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The effect of the maximum stroke of the air spring on the safety of the train under earthquake

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ABSTRACT

The safety performance of the train if an earthquake has a strong correlation with its nonlinear characteristics. The derailment coefficient is an important index to characterize the safety of the train running, so the influence of the air spring compression travel limit is studied in this paper. In this paper, a train-rail coupling model is established, in which the compression gap is simulated using a gap element. In this paper, the Kobe seismic wave is used as an example, and the change of train running performance is analyzed by changing the seismic intensity and air spring compression stroke. The results show that the air spring limit can improve the safety performance of the train, and the smaller the maximum stroke, the more significant the impact on the derailment coefficient, especially in the case of strong earthquakes.

1. INTRODUCTION

The earthquake has been threatening the safety of the train. There have been several tragic accidents in history: Japan’s Shinkansen has experienced several earthquake-induced derailments in its more than 50-year operating history (Ashford and Kawamata 2006; Hata et al. 2016). In 1976, the Tangshan earthquake, China, dozens of trains derailed. It is very urgent to study the safety of train travel under the earthquake. Due to the convenience of operation and cost advantage, train dynamics numerical simulation has become an important means to study the safety of trains under earthquake.

The train derailment seriously threatens people's life safety and property safety, which has aroused the close attention of governments and scholars. Tanabe and Sogabe et al. (2016) proposes a precise time integration method for calculating train-

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structure systems that are included in the seismic process, which eliminates rounding errors caused by time increments. Cheng and Hsu et al. (2016) have studied the derailment of earthquakes when a train is passing through curves under earthquakes, and studies show that vehicles with larger orbital tilts are more likely to derail. Ling et al. (2012) studied the mechanism of the derailment of trains under earthquakes and gave a safe operating range and found that a vertical earthquake is prone to the jump of the wheels. Ju and Hung et al. (2019) studied the effects of soil liquefaction on the train derailment, and the results showed that soil liquefaction increased the derailment factor of wheels. Chung and Chang et al. (2019) considers the wheel flange angle, equivalent cone, and unloading factor to have the greatest impact on the likelihood of derailment. Wu and Chi et al. (2016) studied the flex pattern after a train derailment based on the post-derail model and concluded that the trailer was more self-protective than the locomotive. Ju and Li et al. (2011) use absorb boundary to establish an infinite foundation and point out a strong correlation between the de-orbiting coefficient under an earthquake and the vehicle speed. Jin and Pei et al. (2016) point out that the correlation between bridge acceleration and derailment on the bridge is greater than ground acceleration. The nonlinear effects of the suspension system are considered in the vehicle model by Xiao and Ling et al. (2012). Zeng and Dimitrakopoulos et al. (2018) have established a check-up method that considers rigid contact with wheel-rail separation to simulate train derailment. Nakajima et al. (2017) have experimented with the results of an increase in lateral stop clearance that improves derailment safety. Wang and Zhang et al. (2020) established a multi-point incentive random bridge coupling model, analyzing the most disadvantageous position of the vehicle on the bridge. Montenegro et al. (2016) studied the train's response to medium earthquakes and gave an equivalent stiffness calculation for considering bridge cracking. Nishimura et al. (2015) used a full-size vibrator test to verify the accuracy of the numerical model in large seismic simulations and verify the anti-derailing effect of the rail. Chen et al. (2020) use the principle of energy to build a train model, bridge structure uses ANSYS simulation, uses dynamic substructure method to establish a bridge coupling system, and studies the effects of near-field fault earthquakes on trains.

The nonlinear characteristics of the suspension system are of great significance to the quantitative analysis of driving safety under earthquake to guide train design and evaluate the accuracy of numerical models. This paper focuses on the effect of the extreme compression of air spring on the seismic performance of the train. The vertical impact of the body on the bogie and the nonlinear wheel-rail relationship are considered in the train model. In this paper, the effect of different limit compression sons on the derailment coefficient under different seismic intensity is calculated.

2. VEHICLE TRACK COUPLING MODEL AND COMPUTATIONAL CONDITION

In this paper, a vehicle model is established using multi-rigid body dynamics. The vehicle body, bogie, and wheelset are described by the rigid body with 6 DOFs, and the primary suspension system and secondary suspension system are simulated by three-dimensional spring damper parallel elements. The compression gap of the air spring is described by the seam unit, where the initial stiffness is zero, and when the limit compression is exceeded, the large stiffness is used to reflect the vehicle body's forward collision behavior to the bogie. The rail system is simplified to a Winkler model with discrete support, the rail is modeled using Euler-Bernoulli beam, and the fasteners are modeled with a spring damping parallel element. Wheel-rail contact geometry is considered, and a separable wheel-rail contact model is set up based on elastic contact assumptions. The coupling model is shown in Fig. 1.

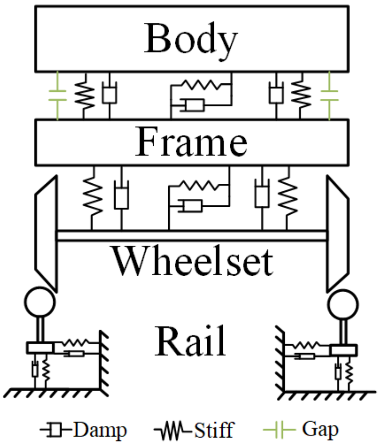

Fig. 1 Train-rail coupling system model

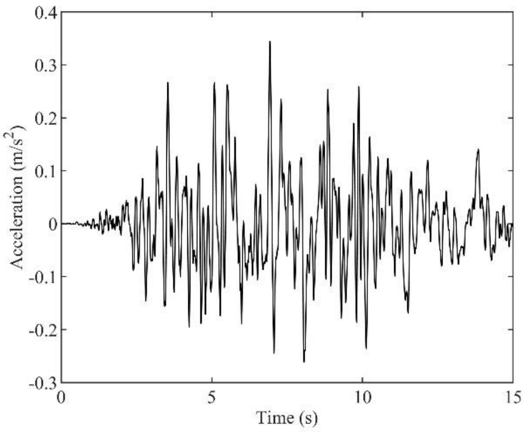

Fig. 2 Kobe seismic wave

In this paper, the incremental dynamic analysis of Kobe ground motion (Fig. 2) is carried out. The PGA is scaled from 0.1g to 0.5g at an interval of 0.2g. The compression stroke of air spring was simulated in the range of 20 mm to 30 mm with an interval of 5 mm, and 1 m was taken as the control group. A total of 12 sets of working conditions are calculated.

3. RESULTS ANALYSIS

The effect of the non-linear effect of the train on the safety of the train is finally reflected in the change of wheel-rail contact relationship. Fig. 3 to Fig. 5 show the contact force and derailment coefficient history of the left wheel of the first wheelset under various working conditions, and Eq. (1) shows the relationship between contact force and derailment coefficient. Comparisons between the groups of the peak of ground acceleration (PGA) show that large shocks are more likely to reach the compression limits of the air springs and that small shock-down trains are insensitive to the compression limits of the air springs.

$$D = F_y/F_z \tag{1}$$

Where D is the derailment coefficient; F_y and F_z is the horizontal contact force and vertical contact force between wheel and rail, respectively.

As shown in Fig. 3, when PGA is 0.1g, the air spring is difficult to strike, regardless of the vertical clearance setting, due to the small movement of the train. The train's dynamics response is highly consistent under all operating conditions.

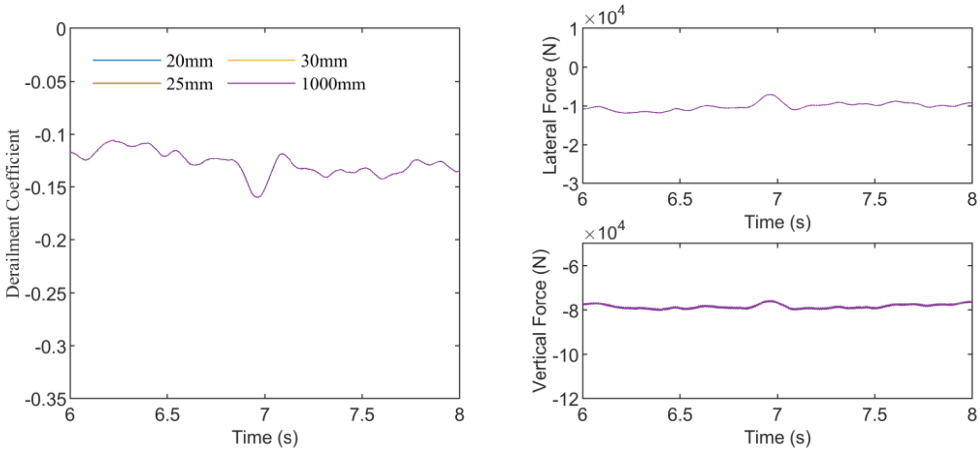

Fig. 3 The wheel response when PGA is 0.1g

With the increase of PGA, the rolling range of car body increases. As shown in Fig. 4, when PGA is 0.3g, the air spring compression increases, making it easier to reach the compression limit. With the reduction of the compression gap limit, the impact effect of the body on the bogie gradually increases. When the clearance is 25mm and 30mm, the body has only a slight impact and the time history of the contact force is not much different from the control group. When the clearance is reduced to 20mm, the high-frequency component of the vertical contact force of the wheel increases significantly due to a large impact on the body and the bogie to the rail.

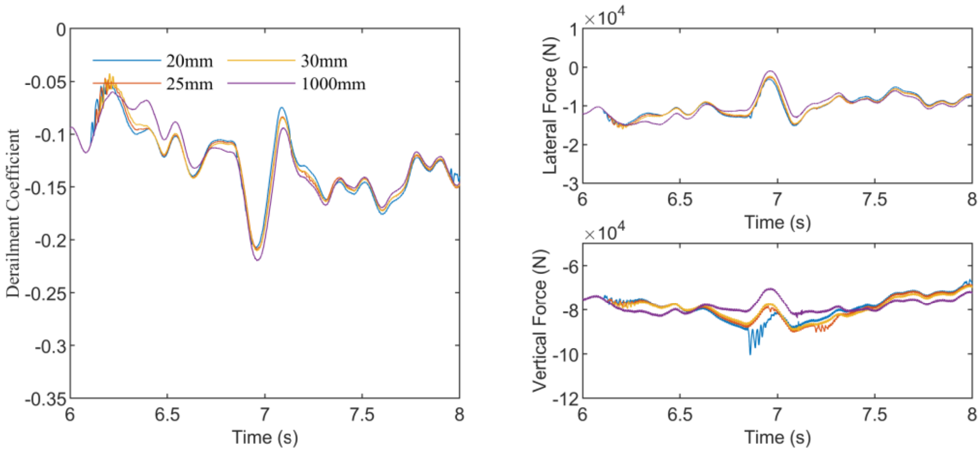

Fig. 4 The wheel response when PGA is 0.3g

Trains produce significant vibrations under strong earthquakes, and as shown in Fig. 5, the air springs can reach the maximum value at any clearance limit and a violent collision occurs, with the vertical contact response of the wheel-rail significantly off the control group. In contrast, the change in the clearance of the air spring has little effect on the wheel lateral force, so it can be observed that the presence of the vertical gap of the air spring will significantly reduce the derailment coefficient. Further, because the gap is smaller, the greater the hammering force of the body, which in turn makes the wheel pressure on the rail smaller, and eventually makes the derailment coefficient smaller.

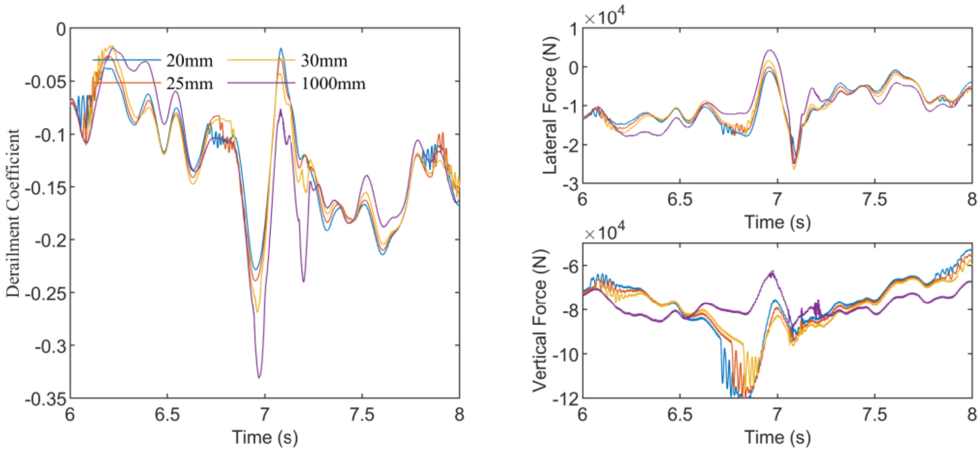

Fig. 5 The wheel response when PGA is 0.5g

4. CONCLUSIONS

In this paper, the vehicle track coupling dynamics system is established using multi-rigid body dynamics and finite elements. The driving safety performance of the train under different compression gap of the air spring was studied by calculating the different seismic intensity. The results show that:

(1) Under a strong earthquake, the air spring can easily reach the maximum amount of compression so that the body hits the bogie. And small earthquake can avoid the impact of the gap.
(2) The hammering of the vehicle body on the bogie will increase the vertical force of the wheel to the rail, reduce the derailment coefficient of the wheel, and make the operation of the vehicle more safely.
(3) The smaller the compression gap, the more obvious the suppression of the derailment coefficient.

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