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IMPROVEMENT OF EVALUATION METHOD FOR EXISTING HIGHWAY BRIDGES

PROBLEM STATEMENT

About 40 percent of the nation's highway bridges are structurally deficient. These deficient structures potentially endanger the safety and economical use of the highway system. The National Bridge Inspection Standards (NBIS) require that every bridge on a public road be inspected at least every two years. Highway agencies across the nation have inspection staffs and programs to collect and update critical bridge inventory and inspection data. Nowadays, there is still an evident need to perform a more precise evaluation of structural function and to find effective solutions. In Florida, short to middle span bridges constitute the majority of highway bridges, and they have been in service for a long period of time. In these bridge structures, local damage unavoidably occurs due to natural corrosion and the long-term action of passing vehicle loads.

Recent research has addressed some robust ways, such as using vibration monitoring of highway bridges, for detecting structural deterioration. The latest results have demonstrated that the global modes of a subject structure are effective both in identifying the development of significant damage and in isolating its location. In this damage detection process, pre-damage and post-damage modal parameters of modes measured from the test structure are utilized to localize the damage. However, it is important to apply these new developments and to establish an improved technique in a deterioration rating system for highway bridges.

The aforementioned method of detecting deterioration is especially efficient for short and medium span bridges, which have been widely used in the state of Florida. Potential dangers may not be found merely by means of human visual inspection. Therefore, it is necessary to develop an advanced diagnostic method to maintain and manage highway bridges.

OBJECTIVES

The objective of this research is to develop a new damage detection and diagnostic method for evaluating highway bridges. The proposed method is based on modal parameters which are frequencies, damping ratios, Energy Transfer Ratios (ETR) index, and static data, such as deflections and strains. Specific objectives include the following:

1. Review the literature relevant to the methods used to detect and locate damage, as well as to monitor structural health conditions.
2. Establish the identification methods of dynamic parameters in the frequency domain and in the time domain. Then, illustrate the basic theory of the modal Energy Transfer Ratio (ETR) and the foundation for the extraction of ETR.
3. Perform static and dynamic testing on the model bridge.
4. Perform damage detection and analysis.

FINDINGS AND CONCLUSIONS

1. The ambient and impact signal processing techniques were studied to implement the bridge monitoring. The cross-correlation function between two response measurements under white noise excitation demonstrated a decaying form, and, therefore, a traditional system identification method can be used to estimate vibration signatures of the structures. The time-domain poly-reference and the Single Degree of Freedom (SDOF) identification methods were adopted to identify the vibration signatures. This study has established the possibility of developing an on-line bridge monitoring system based on the cross-correlation analysis method.

2. A 1:6 scaled signal span slab-on-girder model bridge was manufactured in the laboratory. Similitude laws for static and dynamic modeling were satisfied. The dynamic properties of the model bridge were identified through ambient testing and impact testing, and agreement was achieved between these tests. The linkage between the "controlled damage" of bridge and the vibrational signatures was found to exist. Frequency comparison between testing and finite element calculation indicates that the majority of frequencies are in agreement.

3. The frequencies and damping ratios identified by using SDOF modal identification method under various damage conditions were compared with those under intact condition. Various damage indices were found to have different sensitiveness to different types and extents of damage. Modal parameters, such as frequency and damping ratio, are not sensitive to the bearing damage or girder cracking.

4. Static parameters, such as deflections and strains, were extracted from the experimental data to identify the damage. The findings are as follows:

   (1) The deflection is sensitive to the bearing damage, but not to girder cracking damage.
   (2) The strain is sensitive to girder cracking damage, but not to bearing damage.
   (3) Deflection is a global static signature, while strain is a local static signature. Changes of deflection or strain may indicate the occurrence and the location of damage. However, these indications strongly rely on the measured positions.
   (4) Under the extent of external loading, the load-deflection relationships and the load-strain relationships still remain linear after the damage occurred. That means the non-linearity caused by damage is very small.
   (5) It is difficult to apply the ordinary load-deflection curves to detect the damage. However, the load-strain curves may be used to identify the damage, if the baseline model of intact condition of a structure exists.

5. The primary studies indicate that the ETR index is heavily affected by the signal-to-noise ratio. The primary conclusions are summarized as follows:

   (1) ETR is very sensitive to the bearing removal. The biggest change in ETR before and

after bearing removal is 4524%, which is much larger than the largest changes in natural frequencies (8.43%) and damping ratios (123.47%). The change in ETR can be used to indicate the damage and/or condition changes of bridges due to bearing damage.

(2) ETR is also very sensitive to a simulated girder cracking. The biggest change in ETR is 1614%, which is much larger than the largest changes of natural frequencies (7.45%) and damping ratios (67.26%). The changes in ETR can be used to indicate the damage and/or condition changes of bridges due to girder cracking.

(3) ETR is much more sensitive to the introduced bridge damage than to natural frequencies and damping ratios.

(4) Natural frequencies and damping ratios are global vibrational signatures and can well indicate the occurrence of damage and/or condition change of bridges. However, they cannot be used to locate the position of damage and/or the condition change. They should be used together with ETR for the purpose of bridge damage detection.

BENEFITS

How to detect bridge damage has become one of the most important issues in bridge engineering. The objective of this research project was to investigate a new bridge damage detecting and diagnostic method. In this project, the research team designed a bridge model, simulated different types of bridge damage, and performed different static and dynamic model tests as well as theoretical analysis. The most important finding in this research is that the ETR Index is very sensitive to different types of bridge damage. The sensitivity of the ETR Index to bridge damage is much higher (200 to 500 times) than that of the bridge frequency/damping ratio. If the ETR Index can successfully be applied to the actual bridges, then the majority of bridge damage can be detected by vibration tests. The findings and their application should be of great benefit to Florida Transportation System.

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