

Dynamic simulation analysis of rail track and track structure based on SIMPACK and ABAQUS

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Abstract: With the continuous improvement of China's railway construction level, the requirements for the quality of train operation are also improved. For the mixed passenger and freight railway, it is necessary to transit from the simple design concept of safety to the design concept of the unity of comfort and safety. Therefore, modern numerical calculation method or simulation software method is used to replace the traditional quasi-static calculation method, and SIMPACK, ABAQUS and other related software are mainly used to analyze the operation quality and track structure dynamics of the line design scheme. The derailment coefficient, vertical acceleration and other evaluation indexes are used to evaluate the safety and comfort of the line, and the dynamic analysis of the track structure is carried out based on the vertical force. The research shows that under the condition of this line, when the passenger and freight train run at the designed speed per hour in the curve section, they can meet the specification requirements of various indexes, and there is still room for increasing speed, and the stress and strain value of the track structure can meet the specification requirements.

1 Introduction

With the rapid development of China's railway, the railway operation mileage is increasing, and the railway construction has become very important. However, the data calculation and analysis of the existing line track are based on various assumptions and simplifications, and the results are theoretical values, which can not be more accurate expression for the train state under various working conditions, and can not dynamically express the value of each index. The optimization of coordination and matching between components is inclined to trial calculation, which makes the calculation complex and difficult to understand the comprehensive changes of each index combination. Cai Chengbiao and Yan Hua systematically evaluated the wheel rail system dynamics of Suining Chongqing railway by establishing the train track spatial coupling model; Zhou Jian analyzed the dynamic characteristics of the passenger and freight mixed track structure by establishing the train track coupling dynamic model, and evaluated the stress and deformation of the track structure; Lei, X; Rose, J. G. by establishing a three-layer composite beam model and using Fourier transform^[1],this paper analyzes the influence of passenger trains and freight trains on the dynamic response of track structure under the influence of track irregularity at different speeds, and points out that with the deterioration of track irregularity, the influence of freight trains on track is greater than that of passenger trains. So on the basis of the existing methods, this paper uses SIMPACK to simulate the line and ABAQUS to analyze the track structure, mainly on the

basis of SIMPACK and ABAQUS. Combined with the actual line conditions, the parameters obtained by SIMPACK post-processing system are imported into ABAQUS model for track structure analysis. The difference between this study and other studies is that SIMPACK refines the train model and considers the track irregularity, while ABAQUS refines the track structure. The combination of the two considers not only the dynamic relationship between the train and the line, but also the impact of train operation on the track structure. It makes the result closer to the reality.

2 Passenger and freight train model and track structure model

SIMPACK software is widely used in the railway industry, because it can not only simulate passenger trains, freight trains, locomotives, but also simulate small parts such as lines and wheel rail wear, and use its powerful post-processing system to simulate dynamic analysis of lines.

2.1 Passenger train simulation model

The whole vehicle model of passenger train consists of the whole vehicle model of passenger train, including train body, frame, wheelset, primary suspension, secondary suspension, etc. the passenger train model mainly consists of wheelset and bogie combination, but it involves the wheel rail relationship, the relationship between wheelset and track, and many related

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parameters, Various parameters also directly determine the stability and comfort of the vehicle (as shown in

Figure 1).

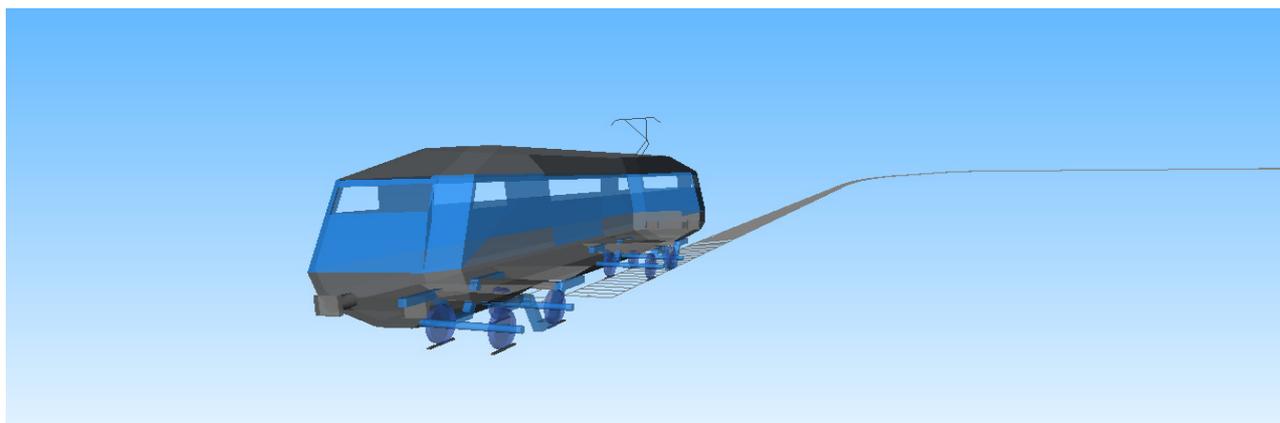


Fig. 1. Passenger train model

2.2 Truck train model

The truck model is mainly composed of vehicle body, load saddle, side frame, bolster, frame, wheel set,

primary and secondary suspension, which is more complex than the freight model. There is also a series of forces defined.(As shown in Fig 2)

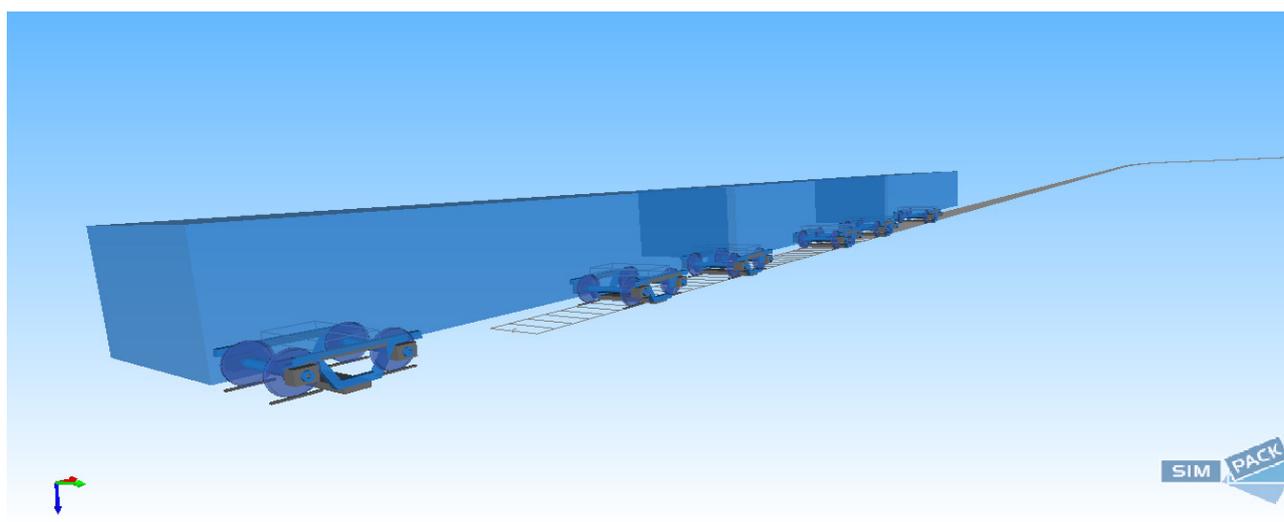


Fig.2. Truck train Model

2.3 Track structure model

ABAQUS can reflect the change process of each part of the track in the form of animation, so that the maximum value of each data index and the time when the maximum value appears can be clearly observed, and the safety and rationality of the track can be better judged

according to the results of stress-strain analysis.

The rail model is mainly composed of rail, sleeper, track bed and subgrade. The fastener is simulated by contact spring. The modeling process in ABAQUS consists of seven parts: component, attribute, interaction, assembly, load, grid and work. The parameters are shown in Table 1.

Table 1. Material property parameters

Part	Mechanical properties	Young's modulus (Mpa)	Poisson's ratio
rail	elastic	2.06×10^5	0.3
sleeper	elastic	3.75×10^4	0.3
Ballast	elastic	150	0.27
subgrade	elastic	60	0.35

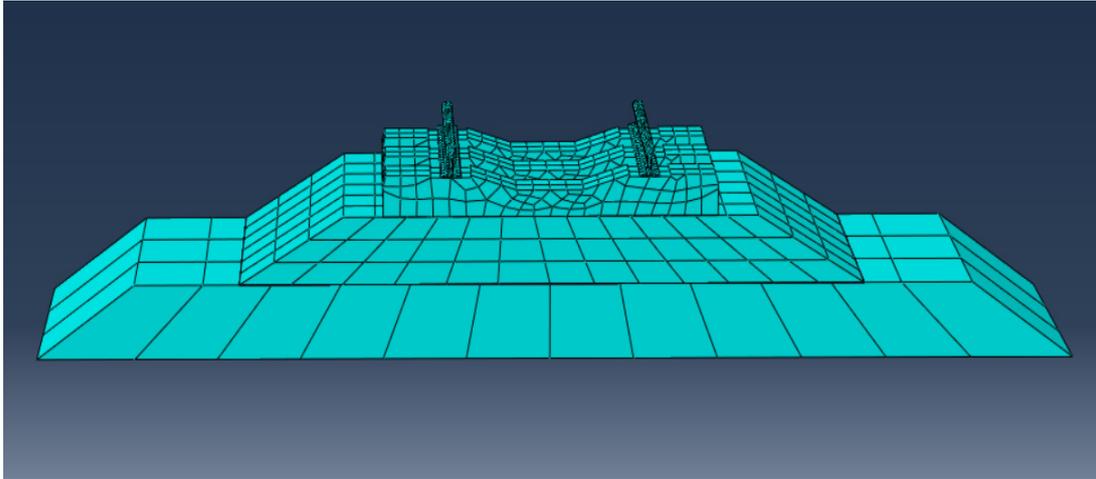


Fig. 3. Track model

In order to simulate the actual track irregularity, the random irregularity power spectral density is used to achieve. Because the wheel rail transverse force is very small compared with the wheel rail vertical force, in the

ABAQUS track model, the role of transverse force can be ignored, just consider the vertical force. Add the actual line parameters to the train model, as shown in Table 2 and Fig 3.

Table 2. Train line parameters

linetype	Length/m	Radius/m	Superelevation/mm
straightway1	52.87	0	0
transition curve1	150	0~800	0~120
circular curve 1	130.14	800	120
transition curve2	150	800~0	120~0
tangent between curves1	281.91	0	0
transition curve3	180	0~800	0~120
circular curve 2	149.88	800	120
transition curve4	180	800~0	120~0
straightway2	350	0	0

3 Evaluation of line dynamics index

3.1 Vehicle operation evaluation index

The evaluation of lines mainly includes safety and comfort. Safety mainly aims at the derailment problem: when the train is running, due to the influence of curve, superelevation, irregularity, vehicle loading and other factors, it produces relatively large vibration. When it exceeds a certain limit value, it will cause the derailment problem of the train and cause traffic accidents. From the perspective of stress, there are two main reasons affecting the derailment of the vehicle: one is the reduction of wheel weight, the other is the transverse vibration of wheel and rail. The force is increasing. Therefore, the safety of the line is evaluated by wheel load reduction rate, vertical force and derailment coefficient, and the main evaluation parameter of comfort is vertical acceleration. Previous studies have shown that the safety evaluation indexes are derailment coefficient and wheel load reduction rate, The

expression of derailment coefficient is as follows:

$$\frac{Q}{P} = \frac{\tan \alpha - T/N}{1 + T \tan \alpha / N} \quad (1)$$

Where in (1): Q is the lateral force on the wheelset, N is the vertical force on the wheelset, and α is the rim angle of the wheel.

According to the safety index of locomotive derailment coefficient specified in "experimental appraisal method and evaluation standard for dynamic performance of railway locomotive" (TB / t213260-93), the safety index of locomotive derailment coefficient is as follows:

Y/Q=0.6	excellent
Y/Q=0.8	good
Y/Q=1.0	qualified

The expression of wheel load reduction rate is:

$$\frac{P}{\bar{P}} = \frac{|P_1 - P_2|}{P_1 + P_2} \quad (2)$$

In equation (2): ΔP wheel weight is reduced, P is the average wheel weight of the wheel, P_1 and P_2 are the wheel rail vertical forces on the left wheel and right wheel respectively.

According to the limit value of wheel load reduction rate specified in the code for evaluation and experimental identification of railway vehicle dynamic performance (gb5599-85):

$$\begin{aligned} \Delta P / P \leq 0.65 & \quad \text{risk limit} \\ \Delta P / P \leq 0.60 & \quad \text{allowable limit} \end{aligned}$$

The main evaluation index of passenger train comfort is vertical acceleration. The standards for vertical acceleration of passenger train are as follows:

$$\begin{aligned} a_z \leq 1.0 \text{m/s}^2 & \quad \text{excellent} \\ a_z \leq 1.3 \text{m/s}^2 & \quad \text{good} \\ a_z \leq 2.0 \text{m/s}^2 & \quad \text{qualified} \end{aligned}$$

a_z is the vertical acceleration (m/s^2)^[2-4]

3.2 Evaluation of line index

Previous research shows that due to the transfer

superposition of front and rear wheel sets, the most severe rear wheel pairs are analyzed, and the relationship between the indicators and time obtained by SIMPACK is analyzed.

3.2.1 Analysis of passenger train power index

The operation index of passenger car mainly focuses on comfort. On the premise of meeting the safety, it pays more attention to the comfort of passengers. Therefore, the index analysis of passenger car should not only analyze the safety such as derailment coefficient and wheel load reduction rate, but also evaluate the comfort index. The evaluation index of comfort mainly considers the vertical acceleration of the train. Comfort is directly reflected in human reaction, especially when passing through the transition curve, it will have a greater impact on human feeling, so comfort should be considered^[5-6].

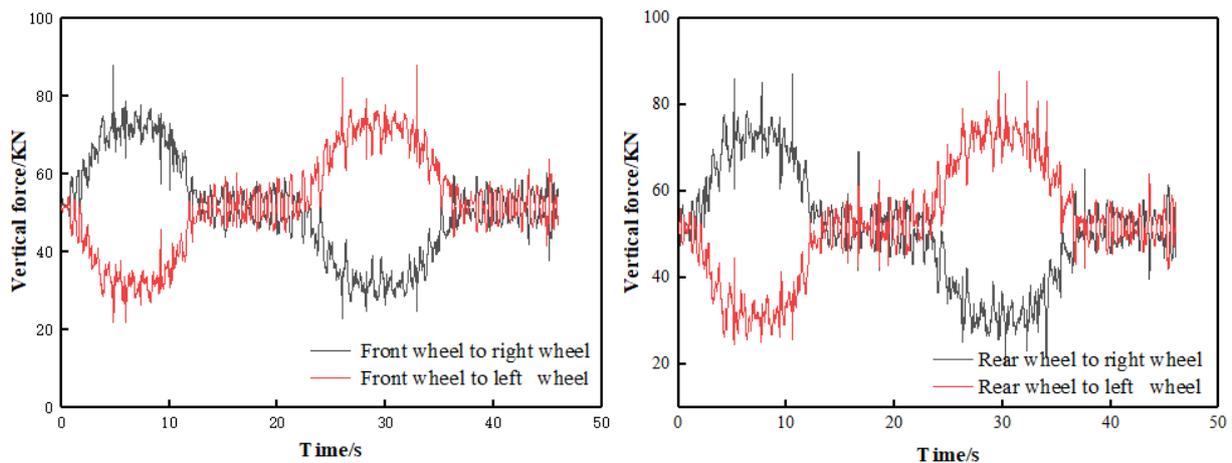


Fig.4. wheel rail vertical force

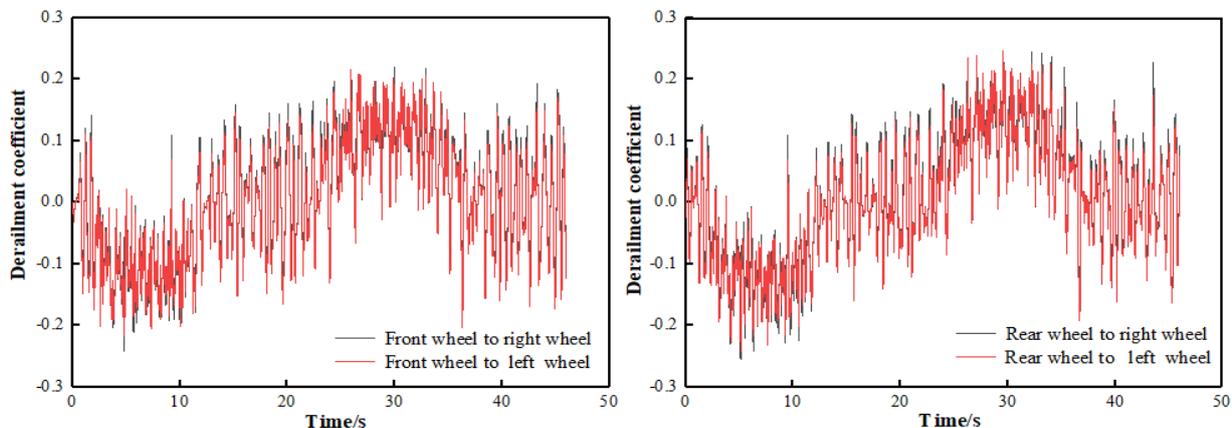


Fig.5. Derailment coefficient at 120km/h speed

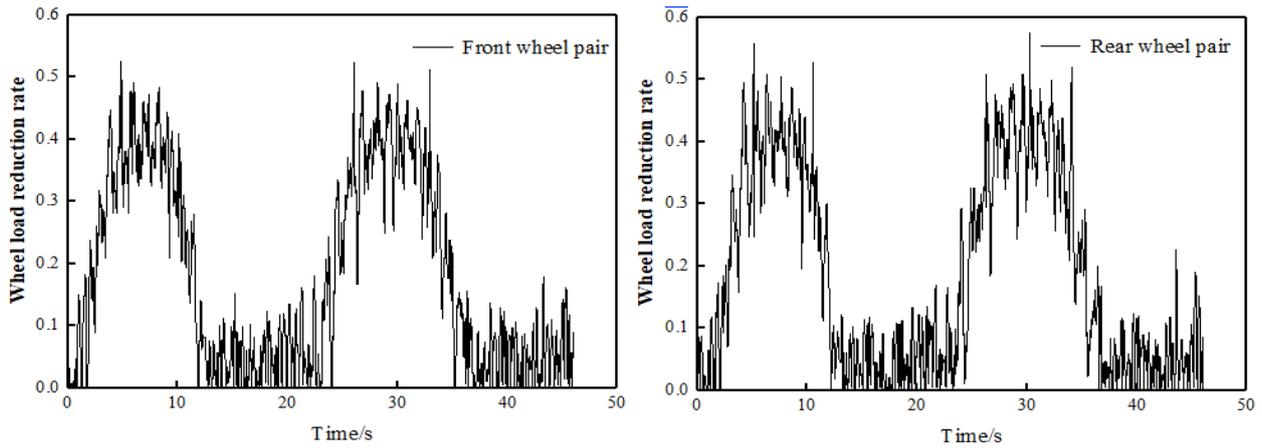


Figure.6. Wheel load reduction rate at 120km/h speed

Through each index chart, it can be seen clearly and intuitively that the index diagrams of front bogie front wheel pair and rear bogie rear wheel pair are basically the same from the trend, but through trainful comparison, there is difference between them. The maximum value of vertical force of front bogie rear wheel pair is different compared with that of rear bogie, which proves that the front bogie wheel pair function will be transmitted to the rear after superposition. The rear wheel pair of bogie makes the rear wheel pair of rear bogie have a large value. The deviation of the transition curve can be obtained, the first transition curve is the right deviation curve; the second transition curve is the left deflection curve. Due to the super high reason, the vertical force on the side not raised is too large, the derailment coefficient and wheel weight reduction rate are larger in the transition curve section, and the transition point gradually increases from the straight slow point to the slow point, and the maximum value appears in the circle curve segment. In this line, the vertical force of the front wheel is 5.9% larger than the front wheel pair, the maximum value is 0.255, and the load reduction rate of the rear wheel to wheel is 9.3% higher than the front wheel pair value. The maximum value is 0.5741. The maximum vertical acceleration of passenger train is 0.5963, which meets the passenger comfort standard according to specified standard of passenger train vertical acceleration.

In summary, according to the derailment coefficient and maximum wheel load reduction rate, it can be seen that when the bus is running at 120km/h, it meets the requirements of the specification.

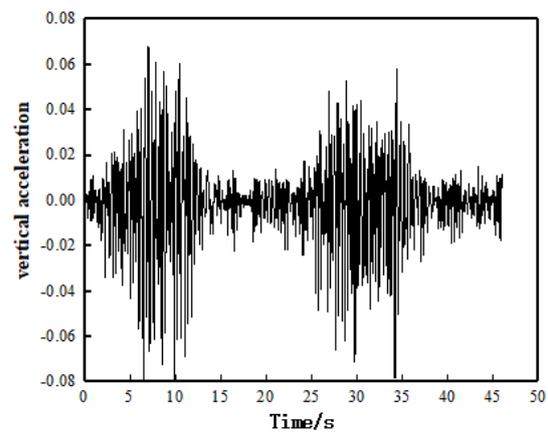


Fig.7. Evaluation index of passenger train comfort

When the bus is running at the initial speed of 160km/h, the vertical acceleration is far less than the allowable limit, so the comfort of the bus greatly meets the requirements of the specification. The vertical acceleration of single train is larger than that of multi train, and the speed of single train at this moment is close to the critical speed. However, the derailment coefficient of passenger trains is relatively small due to the more stable trainbody, but the wheel load reduction rates of both are relatively large, which has great restrictions on the continuous improvement of speed.

3.3 Analysis on dynamic indexes of freight trains

Freight train and passenger train are very different, not only the structure of the train body is different, but also the daily traingo load of freight trains is far greater than that of passenger trains. Just because of this, only the safety of freight trains needs to be considered, and the comfort of trains does not need to be considered. Because of the load, the wheel load reduction rate will be greatly affected. The wheel load reduction rate limits the running speed of trains, and more trucks are used For line

operation evaluation, although the curve radius is larger than that of the existing line, in order to meet the needs of general conditions, the general running speed of freight trains is 80 km/h as the initial speed, and then the line operation evaluation is trainried out. Due to the change of running speed, he curve superelevation should

be corrected. Due to the factors of over superelevation and under superelevation, the superelevation is set to 0.07m, and the line evaluation is carried out by the main indexes such as derailment coefficient and wheel load reduction rate.

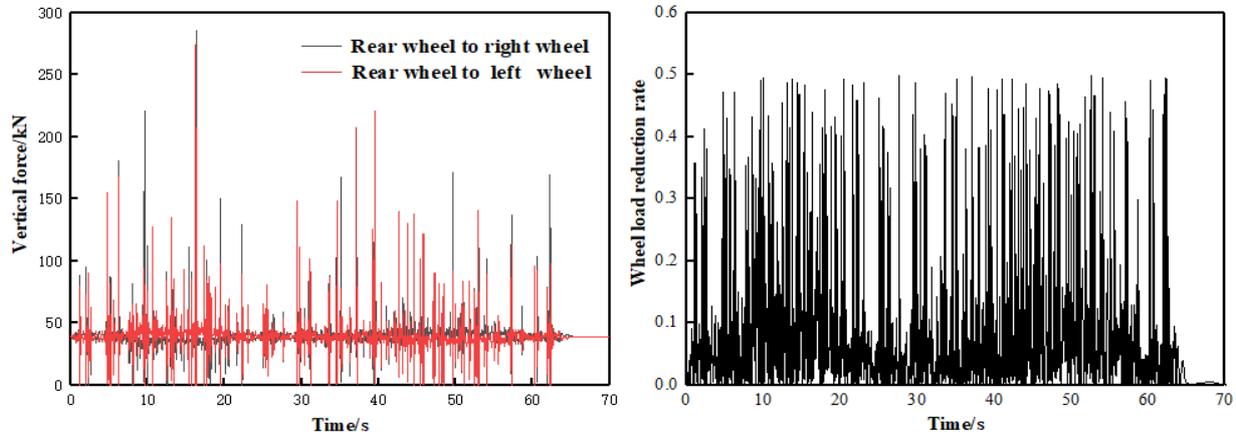


Fig.8. Vertical force and Wheel load reduction rate

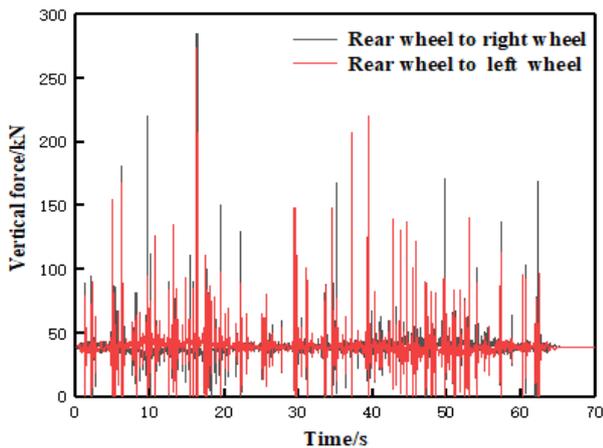


Fig.9. Derailment coefficient of freight train

From the operation index of multi vehicle freight trains, when the speed of multi vehicle freight trains is 80km/h, the vertical force increases greatly compared with that of passenger trains, but the change trend is similar to that of passenger trains. The larger vertical force appears at the transition curve. Due to the existence of track irregularity, the force of left and right wheels of the same wheelset is different, which leads to the larger wheel load reduction rate, still meets the specification requirements. In this section of the line, the vertical force of the front wheel pair and the derailment coefficient of the rear wheel pair are 5.9% larger than those of the front wheel pair, and the maximum value is 0.255. The load reduction rate of the rear wheel pair is 9.3% larger than that of the front wheel pair. The maximum value is 0.5136. Meet the security requirements.

4 Analysis of ABAQUS track structure model

After the track structure model is established by using ABAQUS, the calculation results of SIMPACK are used as the continuous load to load. The continuous load is imported into ABAQUS, the load size is defined, the action plane of the load is specified, and then the work is carried out. The main work is to calculate the stress and displacement of the rail. The stress diagram and displacement diagram of the track structure can be viewed, and the action point of the maximum vertical force can be found. Analyze the stress value here to see if it is within the stress range^[8-9].

4.1 Analysis of passenger train track structure

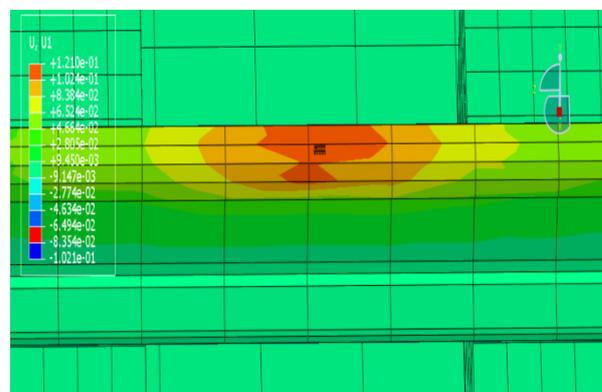


Fig.10. Maximum stress diagram of passenger train

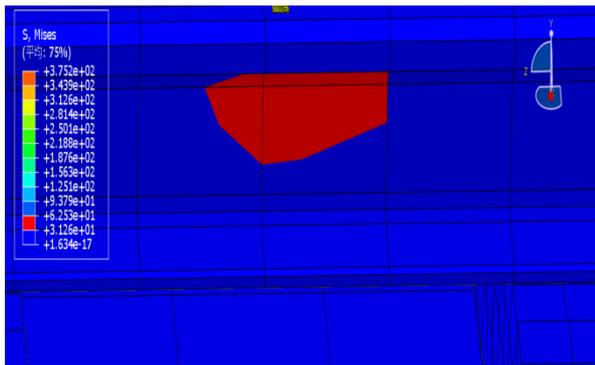


Fig.11.Maximum vertical displacement of rail

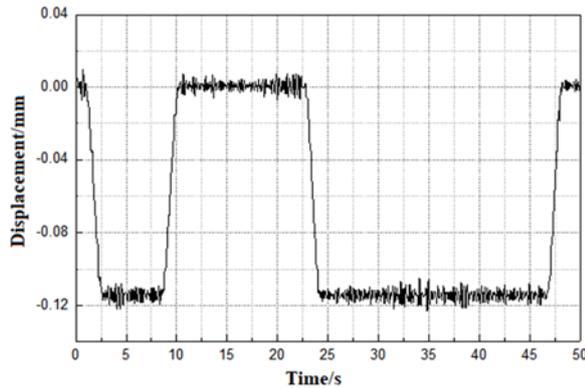


Fig.12.Rail displacement diagram(passenger)

It can be seen from the rail displacement diagram that the maximum displacement of the rail occurs at the transition curve, and the displacement at the straight section is very small, so the influence of the transition curve should be considered for the consideration of the rail, and it can be found that when the load acts on the rail, the maximum vertical stress is mainly concentrated at the top of the rail waist inside the rail, and decreases downward, and the displacement of the upper rail waist is greater than that of the lower rail. The displacement of rail waist in the line is 0.1223mm, less than 2mm, so the displacement diagram of rail is in line with the safety limit, and the selected rail structure meets the operation safety of the line. As shown in Fig 10-12.

4.2 Analysis of freight train track structure

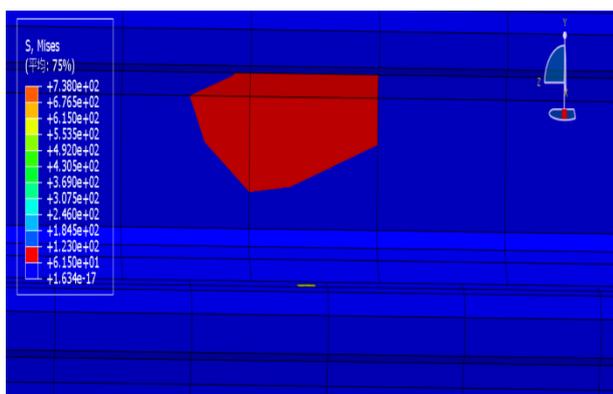


Fig.13.Maximum stress diagram of freight train

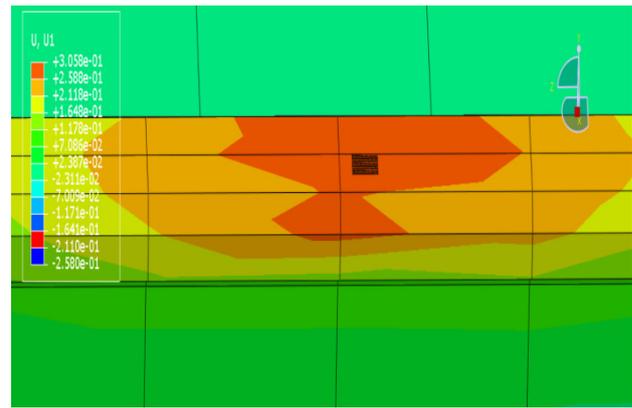


Figure.14. Maximum displacement of freight train

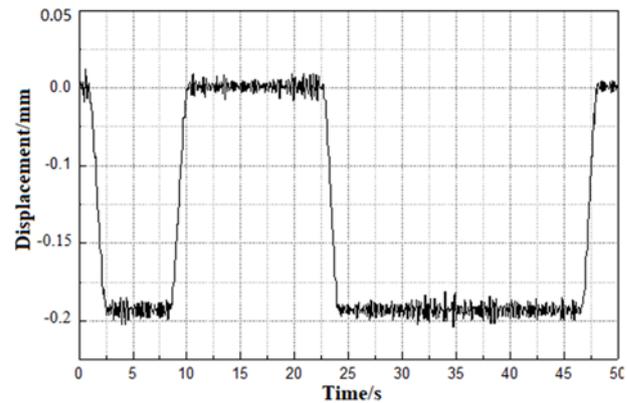


Fig.15.Rail displacement diagram(freight)

When the freight train is running, because the freight train model is a full load model, the vertical force is much larger than that of the passenger train, which makes the stress at the rail very large. The displacement value of the rail not only increases because of the vertical force, but also changes because of the influence of the stiffness of the track bed and cushion. If the stiffness increases, the displacement value will decrease. The distribution position of the maximum stress and displacement of rail is similar to that of passenger train, which is located at the upper part of rail head and rail waist, on the transition curve. As it gets closer to the circular curve, the displacement value is gradually increasing, because the curve radius is also gradually increasing. When it reaches the circular curve segment, the curve radius reaches the maximum, and in each section of the line, the area with larger position value is also distributed here, and the straight line is sandwiched. Compared with the straight line section at both ends, the displacement value of the rail is larger and smaller than that of the curve section. The stress displacement value of the rail in the figure is also within the allowable range. The stress and displacement indexes meet the standard requirements, and the single truck has a larger displacement^[10-12]. As

shown in Fig 13-15.

5 Conclusion

In order to conform to the concept of modern route selection, from the perspective of track dynamics, carry out line evaluation and track structure selection, and realize the transformation from empirical track structure to numerical track structure design concept, this paper takes a mixed passenger and freight line as the background, on the basis of understanding the basic principle of track selection and uses SIMPACK and ABAQUS to analyze the line scheme design and track structure driving power. The main conclusions are as follows:

(1) SIMPACK is used to model passenger trains and freight trains, and the line design scheme is introduced to analyze the driving dynamics. It can be concluded that when the curve radius is 800m and the passenger train runs at the maximum speed of 120km/h specified in the specification, the safety and comfort can meet the specification requirements.

(2) According to the train running speed, the track structure type is 60kg/m, elastic bar type II fastener and concrete type III sleeper. The dynamic simulation results show that when the bus running speed is within 120km/h, all the model indexes of the design scheme meet the standard requirements.

(3) According to this set of methods, the existing and reconstructed line schemes can be preliminarily evaluated and the improvement scheme can be put forward.

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