An Experimental Validation of a Statistical-Based Damage-Detection Approach

tech transfer summary

Damage-detection techniques may provide ways to increase public safety for those who travel over the thousands of bridges currently in use.

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RESEARCH PROJECT TITLE
An Experimental Validation of a Statistical-Based Damage Detection Approach

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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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Objective

This study is primarily an experimental validation of the damage-detection algorithm developed by Lu (2008).

Problem Statement

The United States infrastructure continues to deteriorate and bridge inspections continue to play a crucial part in ensuring the safety of all who cross over the bridges. As visual inspections of each bridge become more difficult and costly, transportation departments are looking toward other methods of measuring the structural integrity of highway bridges, including structural health monitoring (SHM) systems. SHM systems have been in development for many years and are becoming more prominent throughout the United States.

Damage detection, with respect to SHM, is the means of determining if damage exists in the structure by changes in modal parameters, differences in strain, or other changes in behavior over time. The development of damage-detection techniques has been ongoing for about 20 years and can be as straightforward as determining that damage has occurred somewhere in the structure and as complex as determining the location and severity of the damage.

Research Description

For the experimental validation completed in this work, a two-girder, fracture-critical demonstration bridge that was previously instrumented with fiber-optic sensors was utilized. This demonstration bridge, the eastbound US 30 bridge over the South Skunk River, has numerous fatigue-sensitive locations and typifies the need for the SHM system.

A number of sacrificial specimens, to which damage could be introduced, were mounted on the bridge, with loads induced by ambient traffic. The sacrificial specimens modeled the damage-sensitive locations of the test bridge and damage was induced to the sacrificial specimens in the form of cracks and simulated corrosion.

Typical installed sacrificial specimen

Each sacrificial specimen was connected to the existing SHM system and data were collected from the undamaged and damaged sacrificial specimens. The previously-developed algorithm was used to detect the damage in the sacrificial specimens. The damage-detection algorithm was able to identify damage, but it also had a high false-positive rate.

An evaluation of the sub-components of the damage-detection methodology and methods was completed for the purpose of improving the approach. Several of the underlying assumptions within the algorithm were being violated, which was the source of the false-positives.

The linear prediction models and the normalcy of the residual and R-sum data were evaluated to determine if previously-made assumptions held true for collected data. It was determined that some of the data are not taken from a normally-distributed population. This finding is important, as the construction of the control charts is based on the assumption of normally-distributed data. Therefore, new methods of damage quantification were developed and evaluated: orthogonal prediction models and the F-Test.

An orthogonal prediction model is an orthogonally fit line through the strain range data creating orthogonal residuals, which are the perpendicular distance from the strain ranges to the prediction model. The F-Test uses a comparison of two different models and orthogonal residuals to calculate an F-value, which is then used for damage detection; the large F-values represent possible damage indicators.

Findings

1. Damage can be autonomously detected by the damage-detection algorithm as long as the damage is “close enough” to a sensor. However, it is not known how close is “close enough.”
2. There is a loose correlation between the level of damage and the distance between the mean training data and the post-damage data. Specifically, the mean of the data collected from a smaller amount of damage (i.e., a 2.0 in. crack) is closer to the mean of the training data than the data from a larger amount of damage (i.e., a 6.0 in. crack). A comparison of the means of the data collected from incremental amounts of damage proved inconclusive (See future work outlined under Implementation Readiness).
3. The damage-detection algorithm has a relatively high false-positive detection rate. It was determined that the residual values for the sensors nearest to the damage influence the R-sum values for the other sensors during the simplification process.

Implementation Readiness

Additional work is required to create a turnkey system that is ready for full implementation:

1. Finalization of hardware and software components

The initial work on the US 30 bridge used a monitoring system with fiber-optic sensors. Although these sensors have many desirable attributes, there have been instances where sensors have been damaged and the sensors have unexplainably stopped working. Therefore, it is recommended that the hardware system be reconfigured to use traditional sensors. Additionally, because there are multiple recommended changes to the algorithm, it is necessary to modify the existing software applications.

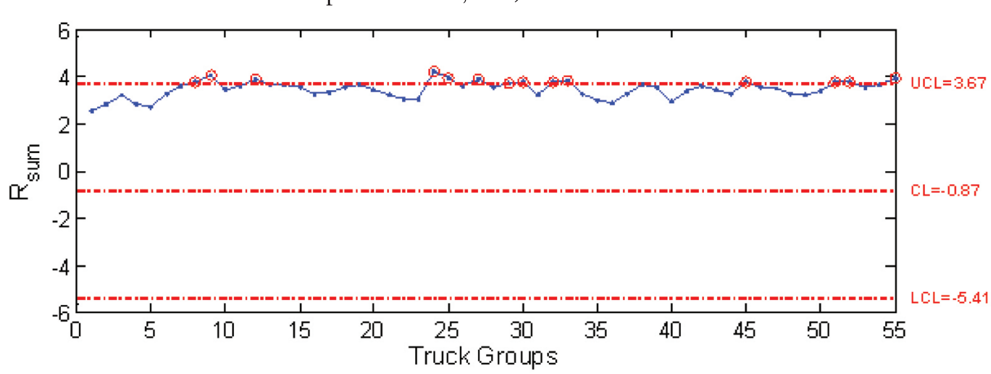
2. Integration of dynamic structural properties

The damage-detection system was originally configured to only use time-domain metrics. With an expressed interest by the Iowa Department of Transportation (DOT) Office of Bridges and Structures in modal measurement approaches, it is recommended that work be conducted to identify frequency domain metrics that fit into the algorithm. Once identified, these metrics would be included in the hardware and software systems.

3. Determination of system Probability of Detection (POD)

This work has demonstrated that the system can autonomously detect damage. It is not known, however, what the probability of detecting different sizes of damage is. It is also not known, in terms of sensor placement, how “close” is “close enough.” Therefore, a POD study is recommended, so that the reliability of damage detection (including crack size, proximity to damage, false-positive rate, etc.) can be determined.

Top of bottom web plate cracking



Sample control chart indicating damage detection (red-circled data points above the upper control limit (UCL)