VIBRATION REDUCTION FOR THE TRAIN-BRIDGE SYSTEM WITH OVERHANGING BEAM EFFECTS

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ABSTRACT

As a train passes through a rail bridge with overhanging beams at high speeds, the overhanging beam would be subjected to intensive vibrations and then excite the running trains over it, which may build up the dynamic response of the train-bridge system. In this study, a finite element modeling that can account for the dynamic interaction of train-bridge coupling system will be used to simulate the dynamic response of the coupling system. To reduce the amplification effect of overhanging beams on the train-bridge system, a set of rotational restraint devices will be installed on the adjacent overhanging beams. From the numerical results, the proposed approach can effectively reduce the amplification of overhanging beams on the train-bridge system.

KEYWORDS: HIGH SPEED RAIL, OVERHANGING BEAM, RESONANCE, VIBRATION REDUCTION, VBI DYNAMICS

Introduction

Speedy delivery, high capacity, relieve congestion, energy efficiency, and less amount of land in operation are primary advantages of high speed rails (HSR) in modern intercity transportation. From the viewpoint of operational safety and riding comfort of a high speed train moving on a rail bridge, the bridge must be designed to provide sufficient structural strength for the traveling train. For this, the vehicle-bridge interaction (VBI) dynamics become one of important subjects for vibration problems of high speed railway. Focusing on the dynamic behavior of rail bridges due to moving loads, many engineering researchers and scientists have devoted themselves to studying the resonant response of a bridge subjected to a series of moving loads with regular intervals. With the VBI considerations in high speed rails, many interesting topics were investigated, such as wind effects, seismic analysis, and ground movements. In this study, the VBI dynamic problem for a train running on simply supported bridges considering the effects of overhanging beams at support ends (see Fig. 1) will be conducted. From numerical investigations, as a high speed train moves on a bridge with overhanging beams, the overhanging beams would be subjected to intensive vibrations. Such vibration would excite the running train over the overhanging beams and further build up the dynamic response of the train-bridge system. In this study, a finite element modeling that can account for the dynamic interaction of train-bridge coupling system will be used to simulate the dynamic response of the coupling system. By finite element method, a number of multi-span simply supported bridges are modeled as a series of beam elements and a train as a sequence of identical moving two-axle systems. To reduce the amplification effect of overhanging beams on the train-bridge system, a set of rotational restraint devices will be installed on the adjacent overhanging beams. From the numerical results, the proposed approach can effectively reduce the amplification of overhanging beams on the train-bridge system.

Figure 1 Overhanging beams at bridge supports

Train-Bridge interaction finite element anaysis

In analyzing the VBI problem, two sets of equations of motion are written, one for the supporting bridge and the other for each of the moving vehicles over the bridge. As the contact points between the running vehicles and the bridge move from time to time, the system matrices must be updated and factorized at each time step in an incremental time-history analysis. Considering the complex procedure, the two sets of differential equations, in general, are solved by the following computational approaches (Yang et al. 2004): (1) full vehicle-bridge coupling system, (2) iterative scheme, and (3) dynamic condensation method.

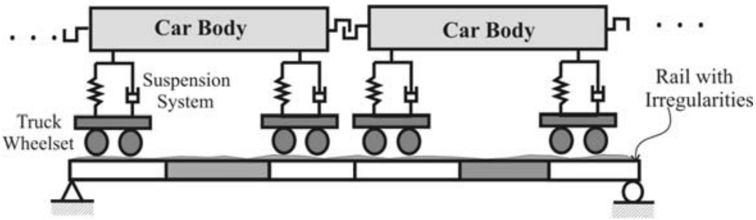


Fig. 2 Schematic diagram of train-bridge model

As shown in Fig. 2, when a train passes a bridge, at a certain instant during the passage of the train, some elements of the bridge will be directly acted upon by the two-axle systems, while the others are not. In this study, the most commonly used 12-DOF beam element will be used to simulate the bridge structure, of which the axial displacement is interpolated by linear functions and the transverse displacements by cubic *interpolation* (*Hermitian*) *functions*. The number of vehicles directly acting on the bridge changes as the train keeps moving, and so do the contact points between each bridge element and the moving vehicles. Typically, a beam element will be acted upon by a wheel-set, as shown in Fig. 2. Such an element has been referred to as the planar vehicle-bridge interaction (VBI) element. For this element, two sets of equations of motion can be written, one for the bridge element and the other for the vehicle system:

$$\begin{aligned} &[m_b]\{\ddot{u}_b\}+[c_b]\{\dot{u}_b\}+[k_b]\{u_b\}=\{p_b\}-\langle N_c\rangle\{f_c\} \\ &[m_v]\{\ddot{u}_v\}+[c_v]\{\dot{u}_v\}+[k_v]\{u_v\}=\{p_v\}+\{f_c\} \end{aligned} \tag{1a,b}$$

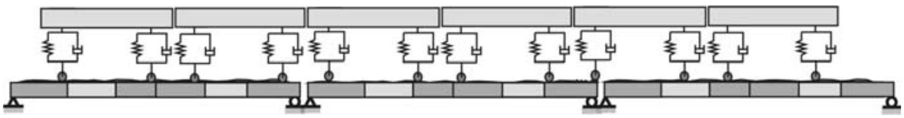
where $[m_b]$, $[c_b]$, $[k_b]$ = the mass, damping, and stiffness matrices of the beam element, and $\{p_b\}$ and $\{f_c\}$ = the external nodal loads and the contact forces existing between the sprung mass and the beam element; $[m_v]$, $[c_v]$, $[k_v]$ = the mass, damping, stiffness matrices of the sprung mass, $\{p_v\}$ = the weight of the lumped part of the vehicle, and and $< N_c >$ = the interpolation function vector. The preceding two equations (1a,b) are coupled through the contact forces $\{f_c\}$, while the coefficients matrices of the planar vehicle system vary according to its acting position on the bridge. To overcome the time-varying nature of the problem, Yang et al. (2004) proposed a method for condensing the degrees-of-freedom (DOFs) of the two-axle system into those of the element in contact, after the two-axle systems are discretized in advance by Newmark's finite difference formulas. The result is a VBI element that possesses the same number of DOFs as the parent element, while the properties of symmetry and bandedness are preserved. Such an element is particularly suitable for analyzing the dynamic responses of the vehicle-bridge interaction problems concerning both the bridge and vehicle responses. Because the VBI element and its parent element are fully compatible, conventional element assembly process can be applied with no difficulty to form the equations of motion for the entire vehicle-bridge system, that is

$$[M]\{\ddot{U}_b\} + [C]\{\dot{U}_b\} + [K]\{U_b\} = \{P_b\} \tag{2}$$

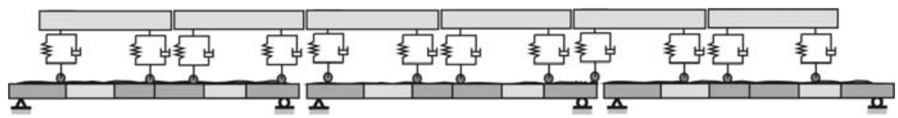
where $[M]$, $[C]$, $[K]$ respectively denote the mass, damping, and stiffness matrices of the entire vehicle-bridge system, $\{U_b\}$ the bridge displacements, and $\{P_b\}$ the external loads acting on the bridge. The preceding equations are typical second-order differential equations, which can be solved by a number of time-marching schemes. In this study, the Newmark β method with a constant average acceleration is employed again to render the preceding equations into a set of equivalent stiffness equations, from which the bridge displacements $\{U_b\}$ can be solved for each time step. Once the bridge displacements $\{U_b\}$ are made available, the bridge accelerations and velocities can be computed accordingly. By a backward procedure, the response of the sprung masses can be computed as well on the element level, which serves as indicator of the riding comfort (Fryba 1999).

Finite Element modeling of the train-bridge system and numerical results

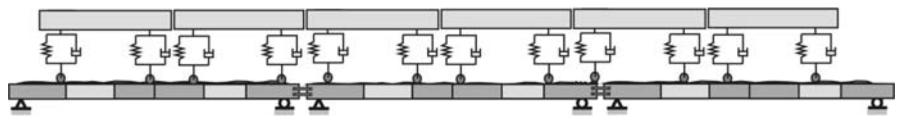
Figure 3 shows the three train-bridge cases to be studied in this paper. Figure 3(a) represents a conventional simply supported bridge for typical structural analysis of railway bridges, Fig. 3(b) the bridge with overhanging beams at both ends for practical considerations, and Fig. 3(c) the overhanging beams of adjacent bridge are connected by an equivalent rotational springs.



(a)



(b)



(c)

Figure 3 VBI model (a) Simple beams; (b) Simple beams with overhanging beams; (c) Simple beam with restraint overhanging beams.

Let v denote the moving speed of the train and L the length of the bridge. The speed parameter S is defined as the ratio of the first excitation frequency of the moving vehicles, i.e., $\pi v/L$ to the fundamental frequency Ω $(=2\pi f)$ of the bridge (Yang et al. 2004)

$$S = \frac{\pi v}{\Omega L} \tag{4}$$

Since the resonant response may result in the ballast destabilization and diminishing of operational safety of trains on track structures, the maximum acceleration will be employed to evaluate the dynamic interaction of vehicle-bridge system for the beams with overhanging arms in the following numerical examples (Fryba 1999). According to the resonant speed given previously, that is, $v_{res} = fD$, the corresponding resonant speed parameter is denoted as S_r and can be expressed as $S_r = D/2L$. The vertical acceleration of the moving vehicles has been regarded as an indicator of the riding comfort or running safety of high-speed trains. For this, the maximum vertical acceleration of the running two-axle systems is defined as:

$$a_{v,\max} = \left|\ddot{u}_v \pm D\ddot{\theta}_v / 2\right|_{\max} \tag{3}$$

Figure 4 presents the maximum acceleration for the beam with span L = 35m and the running train with car length D = 25m against the speed parameter S, which has been defined in Eq. (4), respectively. As indicated, both the responses of the bridge and running two-axle systems are significantly amplified due to the effects of overhanging beams, especially at the resonant speed parameter of $S_r = 0.357$ (= $D/2L$=25/(2*35)).

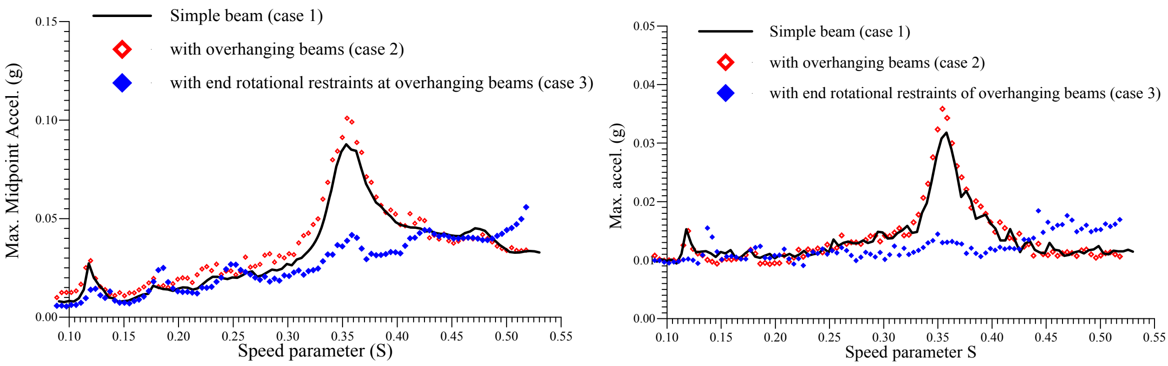


Figure 4 Maximum response vs. S
(a) Midpoint acceleration of the bridge *vs.* S plot (b) $a_{v,max}$ *vs.* S plot

From the numerical results, the following conclusions can be drawn:

1. Significant resonant peak takes place on the dynamic response of the train-bridge system.
2. Installing end rotational restraints on overhanging beams of the adjacent bridges can effectively reduce the amplification of dynamic response for the VBI system due to the overhanging beam effects.
3. The amplification effects of overhanging beams on the VBI system of HSR should be taken into account in design.

References

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