第 I 部門 A Three Dimensional Seismic Response Analysis of High-speed Train and Bridge Interaction System

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1. Introduction

Japanese high-speed train, Shinkansen, is playing an important role in domestic transportation, and it is extremely important to secure the safety of the Shinkansen during strong earthquakes. Therefore, the responses of acceleration and relative displacement of vehicle-bridge interactions under seismic activities are simulated and discussed. Previous studies mainly consider this topic with the assumption that under moving Shinkansen train bridge material performs within its linear range during the earthquake. However, in order to simulate the situation in a more realistic condition, this study takes train dynamics and material non-linearity into consideration and conducts simulations based on a commercial software Abaqus.

2. Methodology

In the VBI system, the differential equation of the vehicle and bridge system can be written as Eq. (1).

$$\begin{aligned} \boldsymbol{M_v}\ddot{\boldsymbol{w}}_{\boldsymbol{v}} + \boldsymbol{C_v}\dot{\boldsymbol{w}}_{\boldsymbol{v}} + \boldsymbol{K_v}\boldsymbol{w_v} &= \boldsymbol{f_v} \\ \boldsymbol{M_b}\ddot{\boldsymbol{w}}_{\boldsymbol{b}} + \boldsymbol{C_b}\dot{\boldsymbol{w}}_{\boldsymbol{b}} + \boldsymbol{K_b}\boldsymbol{w_b} &= \boldsymbol{f_b} \end{aligned} \tag{1}$$

where, M_v, C_v, K_v, w_v and f_v denote mass matrix, damping matrix, stiffness matrix, displacement vector and force vector of train cars. Those with subscript "*b*" are those for the bridge structure.

In the two differential equations above, the force term that comes from vehicle vibrations, results in bridge vibration, and the force term that comes from bridge vibrations, results in vehicle vibration. The dynamic equations of motion for the interactive system can be solved by an iterative approach, obtaining a result of vibration when assumptions for dynamic responses of vehicle and bridge converge at the same time.

As for numerical integration in this study, HHT-α Method is used for integration and Newton-Raphson Method is used for iteration.

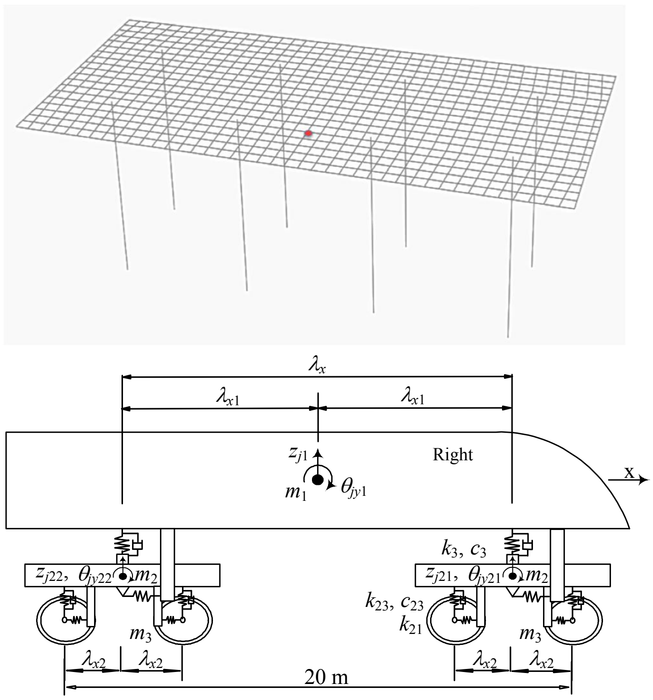

Fig. 1 Bridge model with observation point in red point (top) and train model (bottom). (the latter is reproduced from [1])

3. Seismic Response Analysis

3.1 Bridge Model and Vehicle model

The bridge model and vehicle model are created utilizing commercial structural analysis software Abaqus (see Fig. 1). Each block of the bridge is built with a 24-meter-long and 5.2-meter-wide deck by using shell elements and eight 7-meter-tall piers by beam element with 6 meters intervals. Bridge material is considered as reinforced concrete, whose density is 2500 kg/m^3 and Young's modulus is 2.45×10^6 N/cm^2. Steel rails are installed with 1.5 meters interval, whose density is 7850 kg/m^3 and Young's modulus is 2.06×10^7 N/cm^2. Each vehicle model is consisted of steel car body, bogie and wheelset. The total weight is 365.17 kN and the mass moment of inertia of the car body in transverse direction is 2512.63 kN·s^2·m. The models are then validated by comparing eigen-

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frequencies, mode shapes and seismic responses under a moderate earthquake data with reference results [1].

3.2 Standing Train-Bridge Interaction Analysis under Moderate Earthquake

After confirming the validity of the model, moderate earthquake seismic data is applied to the model. The examined point is the midspan of bridge deck. Seismic data is from earthquake at Saga Prefecture on Mar. 20th, 2005 [2] and was applied in the longitudinal direction. In order to find out the influence of train dynamics to the system, two cases are discussed: system with train as a dynamic system standing on the bridge (train standing) and train as mass on the bridge (train as mass). Their seismic acceleration responses are plotted in Fig. 2, where the peak values and root mean square (RMS) values are also given.

3.3 Standing Train-Bridge Interaction Analysis under Strong Earthquake

When experiencing strong earthquakes, the bridge structure may show nonlinear behavior. Seismic data is from earthquake at Kumamoto Prefecture on the 16th April 2016 [2]. The seismic acceleration responses are plotted in Fig. 3, where the peak values and RMS values are also given.

4. Discussion and Future Work

When bridge material acts elastically under moderate earthquake (Fig. 2), it can be seen that the maximum acceleration in the train-standing case were decreased compared to the train-as-mass case. The same trend also observed in the displacement responses (figures omitted for simplicity). It can be said that train acted as a damper in the system because it mitigated the seismic responses to some extent. Therefore, it is reasonable and conservative to take train as pure mass in designing. However, between 15 second to 20 second, it is possible that the response of the bridge and trains are in the same direction and there happens superposition of their responses. The reason can be further studied by conducting simulations when setting the examined point on the vehicle model to see its response.

When bridge material acts elasto-plastically under strong earthquake (Fig. 3), the results obtained in train as mass-train standing case comparison are not too different from the moderate earthquake results. However, when relative displacement responses were considered, the similar trend were not observed (Figures omitted), leading to the difficulty to conclude from present analysis. This is opposite to the conclusion under moderate earthquake, although standing trains still acted as damper as standing train makes the seismic response of bridge damped out faster than other cases. In order to find out the reasons of such results, future works are expected, including eigenvalue analysis of the bridge and bridge with trains standing on it and hysteresis loops of bottom piers.

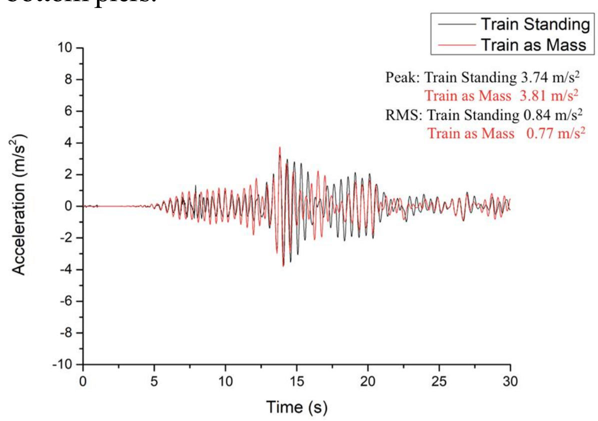

Fig. 2 Acceleration responses under a moderate earthquake.

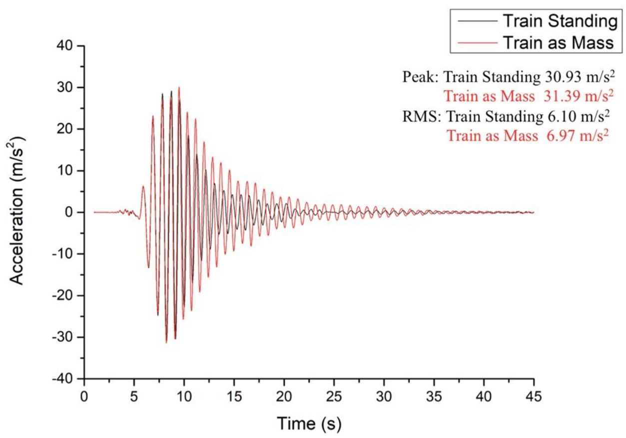

Fig. 3 Acceleration responses under a strong earthquake.

References

[1] He X. Analytical approaches to dynamic issues related to high-speed railway bridge-train interaction system: [D]. Kobe University, 2007;

[2] "http://www.kyoshin.bosai.go.jp/kyoshin/search/", (accessed on January 23, 2018).