The Effect of Longitudinal Shock Absorber on the Vibration Response of Train-Bridge Coupling System in the Articulated Train

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Abstract: On the basis of analyzing the structural characteristics of articulated trains, directly combined with the method of UM software and importing three-dimensional model into the UM software, the dynamics model of the vehicle-bridge coupling system of three-section articulated train and the simple-supported box girder bridge is established. The dynamics model compares the vehicle-bridge coupled vibration response of the articulated train with or without longitudinal shock absorber and analyses the difference. The results show that the vertical vibration of the end train is stronger than that of the intermediate train; the longitudinal shock absorber can effectively suppress the vibration of the intermediate train body of the articulated train, and the vibration suppression effect on the end body is not obvious; the strength of the coupling effect has little effect on the vertical vibration of the bridge.

1. Introduction

When the train passes the bridge, the vehicle load is transferred to the bridge through the wheel-rail connection and the bridge-rail connection, causing the vibration and deformation of the bridge which will in turn aggravate the vibration response of the vehicle. Therefore, it is of great theoretical value and practical significance to study the dynamic performance of vehicle-track-bridge coupling system. G. Diana, F. Cheli [1] established a vehicle-track-bridge dynamic model based on the elastic track and wheel-rail connection. The simulation results were basically consistent with the measured results. Biondi B et al [2] idealized the train as a series of identical vehicles traveling at constant speed. Rails and bridges are modeled as Bernoulli-Euler beams. They proposed a component modal synthesis method that combines continuous (track and bridge) and discrete (train) substructures. The numerical calculations showed that the method can simultaneously calculate the dynamic response of trains, tracks and bridges with high precision and efficiency. Zhai W M, Cai CB [3] established two dynamic models of train operating on ballasted and ballastless tracks. He considered the effects of orbital structure and wheel-rail interaction on system dynamics in the model and studied the effects of random irregularities of track on the train-orbit-bridge dynamic interaction. The most commonly used vehicle model is the vehicle space vibration model based on the rigid body dynamics hypothesis [4,6]. In this model each train is composed of wheelsets, bogies and car bodies which are all regarded as rigid bodies and are connected with each other by spring and damper.

After the French TGV articulated high-speed trains have achieved great success in terms of technology and commercial use, some countries, such as Germany, Spain, South Korea and China,
have joined the ranks of the development and operation of articulated high-speed trains. In recent years, the research on the dynamic performance of the articulated high-speed train-bridge coupling system has also attracted the attention of many scholars. Zhang Nan et al.[7] established the 115-degree-of-free Thalys articulated high-speed train dynamic model and the Antoing bridge dynamics model, and analyzed the vibration acceleration of the train and the dynamic response of the bridge deflection and acceleration, and it is in good agreement with the field test results. Xia He et al.[8] established an articulated vehicle unit model and a coupled dynamic model of finite element bridge model to study the dynamic interaction of articulated high-speed train axles. Zhai Wan Ming[9] established an articulated high-speed train-track vertical coupling dynamics model, and compared the vertical dynamic performance of articulated high-speed trains and non-articulated high-speed trains. The research results show that the articulated high-speed train has good vertical dynamic performance. Wang Fu Tian et al.[10] expounded the design principles and design ideas of the articulated high-speed train bogie. Three kinds of software, SUNDYNA, MEDYNA and TPLDYNA, were used to calculate the running stability and curve passing performance of the vehicle. The above studies all use numerical integration to carry out research, but the use of multi-body dynamics software to study the vibration response of articulated high-speed train car-bridge coupling system is still relatively rare.

In this paper, the UM of multi-body dynamics software is used to establish the three-vehicle group train model of the articulated train and the vehicle-bridge coupling system dynamics model of the simple-supported box girder bridge. Based on the train-bridge coupling relationship, considering the high-speed operation of the train on the bridge, the influence of the longitudinal shock absorber on the vibration response of the articulated train-bridge coupling system is studied.

2. Structural features of articulated trains
The articulated high-speed train uses a traditional power bogie in addition to the conventional power bogie. The intermediate vehicle uses an articulated bogie. The bogie supports the end part of the front train and the front part of the rear vehicle. The front and rear ends of the middle vehicle are supported ends and hinged ends respectively. A two-series suspension spring cap is placed on each side of the supporting end wall, and a lower spherical core seat is arranged in the middle. There is no two-series suspension spring cap on the hinge end, and an upper spherical core seat is placed in the middle. The lower spherical core seat of the supporting end and the upper spherical core seat of the hinged end are hinged together, and a part of the vertical load of the hinged end body is transmitted to the supporting end body through the spherical core seat, and then transmitted to the air spring through the spring bearing platform and turn to the frame. It is equivalent that a bogie can support a vehicle, which greatly reduces the number of bogies in the train and reduces the weight of the train. At the same time, the running resistance and vibration noise of the train are greatly reduced as the number of bogies decreases. The vehicles are tightly hinged by a central elastic hinge, so the coupling between the vehicles is more obvious.

3. The establishment of dynamic model of train-bridge coupling system
The articulated train model established in this paper adopts the TGV bolsterless bogie structure. The train consists of three train bodies (one articulated intermediate train body and two end train bodies) supported by four bogies. The vehicle model consists of a multi-rigid system consisting of a body, a bogie and a wheel pair. According to the steps of body, hinge and force element, they are modelled in order from bottom to top. The geometry of the articulated train is directly combined with the method of UM software and importing three-dimensional model into the UM software. The articulated train model of the three train groups is shown in Figure 1.
Figure 1. Schematic of articulated train model.

The bridge is a prestressed concrete double-line single-hole simple-supported box (single-box single-chamber) beam bridge with a span of 32m. The standard is Tongqiao (2008) 2322A-II. The track adopts C60 rail, and the track irregularity spectrum adopts the low interference spectrum of German high-speed railway. The ANSYS software was used to build a flexible body model of the bridge. The vehicle rigid body subsystem and the bridge flexible subsystem form an axle-coupled system, and the dynamic model of the articulated train-bridge coupling system is shown in Fig 2.

Figure 2. Schematic of dynamic model of an articulated train-bridge coupling system.

4. The analysis of influence of longitudinal shock absorber on vibration response of train-bridge coupling system

In order to analyze the influence of the longitudinal coupling effect of the articulated train on the vibration response of the train-bridge coupling system, the vibration response of articulated trains and Bridges with and without longitudinal shock absorbers was studied when the train passed through the bridge at a speed of 300 km/h.

It can be seen from Fig.3 that the vibration acceleration of the head vehicle with or without the longitudinal shock absorbers is basically the same, and the longitudinal shock absorbers have little influence on the vibration acceleration of the head vehicle of the articulated train. It can be seen from Fig. 4 that the vertical vibration acceleration of the intermediate vehicle of the articulated train is significantly increased in the absence of the longitudinal shock absorbers, indicating that the longitudinal shock absorbers between the articulated trains has a significant effect on suppressing the vibration of the intermediate train body. According to further analysis in Fig. 3 and Fig. 4, the head train body has only longitudinal damping at the end, and the single side damping has no obvious effect on the vibration of the train body, while the intermediate vehicle body has longitudinal damping at both ends, and both sides are damped. The resulting suppression of vibration has a significant effect.
Figure 3. Schematic of the effect of longitudinal shock absorber on the vertical vibration acceleration of the head vehicle of the articulated train.

Figure 4. Schematic of the effect of longitudinal shock absorber on the vertical vibration acceleration of the intermediate vehicle of the articulated train.

Fig. 5 shows that the vertical vibration of the head vehicle of the articulated train is larger than that of the middle vehicle, which reflects that the distribution of the acceleration of hinged train body shows a law of large at both ends and small in the middle. Fig. 6 shows the case where the articulated vehicle removes the longitudinal shock absorbers. At this time, the vertical vibration acceleration of the intermediate vehicle is significantly increased, which is relatively close to the vertical vibration acceleration of the head vehicle, but it is still smaller than the vibration acceleration of the head vehicle. Under normal circumstances, the vibration of the intermediate vehicle is weaker than that of the end vehicle. The comfort of the intermediate vehicle is better than that of the end vehicle. The articulated connection can increase the stability of the train and effectively reduce the vibration of the train body.
Figure 5. Schematic of comparison of the vertical vibration acceleration between the head vehicle and the middle vehicle of the articulated train with longitudinal shock absorbers.

Figure 6. Schematic of comparison of the vertical vibration acceleration between the head vehicle and the middle vehicle of the articulated train without longitudinal shock absorbers.

The vertical vibration acceleration limit of the bridge span is following: the ballasted track bridge is $a_{\text{max}} = 0.35g$, the ballastless track and the Mingqiao bridge is $a_{\text{max}} = 0.50g$. It can be seen from Fig. 7 the longitudinal shock absorber has little effect on the Mid-span vertical vibration acceleration of bridge, indicating that the longitudinal Shock absorber has a limited influence on the coupling between the train and the bridge. The coupling effect between vehicle bodies is less related to the response of bridge vibration. The mid-span vertical vibration of bridge is not caused by longitudinal damping between vehicle bodies, but determined by the performance parameters of the train itself.

Figure 7. Schematic of the effect of longitudinal shock absorber on the mid-span vertical vibration acceleration of bridge
5. Conclusion
In this paper, the UM of the multi-body dynamics software is used to establish the three-vehicle group train model of the articulated train and the train-bridge coupling system dynamics model of the simply supported box girder bridge. When the train is running on the bridge at a speed of 300 km/h, the influence of the longitudinal shock absorber on the vibration response of the articulated train-bridge coupling system is studied. The following conclusions were obtained:

1) The vertical vibration of the end of the articulated train is stronger than the vertical vibration of the intermediate vehicle.

2) The main advantage of the articulated train is that the damping between the vehicle bodies strengthens the coupling between the vehicle bodies, and the vibration of the intermediate vehicle body is effectively suppressed, so that the intermediate vehicle is strongly restrained by coupling and the vibration is weak. However, the damping plays a relatively limited inhibitory role for the head vehicle and the tail vehicle.

3) The strength of the coupling between the body of the articulated train has limited influence on the vertical vibration of the bridge.

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