Drive-by Bridge Modal Parameter Identification for Structural Health Monitoring

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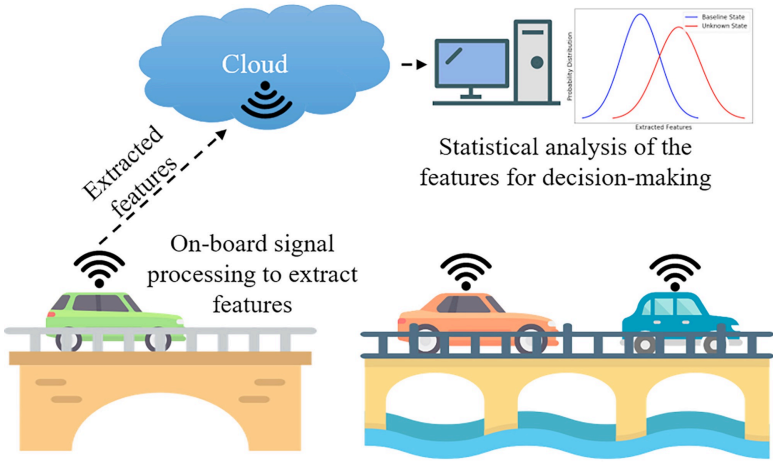
Outline

- Introduction
- Drive-by bridge frequency identification
- Drive-by bridge mode shape extraction
- Summary

Introduction

Drive-by bridge inspection

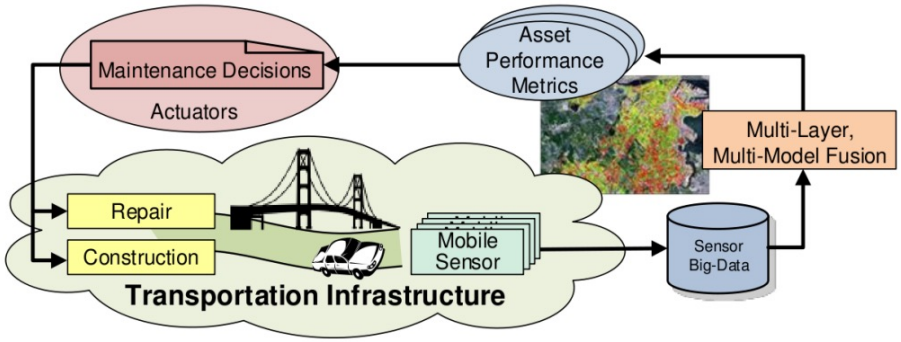
- Indirect bridge health monitoring based on vehicle-bridge interaction (VBI)
- Truck-based mobile sensory system is one of the cost-effective approaches to capture the dynamic VBI information
- The local damage in a region trepassed by the vehicle can be accurately identified by the local responses collected
- A great potential of application for a quick scan of large stock of highway bridges



Mobile crowd-sensing platform (Mei and Gul, 2018)

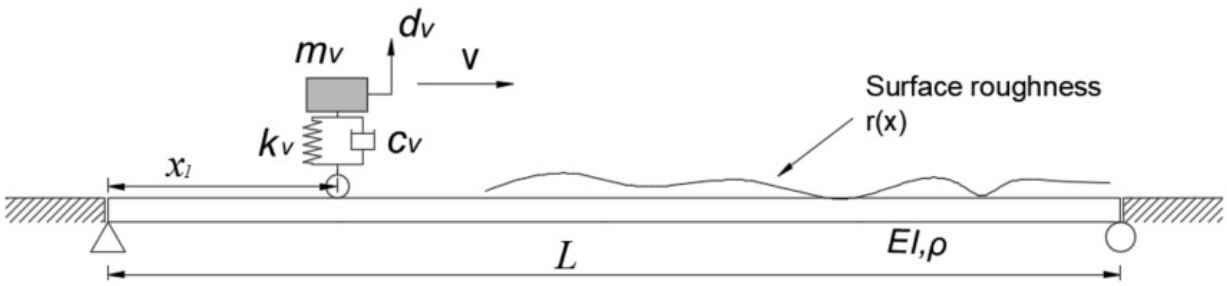
Challenges:

- Fully understanding of vehicle-bridge interaction (VBI)
- Uncertainties, such as road surface roughness, wheel-road contact model

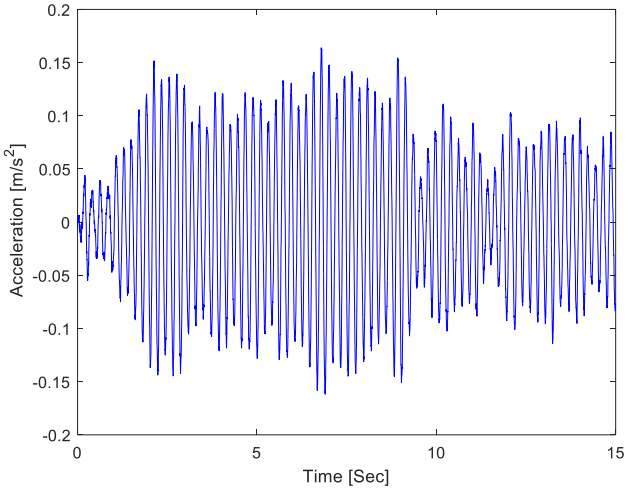


Drive-by inspection

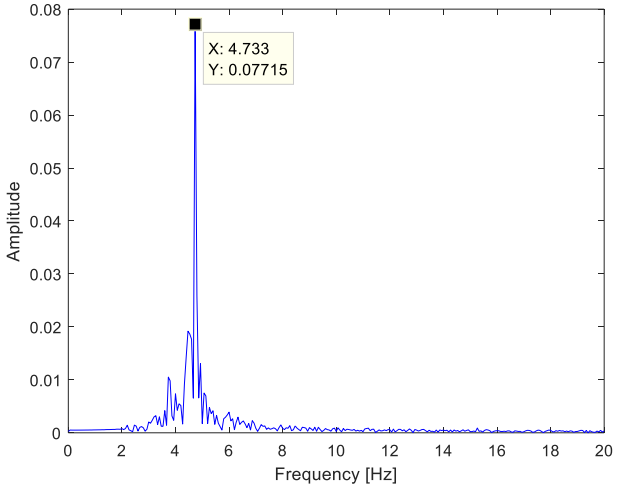
Drive-by blind modal identification using SSA



Note: The vehicle response includes the bridge, vehicle and bridge surface roughness information. The big challenge is to separate those components to extract the bridge information.

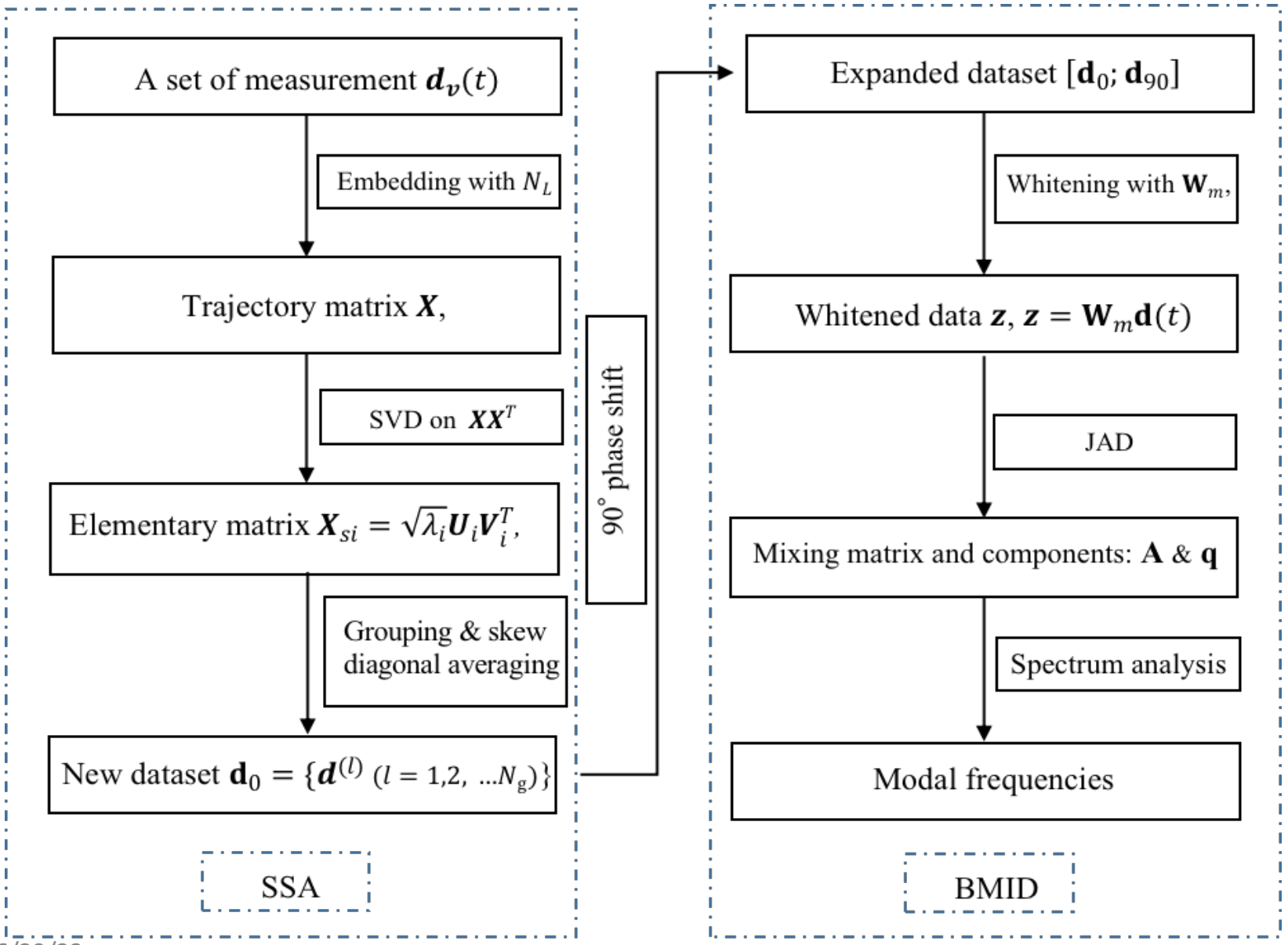


Acceleration of a passing vehicle



Its spectrum

Drive-by blind modal identification using SSA



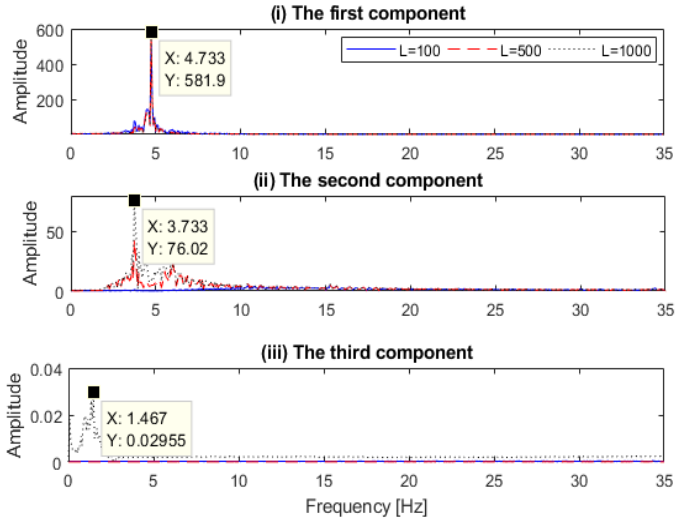
Numerical studies

Vehicle and bridge model parameters:

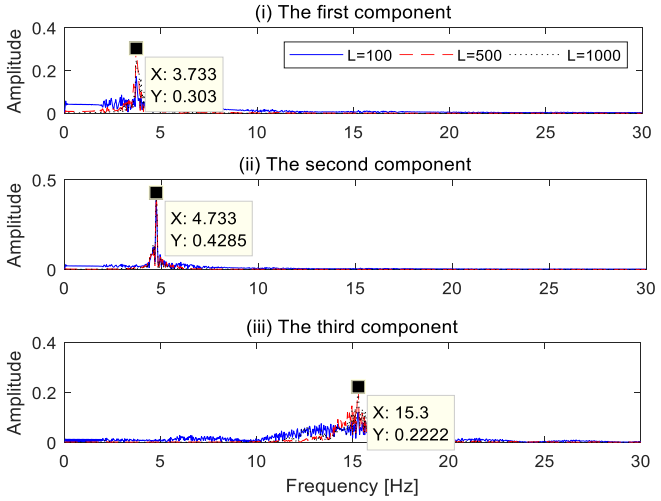
The parameters of the bridge: *L=30m, ρ=1000kg/m, I=0.175m4, E=27.5GPa*. The first two natural frequencies of the bridge are 3.83 and 15.32 Hz, respectively.

The properties for the vehicle are: *mv=200kg, kv=170kN/m*. The vehicle modal frequency is 4.64Hz.

The moving speed of the vehicle is constant at *2m/s* and the time step is set as 0.001s in the simulation. The Class A bridge surface roughness is used (ISO 8606).



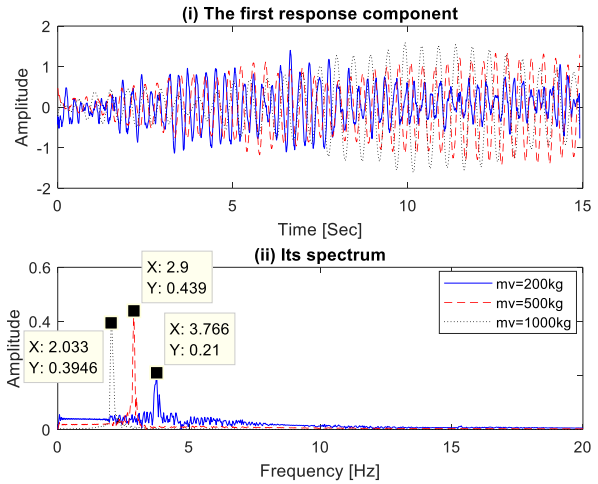
By SSA only

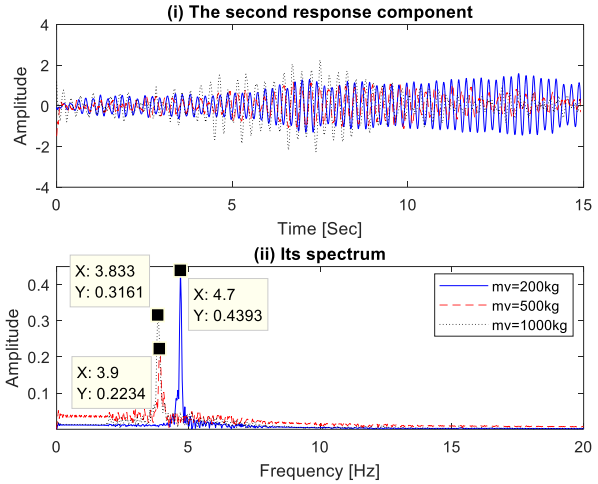


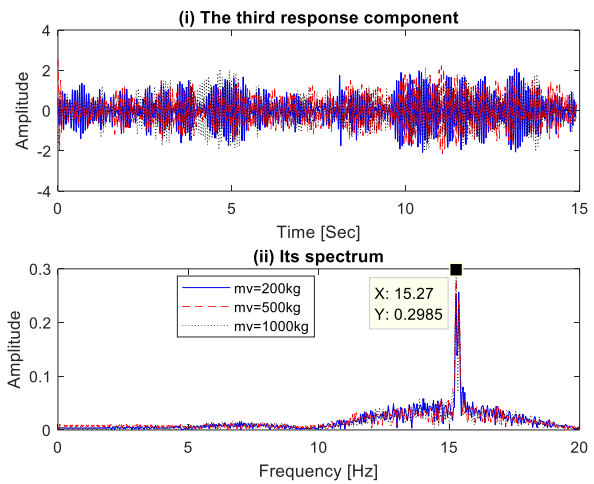
By the proposed method

Numerical studies

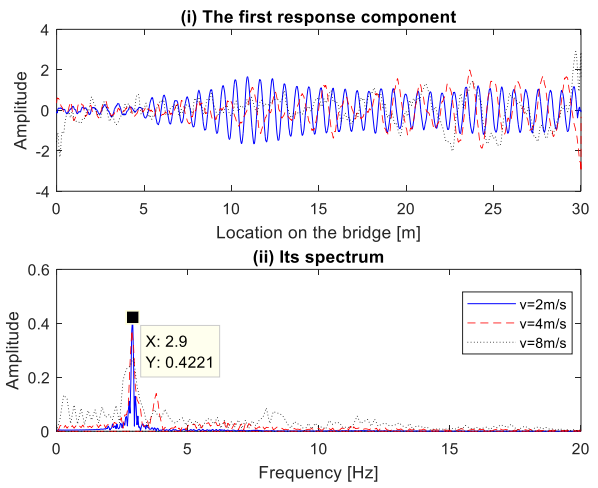
Effect of different vehicle weights:

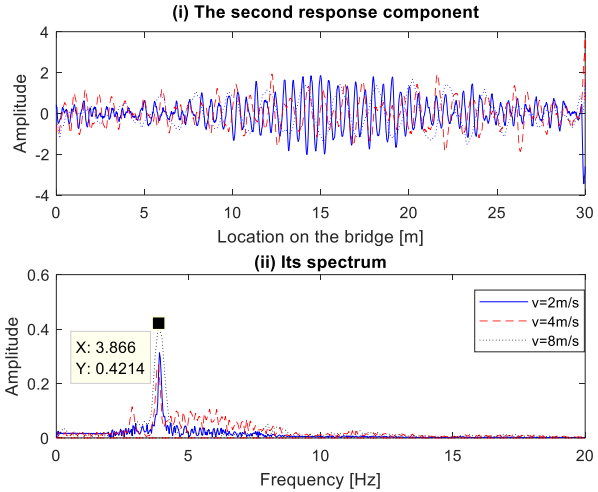


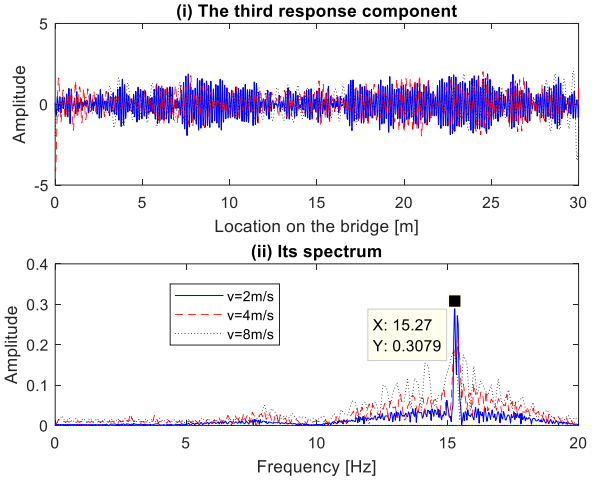




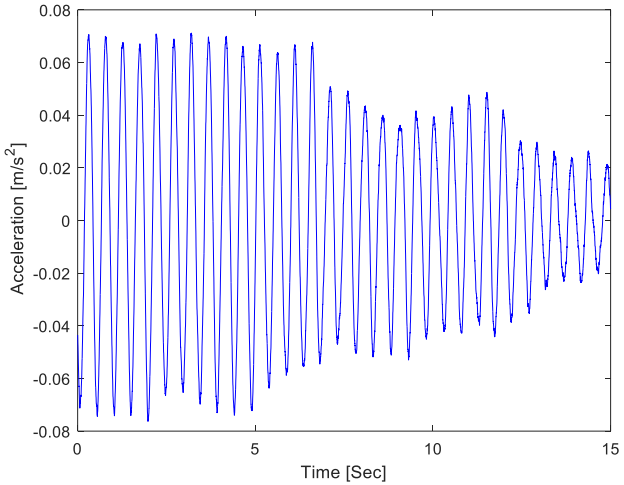
Effect of different vehicle speed:



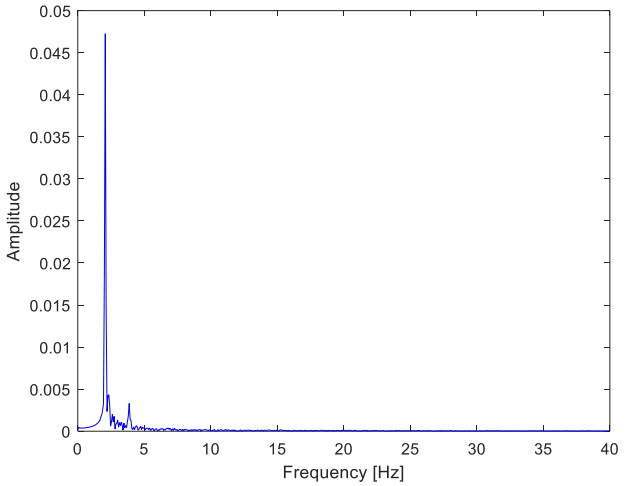




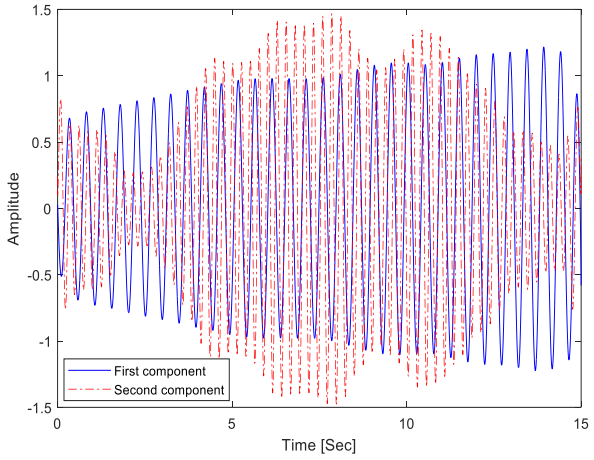
Instantaneous frequency extraction



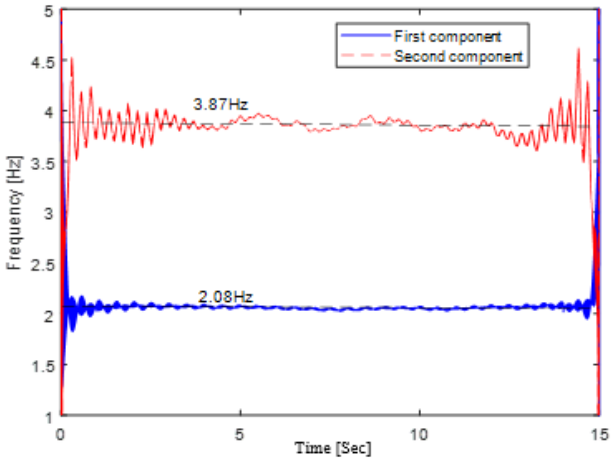
Vehicle response



The spectrum of Vehicle response

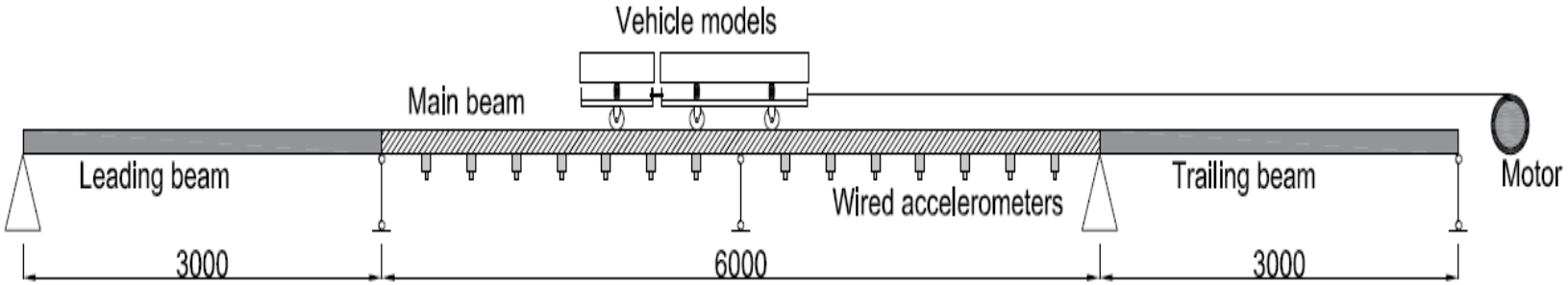


The first two response components



The instantaneous frequency

Experimental verification



(a) Bridge model subjected to moving vehicles

(b) The vehicle-bridge model

(c) Wireless sensor on the vehicle

Identified results

Using one-axle vehicle:

		v1			v2			v3		
		m1	m2	m3	m1	m2	m3	m1	m2	m3
Bridge (Hz)	1st	5.21	5.22	4.93	5.62	5.59	5.55	5.12	5.12	5.09
	2nd	8.31	8.36	8.31	8.50	8.51	8.48	8.54	8.72	8.66
Vehicle (Hz)		29.37	29.40	29.30	29.58	29.56	29.68	29.53	29.39	29.65

Using two-axle vehicle:

		v1			v2			v3		
		m1	m2	m3	m1	m2	m3	m1	m2	m3
Bridge (Hz)	1st	4.94	5.30	5.19	5.68	5.64	5.67	5.86	5.41	5.56
	2nd	8.37	8.35	8.35	8.47	8.47	8.47	8.57	8.62	8.64
Vehicle (Hz)		33.79	32.19	32.15	33.92	32.44	31.65	33.33	32.57	32.37

Note:

1) m1, m2 and m3 represent the mass of the two-axle vehicle with 4kg, 6.5kg and 9kg, respectively.
2) v1, v2 and v3 represent three different speeds about 0.10, 0.14 and 0.21m/s, respectively.

Indirect Bridge Structural Health Monitoring

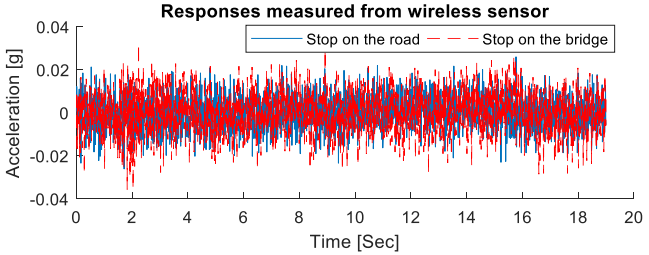
a cable-stayed bridge

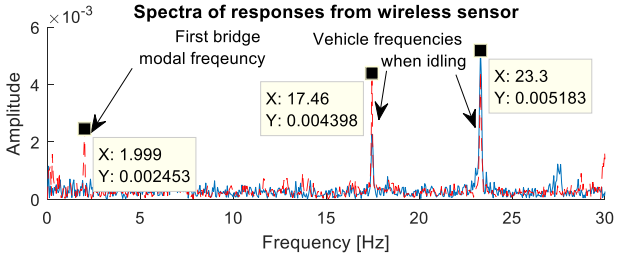
By the modal testing, the first natural frequency of the bridge is 2.00Hz.

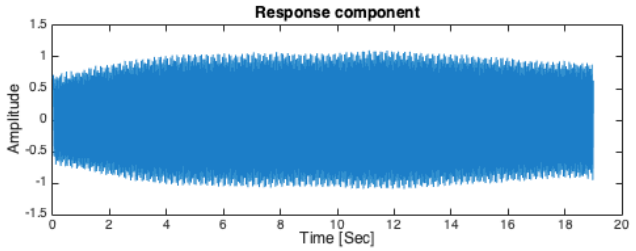
(a) Test vehicle

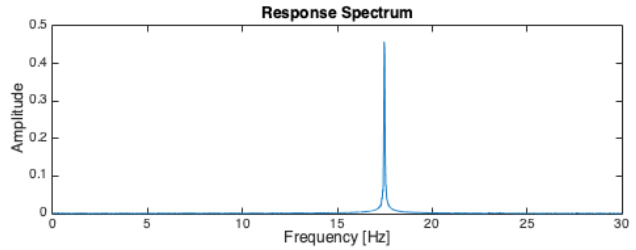
(a) Wireless sensor

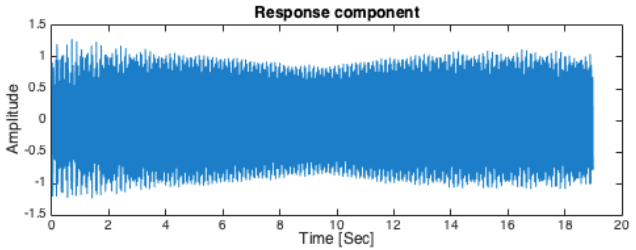
Vehicle stop on the road and the bridge

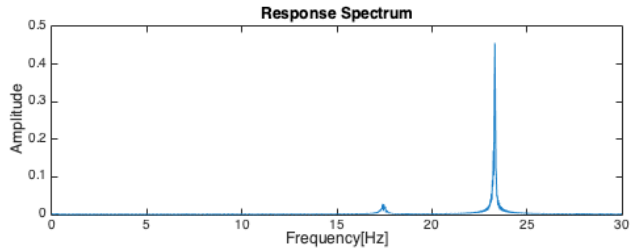




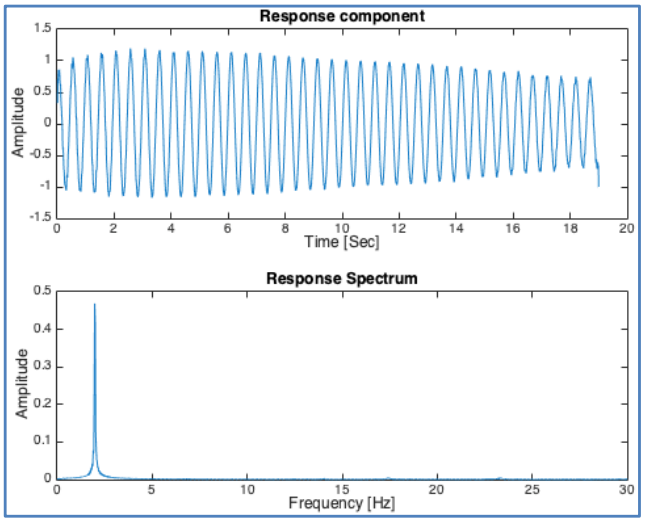


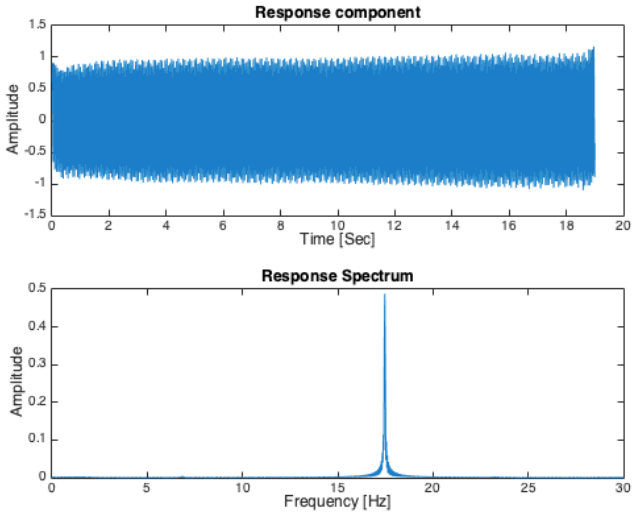


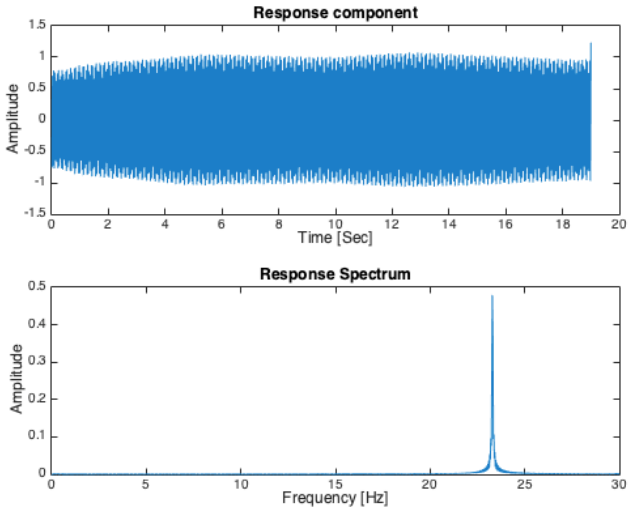




Extracted response components when vehicle park on the road

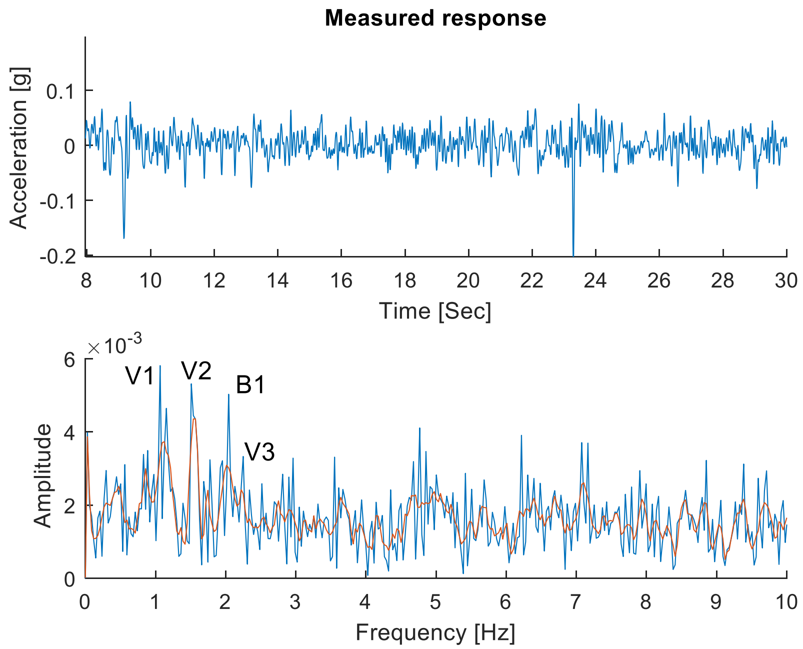


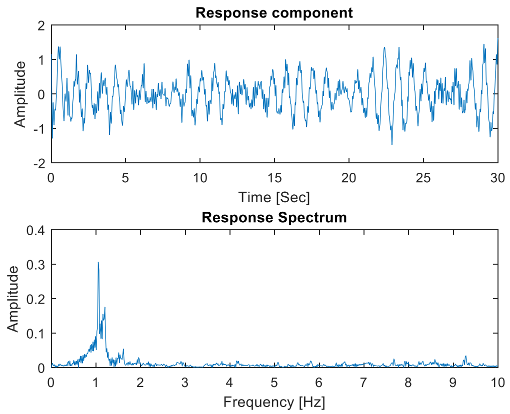


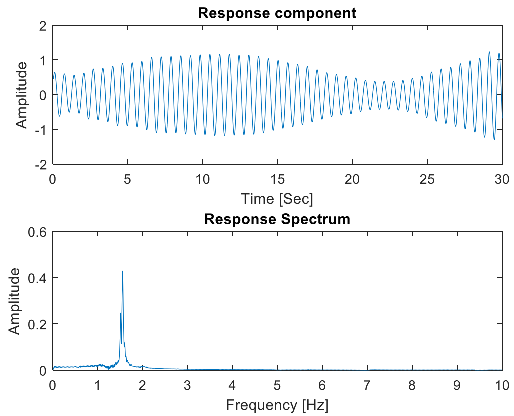


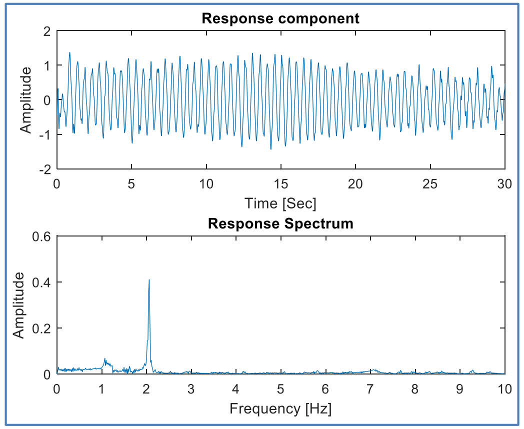
Extracted response components when vehicle park on the bridge

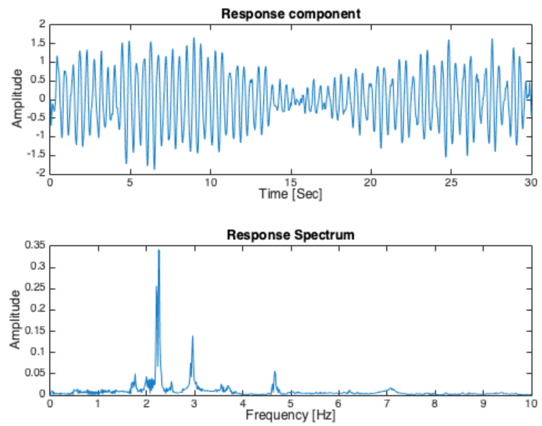
Vehicle passing the bridge with 10km/h







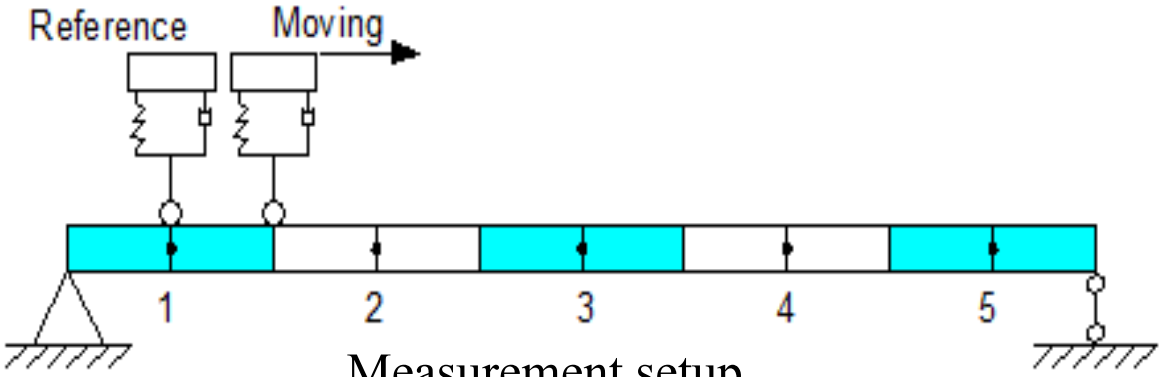




Extracted response components from response when vehicle speed is 10km/h

Drive-by Bridge Modal Shape extraction using SSI

Two sensing vehicles are used: one is a fixed reference sensor, the other one is a moving sensor. Two sets of measurements are divided to form the multi-patch records according to the segmentation of the bridge.



Measurement setup

$$\underbrace{\begin{pmatrix} Y_k^{(1,ref)} \\ Y_k^{(1,mov)} \end{pmatrix}}_{\text{Record 1}} \quad \underbrace{\begin{pmatrix} Y_k^{(2,ref)} \\ Y_k^{(2,mov)} \end{pmatrix}}_{\text{Record 2}} \quad \cdots \quad \underbrace{\begin{pmatrix} Y_k^{(j,ref)} \\ Y_k^{(j,mov)} \end{pmatrix}}_{\text{Record 4}}$$

Multipatch records

For the system including the reference and moving vehicles, each record corresponds a state-space realization in the form:

$$\begin{cases} X_{k+1}^{(j)} = FX_k^{(j)} + V_k^{(j)} \\ Y_k^{(j,ref)} = H^{(ref)} X_k^{(j)} \\ Y_k^{(j,mov)} = H^{(j,mov)} X_k^{(j)} \end{cases}$$

where X_k is the state vector at time instant k,

$H^{(ref)}$ is the observation matrix with respect to the reference sensors,

$H^{(j,mov)}$ is the observation matrix with respect to the moving sensors,

F is the state transition matrix,

V_k is the unmeasured stationary noise,

Rescaling procedure for a local to global mode

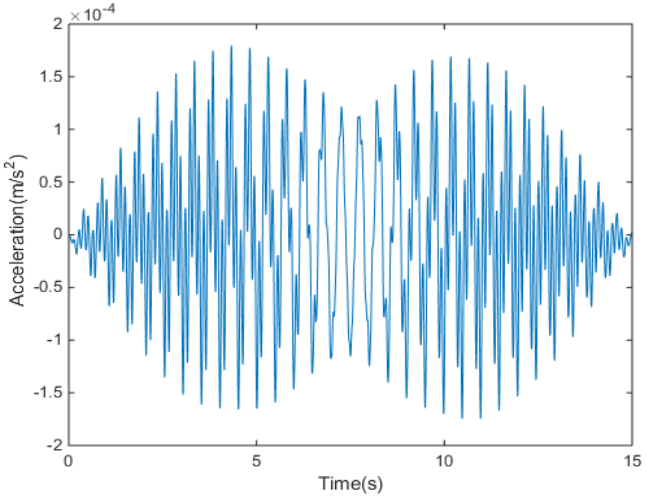
- Local mode shape vectors of each segment are obtained from the records by Ref-SSI
- Global mode shapes are obtained by a rescaling of the local mode shape vectors:

$$\Phi_{j+1} = \frac{\Phi_1}{\phi_{j,1}} \phi_{j,j+1}, \quad j = 2:4$$

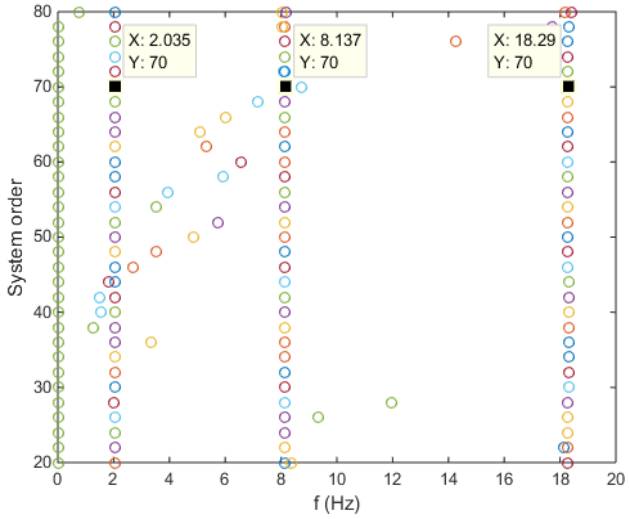
Φ_{j+1} is the global mode shape element corresponding to the *(j+1)th* bridge segment

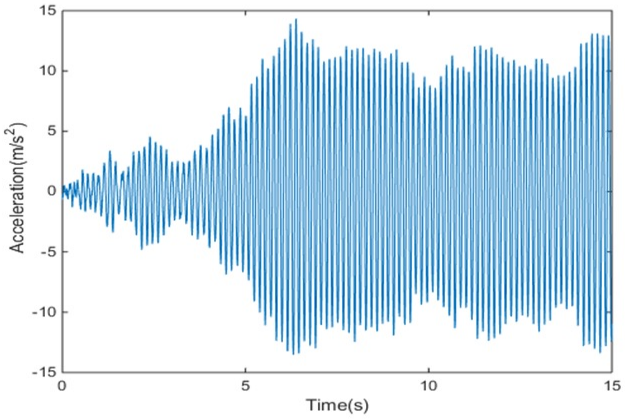
$\phi_{j,j+1}$ is the local mode shape of *(j+1)th* segment obtained from the *jth* record

Frequency identification by SSI



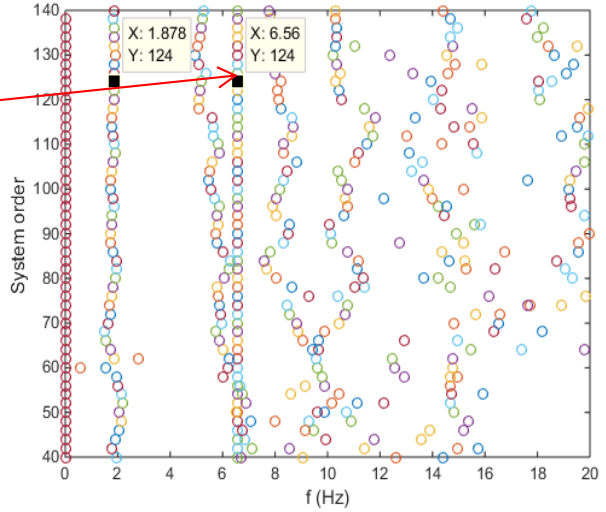
A smooth bridge deck





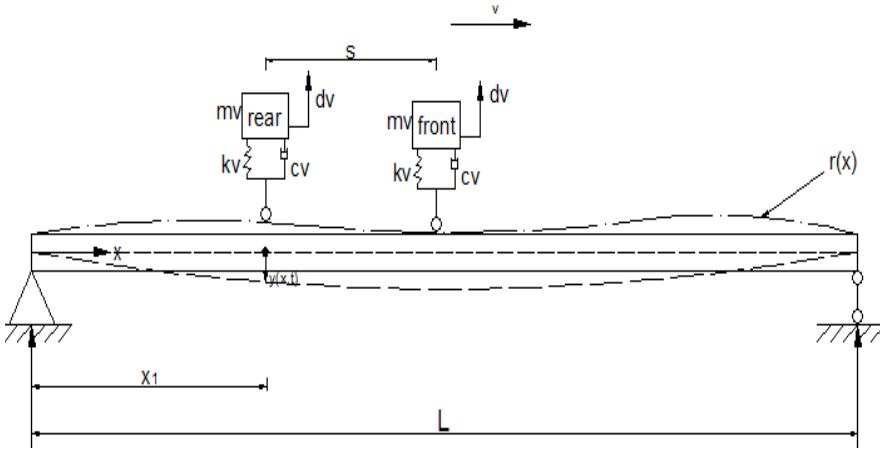
A rough bridge deck

Only the vehicle frequency is clearly identified

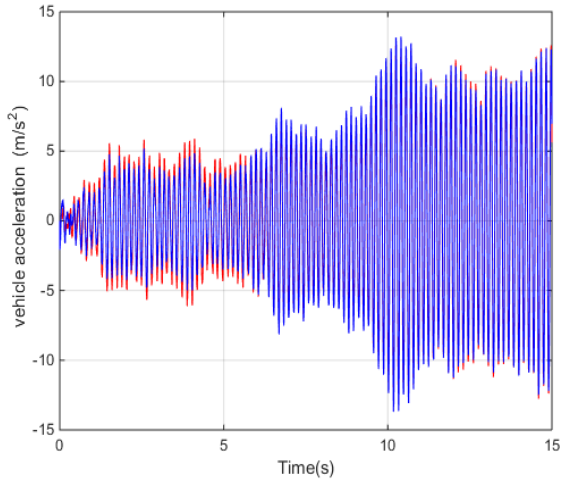


Stabilization graph

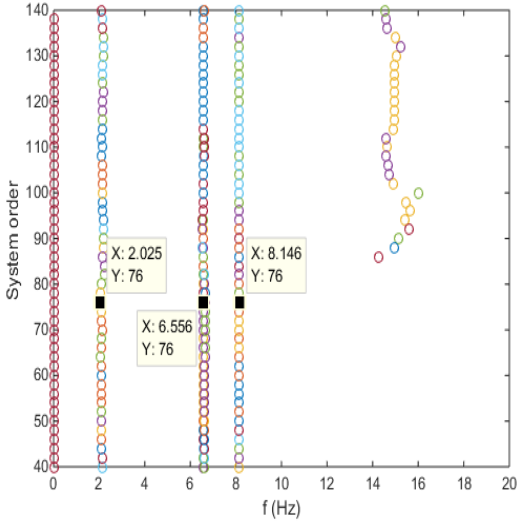
Subtraction technique to reduce the effect of roughness



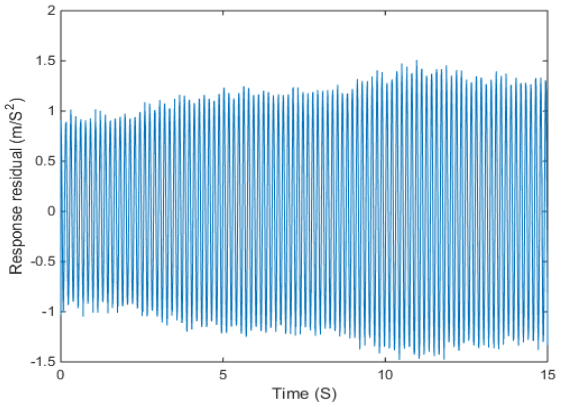
Two SDOF vehicles and bridge model



Dynamic responses of the two vehicles



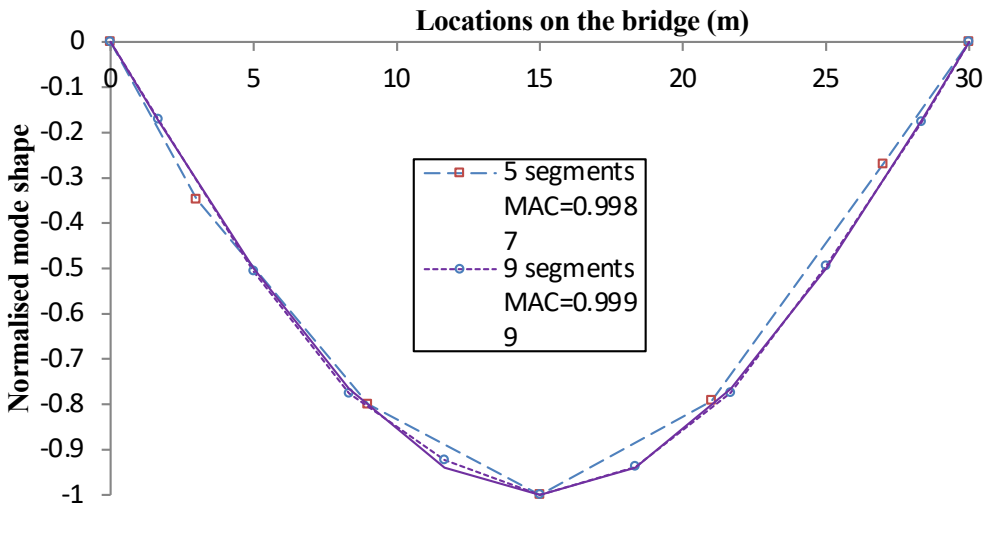
Stabilization graph



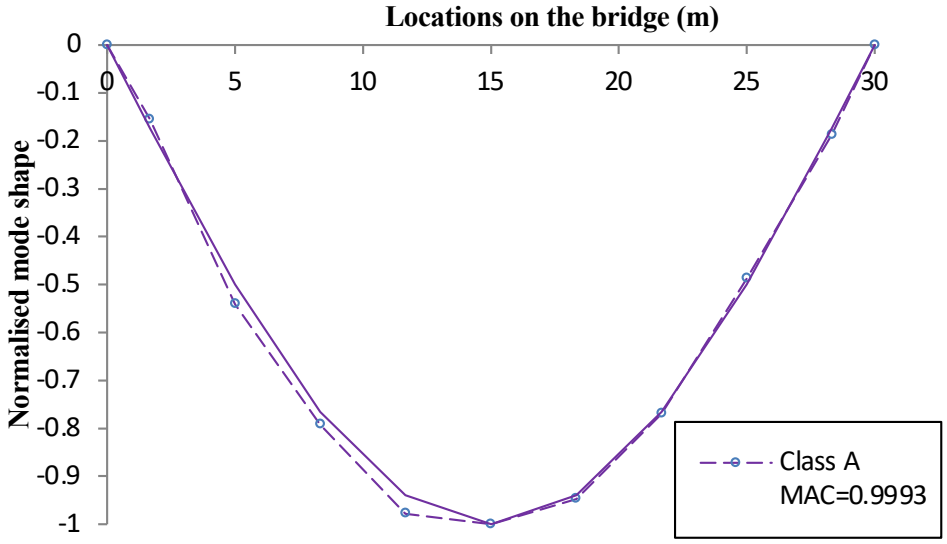
Response residual after subtraction

Bridge mode shape extraction

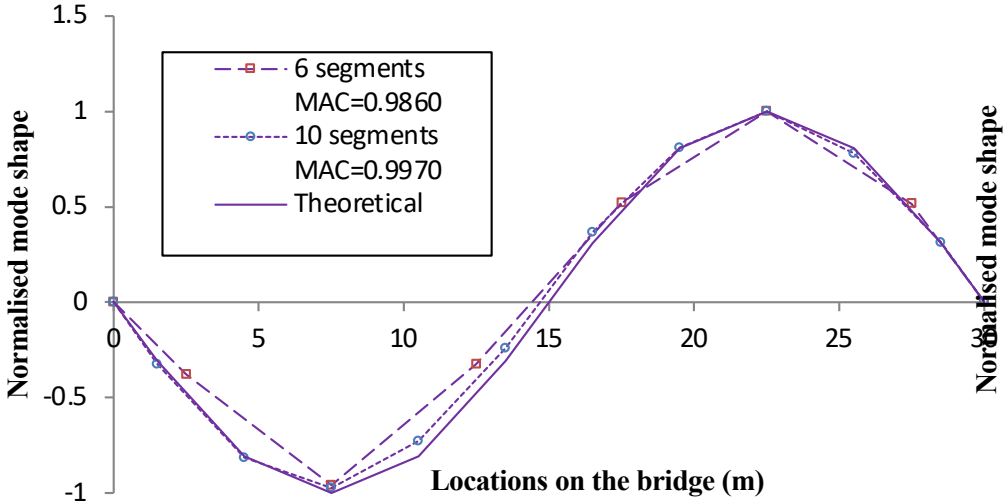
Smooth road

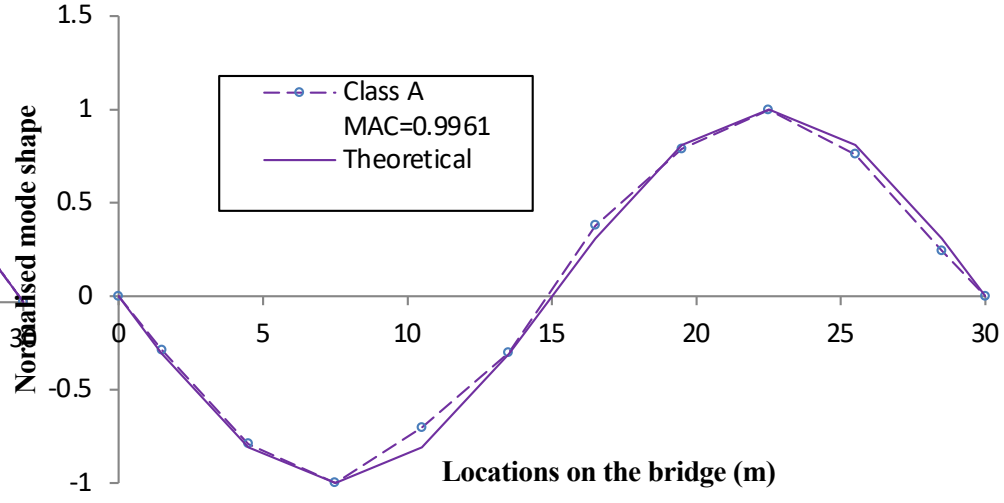


Class A road surface roughness



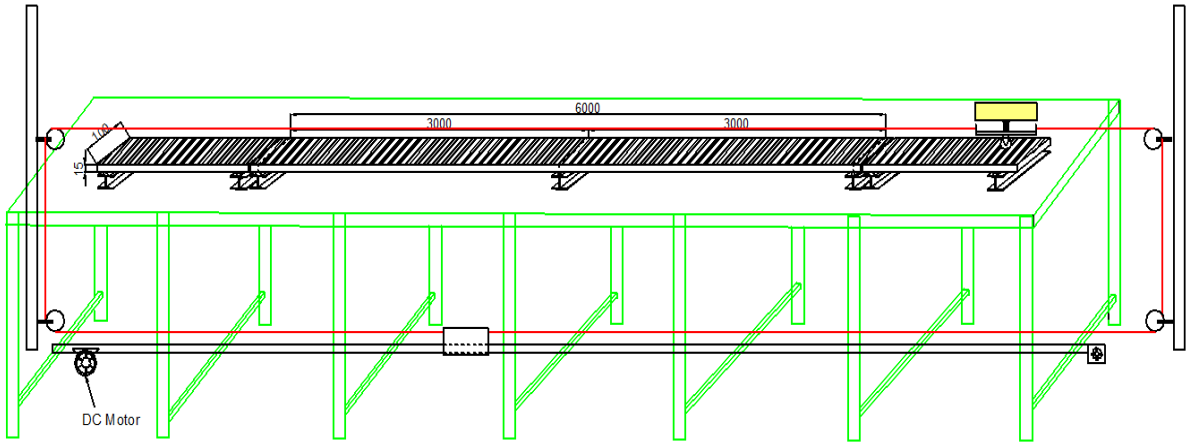
The first mode shape

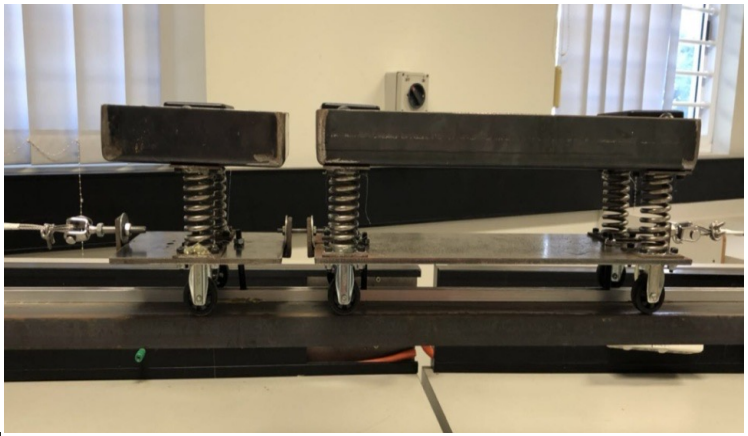




The second mode shape

Experimental verification



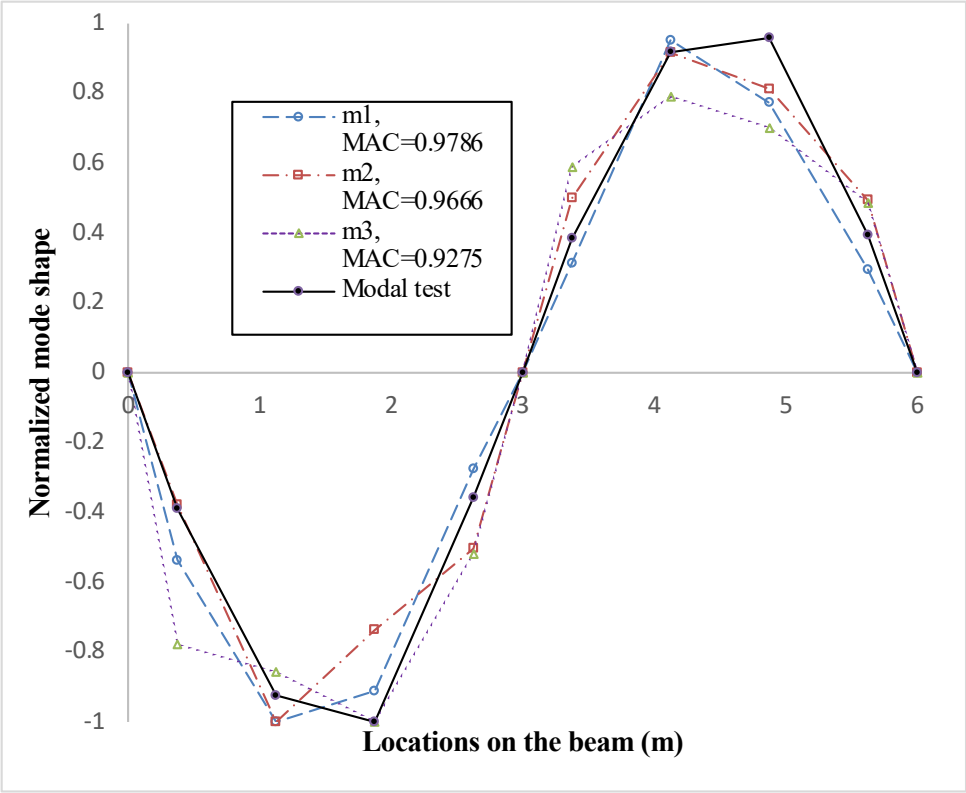


(a) Bridge model subjected to moving vehicles

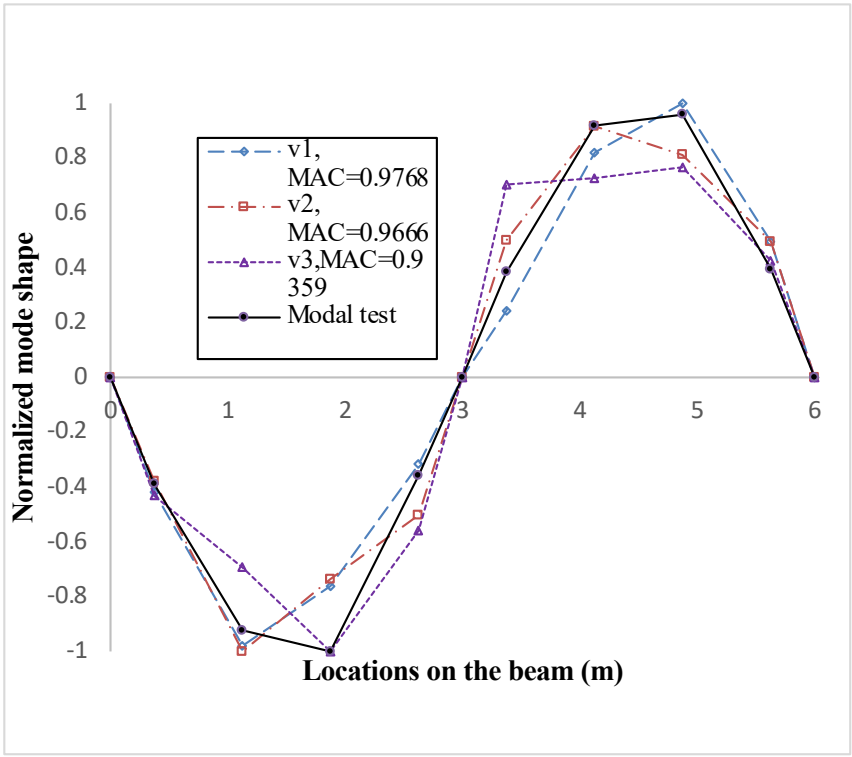
(b) Wireless sensor on the vehicle

(c) Wireless sensor on the bridge

Experimental verification



Identified mode shapes using vehicles with different weights



Identified mode shapes with different moving speeds

Conclusions and Future Research

- **Drive-by blind modal identification using singular spectrum analysis:** A drive by blind modal identification method with singular spectrum analysis has been developed to extract the bridge modal frequencies from the dynamic response of a passing vehicle. A heavier vehicle with a lower speed can get more accurate identified frequency, and the vehicle stiffness does have a big effect on the identified results .
- **Drive-by bridge mode shape extraction using stochastic subspace identification**: A multiple-setup Reference-based SSI method is proposed to identify the bridge modal parameters using two instrumented vehicles. One vehicle remains stationary during the whole procedure as the reference sensor, and the other vehicle measures the dynamic response while moving over the bridge. simultaneously.


Thank You!
Questions?