Experimental Verification of the Frequency Variability in a Vehicle-bridge Interaction System

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1. INTRODUCTION

The natural frequency of a bridge when vibrating with vehicles may vary from that when vibrating alone. Such variability in bridge frequencies may cause the bridge responses deviate from the responses that no vehicle is considered. For example, the seismic response of highway bridge under traffics may differ from the response without considering traffics. In a vibration-based bridge health monitoring, the traffic on the monitoring bridge may affect the identified frequency that differs from the expected frequency without considering traffics. 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 (2DOF) vehicle-bridge interaction (VBI) model[1)]. The objective of this study is to verify the frequency variability in a VBI system and to validate the analytical formula through a laboratory experiment.

2. EXPERIMENT LAYOUT

The laboratory experiment is conducted with a scaled steel bridge and vehicle as shown in Fig.1. The experiment bridge is a simply-supported steel beam of 5.4 m in span length, 7.85×10^3 kg/m^3 in mass per unit volume, 66.56 cm^2 in designed section area, and 2.058×10^{11} N/m^2 in elastic modulus. Two vehicle models, designated as V1 and V2, are adopted in this experiment. Both experiment vehicles are two-axle vehicles with a mass of 21.6kg, but have different spring constants for the suspension. By free vibration tests, the frequencies of V1 and V2 are measured as 3.023 Hz and 3.646 Hz, respectively. Three cases are considered: Case 1 refers to the bridge alone without any vehicle, Case 2 the bridge with V1 parked at its mid-span (V1-VBI system), and Case 3 the bridge with V2 parked at its mid-span (V2-VBI system).

3. EXPERIMENT RESULTS

To obtain the natural frequency for each case, a time domain analysis is performed on free-vibration acceleration responses of the bridge and vehicle. If the bridge or VBI system in each case vibrates freely with the same initial condition, then the natural period is obtainable. Taking the inverse of the natural period yields the natural frequency. To ensure the accuracy, 5 rounds of test are performed for each case.

In Case 1, the natural frequency is calculated as 2.500 Hz. Similarily, in Case 2, the natural frequency of the V1-VBI system is identified as 2.240 Hz, and in Case 3, that of the V2-VBI system as 2.275 Hz, both identified from the responses recorded at the bridge. In comparison with Case 1, a decrease of 10.4% and 9% is observed in Case 2 and 3, respectively, indicating that the existence of a parked vehicle makes the natural frequency of a VBI system differ from that of the bridge alone.

The natural frequencies of the interaction systems can also be obtained from the vehicle responses. In Case 2, the natural frequency identified from V1 response is 2.223 Hz, and in Case 3, that identified from V2 is 2.281 Hz, both matching well with those identified from the bridge responses. Therefore, the reliability of the identified results can be verified.

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4. COMPARISON WITH ANALYTICAL RESULTS

The analytical formula for estimating the natural frequency f of the VBI system that a bridge is parked with a vehicle at its mid-span can be expressed as follows[1]:

$$f^2 = f_{b0}^2 \times \frac{1}{2}\left[1+\beta^2+\mu\beta^2 \pm \sqrt{(1+\beta^2+\mu\beta^2)^2 - 4\beta^2}\right] \quad (1)$$

where μ is defined as the ratio of the vehicle mass m_v to the bridge mass m_b, i.e. $\mu \equiv m_v/m_b$, and β as the ratio of the vehicle natural frequency f_{v0} to the bridge natural frequency f_{b0}, i.e. $\beta \equiv f_{v0}/f_{b0}$.

Figure 2 shows the bridge-corresponded natural frequency f_b, obtained as one of f, of the VBI system with respect to mass ratio μ. In this figure, f_b is approximately equal to f_{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, f_b monotonously increases while μ increases; for the case with β>1, f_b monotonously decreases while μ increases. Such an observation clearly indicates that larger deviation of f_b from f_{b0} is induced by larger vehicle-to-bridge mass ratio, i.e. larger vehicle mass or smaller bridge mass.

The natural frequencies of the interaction systems obtained in Case 2 and 3 are marked as (*) in Fig. 2. It can be seen that the dominant natural frequencies of the interaction systems are smaller than those of the bridge alone (f_{b0}=2.5Hz), verifying that the presence of a parked vehicle makes the natural frequency of the original bridge system varied. Such frequency variability is suggested to be considered in the seismic design and health monitoring of bridges.

According to Eq. (1), the analytical natural frequency of the V1-VBI system is calculated as 2.176 Hz, which matches well with that obtained from the laboratory experiment, with a deviation of 2.9%. Similarily, the analytical natural frequency of the V2-VBI is calculated as 2.238 Hz, with a deviation of 1.6%. Such a match in analytical and experimental results is also revealed in Fig. 2, strongly verifying the validity of the analytical formula shown in Eq. (1).

5. CONCLUSIONS

Through the laboratory experiment, the natural frequency of a VBI system is verified to differ from that of the bridge alone. Specifically in this experimental study, the former one is observed to be 10.4% or 9% smaller than the latter one. In addition, the natural frequency of the interaction system can be estimated from the analytical formula proposed previously, which is also validated in this study in showing good agreements with the experimental results. According to the above observations, the simplified equation for VBI system (see Eq. (1)) would be applicable to consider the effect of vehicles in terms of bridge seismic design as well as bridge health monitoring.

REFERENCES

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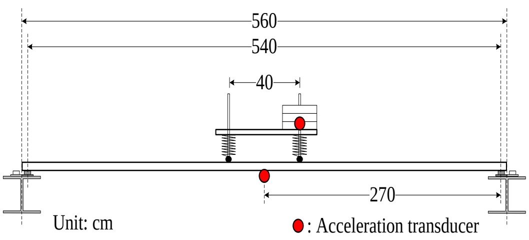

Fig.1. Experiment layout.

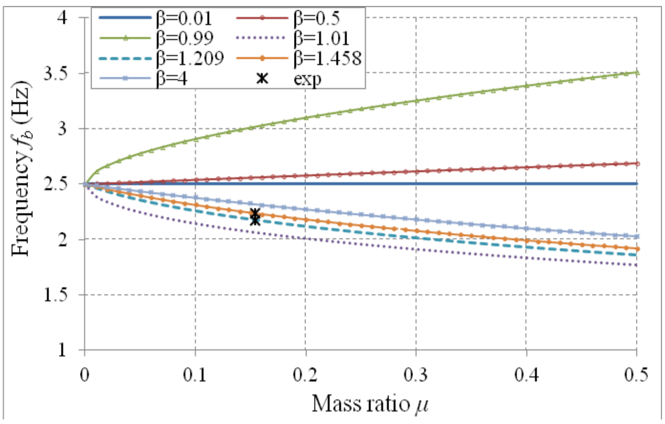

Fig.2. Bridge-corresponded natural frequency f_b of the interaction system with respect to mass ratio μ.