SMART BRIDGES

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Bridging the visual gap

Tobin Bridge goes beyond visual inspections with electronic health monitoring

In the next 18 months, the Massachusetts Port Authority’s (Massport) Tobin Memorial Bridge will be the state’s first bridge to have a wireless high-tech structural health monitoring system (SHM) in place to monitor stresses and strains in a real-time environment.

The Tobin Bridge will be one of only a handful of the nation’s 600,000 bridges to have this “smart,” wireless capability for indirect detection.

The Tobin Bridge, also known as the Mystic River Bridge, is a major arterial link serving Boston and northeastern New England. It was built almost 60 years ago and carries an estimated 26 million vehicle trips each year. The Tobin Bridge is a double-deck, cantilever-style bridge with an overall width of 36 feet between curbs. It is 2 1/4 miles long with three lanes of traffic in each direction along U.S. Rte. 1. It is separated into five components, which include:

• Boston approach: Built-up plate girders with spans (21 upper and 19 lower) ranging from approximately 84 to 103.5 feet;
• Little Mystic truss: Single-span Warren truss over the Little Mystic channel with a span length of 440 feet and a height of 65 feet;
• Toll plaza and administrative offices: This 12-span structure connects the Little Mystic and Big Mystic trusses over the Charlestown section of Boston. Built-up plate girders are used in this area similar to the Boston and Chelsea approaches. To accommodate the toll plaza, the roadway widens from 36 to 110 feet. Bridge administrative offices are situated two levels below the existing toll plaza;
• Big Mystic truss: The main span of the bridge consists of a three-span cantilevered truss with an overall length of approximately 1,530 feet. The suspended span has a length of 800 feet and a vertical clearance of 135 feet for navigation within the Mystic River. The peak of the truss is 115 feet above the lower chord; and
• Chelsea approach: The north approach, located in the city of Chelsea, is constructed of built-up plate girders. The roadway gently curves at this portion of the bridge. The 36-span approach structure has varying span lengths ranging from 77.5 to 103.5 feet.

Weather in the Northeast is notoriously harsh, and use of deicing salts combined with traffic and con-
Construction loads can help speed up both the seen and unseen processes of deterioration on bridges. Federal law requires all bridges in the U.S. to undergo a visual inspection every two years. As the owner and operator of the Tobin Bridge, Massport takes this mandate very seriously. The agency also takes it one step further: Every four years, Massport conducts a comprehensive foot-by-foot inspection to maintain the Tobin Bridge’s good condition. The assessment takes about three months for bridge engineers to complete. The new smart-bridge technology will enhance these regular inspections with real-time continuous information. More importantly, it will help to serve as an early detection system, enabling engineers to address conditions of interest as they develop and before they become potential problems.

**Smart Q&A**

“Smart Bridge” or “Bridge Health Monitoring” concepts center around the idea that a bridge itself can provide engineers with important information about the strains and stresses associated with normal day-to-day use. The trick is to ask the bridge the right questions. The way to do this is determined by the locations where sensors and monitors are placed on the bridge and the types of sensors and monitors used. Tilt meters, strain gauges and GPS monitors are some of the tools that will be used to gather information on the Tobin Bridge. Interpreting the transmitted answers must consider factors such as the external temperature, the temperature of the bridge itself, traffic loads, construction loads and the condition of the members and components being monitored. How “smart” a bridge can be depends on the extent of the monitoring done and the value of the information being provided. 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, providing an overload or insufficient amount of information, can render data impossible to decipher.
Comparing virtual and material bridges

Before the smart technology can be deployed, computerized interactive models of the Tobin Bridge need to be created. These models will be calibrated against actual conditions on the bridge using wireless sensors. The data will then be transmitted back to a remote site for analysis. Conventional two-dimensional (2-D) models are commonly used for determining stresses and deflections. They invoke well-known principles of structural analysis. However, the analysis of complex bridges such as truss structures in 2-D could make assumptions that will not detect problems arising over the life of the bridge. Three-dimensional (3-D) models provide information from all planes. The models take into account sources and movement that cannot be determined from a 2-D analysis.

Smart-bridge technology is real-time information relating to the behavior of a bridge. The more detailed investigation of internal forces and stresses in members, using finite-element analysis, gives engineers more precise information relating to a specific component of the bridge, such as the behavior of a gusset-plate connection. When comparing measured data in the field with the predictions of the computer model, unanticipated forces or movements may indicate the structure is performing in a way that may need repair or maintenance. For example, expansion bearings may be frozen and in need of replacement. This knowledge may result in modification to the expansion joint or bearings to avoid future maintenance problems.

In an effort to learn more about the behavior of the Tobin Bridge, Massport brought in an engineering consulting firm at a total project cost not to exceed $1 million. The firm will conduct structural modeling and analysis of forces and strains on the Tobin Bridge using a 3-D computer engineering model. Fay, Spofford & Thorndike (FST), located in Burlington, Mass., was chosen based on their overall qualifications and innovative approach. The firm’s knowledge base also is strengthened through an academic partnership with experts in the fields of structural engineering and computer analysis from Tufts University and the University of New Hampshire. A fourth member of the team, Geocomp of Boxborough, Mass., brings to the job worldwide expertise in placement and application of instrumentation.

As a starting point, FST is working on the 3-D modeling, verification of results and recommendations for sensor and monitor placement on the Little Mystic truss and a six-span girder plate module on the Boston approach. These portions of the bridge were selected for their relatively simplified geometry in relation to the toll plaza and Big Mystic truss areas. A second phase for the Big Mystic truss also is under way.

The Little Mystic truss contains many more members than the six-span plate-girder unit, and the initial process of inputting the coordinates and member properties can be made quickly with the use of computer-aided design and drafting (CADD) software. The results of the model for dead loads demonstrate accuracy with the dead-load stresses indicated on the original design drawings of the Tobin Bridge prepared in 1948.

A study of the restraint assumed at the connections (fixity) at the Little Mystic truss (pinned vs. fixed) will compare field observations and the analysis of fixed joints. The intention is to confirm the engineer’s understanding that at least partially fixed conditions are a part of the structure’s behavior. Spring constants will be used to modify the Tobin Bridge’s 3-D model as updated information is obtained from the field verification, sensors and monitors.

Tuning the instruments

Further verification of the 3-D model results will be obtained by test loading of the Tobin Bridge once the sensors and monitors are installed. The test loading will consist of positioning fully loaded trucks along the bridge and recording the results. The test must be conducted when no other vehicle loading is on the portion of the span that is being tested. This will require that both decks of the Tobin Bridge be closed to traffic for a short period of time.

The results of the test loading will help Massport engineers verify that the 3-D models are correctly predicting forces within the Tobin Bridge’s members and components. Once the verification process is complete, the models can then reliably be used to identify critical information points for sensor and monitor placement.
These areas will include locations where elevated stress levels or unexpected deflections have been observed.

At this writing, the initial 3-D models of the Tobin Bridge are still in development. Therefore, all key locations for sensor and monitor placement have not yet been finalized along with total project cost. Selected locations were identified allowing for some basic information to be obtained from the Little Mystic truss, Boston approach and the Big Mystic truss. Limited installation is scheduled for strain gauges to detect changes in stress, GPS-unit placement and tilt meters that will gather data resulting from seasonal temperature fluctuations. In addition to the stress and positioning information, the installation will allow engineers to evaluate instrument performance, data transmission and physical damage throughout the winter months.

After initial analysis of the Little Mystic truss, the Boston approach and the Big Mystic truss is complete, the team will evaluate other locations for the placement of additional sensors and monitors. These locations will include areas indicating high levels of stress and where behavior of the Tobin Bridge shows a variation from established benchmarks. These locations will include areas where finite-element studies have been performed. This placement will allow for further verification of stress analysis and possible refinement of the finite-element model.

In 2007, our nation learned a hard lesson from the collapse of the I-35W Bridge in Minnesota. The goal of the structural engineer is to prevent such disasters from taking place. Wireless smart technology is emerging as the cutting-edge approach to assess the structural health of older bridges. And advancements to global positioning systems and wireless technologies make wireless more cost-effective compared with a wired network. The timing is right for Massport to implement it. Massport’s goal is to learn from the sensors and monitors put into operation on the Tobin Bridge. The knowledge will allow engineers to prioritize maintenance and repair work. The results of the new technology also will allow Massport to share findings with other agencies around the country.

Sleiman is the director of capital programs and environmental affairs for the Massachusetts Port Authority.

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