Integration of Structural Health Monitoring (SHM) into Multilayer Statewide Bridge Maintenance and Management Practices – SHM-Facilitated Condition-Based Maintenance (SHM-CBM) Prioritization System

tech transfer summary

A bridge asset management system based on structural health monitoring and condition-based maintenance uses real-time performance and condition data to effectively and efficiently prioritize bridge maintenance and repairs.

Problem Statement

Current bridge inspection and maintenance approaches have several limitations. The bridge condition ratings collected by many agencies only reflect deterioration or damage, not structural deficiency, and the linear models used to predict performance do not capture the actual aging process or individual bridge differences. Moreover, the current corrective and preventive approaches used by bridge owners may lead to under- or over-maintenance.

Objectives

The objectives of this project were to develop a bridge maintenance prioritization system that integrates structural health monitoring (SHM) techniques into current bridge management practices and to financially justify SHM solutions.

Iowa's I-80 Sugar Creek Bridge that was used for the case study

September 2018

RESEARCH PROJECT TITLE
SHM into Multilayer Statewide Bridge Maintenance & Management Practices

SPONSORS
Midwest Transportation Center
U.S. Department of Transportation Office of the Assistant Secretary for Research and Technology
Federal Highway Administration
Transportation Pooled Fund TPF-5(219)
(Part of Intrans Project 10-367)

PRINCIPAL INVESTIGATOR
Brent Phares, Director
Bridge Engineering Center
Iowa State University
515-294-5879 / bphares@iastate.edu
(orcid.org/0000-0001-5894-4774)

MORE INFORMATION
intrans.iastate.edu

MTC
Iowa State University
2711 S. Loop Drive, Suite 4700
Ames, IA 50010-8664
515-294-8103

The Midwest Transportation Center (MTC) is a regional University Transportation Center (UTC). Iowa State University, through its Institute for Transportation (InTrans), is the MTC lead institution.

MTC's research focus area is State of Good Repair, a key program under the 2012 federal transportation bill, the Moving Ahead for Progress in the 21st Century Act (MAP-21). MTC research focuses on data-driven performance measures of transportation infrastructure, traffic safety, and project construction.

IOWA STATE UNIVERSITY
Institute for Transportation

Background

The many rapidly aging bridges in the US require frequent inspections, repairs, or rehabilitation to keep them safe and functional. In addition, bridge owners must balance the need to maintain bridges in good condition against limited maintenance and repair budgets.

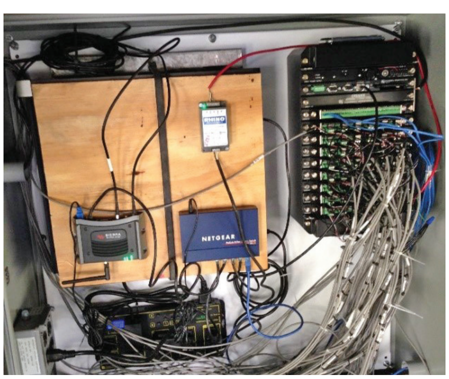
Agencies use bridge management systems (BMS) to predict the future conditions and remaining service lives of their bridges and, thus, schedule needed repairs or maintenance. In many states, biennial visual inspections and standardized condition states are used to rate bridge condition. Future condition is often predicted using a linear model that assumes a consistent decrease in ratings over time.

Inspection and maintenance can be improved with SHM. SHM uses sensors, data acquisition, and communication hardware and software to assess bridge condition in real-time and predict future condition and performance.

Currently, most bridge owners prioritize maintenance funding using corrective and/or preventive maintenance approaches. With corrective maintenance, a bridge is operated until a defect appears, at which point the defect is addressed. With preventive maintenance, maintenance is scheduled based on bridge deterioration models and is performed before a severe failure occurs.

Condition-based maintenance (CBM) is a potentially effective maintenance approach that actively monitors asset condition to perform maintenance only when it is needed and at the most opportune times. CBM is common in other fields but has not been used widely in bridge asset management.

At the same time, SHM systems are often not used due to their relatively high installation and operation costs, and CBM has not been used in bridge asset management because current bridge inventory data are not sufficient to implement CBM. However, by integrating the continuous real-time or near-real-time bridge condition data collected by SHM into bridge inventory data, an SHM-facilitated CBM (SHM-CBM) framework is possible.



Typical field installation of SHM equipment

Methodology and Case Study

The foundation of the proposed SHM-CBM bridge maintenance prioritization system is a ranking index that establishes a maintenance funding priority for all bridges in a particular inventory by assigning each bridge an index number. A higher index number means a lower maintenance funding priority.

The ranking index is computed using two sources of data:

- Biennial bridge inspection and codified structural analysis data from the National Bridge Inventory (NBI) which are used to determine the Inventory Index (II). The II represents the prioritization level of the bridge.
- Continuous real-time or near-real-time SHM sensing data or derived data fed into a formula to obtain an SHM modifier (SHMM). The SHMM tunes the value of the II up or down to reflect up-to-date bridge condition information and the bridge owner's opinion as to how the SHM data should affect maintenance decision making. (If SHM data are not available, the SHMM is simply 1.0.)

To obtain the ranking index, the II and SHMM are multiplied.

To demonstrate the methodology, an Excel spreadsheet was developed using 21 bridges from the Iowa bridge inventory. Only one bridge had SHM data available (I-80 Sugar Creek Bridge, FHWA #22380). IIs were obtained from NBI data, and the SHMM was calculated using SHM inputs and user-configurable factors.

To weigh the costs of SHM equipment, installation, and operation against the benefits in terms of extending bridge service life, reducing maintenance costs, and preventing bridge collapse, a life-cycle cost analysis was performed using Iowa's I-80 Sugar Creek Bridge SHM as a case study. The annual costs of the bridge were determined with and without SHM instrumentation.

Key Findings

- The demonstration of the methodology showed that the replacement of the I-80 Sugar Creek Bridge might be postponed by up to 37 years because the SHM-CBM system showed that the condition of the bridge is better than previously assumed.
- The SHM cost-benefit analysis showed that the potential extension of service life and the anticipated savings in maintenance, repair, and monitoring costs make SHM implementation financially justifiable.
- Using the calculated ranking index measure fulfills the federal law that requires bridge owners to use data-driven approaches to bridge maintenance and repair.

Implementation Readiness

This project provides a framework for implementing an SHM-facilitated CBM prioritization system. This system integrates real-time or near real-time SHM data into the most commonly used statewide bridge maintenance and management practices.

While individual bridges should be evaluated before implementing SHM, the proposed SHM-CBM system can be implemented immediately on appropriate bridges.

SHM may not completely replace traditional bridge health monitoring systems, and the small number of SHM systems currently in place make SHM data impractical to use as a primary prioritization tool. However, SHM data can be a valuable supplement to current bridge inspection procedures and can help bridge owners comply with federal requirements.

Implementation Benefits

SHM-CBM has the following advantages over current decision-making approaches:

- Continuous and near real-time SHM data for maintenance decision making
- Wide range of quantitative data can be gathered using SHM (e.g., strain and temperature, chloride infiltration, tilt, and corrosion)
- Reduced uncertainty about structural performance
- Elimination or reduction of over-maintenance and deterioration or failure due to a lack of information about a bridge's true condition

The initial financial investment into SHM has been shown to be justified in the long term, and SHM is cost-effective over the life of a bridge.