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Seismic damage evaluation of high-speed railway bridge components under different intensities of earthquake excitations

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ABSTRACT

Bridges are common features of high-speed railway infrastructure. However, the performance of such bridges under seismic scenarios has not been well studied. To quantify possible damage levels of bridge components under different intensities of earthquake excitation, a 1/12-scale bridge specimen was constructed and tested using shaking tables. The experimental results of this investigation showed that not all bridge components were damaged when subjected to earthquake with the intensity of 0.20 g. A finite element (FE) model of the prototype bridge was also established and validated by the experimental results with consideration of similarity relationships. Finally, parametric studies involving different intensities of earthquake excitation were carried out by the validated modelling approach to study the damage levels of high-speed railway components under more severe earthquakes (i.e. 0.30 g, 0.40 g and 0.50 g). The results could be applied to quantify the levels of damage of the main components of high-speed railway bridges when subjected to earthquake intensities no greater than 0.50 g. Moreover, the numerical results showed that the shear reinforcement, fixed bearing and the pier installed with the fixed bearing were more vulnerable to earthquake excitation than the shear studs, slide layer, and cement asphalt mortar layer investigated in this study.

1. Introduction

Unlike other common bridges (e.g. highway and low-speed railway bridges), high-speed railway bridges (HSRBs) are more often installed with ballastless track (as shown in Fig. 1) consisting of base plate, track plate, fasteners, and rails. This track system replaces the traditional ballasted track sleepers and bed by using a precast reinforced concrete slab, which is longitudinally continuously connected to the girder. Moreover, a cement asphalt (CA) mortar layer is used to fill the gap between the base plate and track plate. In addition, a slide layer (consisting of geotextile and geomembrane) is also applied between girder and base plate. An example layout of a ballastless track system on a girder between two adjacent bridges is shown in Fig. 2. Considering the high safety importance of such bridge infrastructure and possible earthquake loading, it is essential to study the seismic performance of HSRBs with ballastless track and to evaluate their damage level under different intensities of earthquake excitation.

According to the Chinese code for seismic design of railway engineering (GB50111-2006) and code for seismic design of buildings (GB50011-2010), the seismic design requirements for buildings and bridges in China are typically the same. Specifically, there are three demand levels for both buildings and bridges: (1) no structural damages (building and bridges) under "small earthquake" excitations; (2) certain structural damages under moderate earthquake excitations but can be rehabilitated afterwards; (3) serious damages are allowed under large earthquake excitations but no overall structural collapse. For Chinese seismic codes, the definition of "small earthquake" is that of average recurrence interval (return period) of 50 years; "moderate earthquake" is that of return period 475 years; and "large earthquake" is that of return period around 2000 years.

The seismic performance of bridges has been extensively studied using both experimental and numerical approaches. Among different experimental investigations, the shaking table test has been widely applied for such study. For example, Li et al. [1] conducted a shaking table test of a 1/40 scale model of the Taizhou Changjiang Highway Bridge in China to investigate the seismic performance of different connection configurations between the deck and pylons. Johnson et al. [2] performed the shaking table test of a

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Fig. 1. Ballastless track on a high-speed railway bridge.

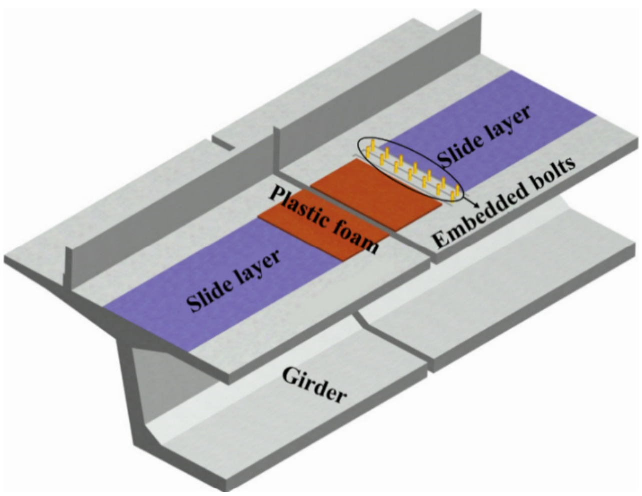

Fig. 2. Typical girder joint for high-speed railway bridge (with ballastless track).

1/4 scale two-span reinforced concrete bridge to understand the effects of soil-structure interaction. Caetano et al. [3] conducted shaking table tests of a cable-stayed bridge to investigate the effect of dynamic cable interaction with the deck and towers. Saiidi et al. [4] established a 1/4 scale bridge model to investigate the seismic response of a bridge system crossing an active fault. Other types of bridges [5–8], such as a crane bridge, a self-centring designed bridge and a hybrid sliding-rocking posttensioned segmental bridge have also been investigated through shaking table testing. These studies, however, did not focus on HSRBs and earthquake evaluation. Although it is acknowledged that large-scale shaking table tests are very costly, they do provide indispensable information on the performance of essential infrastructure.

Due to limitations in acceleration capacity, it may not be easy for shaking tables to produce very severe earthquakes. This constraint introduces difficulties for the study of various forms of seismic damage of bridge components under severe earthquakes. Numerical modelling has often been used to simulate the seismic responses of bridges, especially for severe earthquakes. For example, Ghobarab et al. [9] used a dynamic bridge model to compare the effect of various energy-dissipating concepts when the bridge is subjected to moderate to severe earthquake ground movement. Similarly, Shen et al. [10] established a numerical model to investigate the effect of near-fault ground motions on a bridge with seismic isolation bearings. Bradley et al. [11] applied a 2D FE model to study the probabilistic seismic performance and loss assessment of an actual bridge-foundation-soil system. Choine et al. [12] developed a time-dependent seismic fragility model for a corrosion-damaged 3-span fully integral RC bridge using nonlinear dynamic analysis. Filipov et al. [13] carried out a parametric study to evaluate quasi-isolated bridge behaviour. Nurdan et al. [14] developed a 3D FE model to analyse the seismic performance of two suspension bridges. Meanwhile, Xia et al. [15] established a dynamic model of a coupled train-bridge system and calculated the dynamic responses of the bridge and the vehicles. He et al. [16] developed an analytical approach to simulate the seismic response of the bridge-train interaction system. Du et al. [17] presented a FE-method-based framework for dynamic analysis of a bridge-train system under earthquake excitation. A few studies have also concentrated on bridge-train interaction analysis [18–22]. However, very limited experimental and numerical studies have been conducted with the aim of understanding the seismic performance of HSRBs with ballastless track and evaluating possible damage to bridge components in severe seismic scenarios.

Results from other bridge types (e.g. railway and highway bridges) cannot be directly applied to HSRBs because of different structural stiffness requirements. For example, to ensure the comfort and stability of high-speed train travel, a larger sectional size is commonly seen in HSRB piers. The larger sectional size results in greater structural stiffness and therefore, reduced deformation of bridge piers, in turn reducing vibrations of the bridge superstructure. However, the larger sectional size means an increased dead load and therefore greater seismic force due to earthquake accelerations. Moreover, the live load (the high-speed train) on HSRBs is also obviously different than that on other bridges. According to the code for design of high-speed railway (TB10621-2014), the maximum traveling speed for the studied bridge prototype is about 350 km/h. The live load of high-speed railway bridge prototype applied in China is illustrated in Fig. 3. In addition, because the ballastess track is longitudinally and continuously connected to the HSRB girder between adjacent bridges (i.e. simply-supported girder bridge and continuous girder bridge), the continuity in the longitudinal direction for all spans is enhanced for seismic response (i.e. acceleration, displacement and etc.). Therefore, the seismic performance of the structure may also be different from that of other bridge types. As a result, the conduct of specifically targeted experimental and numerical studies of HSRBs with ballastless track is of high importance.