Influence of Road Load Arrangements on Dynamic Responses of Rail-cum-road Bridge

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Abstract: Accurate analysis of dynamic effects under different road load arrangements is of great significance for ensuring safety and stability of bridge, especially for long-span rail-cum-road steel bridges. The problem is studied by establishing the train-bridge dynamic interaction system. The train model is considered by the rigid-body dynamics method, the bridge model is established by the finite element method, and the wheel/rail interaction is imported by the corresponding assumption and the Kalker linear creep theory, respectively. A case study of the dynamic response of a long span rail-cum-road steel bridge in China is calculated with various road load simulations induced by a CRH2 high-speed train running through the bridge with the speed range from 160 km/h to 240 km/h. The results indicates that the maximum vertical vibrations of mid-span appears with empty road load on highway. The impact of track irregularity contributes largely to the whole vibrations than the road load arrangements.

1. Introduction

With the development of high-speed trains, train-bridge interaction system has attracted constant attentions of many scholars and engineers all over the world. In the long process of research, many studies focus on structural safety, reaction mechanism and service life of concrete bridges. However, relevant achievements pay scant attentions to steel bridges, especially long span rail-cum-road steel bridge. In addition, previous researches generally concern the overall responses of bridge itself and ignore the influence of road load arrangements. Moreover, rough simplifications in establishing of finite element bridge mode also lead to comparative errors between simulated results and actual responses of bridge. Therefore, it is necessary to evaluate the accurate dynamic effects with diverse load arrangements.

Based on the aforementioned condition, firstly, the train subsystem and bridge subsystem in this paper are established separately and combined with the assumed track irregularity and wheel-rail relationship model. Then the dynamic interaction system is solved by the inter-history iteration method. Thirdly, a long span rail-cum-road steel bridge in China is taken as a case study in which dynamic responses of the bridge under different road load arrangements are calculated and compared. The conclusions are followed in the end.

2. Train-bridge Interaction Model

2.1. Train-bridge Model

The train model is composed of vehicles and each vehicle is a multiple degree-of-freedom (DOF) system which consists of car body, bogies, wheel sets with spring-damper suspension system between each of them. The train subsystem model in this paper contains 31 DOFs. Based on multi-rigid-body dynamic equations, the global mass, damping, and stiffness matrices of train subsystem are derived. The bridge model is established by finite element method which can take spatial complexity of actual bridge structure into account. No relative displacement between bridge track and deck is taken as the assumption for building the motion equations of bridge subsystem.

2.2. Wheel/rail Interaction Force

Wheel/rail interaction relation shows the relative movement and interaction force between the wheel and the rail, which is also the connection between train subsystem and bridge subsystem. Wheel/rail interaction contains vertical and lateral relation and the vertical wheel/rail corresponding assumption and the lateral Kalker liner creep theory are adopted in this paper. The vertical wheel/rail corresponding assumption indicates no relative movement between the wheel and the rail. Thus, the vertical wheel/rail force is determined by the motion status of the wheel and the rail. The Kalker linear creep theory demonstrates the problem of three-dimensional steady rolling contact in the elliptical contact zone. The wheel/rail creep force can be obtained using this theory.

2.3. The Inter-system Iteration Method

By assuming the bridge subsystem to be rigid at first, the inter-system iteration method solves the train subsystem using the track irregularities as the excitations and obtains the time histories of the wheel/rail forces. Through applying the interacted forces on bridge deck, the dynamic responses of bridge can be calculated. Combining the bridge movement and the track irregularities as new excitations, the updated wheel/rail forces are calculated again for next iterated steps. The wheel/rail iteration forces are usually taken as indexes for convergence check.

3. Case Study

The case study involves a CRH2 high-speed train passing through a rail-cum-road cable-stayed bridge with different road load conditions. The bridge consists of five spans and two pylons supporting double cable planes. The main span of the bridge is 532 m and the total length is 1092 m, as shown in Figure 1. All the spans are composed of different numbers of 14 m intervals which is inverted trapezoidal cross-section. It can be seen in Figure 2 that the bridge deck is designed by the double-way 6-lane above and the double-line rail traffic space below.

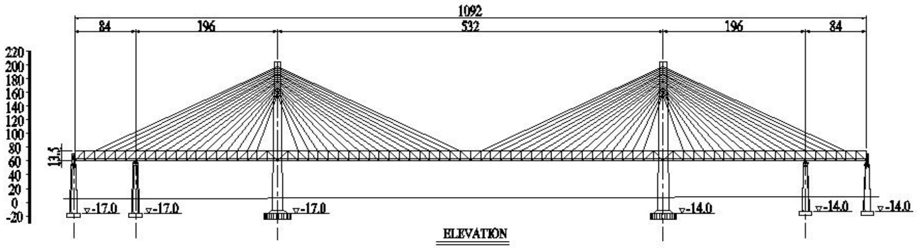

Figure 1: Layout of the cable-stayed bridge (unit: m).

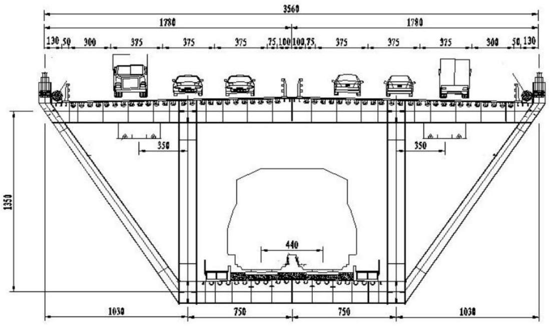

Figure 2: Lane design of the rail-cum-road bridge (unit: m).

The CRH2 train is a common train model of railway system in China. The simulated train consists of 16 cars, organized in two groups of MTMTTMTM. The axial loads for the motor cars (M) is 135 kN and for trailer cars (T) is 120 kN, respectively. The sketch of the adopted train group is as shown in Figure 3.

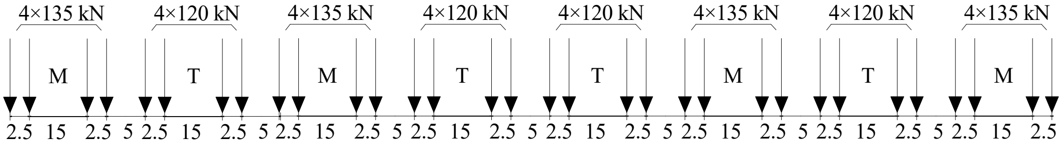

Figure 3: Axial load of the CRH2 train (unit: m).

Track irregularity samples transformed from the German low-disturb spectrum are used as the system exciter. The truncation frequencies and the roughness constant used in this paper are listed in Table 1.

Table 1: Characteristic parameters of PSD of German high-speed rail irregularities.

Ω_c (rad/m)	Ω_r (rad/m)	Ω_s (rad/m)	A_a (cm^2 • rad/m)	A_v (cm^2 • rad/m)
0.8246	0.0206	0.4380	2.119×10^{-7}	4.032×10^{-7}

3.1. Bridge Model

3.1.1. Model Information

The bridge finite element model is established by MIDAS software, applying spatial beam elements to simulate girders and towers, truss elements to build cables, respectively. The connections between the main beam and towers are fixed constraints, while those between the beam and pies are unilateral constraints. The secondary dead load of highway and railway is 54 kN/m and 388 kN/m, respectively, and those two kinds dead load are transferred as additional mass for next calculation. As for the complex orthotropic deck system, sophisticated modelling undoubtedly create redundant elements and nodes, which would inevitably not only improve the computational cost, but also increase the probability of operation collapses. In this paper, adjacent two U ribs along the bridge are taken as one beam element and the orthotropic plate is divided into several beams.

3.1.2. Vibration Characteristics

In order to evaluate the influence of road load, train-bridge dynamic analysis is executed under three conditions, including empty load (I), mid-span with road load (II) and half range with road load (III). The selection of road load references to the first-grade load based on design standard in China. The three road load arrangements are displayed in Figure 4.

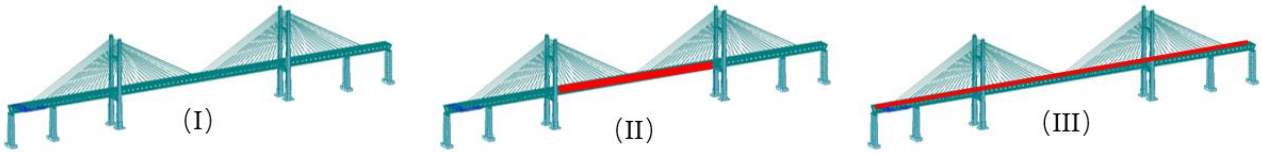

Figure 4: Road load arrangements.

3.2. Dynamic Simulation

Based on the information mentioned above, the dynamic responses of the bridge subsystem are obtained for train speeds from 160 km/h to 240 km/h. The histories of the vertical displacements and accelerations at the middle of main span under three conditions are listed in Table 2. As the road loads mainly affect in vertical direction, the lateral dynamic responses are not discussed here.

Table 2: Vertical displacements and accelerations under three conditions.

Train speed (km/h)	Condition I		Condition II		Condition III	
	Displacement (mm)	Acceleration (m/s^2)	Displacement (mm)	Acceleration (m/s^2)	Displacement (mm)	Acceleration (m/s^2)
160	74.3	0.02	73.9	0.01	73.8	0.01
180	74.7	0.02	74.0	0.01	73.9	0.02
200	74.5	0.02	74.1	0.02	74.1	0.02
220	73.9	0.02	74.0	0.02	74.1	0.02
240	75.1	0.03	74.5	0.03	74.6	0.02

As can be seen in Table 2, all dynamic responses are within allowed limits according to standard in China. In each condition, the vertical displacements mainly keep a constant increase with the growth of train speed. The rise of vertical accelerations are not as obvious as that of displacements. The peak responses appears when empty road load on bridge, though the differences are relatively small compared with three conditions.

4. Conclusions

The dynamic responses of the bridge can be solved effectively based on the established train-bridge interaction system. The vertical displacements increase gradually with the growth of train speed. As different road load arrangements makes less changes in deformation of bridge deck compared with the track irregularity, therefore the key point of influence factor is wheel/rail interaction relation.

Acknowledgments

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