Damage Detection and Damage Localization in Bridges with Low-Density Instrumentations Using the Wave-Method: Application to a Shake-Table Tested Bridge

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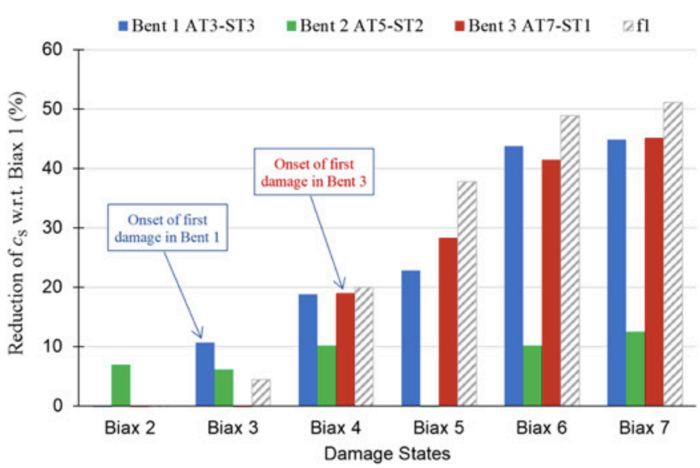

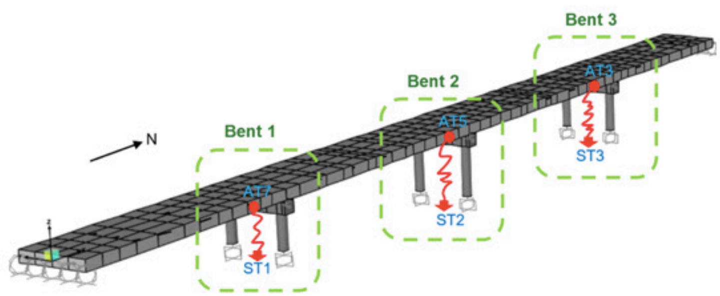

Introduction

This study presents a major development to the wave method, a methodology used for identifying dynamic and material characteristics of a structure via motion waves in the structure. The research team tested the method for use in structural damage detection and damage localization in bridges following an earthquake, the latter being a challenging task. The main goal was to assess the ability of the method by applying it to a shake-table tested prototype bridge. The bridge tested at the University of Nevada Reno, was a 4-span reinforced concrete structure comprising two columns at each bent (6 columns total) and a flat slab. It was tested using seven base excitations, which progressively damaged the bridge to failure.

The team particularly tested the wave method to locate damage in the bridge, which is a very challenging task for bridges with a sparse instrumentation. Using the wave method, the team identified changes in the shear wave velocities in the bridge piers from one event to another. The changes in velocities are proportional to changes in the piers' stiffness and can be used as a damage indicator for the bridge. Availability of a robust and tested method, which can work with sparse recording stations, can be valuable for detecting and localizing damage in bridges soon after an earthquake. Such a rapid health monitoring technique can prevent large monetary losses due to the unnecessary closure of a safe bridge.

Study Methods

The bridge identification method in this study involves a cantilevered Timoshenko beam (TB) model. The process includes estimating the shear (c_S) and the longitudinal (c_L) wave velocities in the bridge by fitting an equivalent uniform TB model in impulse response functions of the recorded response. The identification algorithm is enhanced by adding the model's damping ratio to the unknown parameters. The team further improved this project's algorithm by performing the iterations for a range of initial values to avoid early convergence to a local minimum. Finally, damage was detected by monitoring changes in the identified wave velocities from one damaging event to another. The method utilized the recorded acceleration at different segments of the bridge, which helped localize the most severe damage in the columns. A summary of actual damage observed at the bridge was used to assess the accuracy and limitations of the wave method.

Findings

A comparison between the trends in shear wave velocities (c_s) and the actual observed damages at piers (e.g., concrete cracks, rebar failure, etc.) revealed that the reduction of c_s is generally consistent with the observed distribution and severity of damage during each excitation. At bent 1 and bent 3 (see image below), c_s is consistently reduced with the progression of damage. The trend in reduction of c_s correctly detects the onset of damage at bent 1 during biaxial 3 motion, while the trend shows the onset of damage in bent 3 during biaxial 4, both consistent with surveyed damage in the tested bridge. The most significant reduction was caused by the last two biaxial motions in bents 1 and 3, also consistent with the surveyed damage. In bent 2 (middle bent) the reduction trend in c_s was relatively minor, correctly showing minor damage at this bent. The authors conclude that the enhanced wave method presented in this study was capable of detecting the progression of damage in the tested bridge and was able to identify the location of the most severe damage. This provides an opportunity for using the method for damage detection is similar bridges.

Practice Recommendations

Given its performance, the proposed methodology can be used as a fast and inexpensive tool for near-real-time damage detection and localization in similar types of bridges, especially those with only a few accelerometers deployed on the deck and foundation level. Such instrumentation layouts are common for bridges and overpasses instrumented by the California Geological Survey (CGS); therefore, the method could be a supplementary damage indicator for emergency responders and bridge inspectors in the state of California.

The team's analysis also revealed that placing an accelerometer on top of each pier provides more useful data compared to placing it at the mid-span of the bridge.

About the Author

Dr. Mehran Rahmani is an Assistant Professor in the Civil Engineering and Construction Engineering Management (CECEM) department at California State University, Long Beach. He earned his PhD in Structural and Earthquake Engineering from the University of Southern California (USC) in 2014. He is a registered Professional Engineer (PE) in the state of California.

Ms. Xintong Ji and Mr. Sovann Reach were graduate students majoring in structural engineering at California State University Long Beach. They graduated in summer 2020 and spring 2021, respectively, each with a master's in structural engineering.

To Learn More

For more details about the study, download the full report at **transweb.sjsu.edu/research/2033**

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