Oscillator Experiment of Simple Girder Bridge coupled with Vehicle

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ABSTRACT

This study presents experimental investigations on dynamic characteristics of bridges coupled with vehicles in order to clarify the vehicle-bridge interaction under earthquakes. Oscillator experiment is carried out at a one-box girder bridge coupled with a vehicle. Both acceleration responses of the bridge and those of the vehicle are measured in horizontal and vertical directions. The dynamic responses of the bridge loaded with the vehicle are compared with those responses of the bridge without the vehicle, and the effect of vehicle loading on the seismic response of bridge is discussed. Observations demonstrate that the presence of the vehicle may affect the dynamic characteristic of bridges.

1. INTRODUCTION

The dynamic response of highway bridges under seismic loads is complicated, and requires comprehensive studies considering various conditions. Japan is located on one of the most earthquake prone regions. Therefore, to prevent bridge structures from damages caused by earthquakes is an important technical issue.

Kawada et al. (1995) demonstrate that traffic jam and earthquakes are not likely to occur coincidentally. Moreover, if vehicles are on bridges during earthquakes they suppress the vibration of bridges. According to the dynamic analysis vehicle-bridge coupled system considering dynamic characteristics of heavy vehicles, the effect of vehicles to dynamic responses of the bridge is considered as negligible (Kameda et al. 1999). As a result, seismic design of the current Japanese specifications for highway bridges, the combination of seismic load and traffic load has not been taken into account (Japan Road Association 2012). However, there is a high possibility to encounter an earthquake during rush hour considering the heavy traffic jam in urban areas. It is, thus, required to review the handling of the vehicle load in seismic design.

In recent years the importance of bridge-vehicle interaction under earthquakes has
been widely investigated. Effects of vehicle load on a girder viaduct for urban expressway using dynamic response analysis are investigated (Kameda et al. 1999, Kim et al. 2011). A forced vibration test was conducted with a vehicle loaded on the bridge, and concluded that the parked vehicle affects the dynamic response of the coupled vehicle-bridge system (Kameda et al. 1999). Effects of live load on bridges during an earthquake would be an important consideration for railway and monorail bridges where the ratio of the live load to the dead load is greater than that of highway bridges. The study on the monorail bridge (Kim and Kawatani 2006), points out that vehicle’s vibration system acts as a damper to a viaduct.

In 1993, the design vehicle load was increased from 200kN to 250kN. Therefore this study is intended to investigate the dynamic response of highway bridges through a forced vibration test by loading 250kN vehicle on the bridge. It is also discussed how the vehicle on the bridge affects dynamic characteristics of the viaduct during an earthquake.

2. EXPERIMENTAL SETUP

To verify dynamic responses of the bridge experimentally, a field test is performed on a highway bridge in Osaka, Japan as shown in Fig. 1. The bridge accelerations are measured at two stages. The 1st stage investigates the acceleration for the bridge alone, and the 2nd stage is for the bridge along with a truck parked at mid-span. The resonant curves for both the bridge without vehicle and the bridge coupled with vehicle are obtained by forced vibration tests with an oscillator located at the mid-span of the bridge. During the test, the forced frequency of the oscillator ranges incrementally and acceleration responses of the bridge and vehicle are recorded.

Fig.1 Views of the experimental highway bridge
2.1. Test Bridge
The test bridge is one span of an entrance viaduct of the Hanshin Expressway Route 4, located in Sakai City, Osaka Prefecture. The bridge, shown in Fig. 2, is a steel box girder bridge with simple supports. Its superstructure is supported by the cantilever member connected rigidly with piers of main route. According to the original design, the total mass of the bridge is about 620 ton and the span length is about 62.3 m. In the direction along the bridge, the bearing B is free to move and the bearing C is fixed.

2.2. Test Vehicle
The test vehicle is a cargo truck of model LKG-CD5ZA, produced by UD Trucks Corp. The total weight included the truck body and additional cargo loading is about 250 kN which is shown in Fig. 3.

2.3. Acceleration Transducer and Data Acquisition System
In the field test, two types of transducers are used. One is a wireless acceleration transducer of which the nominal capacity is 20 m/s². Its sample rate is 100 Hz. The other is a wired sensor, which is one-dimensional transducers of model ARF-10A and ARS-10A, and transmitted to and recorded by a data acquisition system of model DC-204R, both produced by Tokyo Sokki Kenkyujo Co., Ltd.. The nominal capacity of transducers is 10 m/s². Its sample rate is 200 Hz.

2.4. Oscillator
The mass of the oscillator is 500 kg, and it is held by a set of jig of 630 kg. The shaker used in the experiment is shown in Fig. 4. It shakes the bridge horizontally (transverse direction) and vertically at the span center. In horizontal excitation, the frequency sweeps between 2.50 Hz and 2.70 Hz for both stages. Especially from 2.55 to 2.65 Hz the experiment is conducted with 0.01 Hz steps. Also, in vertical excitation, they range from 1.54 Hz to 1.60 Hz at 0.01 Hz steps for bridge system alone (the 1st stage) and from 1.50 to 1.60 Hz at 0.01 Hz steps for bridge coupled with the vehicle (the 2nd stage).
3. EXPERIMENTAL RESULTS

3.1. Measured Data Process

For the response of the bridge with the same direction of the shaking, the response of the bridge is analyzed by using measured data from wireless acceleration transducer installed at mid-span. For the response of the bridge with different direction of the shaking, those responses from wired acceleration transducers are used in estimation. The response of the vehicle is measured using the wired acceleration transducer installed on the rear axle of the vehicle. Since noises are included in the signal measured by the wireless sensors as shown in Fig. 5(i b), these noises are removed.

Fig. 3 Test vehicle

Fig. 4 Oscillator

(a) Horizontal direction (horizontally excited)      (b) Vertical direction (vertically excited)
(i) Acceleration of wireless sensors

(a) Vertical direction (horizontally excited)      (b) Horizontal direction (vertically excited)
(ii) Acceleration of wired sensors

Fig. 5 Time histories of dynamic responses
from the signal. For signals from the wired sensors, zero adjustment is conducted to eliminate offset of the signal (see Fig. 5(ii)). The steady-state signals, which are data below the threshold defined from RMS values of the signal, are used in the estimation.

3.2. Horizontal Excitation

The acceleration response of the bridge due to the horizontal excitation is shown in Fig. 6. It can be seen that vertical response values are similar level of horizontal ones even under the horizontal excitation. It shows the maximum acceleration response and RMS value at each frequency of the oscillator. The horizontal axis denotes the frequency (Hz) of the oscillator, the vertical axis is the acceleration (Gal). Peak values of acceleration response are plotted in upper part of the figure, and those in lower are RMS values. The broken line and solid line stand for the results from the 1st and 2nd stages, respectively. As can be seen in Fig. 6(i),(ii), it is difficult to see a trends from those peak and RMS values. In other words, resonance is not observed from both 1st and 2nd stages. It is not clear to see the effect of vehicle loading on the bridge responses.

Vehicle's acceleration responses of the rear axle are shown in Fig. 6(iii). Responses of the vehicle are about a half of those bridge responses.
3.3. Vertical Excitation

The acceleration responses of the bridge and vehicle according to the vertical excitation are shown in Fig. 7. Under the vertical excitation horizontal response values are same level of vertical response values. In the vertical direction, it is clear that the peak value and the RMS value of the bridge response decrease at each frequency when the vehicle parked on the bridge. The maximum peak and RMS values of the acceleration response reduce to about 43% and 52%, respectively. It is found that the frequency of the bridge without vehicle is about 1.56Hz in the horizontal direction. The resonance frequency of the bridge coupled with the vehicle takes smaller value than the bridge without vehicle loading.

The vertical acceleration response of the vehicle is shown in Fig. 7 (iii), which demonstrates a similar trend with the curve between 1.53 and 1.6Hz of the bridge coupled with the vehicle shown in Fig. 7(i). Observations show that the presence of a vehicle may affect the dynamic characteristics of bridges and the coupled effect of the bridge and the vehicle can be confirmed.

![Resonance curve (vertically excited)](image_url)

(i) Vertical acceleration of the bridge  
(ii) Horizontal acceleration of the bridge  
(iii) Vertical acceleration of the vehicle

Fig. 7 Resonance curve (vertically excited)
4. CONCLUSION

This study investigated experimentally how the vehicle affects the dynamic characteristic of bridge through in-site forced vibration experiment on a viaduct. From forced vibration test, in horizontal excitation, dynamic coupling effect due to loading of the vehicle has not been clear. However, when the bridge shakes vertically, acceleration responses of the bridge decrease remarkably in the vertical direction due to vehicle loading, which shows that vehicle has the effect of suppressing the vibration of the bridge. For the horizontal responses actuated by the vertical excitation, it is found that the vehicle loading alters the bridge’s dynamic characteristic to the long-period. Therefore the presence of the vehicle may affect the dynamic characteristic of bridges.

REFERENCES