Development of a Structural Health Monitoring System to Evaluate Structural Capacity and Estimate Remaining Service Life for Bridges

tech transfer summary

A structural health monitoring system and condition rating prediction models developed at the Bridge Engineering Center can aid bridge owner agencies in developing an improved bridge maintenance prioritization system.

Problem Statement

The desire of many departments of transportation (DOTs) is to augment their existing inspection process and maintenance system with a system that can objectively and more accurately quantify the state of bridge health in terms of condition and performance, aid in inspection and maintenance activities, and estimate the remaining life of their bridge inventory in real time.

Background

Bridges constitute the most expensive assets, by mile, for transportation agencies around the US and the world. Most of the bridges in the US were constructed between the 1950s and 1970s. Consequently, an increasing number of bridges are getting old and requiring much more frequent inspection and repairs or rehabilitation to keep them safe and functional. With tight construction and maintenance budgets, bridge owners are faced with the difficult task of balancing the condition of their bridges with the cost of maintaining them.

Bridge maintenance strategies depend on information used to estimate future condition and remaining service lives of bridges. The purpose of future bridge-condition assessment is to determine when to undertake repairs or maintenance to keep bridge condition within acceptable limits. The estimation of residual or remaining life is an important input for budgeting and setting longer-term repair and maintenance priorities.

I-80 SHM system demonstration bridge in Iowa

BRIDGE ENGINEERING CENTER

January 2020

RESEARCH PROJECT TITLE
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SPONSORS
Iowa Department of Transportation
(InTrans Project 10-367)
Federal Highway Administration
Transportation Pooled Fund TPF-5(219)

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The Bridge Engineering Center (BEC) is part of the Institute for Transportation (InTrans) at Iowa State University. The mission of the BEC is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

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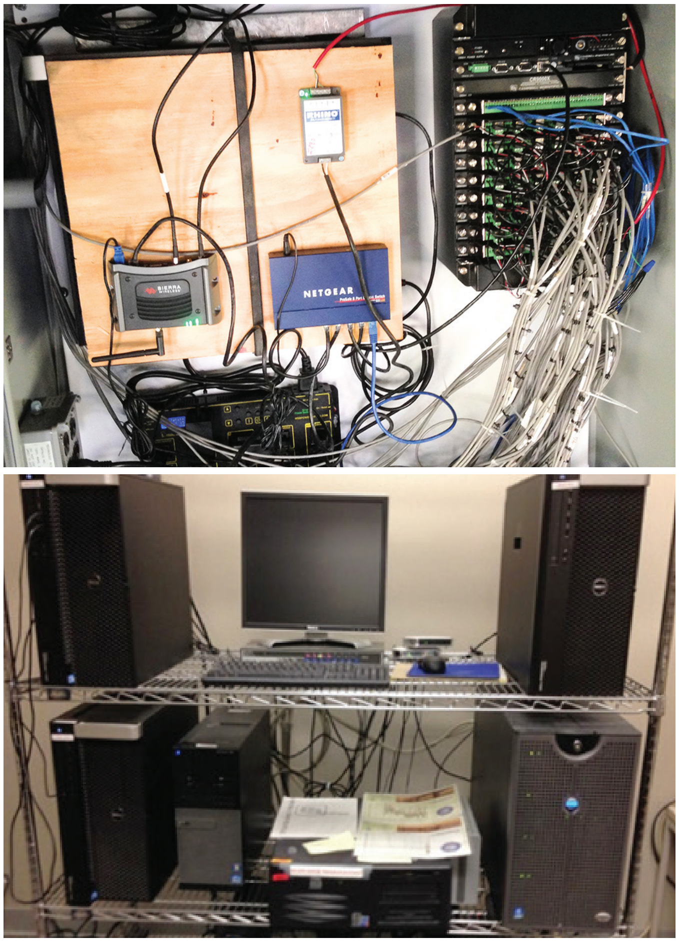

Typical Bridge Engineering Condition Assessment System (BECAS) computer hardware arrangement: field installation in a cabinet on-site (top) and data processing cluster in the office (bottom)

To better manage bridge inventories, tools that can accurately predict the future condition of a bridge, as well as its remaining life (i.e., when a bridge will become substandard in terms of load carrying capacity, serviceability, and/or functionality), are required. Essential to estimating the future condition of structures is having an accurate understanding of the current condition of the structure.

Objectives

This project had three primary objectives, to develop the following:

- An automated structural health monitoring (SHM) system capable of detecting bridge damages and estimating the load ratings of bridges in real-time or near real-time
- Condition rating prediction models, using biennial bridge inspections in the National Bridge Inventory (NBI) database, to predict future condition ratings of bridges
- A bridge maintenance prioritization system that integrates SHM techniques into current bridge management practices

Project Description

Strain-based bridge damage detection: The research team investigated a control chart-based damage detection algorithm, F_{shm}, by minimizing the variability due to temperature and truck configuration. F_{shm} control charts were constructed with different combinations of strain data and statistics- and structure-based limits were established to reduce the false indication rate.

Estimating the load ratings of bridges: Using four steel-concrete composite sections, the research team tested whether there was a relationship between moment of inertia and flexural strength of composite sections. The idea, then, was to use the finite element model (FEM) calibrated moment of inertia from the current load rating process to get an improved estimate of flexural strength.

Condition rating prediction models: The research team developed two different types of future condition rating prediction models—using NBI database data and sojourn time types. The models were called the current practice model (CPM) and the deterioration prediction model (DPM). CPM is capable of simulating the effects of historical maintenance activities when predicting the future condition rating probabilities, whereas DPM does not consider the effects of historical maintenance activities when predicting the future condition rating probabilities.

Bridge maintenance prioritization system: The research team developed a method of calculating a ranking index by using an inventory index, such as NBI data, and an SHM modifier (SHMM). The SHMM uses seven parameters (load rating ratio, load rating rate of change, behavior change, service level stress rate of change, service level stress margin, expert opinion, and reduced uncertainty), with each given a weighting factor to provide owner agencies the opportunity to customize their approach.

Key Findings

- For improved damage detection, in order to obtain enough strain data for limits, increasing the temperature bin size is required. However, a higher temperature bin range also creates higher strain variability. Therefore, a suitable temperature bin size is an important factor in terms of the amount of strain data available for establishing limits and strain variability.
- To estimate load ratings, the result of the team's experiments indicated that the theory of strength of materials and the American Association of State Highway and Transportation Officials (AASHTO) guidelines, along with actual material properties (when available), can accurately predict the moment of inertia and flexural strength of a section. In the absence of actual material properties, a Monte Carlo simulation along with the moment of inertia from the calibrated load rating model may significantly improve the rating factor of a bridge.

- For condition rating prediction models, quantitative evaluation results show that sojourn time is an important parameter when predicting future condition ratings, whereas the age of the bridges does not play as an important role in predicting the future condition ratings of bridges. The predictions, however, were entirely dependent on the original historical data of the bridges, which are subjective.
- For the condition rating prediction models, the CPMs tended to converge to condition rating 6 on a scale of 0 to 9 within 15 years, whereas the DPMs tended to converge to condition rating 4 with 15 years. This suggested that conducting current maintenance activities helps to keep the nation's bridges in at least satisfactory condition. However, not performing any maintenance could lead bridges to be structurally deficient within 15 years.
- For a bridge maintenance prioritization system, using SHM data as a "tuning" factor rather than the dominant factor is the most practical way to implement SHM in the short term due to the relatively limited availability of SHM systems, and may well be more practical over the long term as well.

I-280 in Illinois (top) and US 151 in Wisconsin (bottom) SHM system demonstration bridges

Implementation Readiness and Benefits

For this project, the research team developed an automated SHM system that could detect bridge damage and estimate load ratings of bridges, and also developed models to predict future condition ratings of bridges. The SHM system and models were then used to develop a bridge maintenance prioritization system that can help DOTs and other bridge owners to augment their current bridge management practices.

Based on past performance of the SHM system in implementation over approximately the past five years, the system is working well and providing useful information for bridge engineers. The SHM system provides comprehensive and significant information for assessing bridge condition in real time. The SHM system has multiple capabilities including (1) bridge engineering condition assessment, (2) truck detection methodology, (3) strain-based damage detection, (4) changes in bridge behavior, (5) load rating using ambient traffic, (6) prediction of bridge condition ratings, and (7) bridge condition-based prioritization system using SHM and CBM.