An Artificially-damaged Real Steel Truss Bridge and Its Numerical Modelling for Vibration-based Damage Detection

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In this study, a field damage experiment was conducted on a real simply-supported steel Warren-truss bridge with four artificial damage scenarios applied. The elevation and plan views of the experiment bridge and the layout of sensors are shown in Fig. 1. The damage scenarios are summarized in Table 1. For each damage scenario, the dynamic characteristics, specifically the dominant frequencies and mode shapes, of the bridge were identified from the dynamic responses excited by a passing experiment vehicle. On the other hand, finite-element (FE) models (see Fig. 2) were constructed with commercial FE-analysis software ABAQUS®, and then their eigen-frequencies and corresponding mode shapes were compared with field-experiment results. Several concluding remarks were drawn as follows.

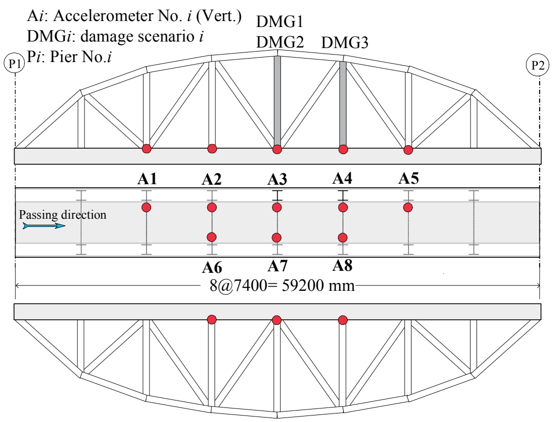


Fig. 1 Experiment bridge with sensor layout.

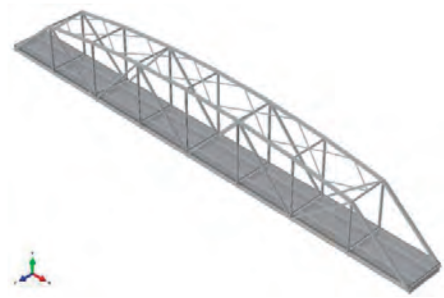


Fig. 2 FE model of the experiment bridge.

Firstly, in the field experiment, the modal frequencies and mode shapes of the bridge were identified with high precision and accuracy. The precision was indicated by little variations between different test runs and the accuracy was verified by the FE numerical model.

Table 1. Damage scenario.

Scenario	Description
INT	Intact bridge
DMG1	Half cut in vertical member @midspan
DMG2	Full cut in vertical member @midspan
RCV	Recovery of the cut member (DMG2)
DMG3	Full cut in vertical member @5/8-span

Table 2. Comparison between numerical (FE) and experimental (EX) modal frequencies and mode shapes (INT scenario).

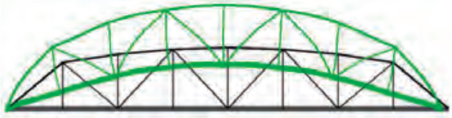
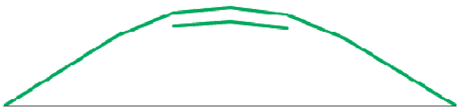
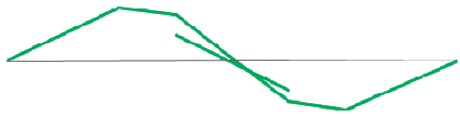
	1st mode	2nd mode
FE	 $f_{1,n}$ = 2.978 Hz	 $f_{2,n}$ = 6.776 Hz
EX	 $f_{1,e}$ = 2.975 Hz	 $f_{2,e}$ = 6.872 Hz
Δ	0.1 %	1.4 %

Table 3. Comparison between numerical and experimental modal frequencies (DMG3 scenario).

	1st mode	2nd mode	3rd mode	4th mode	5th mode
Numerical (Hz)	2.927	6.209	9.831	10.930	13.438
Experimental (Hz)	2.922	6.457	8.651	10.040	13.397
Discrepancy	0.2 %	4.0 %	12.0 %	8.1 %	0.3 %

Secondly, the eigen-frequencies and corresponding mode shapes calculated with the FE models match with the experiment results very well for INT (e.g. the first two modes as shown in Table 2) and DMG2 scenarios, indicating that those FE models could serve as an alternative for vibration-based damage detection studies. However it is not true for DMG3 scenario (see Table 3 for example), probably due to the inconsistency of initial conditions between the FE model and real bridge. To develop a more proper model to model the real bridge of DMG3 scenario, as well as of RCV scenario, could be one of our current challenges. Existing model updating techniques could be appropriate tools.

Table 4. Change in identified modal frequencies and mode shapes due to damage.

Scenario	Frequency	Mode shape
<u>1st mode</u>		
DMG1	+ 0.03%	Little variation
DMG2	- 3.03%	Conspicuous in damage side
DMG3	- 1.52%	Slight distortion
<u>2nd mode</u>		
DMG1	+ 0.32%	Little variation
DMG2	+ 0.16%	Little variation
DMG3	- 5.61%	Distortion
<u>3rd mode</u>		
DMG1	+ 0.58%	Little variation
DMG2	+ 0.35%	Little variation
DMG3	- 9.57%	Distortion
<u>4th mode</u>		
DMG1	+0.45%	Little variation
DMG2	+ 0.20%	Little variation
DMG3	- 3.94%	Distortion
<u>5th mode</u>		
DMG1	+0.49%	Little variation
DMG2	+ 0.25%	Little variation
DMG3	+ 0.03%	Slight distortion

Thirdly, changes in the identified modal frequencies and mode shapes were observed. For modal frequencies, they decreased as damage causing high stress redistribution was applied, signifying a global stiffness loss. Such a change was especially obvious as damage was applied asymmetrically. For mode shapes, both symmetric and anti-symmetric ones were distorted as damage was applied asymmetrically. To test if those parameters are effective damage sensitive features for damage detection could be another challenge.