第Ⅰ部門　**FE analysis for seismic responses of a bridge under vehicles during strong earthquakes**

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1. INTRODUCTION

The design code of highway bridges in most countries do not consider vehicle load in the seismic design due to the low probability of encountering critical vehicle load and a strong earthquake simultaneously. However, the high probability of traffic jam in urban areas of earthquake prone regions suggests investigations on the seismic responses of highway bridges under vehicles during strong earthquakes[1), 2)] . The goal of this research is to analyze non-linear seismic responses of highway bridges under multiple vehicles during strong earthquakes. The second goal is to provide a simpler and less time-consuming method to analyze seismic responses of bridges considering vehicles without great loss of accuracy compared to the existing method considering vehicle-bridge interaction.

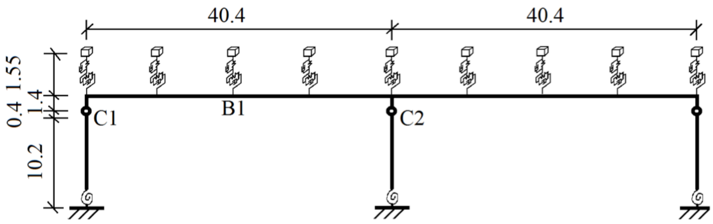

Fig. 1 Bridge and vehicles model: C1, C2 and B1 are observation points. (unit: meter)

Table 1 Parameter of vehicle model.

Parameter	Unit	Value
Mass	kg	17,870
Vertical spring const.	N/m	5.33×10^6
Transversal spring const.	N/m	1.67×10^6
Vertical damping constant	N.s/m	2.78×10^4
Transverse damping constant	N.s/m	2.78×10^4

Table 2 Natural frequencies of transversal modes of the bridge.

	Before yielding			After yielding		
	W/O vehicle	W/ vehicles	W/vehicles as mass	W/O vehicle	W/ vehicles	W/vehicles as mass
1st (Hz)	1.61	1.21	1.41	0.61	0.53	0.54
2nd (Hz)	3.77	3.88	3.30	2.30	2.51	2.04
3rd (Hz)	8.71	8.75	7.71	8.00	8.04	7.21

Table 3 Average of the change of seismic responses in 3 observation points (B1, C1 & C2) compared with the case of bridge without vehicle.

Seismic models	Increment in response	With vehicles	With vehicles as mass
JR Takatori Station (NS)	Max. displ.	0.180 m (49.5%)	0.077 m (21.1%)
	Permanent displ.	0.134 m (63.3%)	0.026 m (12.5%)
JR Takatori Station (EW)	Max. displ.	-0.026 m (-10.1%)	-0.063 m (-25.0%)
	Permanent displ.	-0.124 m (-82.4%)	-0.092 m (-61.2%)
Osaka Gas Fukiai (EW)	Max. displ.	0.074 m (37.2%)	0.048 m (24.5%)
	Permanent displ.	-0.055 m (-54.4%)	-0.094 m (-93.3%)

Max: Maximum, Perm: Permanent, displ.:displacement

2. ANALYTICAL MODEL

2.1 Bridge and Vehicles Model

ABAQUS was utilized to simulate the bridge and the vehicles. The simplified bridge model used in this study is a two-span steel girder bridge, as shown in **Fig. 1**. The steel girders and concrete piers were connected by rigid bearings. The non-linear behavior of the bridge was assumed to be concentrated at the base of the piers, and modeled as rotational spring. The properties of the bilinear rotational spring were as follows: yielding moment = 7.69×10^6 N.m, yielding angle = 0.001078 rad, ultimate moment = 1.15×10^7 N.m, and ultimate angle = 0.008093 rad.

In the case when the vehicles were considered as dynamic systems, they were modeled as mass-spring-damper, and have 2 DOF (in the transversal and vertical directions). In the case when the vehicles were considered as mass, the lumped mass was connected into the bridge with rigid connector. The properties of the vehicle model are shown in **Table 1**. On the simulation, 9 stationary vehicles were connected to the top of the bridge and treated as structural member of the bridge. Due to the nonlinearity, the natural frequencies of the bridge changed depending on property before and after yielding, these frequencies also changed with the addition of vehicles; the values can be seen in **Table 2**.

2.2 Seismic Data

Three strong earthquakes were considered in this study: JR Takatori Station NS component, JR Takatori Station EW component, and Osaka Gas Fukiai EW component. The vertical acceleration assumed half of the transversal acceleration was also considered in the analysis.

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3. RESULTS

3.1 Comparison with VBI model

The analytical results in this study were verified by comparing to the seismic responses o f the highway bridge under stationary vehicles that were simulated by means of the iterative partitioned algorithm considering vehicle bridge interaction (VBI) developed by Borjigin *et al.*[3], which is a more proper way to simulate the bridge and the vehicles but needs more computational time. To simulate nonlinear seismic responses of the bridge under vehicles subjects to 40-second earthquake with 100 Hz time step analysis, the approach by Borjigin *et al.*[3] needed about three days to finish the analysis; while the model in this study only needed 10 – 15 minutes. The trends in both models were similar, but the transversal displacements in the model used in this study were larger in both maximum displacement and permanent displacement. The error of the model in this study compared to the VBI model was 3.7% in the maximum displacement and 10.9% in the permanent displacement.

3.2 Effect of vehicles in Transversal Displacement

For each seismic data, the transversal displacements of three cases were compared and shown in **Fig. 2** and **Table 3**. Under the three earthquakes used in this study, it can be concluded that: a) vehicles might raise or reduce the seismic response of the bridge, depending on the earthquake; and b) in most of the cases, the seismic response is larger when the vehicles are considered as dynamic systems than when they are considered as mass.

3.3 Effect of vehicles in Transversal Acceleration

Additional vehicles (either as dynamic system or as mass) change the frequency characteristic of the bridge (**Table 2**), and thus change the seismic response as shown in **Fig. 3**.

4. CONCLUSION

1) The model in this study gives comparable result with the proper VBI model; 2) Vehicles may raise or reduce the seismic response of the bridge, depending on the earthquake; 3) Additional vehicles (either as dynamic system or as mass) change the frequency characteristic of the bridge, and thus change the seismic response.

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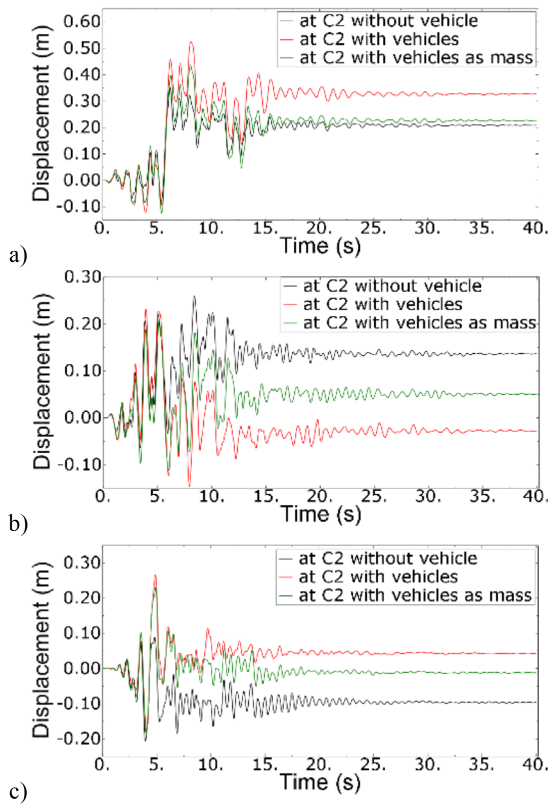

Fig. 2 Transversal displacements of bridge without vehicle, with vehicles, and with vehicles as mass at C2 under: a) JR Takatori Station NS component, b) JR Takatori Station EW component, and c) Osaka Gas Fukiai EW component.

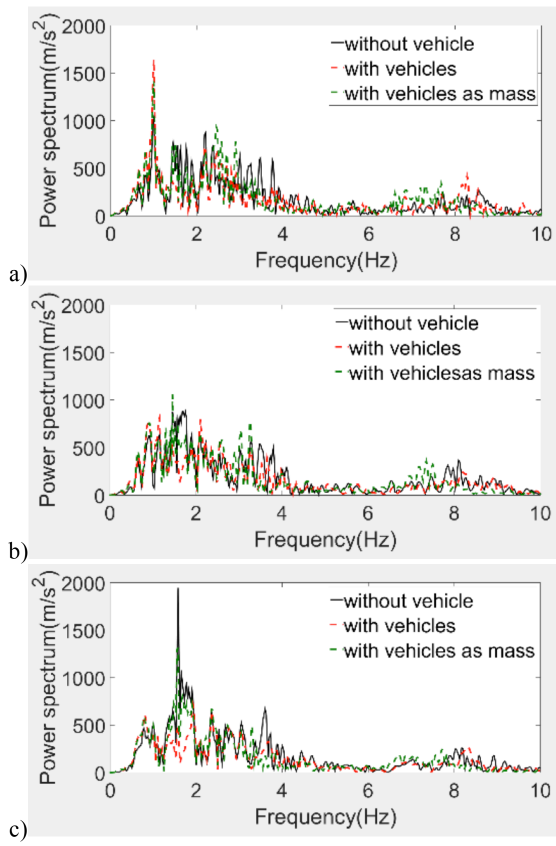

Fig. 3 Seismic response of bridge without vehicle, with vehicles, and with vehicles as mass at C2 under: a) JR Takatori Station NS component, b) JR Takatori Station EW component, and c) Osaka Gas Fukiai EW component.