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Residual Contact Response Generated by Two Consecutive Moving Wheels for Bridge Detection

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Abstract

The vehicle scanning method (VSM) proposed by Yang and co-workers in 2004 [1] is an indirect approach for bridge measurement. Normally, the test vehicle's recorded response was used to extract the bridge properties. Two issues eixst in this regard. One is the masking effect of the vehicle's self frequencies on the bridge frequencies, making the latter indistinguishable. The other is the pollution effect caused by pavement roughness, which becomes even worse as the vehicle speed increases. The two issue can be overcome through the combined use of the vehicle-bridge contact response (for removing vehicle's frequencies) and the residual response (for eliminating the roughness effect) generated by two wheels. The purpose of this paper is describe the essence of such an approach.

Keywords: Bridge, damage detection, modal identification; vehicle, vehicle–bridge interaction, vehicle scanning method.

1 Introduction

The modal parameters of a bridge, such as frequencies, mode shapes, and damping ratios, are key parameters for various applications, such as damage detection, model updating, and vibration control of the bridge. For bridges in use, a regular monitoring of the modal properties and their trend of variations provides the most useful data for evaluating the source of degradation in various parts of the bridge, which are helpful to the overall judgment in maintenance or rehabilitation of the bridge.

The vehicle scanning method (VSM) is featured by the fact that only few vibration sensors need to be installed on the test vehicle, but not on the bridge [1]. This method was extended to detection of various dynamic properteis for bridges. Compared with the methods that rely on fixed sensors on the bridge, the advantage of the VSM is obvious: mobility, economy, and efficiency. In the last two decades, a rapidly growing number of research works have been conducted along the lines of the VSM for bridge measurement, for which an up-to-date reivew was given by Wang et al. [2].

Normally, the test vehicle's recorded response was used to extract the bridge properties. Two difficulties occur in this regard. One is the masking effect of the vehicle's self frequencies on the bridge frequencies, making the latter indistinguishable. The other is the pollution effect caused by pavement roughness, which becomes worse for high vehicle speeds. The vehicle's masking effect can be tackled by using the response of the contact point between the wheels and bridge [3], and the pollution effect of roughness by the residual response of two wheels passing through the same roughness [4]. The latter can be generated by two separate single-axle vehicles [5], or by two wheels of a two-axle vehicle [6], as will be described below.

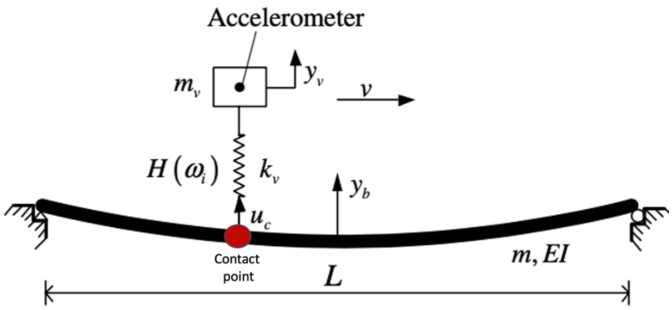
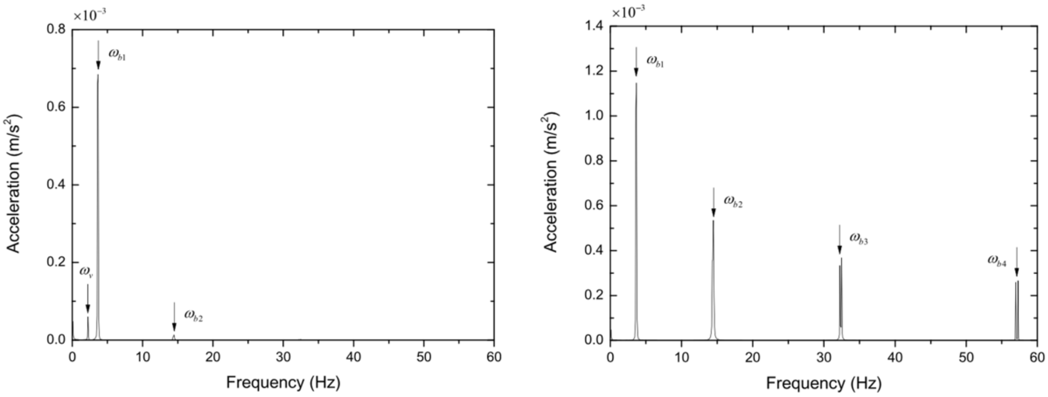


Figure 1: Vehicle-bridge interaction model (modified from [5]).

2 Methods of Resolution

In Figure 1, the vehicle-bridge model considered is shown. Previously, the dynamic response recorded by the car body of the test vehicle during its passage over a bridge has been used in the extraction of the bridge properties. One typical problem herein is that the vehicle frequencies often appear such outstanding that the bridge frequencies to be detected were overshadowed, as shown in Figure 2(a). This is the co-called *masking effect* by the vehicle' frequencies. To overcome such an effect, it was suggested in [3] that the response of the *contact* point between the wheel and bridge be used instead to retrieve the dynamic properties of the bridge.

The contact response cannot be directly measured, but can be back-calculated from the vehicle (body) response by using the equation of equilibrium of the test vehicle. As shown in Figure 2(b), the contact response can be used to retrieve many more high frequencies of the bridge, due to elimination of the vehicle frequencies. Such an approach has also been verified to be feasible in the field test [6].



(a) (b)

Figure 2: Acceleration spectrum: (a) vehicle response; (b) contact response [3].

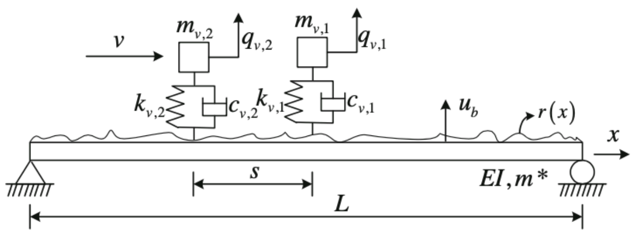


Figure 3: Two single-axle vehicles with the connection link not shown [4].

As for pavement roughness, its pollution effect can be removed or reduced through use of two connected vehicles shown in Figure 3, as they basically move over the path with the same roughness [4]. For example, for a simply supported beam of length L = 30 m and for the roughness profile generated according to the PSD curve of Class C of ISO8608 [14], the spectra generated for the two single-axle connected vehicles moving at 2 m/s were presented in Figure 3(a). As can be seen, no bridge frequencies can be identified, except for the vehicle frequency marked by “v”. However, if the spectrum of one vehicle is subtracted from the other, then one can obtain the residual spectrum in Figure 4(b). This figure indicates clearly that three bridge frequencies can be identified with no difficulty.

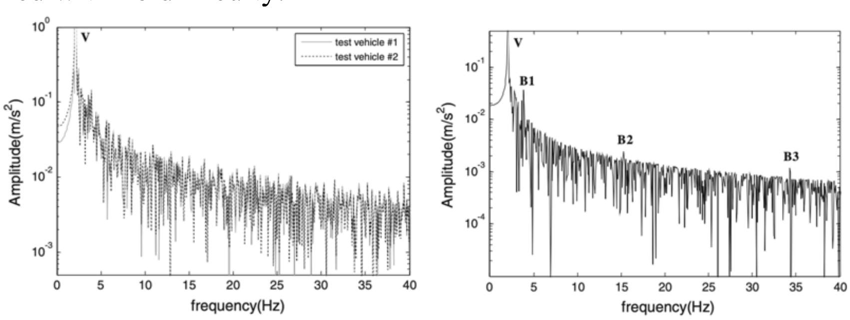


Figure 4

Figure 4: Fourier spectrum: (a) single axle response; (b) residual response [4].

3 Residual Contact Response

Based on the examples of the preceding section, it is natural to imagine that the residual contact response generated by two consecutive moving wheels can overcome both the disturbing issues of vehicle's self frequencies and pavement roughness. For roughness class A of the specification ISO 8606, the FFT spectra for the residual responses of the vehicles (R_v) and contact points (R_c) obtained by two single-axle connected vehicles have been plotted in Figure 5(a), along with an exaggerated view of the contact residual R_c in Figure 5(b) [5]. It is interesting to observe that for the bridge of rough pavements, basically no bridge frequencies can be detected from the vehicles residual (R_v), expect the vehicle frequency. To the contrary, several bridge frequencies can be detected from the contact residual R_c, but not the vehicle frequency. This is a clear a demonstration of the advantage of using the contact residual for bridge frequency extraction.

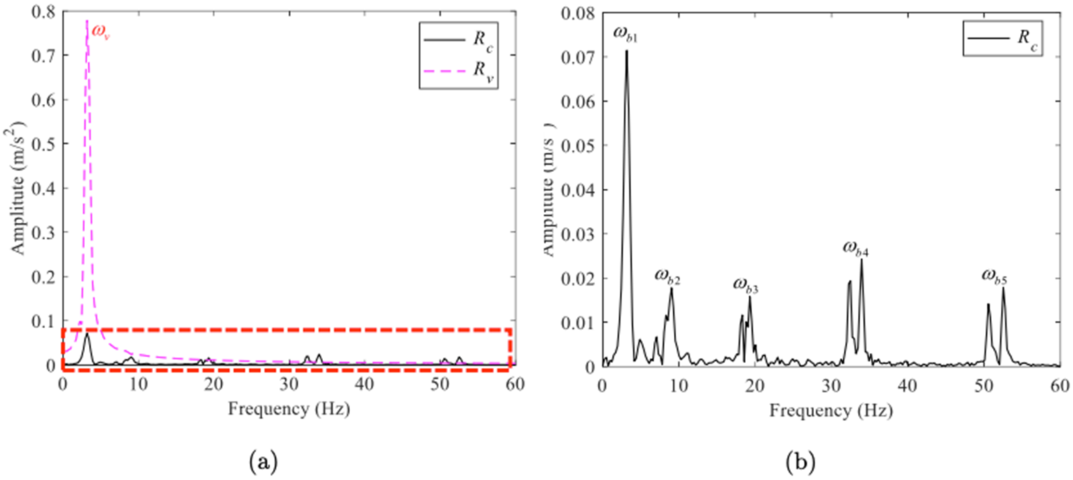


Figure 5: FFT spectra of residual responses for roughness Class A: (a) global view; (b) exaggerated view for contact residual in (a) [5].

In another study, it was shown that the contact residual need not be generated by two separate but connected single-axle vehicles as shown in Figure 3. In fact, the two wheels of a two-axle test vehicle shown in Figure 6 can be used to generate the contact residual, which can be processed by the variational mode decomposition (VMD) and Hilbert transform (HT) to yield the bridge mode shapes in addition to frequencies [6].

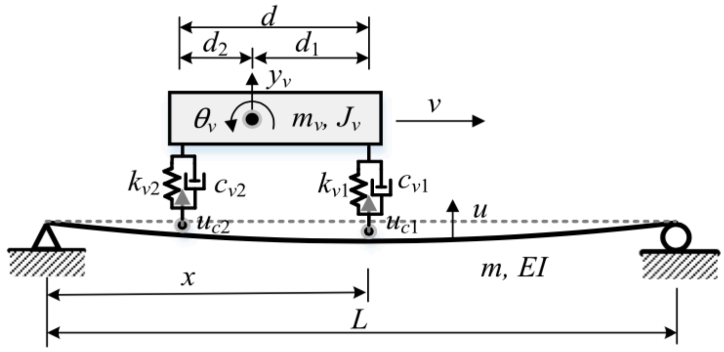


Figure 6: A two-axle test vehicle travelling over a simply-supported beam [6].

For example, the contact residual of the front wheel of a two-axle test vehicle moving over a bridge was compared with the finite element solution and analytical solution in Figures 7(a) and (b) for the acceleration and spectra, respectively [6]. Evidently, three (and maybe more) bridge frequencies can be clearly identified from the contact residual of the front wheel [6]. The result for the rear contact residual is similar and not shown.

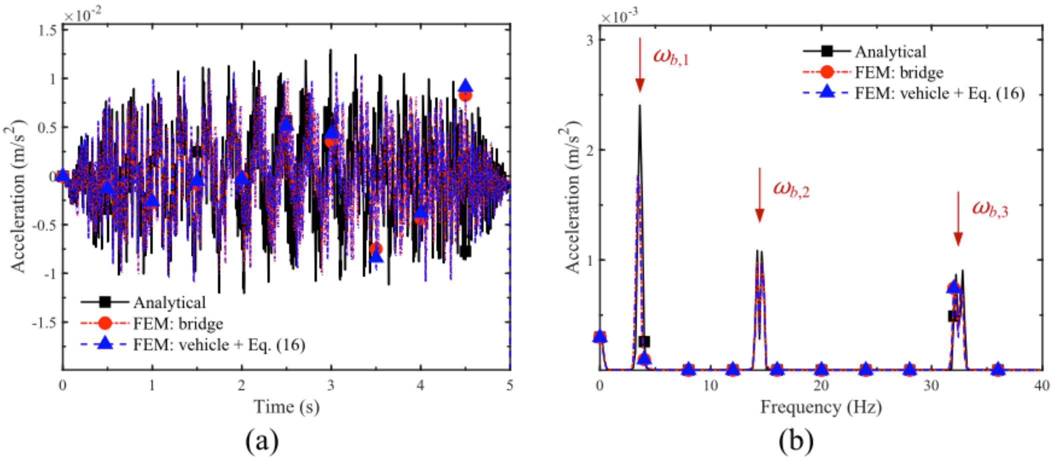


Figure 7: Front contact responses: (a) accelerations; (b) spectra.

By first applying the VMD to filtering out the three component response of the contact residual, the HT can be called on to generate the mode shape for each of the component responses of the simply supported bridge, as shown in Figure 8 [6].

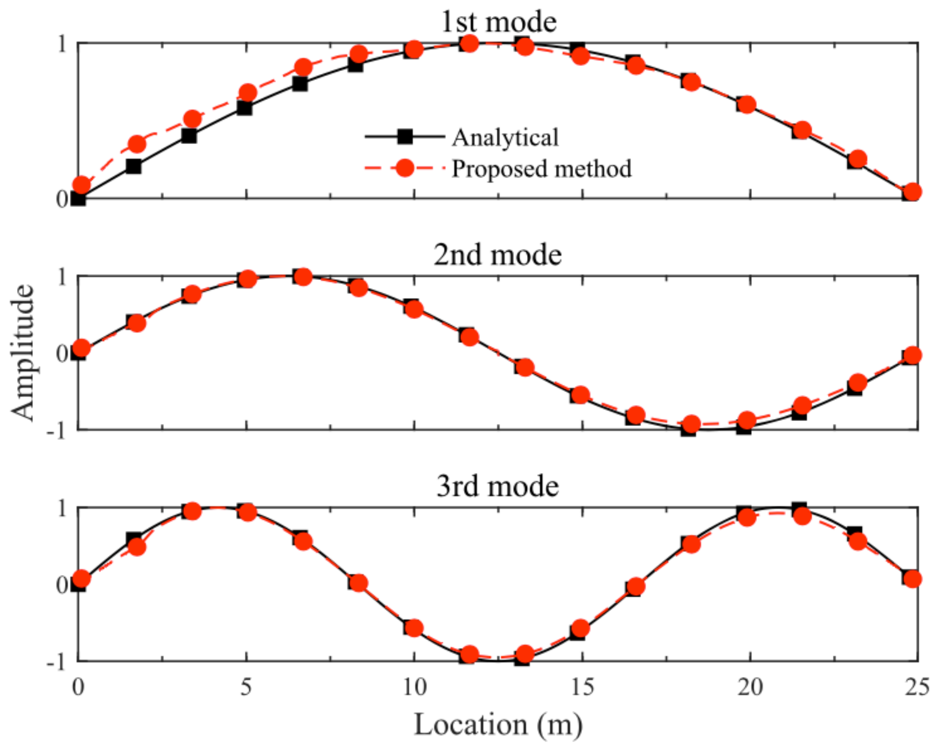
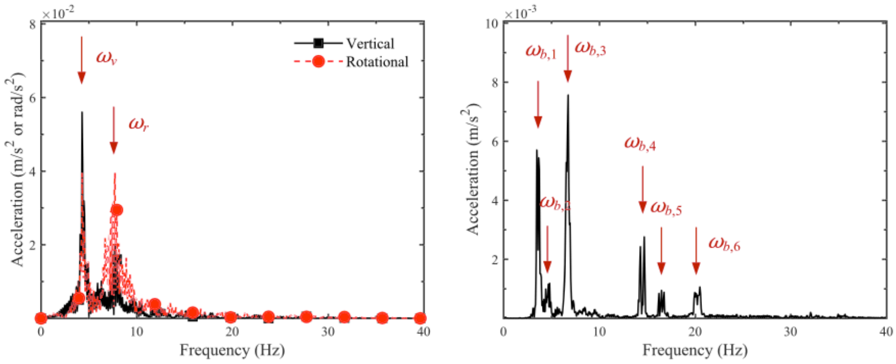


Figure 8: Bridge mode shapes recovered from the front contact residual [6].

For the case of a three-span bridge with rough surface, the vehicle's vertical and rotational spectra obtained were shown in Figure 9(a), from which no bridge frequencies can be identified, as expected. But from the contact residual in Figure 9(b), several bridge frequencies can be clearly identified. Moreover, the first mode shapes constructed for the single- two- and three-span bridges of rough pavement have been given in Figure 10.



(a) (b)

Figure 9: Spectra for three-span bridge with road roughness: (a) vehicle (vertical and rotational) spectra; (b) residual contact spectra [6].

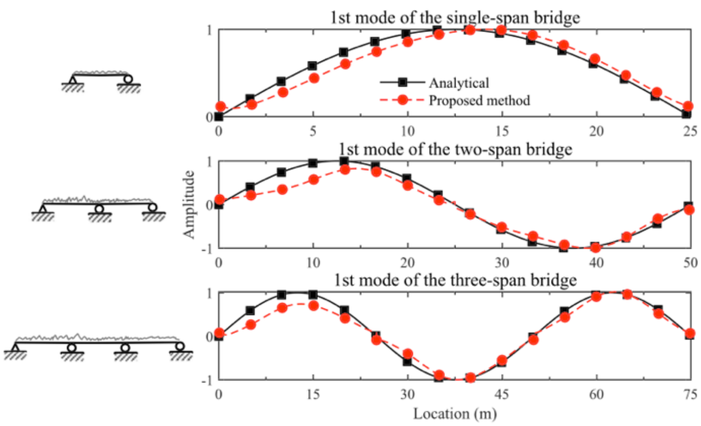


Figure 10: First mode shapes of bridges with different numbers of spans in the presence of road roughness [6].

4 Conclusions

This paper summarizes the previous works on the contact and residual responses of test vehicles for tackling the masking effect of vehicle's self frequencies and the pollution effect of pavement roughness. It was demonstrated that the combined contact residual can be employed to tackle the above two effects effectively. The contact residual can be generated either by two separate but connected single-axle vehicles or by the two wheels of a two-axle test vehicle.

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