Dynamic characterization and structural identification for civil engineering applications

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Background

Structural health monitoring and condition assessment is an important topic in civil engineering; undetected damage growth in a structure could lead to catastrophic failure.

Vibration based methods concern the global assessment of a structure, using modal data (eigen frequencies, damping ratios and mode shapes) and other damage sensitive features extracted from dynamic measurements.

Sung-Soo Grand Bridge in Seoul: one span fell into the river as a result of breakup of the linkage pins due to heady traffic, 1994

The key to the success of a method in the real structural and measurement environment lies on the practicality in obtaining the required dynamic data and the robustness of the parameter identification (or model updating) procedure.

This research aims to develop a robust structural identification framework using reliable dynamic data (particularly natural and artificial boundary condition frequencies) with the aid of artificial intelligence algorithms. The framework will be employed in the dynamic characterization and assessment of railway bridges

Methodology

- Using artificial boundary condition (ABC) method to expand the measurable frequency dataset.
- Using a robust genetic algorithm in a FE model based parameter identification procedure with enhanced (frequency) measurement dataset.
- Verifying the procedure with laboratory experiments.
- Improving the experimental methods (such as using controlled random excitation where possible); improving the measured frequency response data with special processing techniques to minimize the noise influence.
- Extracting modal data from real measurements on railway bridges; conducting numerical parametric studies using updated FE model to investigate the dynamic effects of the passing trains on the bridge response.

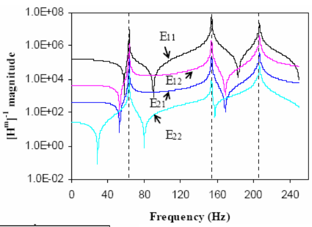
ABC frequencies and GA based parameter identification framework

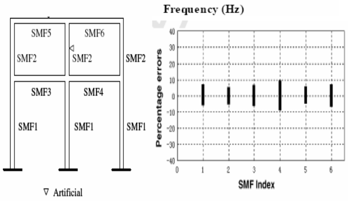
ABC frequencies can be extracted by inverting an incomplete frequency response function (FRF) matrix measured at targeted "pin" support locations.

Such frequencies proved to be effective in identifying structural stiffness parameters in a previous study by the research group (Tu and Lu 2007).

The ABC frequencies, together with natural frequencies, can be fed into GA for identifying the stiffness parameters by minimizing an objective function in the following form:

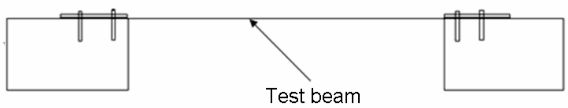
$$J_\omega = \sum_{i=1}^{N_f}\left[W_{\omega i}\left|\frac{\omega_{mi}-\omega_{ai}}{\omega_{mi}}\right| + W_{\omega i}^{ABC}\left|\frac{\omega_{mi}^{ABC}-\omega_{ai}^{ABC}}{\omega_{mi}^{ABC}}\right|\right]$$





ABC frequencies and application in assessing structural frames (Tu and Lu 2007)

Practical issues in real measurements



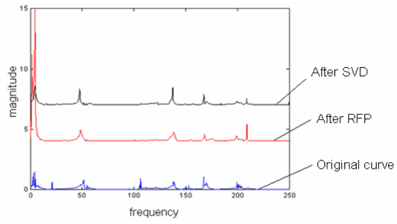
In a real measurement environment, many factors can influence the quality of measured frequency response functions, such as the measurement noise and duration of input excitation. Effective measurement and data processing techniques need be implemented in order to ensure a reliable extraction of the eigen frequencies, especially the ABC frequencies.

Two noise reduction techniques are considered in treating the measured frequency response function curves

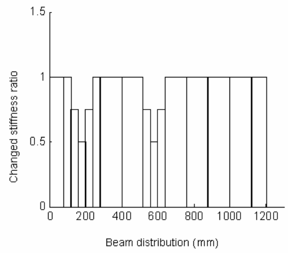
a) rational fraction polynomial (RFP) curve fitting method

b) and singular value decomposition (SVD) technique are used to reduce the noise influence.

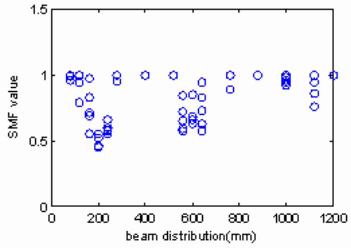
Using the above techniques, considerably improved accuracy in the ABC frequency extraction can be achieved. Investigations using the experimental data from a laboratory beam test indicate that with a series of ABC frequencies and using GA it is possible to identify the location and degree of stiffness changes in a continuous system



Effect of RFP and SVD techniques



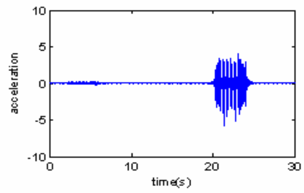
Actual stiffness distribution in experiment



Stiffness parameter identification results

Data analysis and interpretation for railway bridges

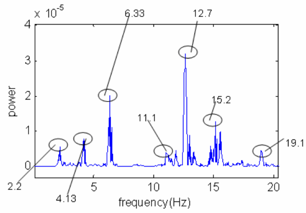
Photo of the bridge



Measured bridge acceleration due to a passing train

A series of measured dynamic response data from a railway bridge is analyzed in an attempt to establish a procedure for the extraction of the driving and dominant frequencies from the passing trains, and the natural frequencies of the bridge system.

The driving and dominant frequencies may be distinguished from the response frequency spectrum (power-density spectra or PDF) based on the train speed, bridge dimensions, and the configuration of the axle-sets of the carriages. With this information, it would be possible to extract the natural frequencies of the bridge system from the forced vibration response signals.

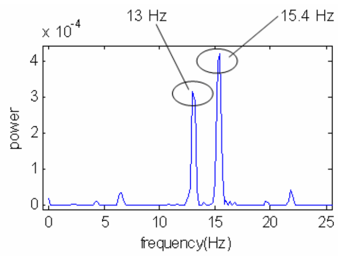


A typical frequency spectrum (PSD) from measured acceleration response (laden train)

Another possible way of identifying the natural frequencies of the bridge is to use the truncated free-vibration segments of the measured signals.

If the mass of the carriages is relatively low (large bridge or un-laden train), the bridge frequencies may be determined directly from the PSD of the measured response.

The analysis results using the above different approaches are cross-checked to ensure the reliability of the outcome.



Bridge natural frequencies from measured bridge accelerations (un-laden train)

Future work

- To further improve the quality of the measured frequencies in real structural and measurement environment by means of using noise reduction techniques and considering including more effective excitation method
- To incorporate pertinent local methods in the framework to assist in the identification of local damages and enable the assessment of complex systems
- To further study the dynamic behaviour of typical railway bridge systems; develop an effective procedure for the determination of the various frequency components in the bridge response; and investigate the dynamic interaction between the passing trains and the bridge.