Numerical Simulation on Dynamic Behavior of High-speed Railway Cutting Bedding in Expansive Soil Area

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Abstract. The cutting bedding defect of expansive soil is one of the most difficult problems in railway constructions. Based on analysis results of the character and mechanism of subgrade disease, semi-rigid waterproof and drainage structure layer is researched, fully-enclosed subgrade is designed. Based on work of predecessors, the article simplify the train load equation and study the dynamic characters of new cutting and bedding. The results show that laying waterproof and drainage structure can increase the speed of decay of dynamic stress in the bedding, decrease the dynamic displacement of bedding surface substantially, and make the standard of high speed railway.

1. Introduction
Expansive soil is a kind of special soil composed of montmorillonite, a strongly hydrophilic clay mineral, and its mix-layer clay minerals [1, 2]. The Nan-Bei section of newly built Yunnan-Guangxi railway and the existing Nanning-Kunming railway is in the same corridor belt and there are the same geological conditions and a large number of expansive soil subgrade along the railway. Lots of subgrade bed diseases still occurred in the existing Nanning-Kunming railway after years of renovation [3], which shows that the treatment effect of conventional foundation treatment method is not ideal. The swelling property of expansive soil is closely related to the change of moisture content in soil [4, 5] and expansive soil with long-term steady moisture content has a good engineering characteristics. In this paper, the characteristics of expansive soil are fully utilized, and the new type of waterproof structure layer is used to control the change of moisture content of expansive soil to renovate expansive soil.

In view of the characteristics and mechanism of railway cuttingbedding disease in expansive soil area, the numerical simulation of new cutting bedding based on semi-rigid anti-drainage structure is carried out and the dynamic characteristics of new type cutting bedding is analyzed and studied.

2. Introduction of New Type Cutting Bedding Structure
Figure 1 is schematic diagram of new type cutting bedding structure, and the subgrade is medium-weak expansive soil. The section is made up of 0.5m replacement layer, 0.2m new type water-proof structure layer, 0.05m medium-coarse sand and 0.65m surface layer of subgrade. Each part of the model calculates parameters in the table 1.
Table 1. Material parameters of model

| Location                                      | Constitutive model | Thickness (m) | Dynamic elastic modulus (MPa) | Poisson ratio | Density (kg/m³) | Cohesion (kPa) | Friction angle(°) | Partial damping coefficient |
|-----------------------------------------------|--------------------|---------------|-------------------------------|---------------|-----------------|----------------|------------------|----------------------------|
| Type III sleeper                              | Elastic model      | 0.15          | 30000                         | 0.17          | 2300            | -              | -                | 0.063                      |
| Ballast                                       | Mohr-coulomb model | 0.35          | 200                           | 0.25          | 2200            | 0              | 38               | 0.094                      |
| Graded gravel in surface layer of subgrade    | Mohr-coulomb model | 0.7           | 190                           | 0.27          | 2140            | 15             | 19               | 0.088                      |
| A/B filler in replacement layer               | Mohr-coulomb model | 0.5           | 110                           | 0.32          | 1950            | 20             | 17               | 0.110                      |
| Medium-weak expansive soil (rock) subgrade    | Mohr-coulomb model | 3.5           | 67                            | 0.33          | 1860            | 41.4           | 11.2             | 0.088                      |
| New type water-proof structure layer          | Elastic model      | 0.2           | 1500                          | 0.25          | 1900            | -              | -                | 0.157                      |

According to the section in figure 1, this paper established a finite difference model. As shown in figure 2, there are 77520 cells and 82859 nodes in the model. Applying static constraints on the basis of the actual stress state of model, namely, restraining the velocity of all nodes in z direction which in the bottom of model. Restraining the velocity of all nodes in x direction which in the both side of model, and restraining the velocity of all nodes in y direction which in the back and forth of model. During the dynamic calculation, because of the existence of wave reflection, if it was not treated, which will cause great influence on the calculation results. The effect of wave reflection can be reduced by building a large model, but it will greatly increase the time required to calculate. In order to effectively resolve the contradiction between these questions, FLAC3D provides two dynamic calculation boundaries which are static boundary and free field boundary. This calculation sets the static boundary, and apply partial damping.
3. Study on Train Load Realization in FLAC3D

This paper focuses on the dynamic response of the subgrade under the track. According to the previous research data, the vibration load is more severe in the middle frequency section \([6]\), the load is simplified as sinusoidal load only in the intermediate frequency range:

\[
\begin{aligned}
P(t) &= P_0 + P \cdot \sin \omega t \\
\omega &= 2\pi \cdot \frac{v}{L}
\end{aligned}
\]  

Type: \(P(t)\) is train vibration load (kN); \(P_0\) is the axle load of locomotive and rolling stock (kN) (according to ZK live load value); \(P\) is the vibration load corresponding to a typical value in the control conditions in the preceding table (kN); \(\omega\) is vibration circle frequency (Hz); \(v\) is running speed (m/s); \(L\) is wavelength of track irregularity curve (m).

In the analysis the running speed is \(v = 250\text{km/h}\), single rail static load of single strand is \(P_0 = 100\text{kN}\), the track geometry irregularity wavelength is 2m, the rail bottom end is 0.15m wide, the width of the cross section of the sleeper is 0.32m, and area of the contact surface between rail and sleeper is \(s = 0.048\text{m}^2\). According to the data, the maximum value of dynamic stress of the subgrade surface is \(\sigma = 100\text{kPa}\). In order to get the most unfavourable force condition of the subgrade the vibration load of the train is calculated as \(P = 35\text{kN}\), which is based on the maximum dynamic stress value of the road surface in this paper. According to the data above, the stress history of each sleeper can be calculated. Taking into account that the ballast cannot withstand tension, the calculated stress value of tensile stress is adjusted to 0kPa and Figure 3 shows the stress time history curve of the model sleeper. It can be seen that the four peak points in the curve correspond to the stress values when the wheel rail is just above the sleeper, which is in good agreement with the actual situation.
4. Study on Dynamic Characteristics of New Type of Subgrade Bed Structure

4.1 Distribution of Dynamic Stress

Figure 4 is the attenuation curve of the vertical dynamic stress along the depth of the bedding. It can be seen that the vertical dynamic stress under the orbit projection is similar to that under the projection of the center of the road. In the surface layer of the subgrade, the vertical dynamic stress is approximately two times as that under the projection of the end of the sleeper. With the increase of depth, the vertical dynamic stress at three locations tends to be the same. This is due to facts as follow.

(1) The end of the sleeper is mainly affected by closer train loads, but it is affected by the two rails at the same time in the center projection.

(2) With the increase of depth, the distribution of train load in the cross section is more and more wide, the distribution curve is more and more gentle, and the dynamic stress in the direction of cross section of the line is similar.

Figure 5 is the curve of dynamic stress attenuation coefficient along with depth in bedding, which shows that the attenuation law at three locations is consistent that the dynamic stress attenuates most severely above the filling layer (0.9m under the subgrade surface), where attenuation coefficient of dynamic stress is 68 % ~ 76 %. In the replacement layer it tends to be relaxed and the dynamic stress attenuation coefficient of three different situation at 4.5m are equal.
4.2 Attenuation Law of Dynamic Displacement

Figure 6 is the attenuation curve of dynamic displacement of the new cutting bedding and traditional bedding along with depth. The figure shows that dynamic displacement attenuates exponentially approximately and attenuates faster in bedding than in foundation. The dynamic displacement of the subgrade surface decreases with the increase of the thickness of the replacement layer, which can be brought by comparing the dynamic displacement with different replacement layer thickness. By comparing the new bed structure with traditional bedding structure, it can be seen that when the thickness of bedding is same the new type of waterproof structure layer can reduce the dynamic displacement of subgrade surface effectively.

In terms of numerical value, when the 0.2m thick traditional bedding replacement layer is replaced by the new type of waterproof structure layer, the dynamic displacement of subgrade surface can reduce from 1.06 mm to 0.95 mm, which is similar to the dynamic displacement of subgrade surface of traditional bedding structure with 2.3m thick replacement layer, and which meets the requirements that the dynamic displacement of subgrade surface of high-speed railway is not more than 1mm in specification of Code for Design of High Speed Railway (2009).

5. Conclusions

(1) The train load equation in this paper can well reflect the wheelset effect of train load in subgrade, which can be brought from the time-history curve of dynamic stress in bedding.
(2) The dynamic stress of the new cutting bedding decays exponentially, and the laying of semi-rigid waterproof and drainage structure layer can accelerate the dynamic stress attenuation rate in bedding.

(3) Laying of semi-rigid waterproof structure layer can reduce the dynamic displacement of subgrade surface. The dynamic displacement value in the semi-rigid waterproof and drainage structure layer is constant and the deformation value of semi-rigid waterproof and drainage structure layer under train load is very small.

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7. References
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