitors must be balanced with the desired information sought in order to make the best use of the data collected. Too many or too few monitors or sensors can provide an overload or an insufficient amount of information, rendering data hard to decipher.

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 continuously collected 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.

What Made The Project Unique?

The most unique aspect of the Vernon Avenue Bridge project was how SHM



The Vernon Avenue Bridge project serves as an example of how to successfully instrument a structural health monitoring system during the construction process.



A strain gauge is installed on a prepared surface.

instrumentation was completed during the construction phase. The strain gauges and thermistors were installed at the steel fabrication yard of High Steel, Inc., in Lancaster, Pennsylvania. The installation was done after steel fabrication was complete and prior to delivery to the construction site.

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 the concrete deck pour and during the load test, which took place after completion of the bridge.

This element of Vernon Avenue Bridge project allowed the research and construction teams to work together closely. Instrumentation and data acquisition never impeded on the construction schedule. Also, project costs were not adversely impacted.

Overall, the construction and research 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 due to 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 Transportation Officials (AASHTO) allows for the use of nondestructive test data for capturing the three-dimensional system behavior of the bridge, which may lead to determination of a higher load carrying capacity.

Three-dimensional computer models of the Vernon Avenue Bridge were calibrated using the nondestructive static and dynamic test data. Calculations from the calibrated models showed some additional load carrying capacity in comparison to the traditional analysis approach.

Studying the Effects of Temperature on Bridge Response

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 an SHM system. Since load tests can be expensive and disruptive, successful application of temperature effects in this way would greatly improve the feasibility and use of SHM to assist bridge monitoring and maintenance.

In 2011, the research team has focused on calibrating structural models by temperature response. To date, this approach has been 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.

A Smart Decision

The Vernon Avenue Bridge, which opened to traffic in September of 2009, is now serving residents and visitors of Barre. Just as important is that the project will serve as an example of how to successfully instrument a structural health monitoring system during the construction process for use in short-term and long-term bridge structural health monitoring.

During a time of aging bridge infrastructure and limited funds for improvements, this type of SHM instrumentation can be a smart decision. Installation during construction may reduce overall costs of SHM systems and improves feasibility of their use. In the long run, successful leveraging instrumentation, monitoring, and modeling technologies will allow for more accurate and cost-effective bridge management both today and in the future. ■

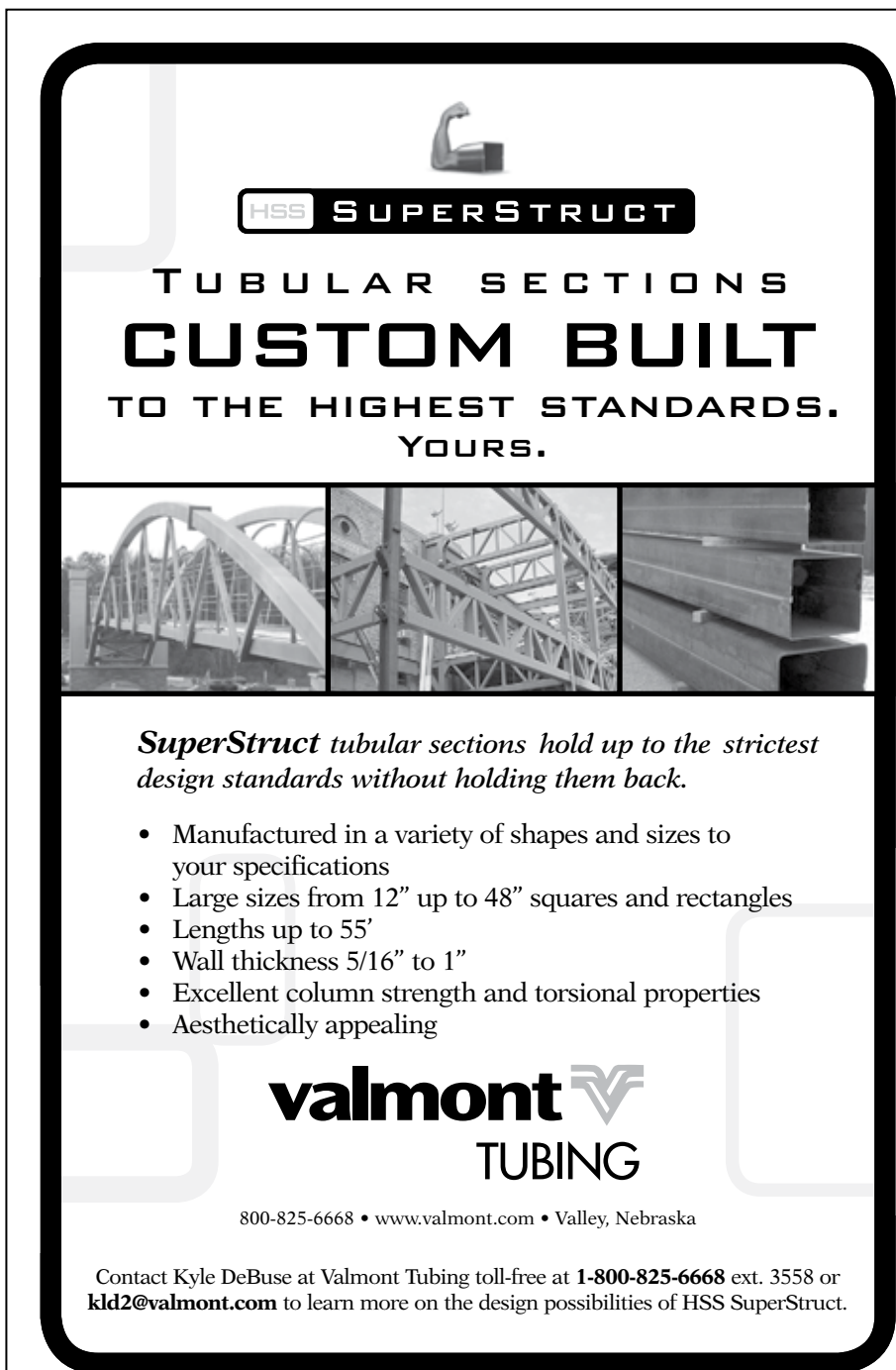
The Research Team


Professor Masoud Sanayei of Tufts University served as Principal Investigator (PI).


Associate Professor Erin Santini Bell of the University of New Hampshire served as the Co-PI. Brian Brenner, a Vice President at Fay Spofford and Thorndike and a Professor of the Practice at Tufts, also contributed as a Co-PI for the project. Dr. Allen Marr of 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 the instrumentation, data acquisition, and analysis of the Vernon Avenue Bridge using the measured nondestructive test 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 their steel fabricator, High Steel, Inc., provided access, assistance, and coordination during bridge construction.





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