NUMERICAL INVESTIGATIONS ON DYNAMIC RESPONSES OF A HIGHWAY BRIDGE UNDER MOVING VEHICLES SUBJECT TO STRONG EARTHQUAKES

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1. INTRODUCTION

Seismic designs for bridges in most countries do not require the simultaneous presence of live load and earthquakes to be considered. However, the inertial effect of vehicles during earthquakes could be significant in the case where the total mass of the vehicles are large enough, e.g. in the traffic congestion, which commonly takes place in busy cities[1), 2)]. There are some studies that investigate linear seismic responses of highway and railway bridges under moderate ground motions[1)]. However few studies investigate nonlinear behaviors of the bridges considering traffic under strong earthquakes. The objective of this study is to propose a method to analyze nonlinear seismic responses of highway bridges under traffic. For this objective, an iterative partition integrated method combining ABAQUS and MATLAB is proposed for the nonlinear dynamic analysis of vehicle-bridge interactive system under strong earthquakes. Through numerical examples, this study investigates the effect (beneficial or adverse) of vehicle dynamics on the seismic responses of highway bridge structures.

2. PARTITION INTEGRATED METHOD

A partition integrated method was developed to simulate the dynamic interaction between the bridge and moving vehicles, incorporating the effect of nonlinear behavior, earthquake and road surface roughness. Bridge and vehicles were modelled in different software suite. The finite element (FE) bridge model was established in ABAQUS and moving vehicle model was established in MATLAB. The above two partitions were integrated and a step-by-step analysis scheme were controlled by an MATLAB program.

At each time step, ABAQUS calculated the dynamic responses of the bridge subjected to seismic loading and moving vehicle loading and outputted its responses to a data file. The MATLAB program then extracted the bridge responses, with which the contact forces and vehicle responses were calculated. Following force equilibrium principles, the contact forces calculated here were supposed to equal (differ within a tolerance from) the vehicle loadings applied at the bridge. If not, an iteration procedure repeating the above steps was conducted, until the pre-defined tolerance was satisfied. The computation continued step by step for all time steps.

3. BRIDGE AND VEHICLE MODELS

A three-dimensional FE two-span simply-supported bridge model, as shown in **Fig. 1**, was used in this study. The superstructure was with steel plate girders and the length of each span was 40.4 m. The substructure of the bridge model was with concrete piers with height of 10.2 m. Damping ratio was set as 0.05. **Fig. 1** also shows observation points denoted as B1, C1, and C2, where B1 is the mid-span of the girder, and C1 and C2 are top of piers. The plastic hinges were assumed to concentrate at the base of piers and modeled as rotational springs of a bilinear elastoplastic behavior. The properties of the bilinear rotational spring were as follows: yielding moment=7.69×10^{6}N・m, yielding rotation=2.839×10^{-3}rad, ultimate moment=1.15×10^{7} N・m, and ultimate rotation=8.841×10^{-3}rad.

Vehicles were simplified as sprung-dashpot-mass models of 2 DOFs with bouncing and sway modes. Properties of vehicle model are listed as follows: the mass m is 17870 kg, bouncing spring constant K_v is 5.33×10^{6} N/m, damping coefficient C_v is 2.78×10^{4} N·s/m, sway spring constant K_H is 1.67×10^{6} N/m, and damping coefficient C_H is 2.78×10^{4} N·s/m. During earthquakes, eight vehicles were assumed to pass over the bridge at a constant speed of 10.1 m/s. Two Level-II ground motions of JRA[3)] code were considered in the study: JR Takatori Station NS component and JR Takatori Station EW component. Both transverse and vertical ground motions were applied on the bridge and the vertical ground motion time history was taken as half of the transverse one in magnitude.

4. SEISMIC RESPONSES OF THE HIGHWAY BRIDGE

The hysteresis loops of nonlinear spring at middle pier base are shown in **Fig. 2**, and the transverse displacements of C2 with and without moving vehicles are compared and shown in **Fig. 3**. The permanent lateral displacement of B1, C1 and C2 are summarized in **Table 1**. Under the JR Takatori Station NS component, the existence of moving vehicles raised the seismic response of the bridge (both maximum displacement and permanent displacement). Under the JR Takatori Station EW component, the existence of vehicles amplified the maximum displacement, both in positive and negative

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directions, but reduced the permanent displacement of the bridge. Specifically, the permanent displacements increased by about 6.5% under the JR Takatori Station NS component when moving vehicles are considered, but they varied by up to 60% in absolute value under the JR Takatori Station EW component. Hysteresis loops in Fig.2 showed that the moment at pier base excessed the yielding moment and entered the plastic region during the strong earthquakes. In the case with vehicle, the size of loop tends to be bigger, indicating the bridge suffered from a more severe plastic behavior. Therefore it can be said that moving vehicles might introduce noteworthy effects on seismic responses of bridges under some ground motions. Taking moving vehicles in seismic analysis amplifies the maximum displacement under both ground motions studied herein and the permanent displacement under one ground motion, supporting the needs to investigate traffics on seismic behaviors of highway bridges.

5. CONCLUSIONS

The vehicle-bridge interaction responses during strong earthquakes could be simulated and the effect of vehicles on seismic responses of a highway bridge was studied by the proposed partition integrated method. Observations showed that moving vehicles are likely to cause changes in seismic responses under a certain ground motion. Specifically, the moving vehicles amplified the maximum displacement and amplified the permanent displacement slightly under one earthquake. However more comprehensive investigations are needed to conclude the effect of moving vehicles on nonlinear seismic responses of highway bridges by considering more earthquakes and bridge types.

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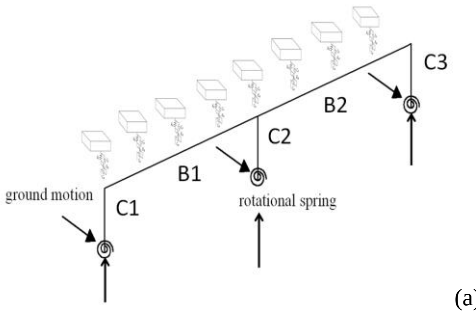

Fig.1 Idealized bridge model with vehicle model.

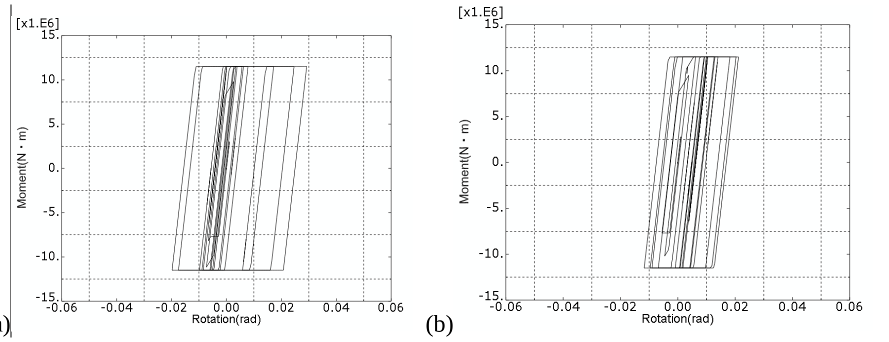

Fig.2 The hysteresis of nonlinear spring under JR Takatori Station EW component: (a) with vehicle, (b) without vehicle.

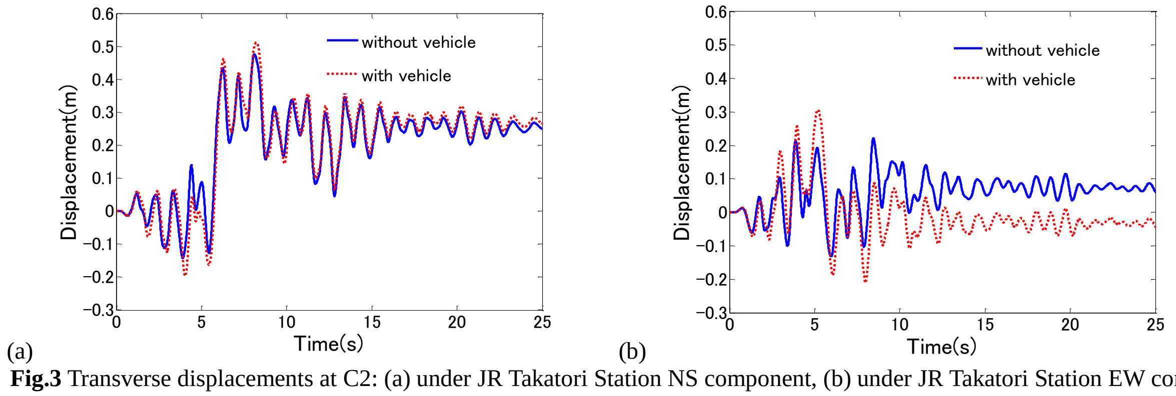

Fig.3 Transverse displacements at C2: (a) under JR Takatori Station NS component, (b) under JR Takatori Station EW component.

Table 1 Permanent lateral displacements (mm).

	Seismic 1			Seismic 2		
	B1 (mid-span)	C1 (pier top)	C2 (pier top)	B1 (mid-span)	C1 (pier top)	C2 (pier top)
Without vehicle	294.1	246.1	253.5	78.1	73.2	61.3
With vehicles	313	263	270	-44	-29	-43
Variation (in absolute value)	6.4%	6.9%	6.5%	43.7%	60.4%	29.9%