ANALYSIS OF STRESSS DISTRIBUTION CHARACTERISTICS OF SUBGRADE

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Abstract: *Railways are the key transportation infrastructure for each country to compete for development, and are of great significance to economic development and social progress. In recent years, with the development of high-speed railways, strict control requirements for vibration and settlement of railway subgrades are required, and researchers need to break through the traditional geotechnical theory and technology. Nowadays, high-speed railway subgrade dynamics has become an international frontier and research hotspot of multidisciplinary intersections such as railway engineering, geotechnical engineering and structural dynamics. This paper summarizes the measured data of railway subgrade dynamics in China, and focuses on the dynamic stress distribution characteristics of the subgrade under train load.*

Keywords: *Railway, subgrade dynamics, stress distribution, field measurement*

I. INTRODUCTION

Railway is an important transportation infrastructure of the country and plays an important role in economic development and social progress. At the end of 2017, China has built 25,000 kilometers of high-speed railway, accounting for 2/3 of the total length of the world's high-speed railway. China has basically formed a high-speed railway network covering densely populated areas, and it is also the country with the largest scale of high-speed railways in the world. The biggest characteristic of high-speed railway is that the train has a high running speed. At present, the running speed in China has reached 350km/h, and some test line speeds are even higher than 500km/h, which is close to or exceeds the wave propagation speed of the subgrade soil. In 1998, the Swedish Railways discovered the Mach effect of high-speed rail operation for the first time on the soft ground. The impact load generated by the train in the track structure and subgrade is several times that of the low-speed operation, and the maximum is even more than ten times [1].

Under the conditions of high-speed train operation, the problems of settlement and disease of high-speed railway subgrade are more prominent, which is more likely to affect the normal operation of trains than ordinary train lines. Japan, Germany and other countries have monitored the excessive settlement of high-speed railway subgrade under the train running load [2-3]. The high-speed railway subgrade dynamics mainly studies the dynamics of the subgrade under the operating conditions of high-speed trains, and the resulting cumulative settlement deformation of the power to ensure the smoothness of the line and the safety of train operation.

High-speed railways at home and abroad generally use ballast or ballastless tracks. The ballast track structure (*fig. 1*) is to fix the rails to the sleepers through the fastener system, and the sleepers are laid at a certain distance on the track bed formed by the bulk ballasts. The track bed receives the dynamic stress from the sleeper and is further transmitted to the subgrade. The ballasted track has the advantages of convenient laying, low cost and easy maintenance, and has long been the main structural form of railway tracks in various countries of the world. With the increase of train speed, the track vibration is intensified, and problems such as granulating of the ballast bed and acceleration of settlement are becoming more and more serious. The newly developed ballastless track structure (*fig. 2*) is to fix the rail to the concrete track plate through the fastener system, and the concrete base placed on the site below the track plate. The track plate and concrete base transfer the upper vehicle load evenly to the subgrade. Compared with the ballasted track, the ballastless track removes the track bed layer, eliminates the main source of track settlement deformation, and is beneficial to improve the running stability. The concrete base has a good dispersion effect on the load, making the base stress uniform and the service life of the roadbed long. The shortcomings of ballastless track are mainly the high initial cost, and the low adaptability to uneven settlement of the roadbed. If damage occurs, it is difficult to repair or rectify.

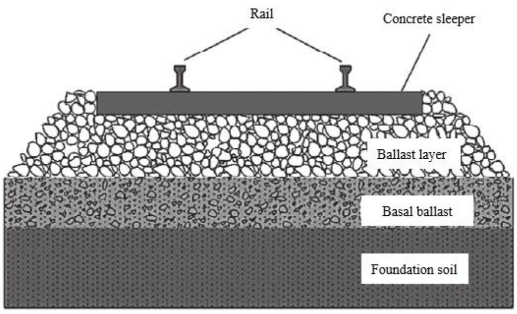


Figure 1. *Ballast track structure*

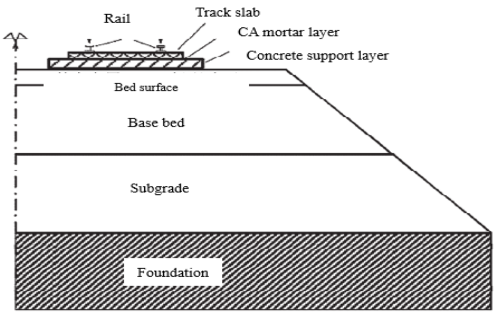


Figure 2. *Ballastless track structure*

II. DEVELOPMENT OF SUBGRADE STRESS RESEARCH

The vibration generated by train operation propagates to the subgrade and surrounding soil through the track structure. The mechanism of the subgrade vibration caused by train operation can be mainly attributed to the following five categories[4] (1).Vibration generated by the moving load of the axle: The traveling wave in the subgrade generated by the movement of the wheel axles, once the train running speed approaches the critical speed of the track-subgrade, the amplitude of the vibration excited is very large, that is, the resonance phenomenon occurs (2). Vibration caused by movements such as ups and downs, shaking heads, nodding heads, and snakes during the running of the train (3). Discrete support of the sleeper or fastener will cause periodic changes in the stiffness of the track structure along the longitudinal direction. The train will generate periodic excitation when moving on the track (4) Various excitations caused by wheel eccentricity, irregular surface of the rail, uneven wear of the rails and wheel treads (5) Vibration caused by Rail joint stiffness variation and turnouts, etc. Previous studies have shown that wheel tread irregularity and rail surface irregularity are the main factors causing vibration when train speed is lower than the critical velocity of track-subgrade. The vibration generated by the train running on the track is transmitted to the lower foundation via the roadbed. The research in this area has been paid more and more attention with the development of high-speed railway. The following summarizes the development of relevant theories.

A. Early research

Cai Ying[5] analyzed the measured results of the Da-qin line. The vehicle speed has no effect on the dynamic stress when the vehicle speed is lower than 70km/h. The distribution of dynamic stress on the bed surface and the dynamic stress along the depth are: The dynamic stress of the bed surface of the low-speed railway is 60~120 kPa, the dynamic stress attenuation is 60% at a depth of 0.6 m, and the dynamic stress change tends to be stable at a depth of 1.5 m. The dynamic stress at the depth of 3.0 m is only about 10% of the base dynamic stress. The double logarithmic coordinates and exponential relationship can be used to simulate the dynamic distribution of subgrade dynamic stress along the depth.

According to the analysis results of Beijing Ring Test Base and Guangzhou-Shenzhen Line, Zhou Shengen[6] showed that the dynamic load of the subgrade design is linear with the train speed. When the vehicle speed is less than 160km/h, the relationship between the subgrade design dynamic load σ_v and the vehicle speed V is:

$$\sigma_v = 52(1+00035V)$$

The dynamic stress is proportional to the significant value of the shaft, and the higher the speed, the greater the influence of the axle weight.

Wang Binglong[7] analyzed the measured results of dynamic stress of Shanghai-Nanjing line. It shows that when the vehicle speed is less than 140km/h, the dynamic stress value of the subgrade increases with the increase of train speed, but the increase value is not large. The dynamic stress of the subgrade surface is saddle-shaped, that is, the dynamic stress under the rail is larger than the dynamic stress at both ends of the sleeper and the center of the sleeper.

However, Limited to the test conditions, the quantity and accuracy of these research test data needs to be improved. At the same time, with the continuous development of high-speed and heavy-duty railways, new problems have arisen.

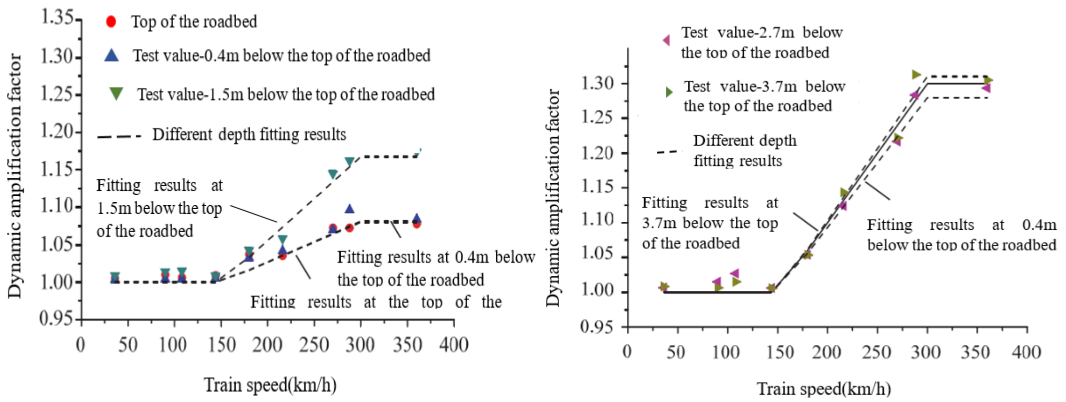
B. Influence of train speed on dynamic stress of subgrade

Table 1[8] shows the distribution range of the dynamic stress peaks of the subgrade surface in the field tests at home and abroad. The plate-type ballastless track has better integrity and the dynamic stress distribution under the track plate is relatively uniform, all in the range of 13~20k Pa. The dynamic stress on the top surface of the subgrade under the track sleeper is 50~100k Pa.

__Table 1.__ The measured dynamic stress amplitudes on the roadbed surface

Railway line	Model	Track type	Train speed (km/h)	Subgrade surface dynamic stress(kPa)
Wuhan-Guangzhou Passenger Dedicated Line	CRH-2	Ballastless track	280~350	14.6~16.9
Cologne-Rhine New Line, Germany	ICE-3		140~326	15.0~20.0
Nuremberg-Ingolstadt line, Germany	ICE-3		220~297	13.0~20.0
Qin-shen Passenger Dedicated Line	Chinese Star	Ballast track	200~330	50.0~100.0
Hannover-Wursburg New Line, Germany	ICE-V		10~400	70.0~100.0

Based on the measured data of the German high-speed railway, Hu Yifeng and Li Rongfang[9] divided the relationship between dynamic stress of subgrade and speed of train into three sections: below 150km/h and above 300km/h, the dynamic stress of the subgrade has nothing to do with the speed of the train. When the vehicle speed is between 150~300km/h, the dynamic stress of the roadbed increases linearly with the speed of the vehicle. As shown in *fig. 3*, Bian Xuecheng et al. [10] obtained the test results of the ground pressure dynamic amplification factor of the foundation part through the full-scale physical model test of the high-speed railway, which is consistent with the description of Hu Yifeng and Li Rongfang, reaching 1.30. However, the dynamic amplification factor of the shallow bed is relatively low, about 1.15.



(a) Bed section *(b) Foundation part*

***Figure 3.** Variation in the dynamic amplification factor of dynamic soil stresses with train speeds*

C. Dynamic stress distribution of subgrade caused by train operation

Luo Qiang et al. [11,12] compared the dynamic stress time-history curve of the track surface of the ballast track during the driving of 12 groups of EMUs [13] and the dynamic stress time-history curve of the track surface of the ballastless track during the driving of 16 groups of EMUs [14]. The results show that the former contains 24 peaks, which corresponds to the total number of axles, indicating that the loading and unloading process of the railroad track with the dynamic load of the train is completed by a single axle load. The latter contains 32 peaks, corresponding to the number of train bogies, indicating that the dynamic loading of the ballastless track subgrade is performed by a combination of two axle loads on the same bogie.

Under the train load, the dynamic stress along the subgrade of the ballastless track and the ballasted track has a large difference along the lateral distribution. When Dong Liang [15] calculated that the "Shenzhou" locomotive passed through the ballasted track (*fig. 4*), the stress ratio of the end of the sleeper to the base surface directly below the rail was about 0.33, and the stress ratio of the center of the line to the base surface directly below the rail was about 0.63. The dynamic stress of the subgrade is the largest under the rail, and the dynamic stress at the two ends of the sleeper and the center of the line is relatively small, and it is distributed in a saddle shape along the lateral direction.

In the measured results of the Suining-Chongqing ballastless track [16], the ratio of the dynamic stress of the center of the line and the edge of the supporting layer to the surface of the road directly under the rail is 0.85 and 0.93 respectively. In the measured results of Wuhan-Guangzhou high-speed railway [17], the ratio of the dynamic stress of the center of the line and the edge of the track plate to the base of the lower rail directly below the rail are 1.11 and 0.91, respectively. As shown in *fig. 5*, the typical values of the dynamic stress ratio of the subgrade in the lateral direction fluctuate around 1.0, and the dynamic stress distribution decreases slightly from the position directly under the rail to the outside, but the proportion of reduction is more than 10%. The deviation between the dynamic stress of the subgrade at the center of the line and the dynamic stress directly under the rail is also within 15%. Therefore, it can be considered that the dynamic stress of the base surface of the ballastless track is substantially evenly distributed along the lateral direction, and the distribution range is consistent with the width of the support layer (or the base).

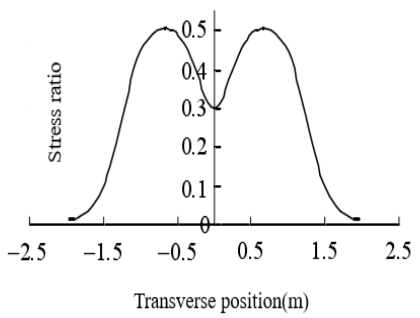


Figure 4. *Lateral distribution of subgrade*

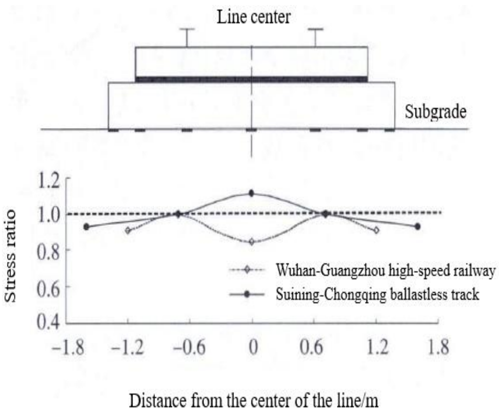


Figure 5. *Roadbed stress lateral distribution map*

III. CONCLUSIONS

With the increase of train speed, the dynamic amplification effect of the subgrade becomes more and more obvious, and the dynamic load of the subgrade is intensified. The test results show that the dynamic stress amplification factor inside the subgrade bed reaches 1.15, and the dynamic stress amplification factor in the lower foundation can reach 1.30.

The one-load loading and unloading process of the ballast subgrade bearing the dynamic load of the train is completed by the single-axis load, and the one-load loading and unloading process of the ballastless track subgrade bearing the train load is completed by the two axle loads of the same bogie.

For the ballasted track structure, the lateral distribution of the dynamic stress of the actual subgrade is irregular, showing a "saddle type" distribution; for the ballastless track, the dynamic stress of the roadbed surface is basically evenly distributed along the lateral direction.

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