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Influence of Emulsified Cement Asphalt Mortar Seam on Dynamic Characteristics of Vehicle- China Railway Track System II Ballastless Track System

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Abstract

Emulsified cement asphalt mortar (CA mortar) seam is a common defect in the running of China Railway Track System II (CRTS II) slab ballastless track, and this error affects safety during high-speed driving. The influence of CA mortar seam on track structural performance is analyzed on account of the temperature and static loads of the train in previous studies. To explore the influence law of CA mortar seam on the safety of vehicle-CRTS II slab ballastless track system under dynamic load, a nonlinear finite element model for the vehicle-CRTS II slab ballastless track-subgrade system under track irregularity is proposed in this study. The finite element calculation models for vehicle-CRTS II slab ballastless track and seam were respectively established on the basis of the coupling dynamics of wheel rail system and finite element method. MATLAB program was also compiled to simulate the track irregularity of medium-long wave and short wave. The system model and track irregularity were then both applied to ABAQUS numerical analysis. The influence of CA mortar seam on the system dynamic characteristics with different train speeds, seam lengths, and heights was studied. Results show that when the train speed is 300 km/h, the length of seam is 1.2 m and the height of seam is 3 mm. The seam exerts minimal effect on the dynamic characteristics of the vehicle system, which significantly influences the vertical acceleration of track slab, with an increase of 144.3%; the higher the train speed, the greater the dynamic response of vehicle and track system, and the greater the influence of seam on driving safety; the vehicle dynamic response of rail and track slab increases with the increase of the length of seam, which is significant when the seam length is more than 1.2 m. When the seam height tends to 1 mm, the dynamic response of rail and track slab increases significantly and then stabilizes. This study provides theoretical reference for the safety assessment of slab ballastless track.

Keywords: Slab ballastless track, Emulsified cement asphalt mortar seam, Track irregularity, Dynamic characteristics

1. Introduction

China Railway Track System II (CRTS II) slab ballastless track, characterized by high stability, high ride performance, and less demand for maintenance, has been widely used in China's high-speed railway. Currently, the total length of CRTS II slab ballastless track is approximately 10,000 km [1]. As one of the key structure layers of CRTS II slab ballastless track, emulsified cement asphalt mortar (CA mortar) plays the roles of support, adjustment, force transmission, load bearing, and vibration isolation and damping [2-4]. During operation, due to the effect of train load and other external loads, the seam between the track slab and CA mortar, that is, CA mortar seam, is easily caused [5]. The seam will decrease the long-term service performance of track slab, thereby affecting passenger comfort and train operation safety. This change brings new challenges to the maintenance and safe operation of high-speed railway. Revealing the influence law of CA mortar seam on the system characteristics of CRTS II slab track and ensuring the safety of CRTS II slab ballastless track structure are new topics to be solved urgently.

With the development of computer technology, the finite element method has provided an effective analytical tool for many scholars to perform in-depth study on the influence of CA mortar seam on CRTS II slab ballastless track. Scholars conducted theoretical analysis of changes in performance of CRTS II slab ballastless track when the seam occurs under different static loads and temperature gradients [6-8]. Moreover, they carried out a large number of experiments and tests [9-10] and achieved satisfactory results, which are quite useful in understanding the performance of CRTS II slab ballastless track. However, due to the actual difference between the static force calculation methods and dynamic operation, as well as the limitation of test conditions, the CA mortar seam still cannot be effectively controlled at present. A filed survey on a high-speed railway reports that 141 seams appeared in the CRTS II slab ballastless track on the south section of the high-speed railway in summer 2013. The appearance of seams caused certain sections to be speed limited, resulting in a large area delay of trains. Therefore, the crucial issues for the operation safety of high-speed railway are make the result of the study close to the actual situation, study the influence law of the occurrence and variation of the CA mortar seam on the dynamic performance of the vehicle-CRTS II slab ballastless track under dynamic load, further discuss the influence of seam on driving safety, and propose the seam control and improvement methods.

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Therefore, using the coupling dynamics of wheel rail system and the finite element method as basis, the author establishes the calculation model of vehicle-CRTS II slab track-subgrade nonlinear finite element coupling dynamics, allowing for the properties of CA mortar filling layer. To provide a theoretical basis for the optimization, construction, and maintenance of CRTS II slab ballastless track structure, the influence of CA mortar layer seam on the dynamic characteristics of vehicle-track system is studied, with the influence of track irregularity taken into account. The influence of traveling speed and changes in the length and height of seam on traveling safety is also discussed.

2. State of the art

The safety of CRTS II slab ballastless track structure, which has the longest laying miles in China's high-speed railway, has received widespread attention. In recent years, scholars at home and abroad performed numerous theoretical analyses and experimental studies on the occurrence of seam in the running of CRTS II slab ballastless track and provided suggestions in design improvement, maintenance, and repair. Brensched et al. [11-12] performed a parameter analysis of the dynamic response of the slab ballastless track structure and verified the model using the data measured in the site. Husseinet et al. [13-16] studied slab ballastless track structure by gradually transiting from static and quasi-static to dynamic analysis, and realized the reasonable match of train-ballastless track-under-rail foundation. This study laid a firm foundation for the further analysis of defects of CRTS II slab ballastless track. Wang et al. [17] established a three-dimensional solid model for the ballastless track and analyzed two track defects, that is, the edge degradation of CA mortar layer and the interlayer suspension between the mortar layer and track slab. They also discussed the influence of the defects on the track geometry and stress condition of track slab and proposed the basic damage theory for the mortar. However, ZK live load was used in the calculation of train load. He [18] discussed the causes and development mechanism of seams and established the finite element analysis model of slab track static force considering train load, temperature gradient, and overall cooling effect. He [18] also performed an in-depth study on the influence of mortar defects with different positions and sizes on the track structure stress. However, the calculation only considered the effect of temperature and static load. Zeng et al. [19] established the analysis model of mechanics properties for the CRTS II slab ballastless track structure under the action of temperature gradient load. They determined the reasons why the interlamination open joint appeared during the early stage of CRTS II slab track structure. They also proposed the construction and technology measures for the CRTS II track slab and mortar seam, but the calculation only considered the influence of temperature gradient instead of the role of train load. Jiang et al. [20] studied the defect characteristics, the limiting value of defect repair, and the influence of temperature load on the deformation of track structure by doing statistics of on-site seam measurement, but the calculation of train load was simplified to double-wheel 150 kN static load. Zhu et al. [21] studied the influence of the length and height of seam between the track slab and the layer of emulsified CA mortar under the common action of train static load and temperature load. However, the train load is calculated on the basis of single axle and double wheel of 300 kN, without considering the dynamic load of the train. Xu et al. [22] established the finite element model for the CRTS II slab ballastless track and analyzed the influence of different lengths and positions of seam on the mechanics performance of track structure under different temperature loads and self-supporting effects. They also suggested that the length of seam between the track slab and CA mortar layer should not exceed 1.95 m, but the calculation did not consider the function of the dynamic load of the train. Ren [23] established the vertical coupling static force and dynamic analysis model for the bridge-horizontally connected turnout, calculated and analyzed the influence of mortar seam on the structure deformation of turnout under the turnout slab of different degrees, and preliminarily proposed the limiting values of sizes of mortar open joint. However, her analysis is limited to the turnout on the bridge, without considering the roadbed sections with the irregularity of the track. Zhao et al. [24] established the elaborate analysis model of vehicle-track space coupling dynamics for the seam between track slab and CA mortar and studied the influence of different seam volumes, seam scopes, and running speeds of the vehicle. However, the introduction of irregularity did not consider the impact of shortwave irregularity.

The aforementioned studies show that the current study is mainly focused on the influence of small-scale CA mortar seam under different temperature loads and train static loads. The study on the influence of large-scale mortar layer seam on the dynamic response of traveling train is relatively few. Especially under the condition of irregularity, study on the proposal of the length and width of seam and the running speed under the seam is lacking.

To address the lack of existing study, the author proposed the nonlinear finite element calculation model of coupling dynamics for the vehicle-CRTS II slab track-subgrade system by using the coupling dynamics of wheel rail system and the finite element method as basis. The model was applied to the ABAQUS numerical analysis. The influence of track irregularity with medium-long wave and short wave was considered in the dynamic analysis. The influence of CA mortar seam on the vehicle and the components of the track system was also studied. The influence of running speed and changes in the length and height of seam on the traveling safety was also discussed. These improvements provide theoretical basis for the optimization, construction, and maintenance of CRTS II slab ballastless track structure.

The remainder of this study is organized as follows: Section 3 establishes the nonlinear finite element calculation model of coupling dynamics for vehicle-CRTS II slab track-subgrade to verify the correctness of the model. Section 4 considers the influence of track irregularity. The influence of CA mortar seam on the dynamic characteristics of vehicle-CRTS II slab track system is calculated. In addition, the change law of system powers with different speeds, lengths, and heights of seam and their influence on the traveling safety are obtained. The last section presents relevant conclusions.

3. Methodology

3.1 Model establishment

The Using the wheel rail coupling system dynamics and finite element method [25] as basis, the author adopts ABAQUS and establishes vehicle-track-subgrade coupling system vertical vibration calculation model. The entire system is divided into two subsystems of upper vehicle model and lower track model. The upper vehicle is composed of single- and double-stage spring-damper system. The lower track is composed of rail, fastening system, track slab, CA mortar, bed plate, and subgrade. The coupling function between two subsystems is considered. Two subsystems are solved in a crossed style using the iteration method by means of the establishment of geometric compatibility and the equilibrium condition of the force for wheel-track contact surface. The dynamic response of coupled system is developed.

3.1.1 Vehicle model

The single-carriage vehicle is simulated and taken as multiple rigid body models running on the track structure in a certain speed with single and double suspension gears, as shown in Figure 1, where M_c and J_c is 1/2 vehicle body quality and rotational inertia, M_t and J_t represent 1/2 bogie quality and rotational inertia, M_{wm} (m=1, 2, 3, 4) refers to the quality of m th wheel, k_{s1} and k_{s2} denote the primary and secondary suspension rigidity of 1/2 vehicle element, c_{s1} and c_{s2} are the primary and secondary suspension damping of 1/2 vehicle element, k_c stands for the contact rigidity between wheel and track, v_9 and θ_9 represent the vertical displacement (vibration of ups and downs) and angular displacement of the vehicle body (nodding), v_m and θ_m (m =10, 11) denote the vertical displacement (ups and downs) and the angular displacement (nodding) of front and rear bogies, v_{1n} (n=2, 3, 4, 5) is $n-1$ the wheel's vertical displacement (vibration of ups and downs), v_{ncm} (m =1, 2, 3, 4) refers to the vertical displacement of the steel rail at m th wheel-track contact, v_m (m =1, 2, 3,...,8) stands for the vertical displacement of the m th nodes of the steel rail, and θ_m (m=1, 2, 3,...,8) represents the corner of the m th of the steel rail. Considering the random irregularity of rail surface, the irregular amplitude is ε , ε_1, ε_2, ε_3, and ε_4 denoting the irregularity amplitude at the contacts with four wheels.

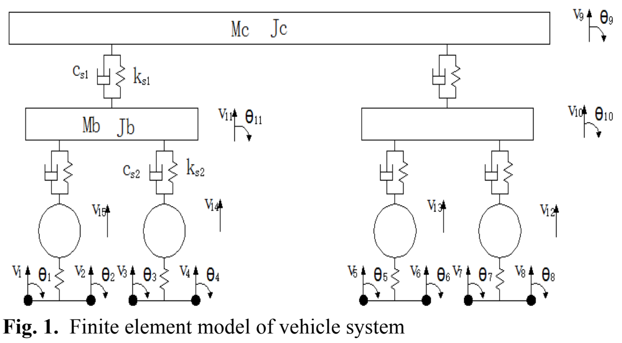


Fig. 1. Finite element model of vehicle system

3.1.2 Track model

In accordance with [26], the CRTS II slab ballastless track of the roadbed section is composed of roadbed, hydraulic concrete supporting layer (bed plate), CA mortar layer, track slab, elastic fastener, and rail, as shown in Figure 2 from bottom to top. The picture shows the vertical displacement of steel rail for v_1 and v_4 , θ_1 and θ_4 denote the corner of the steel rail, k_{y1} and c_{y1} represent the elastic and damping coefficient of fasteners, v_2 and v_5 refer to the vertical displacement of track slab, θ_2 and θ_5 stand for the corner of track slab, k_{y2} and c_{y2} denote the CA mortar elastic and damping coefficients, v_3 and v_6 represent the vertical displacement of bed plate, θ_3 and θ_6 are the corner of bed plate, and k_{y3} and c_{y3} refer to the elastic and damping coefficients of fasteners.

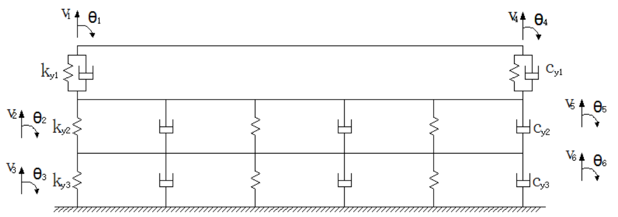


Fig. 2. Finite element model of CRTS II slab ballastless track

3.1.3 Seam model

Without considering the influence of dampening effect, the nonlinear spring element simulation is adopted for seam, as shown in Figure 3, in which u_0 is the maximum value of CA mortar seam. The nonlinearity of spring is shown in Figure 4. The section with the rate of curve equaling 0 is the height of CA mortar seam, and the rate of curve k is the rigidity of mortar.

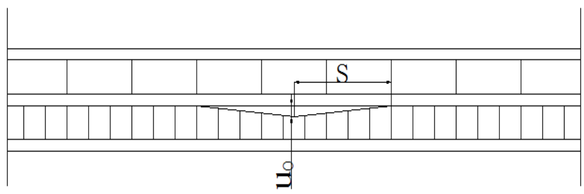


Fig. 3. Schematic diagram of CA mortar seam

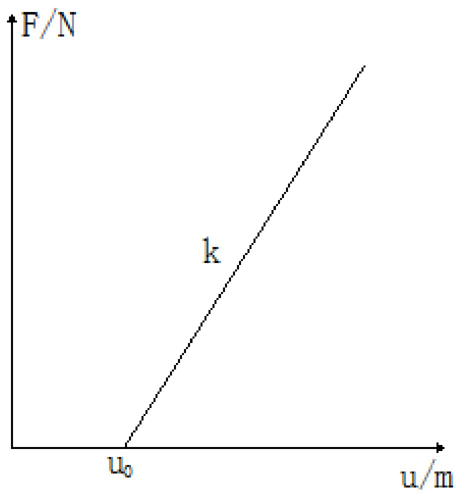


Fig. 4. Nonlinear spring force-displacement diagram for the mortar seam area

In conclusion, the calculation model for the vehicle-track-subgrade system vehicle coupled vibrations under the condition of CA mortar seam is established, as shown in Figure 5.

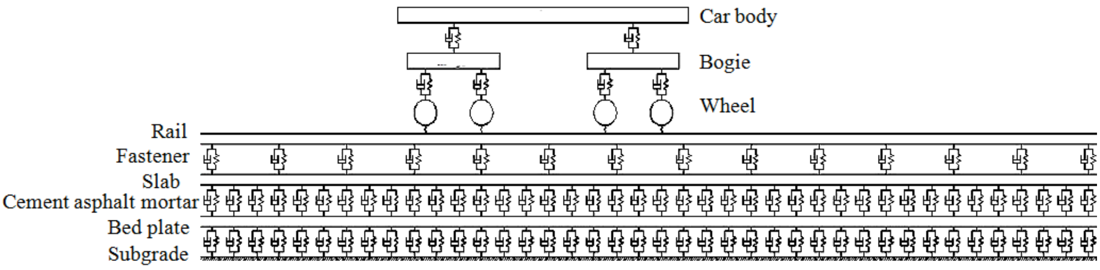


Fig. 5. Vehicle-track-subgrade system model

3.2 Track irregularity

In China, when calculation is made using the track spectrum, the low-interference spectrum of the irregularity of Germany track is usually adopted. However, the low-interference spectrum density of the irregularity of Germany track is dominated by medium-long wave. They cannot reflect the influence of random irregularity of short wave on the dynamic characteristic of wheel rail system. The short wave random geometry irregularity [27] with the wave length between 0.01 and 1 m would have a large influence on the dynamic characteristic. The jointless track is widely used on the track of China's high-speed railway, in which the short wave random irregularity of high-speed railway is reflected by the irregularity of rail surface at the welded joint. When considering the influence of short wave random irregularity on the dynamic characteristic of wheel rail system, the irregularity spectrum of welded female fitting is adopted.

Therefore, during calculation, the common influence of medium-long wave and short-wave irregularity is considered. The low-interference spectrum density of Germany high-speed railway is adopted to simulate the medium-long wave (wave length is of 1-50 m) random irregularity. The irregularity spectrum of welded female fitting is adopted to simulate the short wave random irregularity. For the convenience of calculation, the irregularity of welded joint of female fitting is simplified, and it is assumed to be a cosine wave at the length of 1.0 m superposed by the short wave irregularity at the length of 0.1 m [28,29]. The medium-long wave and short wave irregularity is compiled by MATLAB program, and the simulation results are shown in Figures 6 and 7.

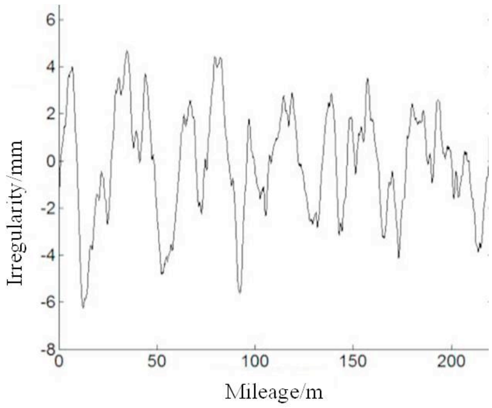


Fig. 6. Space distribution based on Germany low-interference spectrum

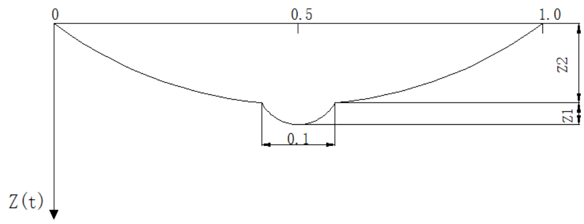


Fig. 7. Irregularity of female fitting of rail surface in the welded zone of rail

3.3 Selection of structure parameters for the model of vehicle and track system

When the dynamic response of the track system is analyzed using vehicle-track system-coupled vehicle dynamic model, the high-speed train CRH3 bearing the independent intellectual property rights of China is used. Table 1 presents the structural parameters. CRTS II slab track structure is used in the model, and structure parameters are shown in Table 2.

Table 1. CRH3 vehicle parameters

Parameters	Value
Weight of vehicle body $2M_c\,(kg)$	40000
Weight of bogie $2M_b\,(kg)$	3200
Axle weight $M_w\,(kg)$	1200
Inertia moment of vehicle body $2J_c\,(kg\cdot m^2)$	$5.47*10^5$
Inertia moment of bogie $2J_b\,(kg\cdot m^2)$	6800
Rigidity of single-stage suspension of vehicle $2k_1(MN/m)$	2.08
Rigidity of single-stage suspension damping of vehicle $2c_1\,(kN\cdot s/m)$	100
Rigidity of secondary stage suspension of vehicle $2k_2\,(MN/m)$	0.8
Rigidity of secondary suspension damping of vehicle $2c_2\,(kN\cdot s/m)$	120
Fixed wheel base $2l_1\,(m)$	2.5
Distance of framework centers $2l_2\,(m)$	17.375
The rigidity of contact spring of wheel-track $K_c\,(N/m)$	$1.325*10^9$

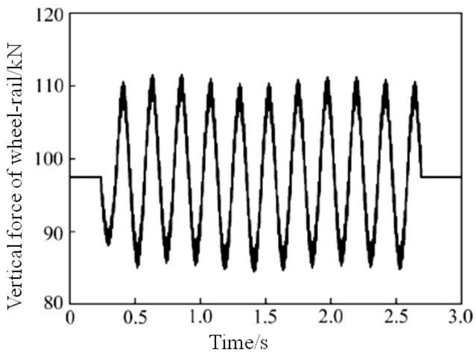
Table 2. Calculation parameters of track structure

Parameters		Value
Fastening system	Space distance $l\,(m)$	0.65
	Rigidity coefficient $k_{sy1}\,(MN/m)$	60
	Damping coefficient $c_{sy1}\,(kN\cdot s/m)$	47.7
Track slab	Length (mm)	6450
	Width (mm)	2550
	Height (mm)	200
	Density $\sigma_{s1}\,(kg/m^3)$	2500
	Elasticity modulus $E_{s1}\,(MPa)$	$3.9*10^4$

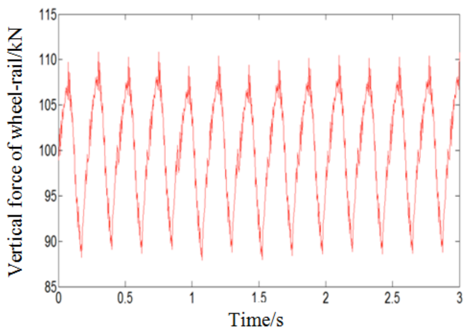
CA mortar	Rigidity coefficient k_{sy2} (MN/m)	$0.9*10^3$
	Damping coefficient c_{sy2} ($kN \cdot s/m$)	83
Concrete bed plate	Length (mm)	6450
	Width (mm)	2950
	Height (mm)	300
	Density σ_{s2} (kg/m^3)	2500
	Elasticity modulus E_{s2} (MPa)	$3.0*10^4$
Roadbed	Rigidity coefficient k_{sy3} (MN/m)	60
	Damping coefficient c_{sy3} ($kN \cdot s/m$)	90

3.4 Model verification

To verify the correctness of the model, the single-carriage train-three-layer track model proposed in [30] is adopted: assuming a single-carriage high-speed train travels on the ballastless track at the speed of 200 km/h. The periodical sine function with the wave length of 12.5 m and the amplitude of 3 mm is taken as the vibration source of track irregularity. The calculation result is compared with [30], which is shown in Figures 8-11.

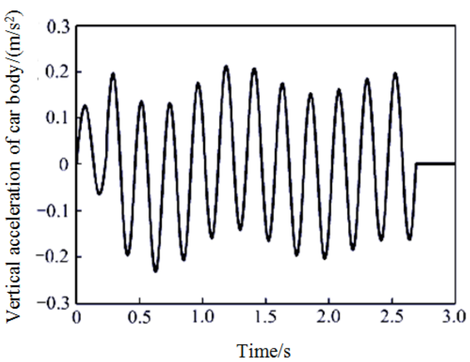


(a) The result of literature [30]

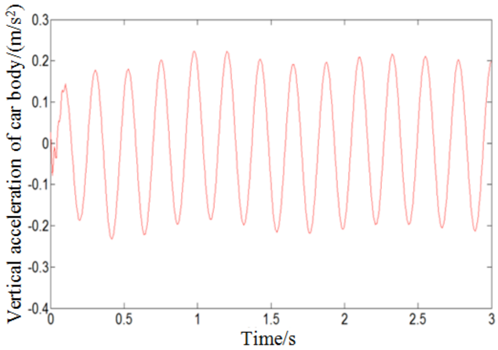


(b) The result of this study

Fig. 8. Vertical wheel rail force

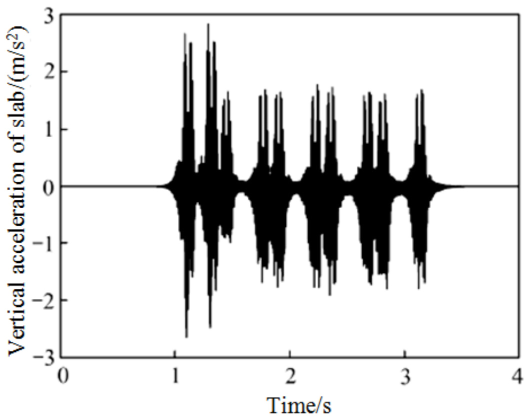


(a) The result of literature [30]

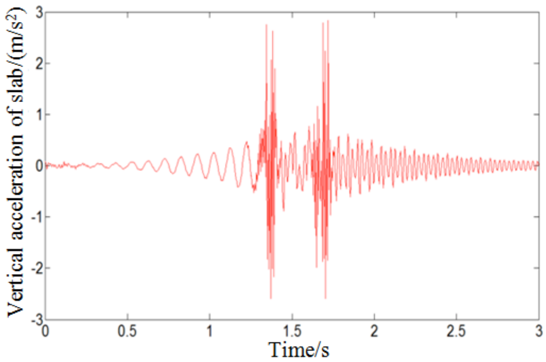


(b) The result of this study

Fig. 9. Accelerated speed of vehicle body

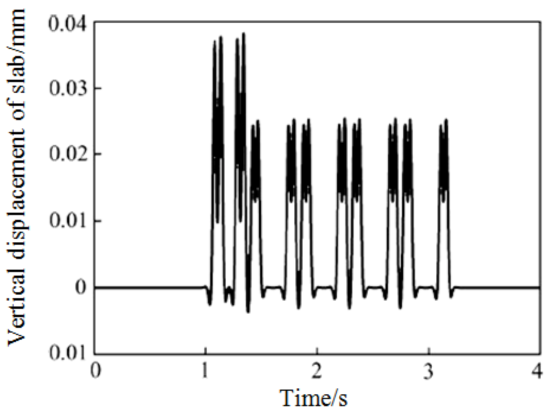


(a) The result of literature [30]

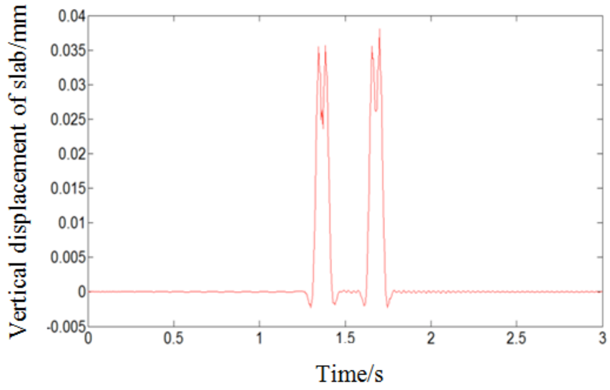


(b) The result of this study

Fig. 10. Accelerated speed of track slab



(a) The result of literature [30]



(b) The result of this study
Fig. 11. Displacement of track slab

The figure above shows that the curvilinear trend of both results is the same, which indicates that the model adopted is correct and feasible. Thus, the model can be adopted to further analyze the dynamic effect of CA mortar seam.

4. Result Analysis and Discussion

In actual operation, the CA mortar seams of ballastless track often co-exist with the irregularity of track. Therefore, when analyzing the influence of seam on the power performance of vehicle-track-subgrade system, the function of irregularity cannot be ignored. In the study, the random irregularity of medium-long wave and short wave is considered. The vertical dynamic responses of vehicle-track system are developed when the train speed is 300 km/h, the height of seam is 3 mm, and the length is 1.2 m.

4.1 Comparison of vibration response of vehicle system with and without seam

The results of vibration response of the vehicle system include the compared time travel curve of the vehicle body, bogie and wheel vibration accelerated speed, and wheel-track contact force, as shown in Figures 12-15 and Table 3.

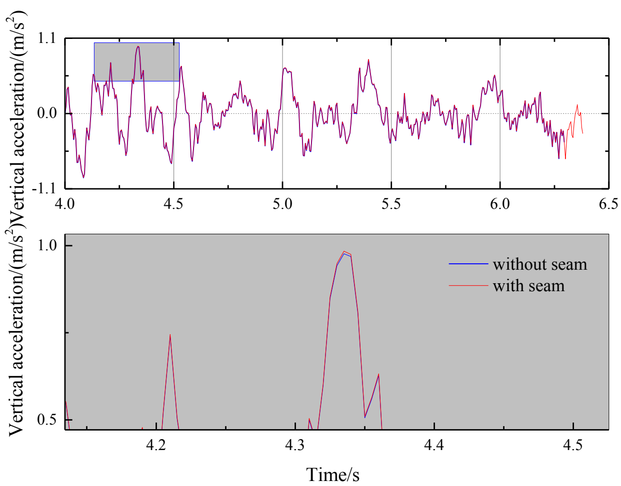


Fig. 12. Vertical accelerated speed of vehicle body with and without seam

The table above shows that when the train passes across the section right above the area of mortar seam, the dynamic response of all parts of the vehicle system is hardly influenced. The vertical accelerated speed of vehicle body has increased by 0.7% compared with that without seam. The vertical accelerated speed of bogie and wheel set has increased by 0.2% and 0.6%, respectively, compared with that without seam. The vertical wheel rail force has increased by 0.04% compared with that without seam. The influence of CA mortar seam on the wheel-track interplay and the dynamic response of vehicle system are relatively small. In addition, the main influencing factor is the track irregularity.

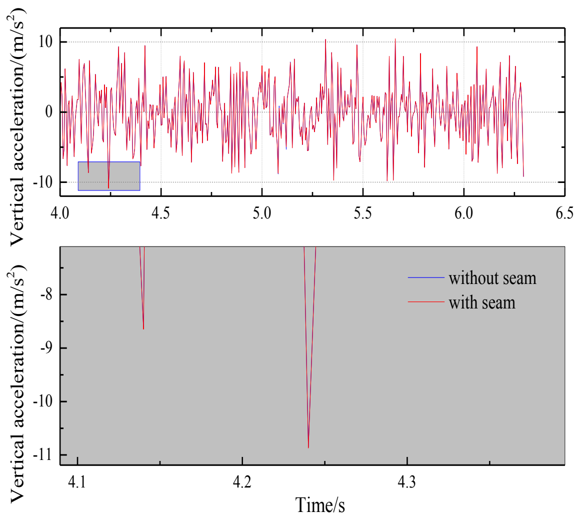


Fig. 13. Vertical accelerated speed of bogie with and without seam

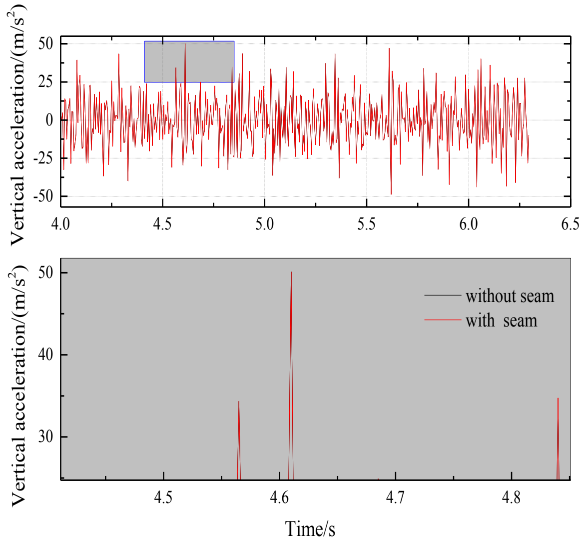


Fig. 14. Vertical accelerated speed of wheel with and without seam

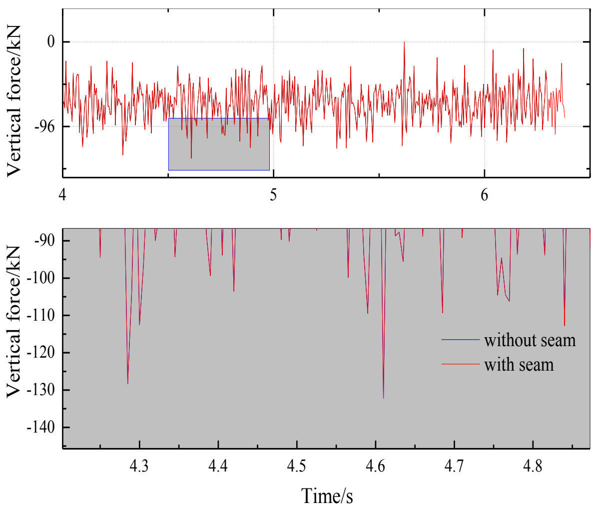


Fig. 15. Vertical wheel rail force with and without seam

Table 3. Maximum value of response of vertical accelerated speed of each vehicle element with and without seam

Operating condition	Vehicle body vertical acceleration (m/s^2)	Bogie vertical acceleration (m/s^2)	Wheel set vertical acceleration (m/s^2)	Maximum vertical wheel rail force (kN)
Without seam	0.977	10.854	48.634	132.039
With seam	0.984	10.871	48.951	132.089

4.2 Comparison of vibration response of track structure with and without seam

The vibration response of track structure includes the compared time travel curve of rail, track slab displacement, and accelerated speed, as shown in Figures 16-18 and Table 4.

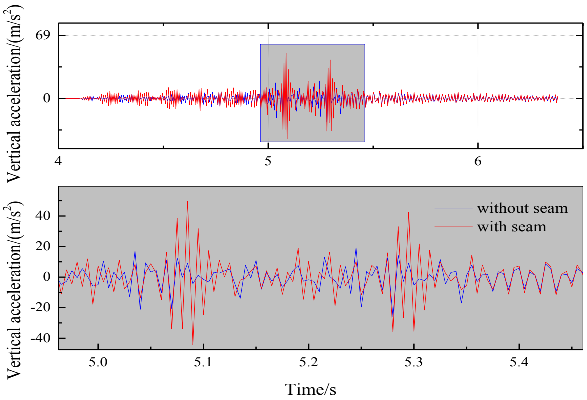


Fig. 16. Vertical accelerated speed of track slab with and without seam

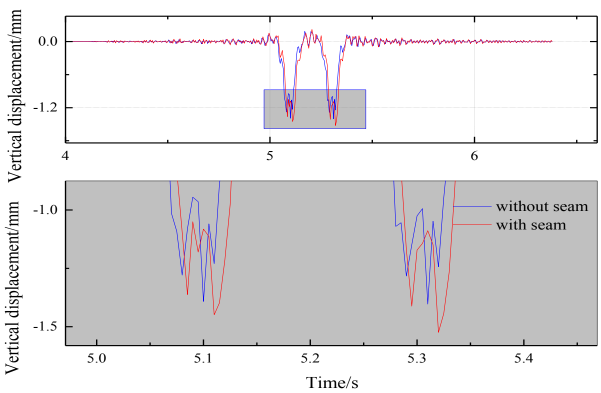


Fig. 17. Vertical displacement of rail with and without seam

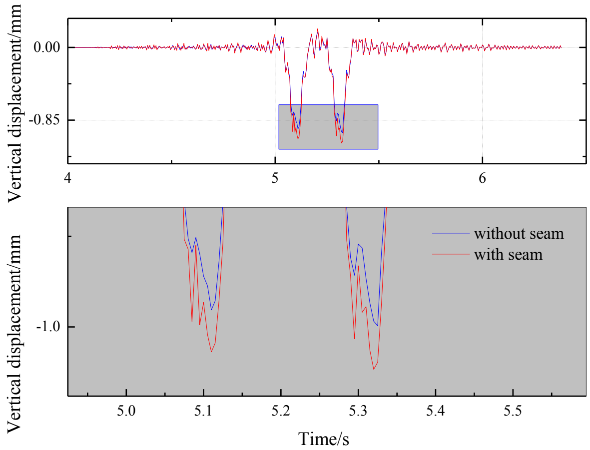


Fig. 18. Vertical displacement of track slab with and without seam

Table 4. Maximum value of response of vertical accelerated speed of each vehicle element of the track system

Operating condition	Vertical accelerated speed of rail (m/s^2)	Vertical displacement of rail (*mm*)	Vertical accelerated speed of track slab (m/s^2)	Vertical displacement of track slab (*mm*)
Without seam	72.377	1.434	25.163	0.997
With seam	73.462	1.524	62.159	1.117

The diagram above shows that when the train passes across the section right above the area of mortar seam, the vertical accelerated speed of rail is hardly affected. The vertical accelerated speed is only increased by 0.1%. The vertical displacement of rail increases from 1.434 to 1.524 mm, which is increased by 6.3%. The vertical displacement of track slab increases from 0.997 to 1.117 mm, which is increased by 12.0%. The influence on the vertical accelerated speed of track slab is significant, increasing from 25.163 to 62.159 m/s2, which is increased by 144.3%. Therefore, the generation of CA mortar seam has the largest influence on the vertical accelerated speed of track slab, followed by the influence on the vertical displacement of track and track slab. The influence on the vertical accelerated speed of steel rail is the smallest.

4.3 Influence of train speed on track - vibration response of the vehicle system

To study the law of influence of train speed on the vehicle and the dynamic characteristics of ballastless track, the operating condition of mortar seam is set at 3 mm/1.2 m, and the different train speeds are selected for the computation of dynamics. The operating conditions of train speeds are 200, 250, 300, 350, and 400 km/h. The dynamic response of the vehicle and track systems at different train speeds is shown in Figures 19-21.

The diagram above shows that when the size of seam remains unchanged, the train speed gradually increases from 200 to 400 km/h. The dynamic responses of vehicle and ballastless track are increased accordingly. The vertical accelerated speed of vehicle body increases from 0.664 to 1.253 m/s^2, which is increased by 88.7%; the vertical wheel rail force increases from 127.151 to 170.455 kN, which is increased by 34.1%; the vertical accelerated speed of steel rail increases from 52.190 to 98.267m/s^2, which is increased by 88.3%; the vertical deviation of steel rail increases from 1.405 to 1.690 mm, which is increased by 20.3%; the vertical accelerated speed of track slab increases from 23.570 to 57.911m/s^2, which is increased by 145.7%; the vertical deviation of track slab increases from 1.016 to 1.260 mm, which is increased by 24.0%; the vertical accelerated speed of bed plate increases from 13.823 to 30.573m/s^2, which is increased by 121.2%; the vertical deviation of bed plate increases from 0.876 to 0.991 mm, which is increased by 13.1%; When the train speed is greater than 300 km/h, the rate of wheel load reduction exceeds the limiting value specified in the norms. In conclusion, the greater the train speed, the more detrimental the traveling safety of the train.

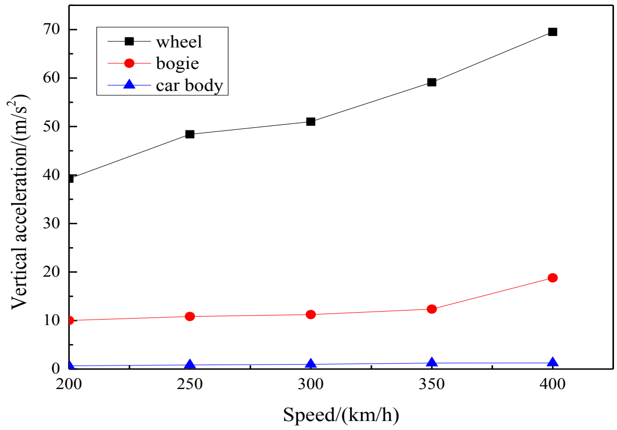


Fig. 19. Accelerated speed of vehicle system

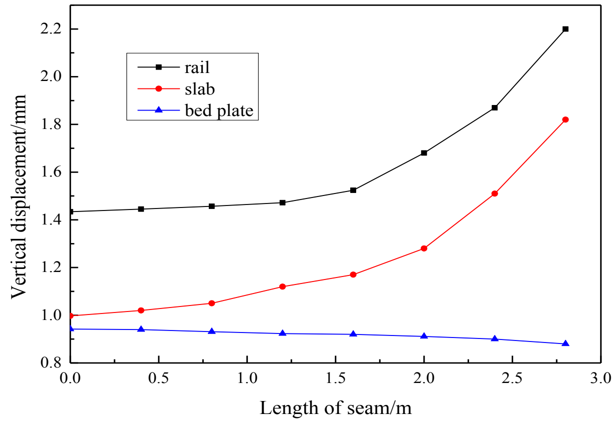


Fig. 22. Vertical displacement of track system

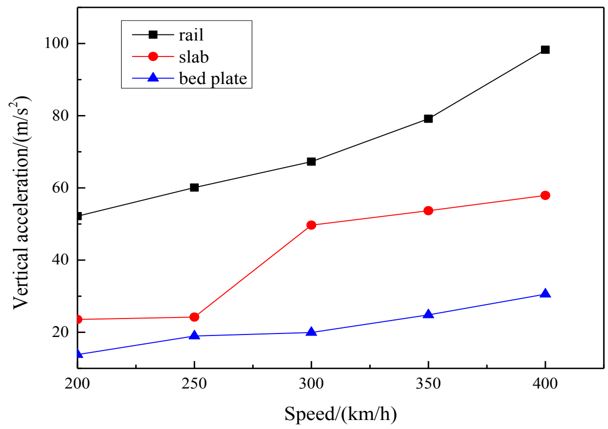


Fig. 20. Vertical accelerated speed of track system

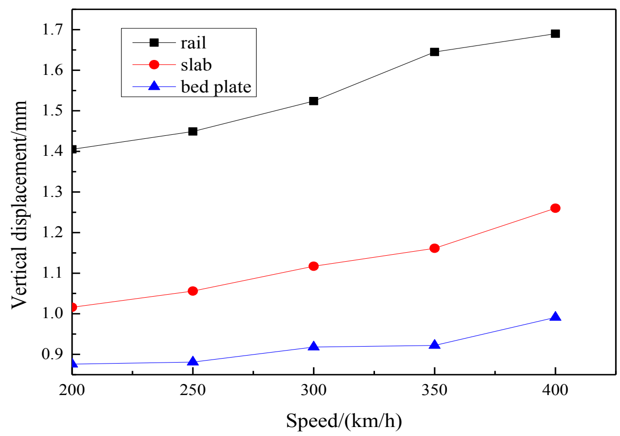


Fig. 21. Vertical displacement of track system

Table 5. Dynamic response of vehicle-ballastless track system at different vehicle speeds

Operating condition of speed (km/h)	200	250	300	350	400
Vehicle body vertical acceleration (m/s^2)	0.664	0.831	0.977	1.245	1.253
Maximum vertical wheel rail force (kN)	127.151	128.334	132.089	152.425	170.455
Vertical accelerated speed of steel rail (m/s^2)	52.190	60.097	67.252	79.137	98.267
Vertical displacement of rail (mm)	1.405	1.449	1.524	1.645	1.690
Vertical accelerated speed of track slab (m/s^2)	23.570	24.200	49.680	53.662	57.911
Vertical displacement of track slab (mm)	1.016	1.056	1.117	1.1613	1.260
Vertical accelerated speed of bed plate (m/s^2)	13.823	18.975	19.953	24.811	30.573
Vertical displacement of bed plate (mm)	0.876	0.881	0.918	0.922	0.991
Rate of wheel load reduction	0.74	0.76	0.81	1	1

4.4 Influence of length of seam on the dynamic characteristics of wheel rail system

With other calculation parameters unchanged, the length of seam along the track slab, if divided by the times of space between mortars (0.2 m), is 0, 0.4, 0.8, 1.2, 1.6, 2.0, 2.4, and 2.8 m. The influence on the dynamic characteristics of wheel rail system is analyzed. The results are shown in Figures 22-23.

Figure 22 shows that as the length of seam increases, the vertical deviation between the steel rail and track slab increases. Due to the CA mortar seam, the force transmission between structural layers of the track system weakens, so the vertical deviation of the bed plate is slightly decreased as the length of seam increases. When the length of seam is smaller than 1.2 m, the changes in the vertical deviation between rail and track slab is not significant. When the length of seam is greater than 1.2 m, the vertical deviation between rail and track slab is increased significantly. Figure 23 shows that the influence on the vertical accelerated speed of rail is not significant. The vertical accelerated speed of track slab increases significantly as the length of seam increases. When the length of seam is greater than 0.8 m, the vertical accelerated speed of track slab is increased significantly as the length of seam increases.

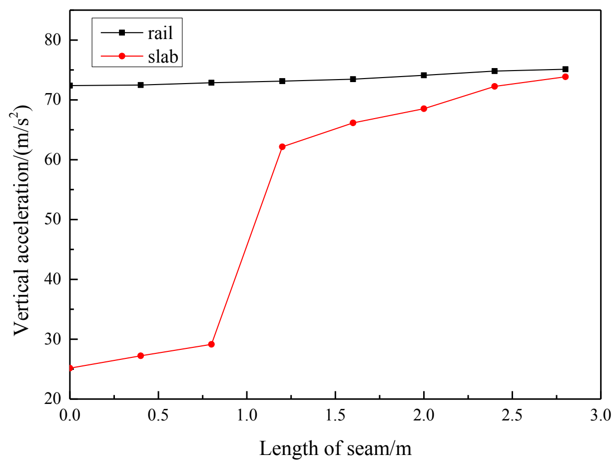


Fig. 23. Vertical accelerated speed of the track system

4.5 Influence of the height of seam on the dynamic response of track structure

With other calculation parameters unchanged, the height of seam area, that is, the height from the floor of the track slab, is calculated on the basis of 0, 0.5, 1, 1.5, 2, 2.5, and 3 mm. The influence on the dynamic characteristics of wheel rail system is analyzed. The results are shown in Figures 24-25.

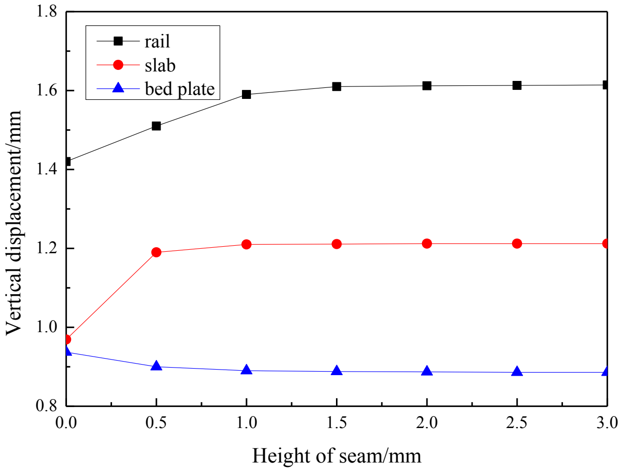


Fig. 24. Vertical displacement of the track system

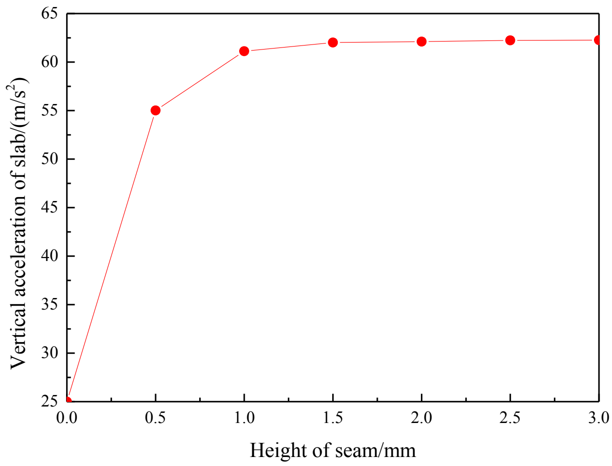


Fig. 25. Vertical accelerated speed of the track system

The figure above shows that when the train passes across the section right above the area of seam, if the height of seam is smaller than 1 mm, then the vertical deviation of the rail and track slab and the vertical accelerated speed of the track slab increase significantly. If the height of seam exceeds 1 mm, then the changes in the height of seam have minimal influence on the vertical deviation of rail and track slab and the vertical accelerated speed of track slab. Thus, CRTS II slab track is horizontally connected, and the track structure on both sides of the seam area constrains the track structure of the seam area. The deformation and stress of the track structure will tend to become a constant as the height of CA mortar seam increases because of the function of restraint of the track structure.

5. Conclusions

To explore the influence law of CA mortar seam on the dynamic characteristics of different parts of vehicle-CRTS II slab ballastless track system, the characteristics of CRTS II slab track structure were considered. The nonlinear finite element model of vehicle-CRTS II slab track-subgrade system was proposed under the medium-long wave and short wave irregularity. The influence of CA mortar seam on the dynamic characteristics of parts of the vehicle and track system was analyzed by adopting the method of numerical simulation. The influence of running speed and the changes in the length and height of seam on the traveling safety was also studied. The following conclusions were drawn:

(1) CA mortar seam exerts relatively minimal influence on the dynamic performance of vehicle system, whereas the dynamic performance of the vehicle system is mainly determined by the track irregularity.

(2) CA mortar seam exerts the greatest influence on the vertical accelerated speed of track slab in the track system, followed by the influence on the vertical displacement of track and track slab. Moreover, the influence on the vertical accelerated speed of the rail is the smallest.

(3) The influence of CA mortar seam on the dynamic performance of all parts of vehicle-track system is in direct proportion to the train speed and will threaten the traveling safety when the train speed is too high.

(4) The vertical dynamic response of rail and track slab increases as the length of seam increases. The vertical displacement of bed plate slightly decreases as the length of seam increases.

(5) When the height of seam tends to 1 mm, the vertical dynamic response of rail and track slab increases significantly, and then it tends to be stable as a result of the constraining effect of the track structure.

The nonlinear finite element model of vehicle-CRTS II slab track-subgrade system is relatively clear and distinct. Given the influence of medium-long wave and short wave irregularity added in the calculation, the calculation result is more reliable and closer to the actual operation situations, which provides some theoretical reference for the formulation of maintenance and repair standards of CRTS II slab track. However, due to the limited field testing of high-speed railway and the lack of actual data of on-site monitoring, field monitoring work should be conducted in future studies as much as possible. In addition, the monitoring data obtained should be used to correct the calculation model and add additional complex conditions, such as temperature and subgrade settlement, so that the model is accurate and close to the actual site.

Acknowledgements

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