第 I 部門　**Parametric study on frequency variability in a vehicle-bridge interaction system**

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Introduction

Natural frequency is an important characteristic in bridge dynamics and health monitoring. The natural frequency of a bridge in the vehicle-bridge interaction (VBI) system may vary from that vibrating alone. Under seismic loadings, the dynamic characteristics of the bridge interacting with the vehicle may deviate from design characteristics, where generally no vehicle is taken into consideration according to current highway bridge design codes. This paper is to analytically explore how the key parameters dominate the frequency variability in a VBI system.

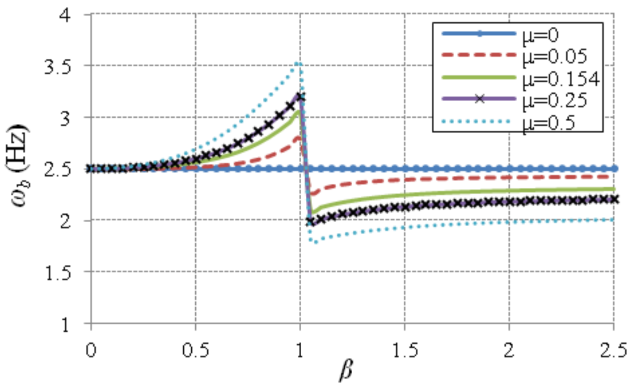

Fig.1.Bridge-related natural frequency ω_b of the VBI system v.s. frequency ratio β.

Theoretical Basis

For estimating the frequency variability induced by a vehicle parked at the bridge mid-span, an analytical formula is derived, based on a simplified two-degree-of-freedom VBI model, to calculate the natural frequency ω for the VBI system as follows [1]:

$$\omega^2 = \omega_{b,0}^2 \times \frac{1}{2}\left[1+\beta^2+\mu\beta^2 \pm \sqrt{(1+\beta^2+\mu\beta^2)^2 - 4\beta^2}\right] \tag{1}$$

where μ is defined as the mass ratio of the vehicle to the bridge, i.e. $\mu \equiv m_v/m_b$, and β as the frequency ratio of the vehicle to bridge, i.e. $\beta \equiv \omega_{v0}/\omega_{b0}$. Parameters m_v and m_b denote the masses of vehicle and bridge, and ω_{v0} and ω_{b0} the natural frequencies of vehicle and bridge, respectively, when they vibrate independently.

According to the above formula, the natural frequency of the VBI system is dominated by two parameters: the mass ratio μ and frequency ratio β. How those two parameters affect the variability of the natural frequency in the VBI system will be studied as follows.

Frequency Ratio

In this study, the natural frequency ω_{b0} of the bridge alone is selected as 2.5 Hz. Figure 1 shows the bridge-corresponded natural frequency ω_b of the VBI system with respect to β for μ= 0, 0.05, 0.154, 0.25 and 0.5. It can be observed that, when β approaches 0, ω_b approximately remains ω_{b0}, meaning that a vehicle with relatively low frequency may not influence the natural frequency of the interaction system. In the interval of β<1, ω_b increases from 2.5 Hz as β increases; in the interval of β>1, ω_b increases, from a value smaller than 2.5 Hz, as β increases, but the slope is not as steep as that in the former interval. What is worthy of noting is that there is a discontinuity at the point β=1, where ω_b reaches its maximum in the interval of β>1 and its minimum in the interval of β>1. It indicates that the largest deviation of ω_b from ω_b occurs at the near resonance condition. The trend observed in

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this section is more obvious for larger μ values, which can be illustrated in the following section.

Mass Ratio

Figure 2 shows the bridge-corresponded natural frequency ω_b of the VBI system with respect to μ for β= 0.01, 0.5, 0.99, 1.01, 1.209, 1.458, and 4. In this figure, ω_b is approximately equal to ω_{b0} when μ approaches 0, illustrating that vehicle with relatively small mass may hardly affect the natural frequency of the interaction system. For the case with β<1, ω_b monotonously increases while μ increases; for the case with β>1, ω_b monotonously decreases while μ increases. Such an observation clearly indicates that larger deviation of ω_b from ω_{b0} is induced by larger vehicle-to-bridge mass ratio, i.e. larger vehicle mass or smaller bridge mass.

Figure 3 shows the variation of natural frequency of the VBI system with respective to μ under resonance condition, i.e. the natural frequency ω_v of the vehicle alone is equivalent to the natural frequency ω_b of the bridge alone, namely β=1. It is observed that the natural frequencies of the two modes deviate symmetrically from the original one and deviations increase as μ increases. Compared with non-resonance conditions, the deviations of the natural frequency of the VBI system are larger for the same μ value.

Conclusions

Observed from the analytical formula shown in Eq.(1), the variability in the natural frequency of a VBI system is dominated by both the frequency ratio and mass ratio of the vehicle to the bridge. For the frequency ratio, the deviation of bridge-related natural frequency of VBI system from the natural frequency of the bridge alone reaches its maximum at near resonance conditions. For the mass ratio, the deviations increase as the mass ratio increases. Also, it is illustrated that a vehicle with relatively small mass or natural frequency may hardly affect the natural frequency of the interaction system.

The analytical results as well as the present figures can be useful in bridge seismic designs, especially for the cases that large frequency variability may occur. More numerical studies should be performed with more complicated VBI models and more field experiments should be carried out to verify the applicability of this analytical formula to the real bridge structures, which will be the next step of this study.

Reference

1) K.C. Chang and C.W. Kim, Variability in Bridge frequency induced by a parked vehicle, *Proc.of the 24th KKCNN Symposium on Civil Engineering, Hyogo, Japan,* pp.75-78, 2011.

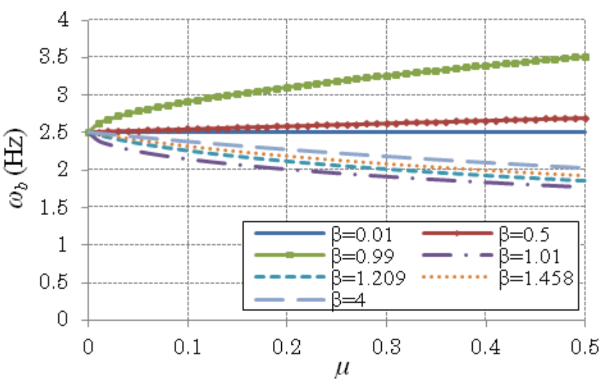

Fig. 2. Bridge-related natural frequency ω_b of the VBI system v.s. mass ratio μ.

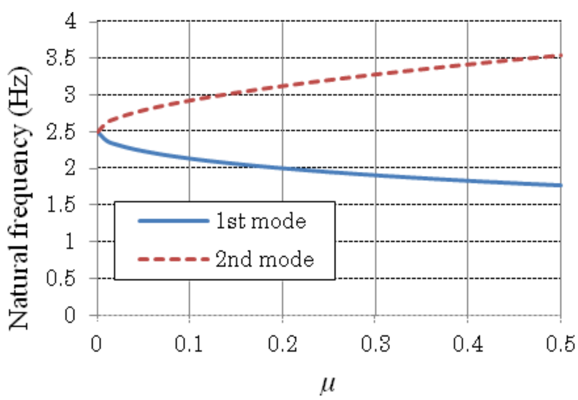

Fig.3.Natural frequency of the VBI system v.s. mass ratio μ in resonance case.