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Analysis of Vibration Reduction Effect of the Floating Slab Track with Different Base Forms in a Small Radius Curve of Subway Lines

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Abstract. This paper compares the vibration characteristics of the floating slab track with different base forms and proposes a method to comparatively improve the vibration reduction effect of the" integrated assembly" construction method. Firstly, the wheel-rail force of the train passing through the small radius curve section is obtained by the dynamic simulation, and steel spring floating slabs with the flat and inclined base, tunnel models with different superelevation are established by the finite element method. Next the fundamental frequencies of slab tracks are analysed and the reaction forces of the bottom of the steel spring and the 1/3 octave vibration level of tunnel wall nodes are calculated. The results show the vibration levels of nodes of the tunnel with inclined base is larger when the train speed and the superelevation are the same, which is due to the vertical forces being applied to the different base forms of the tunnel have different vibration effects, and the larger the superelevation is, the greater the difference becomes. In view of this, we could redistribute the superelevation between the floating slab track and tunnel base instead of being completely provided by the floating slab track or tunnel base as before.

1. Introduction

With the rapid development of urban rail transit, the vibration problem caused by subway operation has attracted more and more attention. Among them, the floating slab track is widely adopted as the best measure for vibration reduction, which is because the base frequency of floating slab track is usually below 20Hz, so it can significantly absorb the track vibration, especially for medium and high frequency vibration [1-4].

The traditional construction method of the steel spring floating slab track includes transporting the rails, steel bars, templates and other construction materials by gantry cranes through the latest shaft or feed opening to expected location, and then manually installing rails, tying steel bars, installing vibration isolators and templates, finally pumping concrete to build the floating slab track. In this method, the superelevation of small radius curve is provided by the upper surface of floating slab track and the base of the tunnel is flat (as shown in Figure 1 [5]), therefore there are more standard sections of the slabs to design, which will reduce the design efficiency, increase the difficulty of construction and directly affect the construction progress. At present, the construction method called "integrated assembly" of floating slab track is mainly adopted, i.e., the track is prefabricated in the factory and carried to the construction site, simultaneously the inclined base of the tunnel is built, eventually the floating slab track is put in place on the tunnel base (as shown in Figure 2 [5]), which transfers the superelevation from upper surface of the floating slab track to the tunnel base so that the geometric shape of the slab track can remain relatively constant [6].

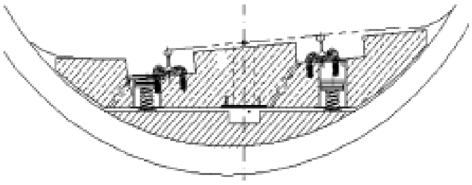

Figure 1. The traditional curve section.

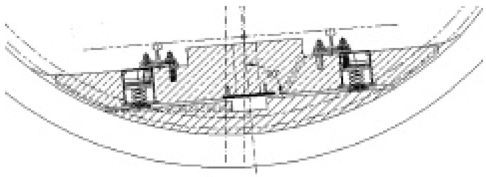

Figure 2. The" integrated assembly" curve section.

However, with the change of sections from Figure 1 to Figure 2 in the small radius curve section, the mechanical characteristics of floating slab track also change accordingly. As far as the current situation is concerned, there are few comparative studies on the traditional construction methods (i.e., flat base) and " integrated assembly " (i.e., inclined base). In this paper, the floating slab track with different base forms caused by different construction methods are studied, furthermore, a method that can comparatively improve the vibration reduction effect of the" integrated assembly" method in a small radius curve will be put forward.

2. Model introduction

2.1UM dynamic simulation model

As shown in Figure 3, the UM software is used to build a dynamic simulation model of a carriage, in which the axle weight of it is 12t, the curve radius is 300m, and the weight of rail is 60 kg/m. Firstly, the vehicle is allowed to pass the curve sections with the speeds of 40km/h, 60km/h and 80km/h, simultaneously the superelevation of the curve is respectively 60mm, 90mm and 120mm.Take a bogie as the research object (as shown in Figure 4), the vertical and horizontal wheel-rail forces parallel to the rail cross section will be obtained. In this process, the train is always in the state of deficient superelevation, which is because the theoretical value of the superelevation is very large, if the low-speed train passes by, it could be in danger of overturning. Therefore, the maximum value of superelevation is set as 120mm.

2.2ANSYS finite element model of the floating slab track

The floating slab tracks with the flat and inclined base are respectively established by ANSYS. The models are shown in Figure 5 and Figure 6 (take the superelevation value of 120mm as an example) respectively. Main calculation parameters are shown in Table 1, the length of the slab is 25m, the superelevation of the curve is still respectively 60mm, 90mm and 120mm. The full constraint is applied to both ends of rail to simulate infinite length [7]. Moreover, only consider the vertical displacement of the model. Firstly, the modal analysis is carried out to obtain the vibration modes and frequencies, and then the wheel-rail forces computed by Model 2.1 are applied to the track for transient dynamic analysis, finally the reaction forces of the nodes at the bottom of the steel spring is obtained successively, which is equivalent to the force transferred from the floating slab track to the tunnel.

Figure 3. Dynamic simulation model of carriage.

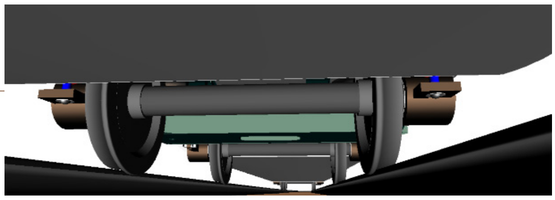

Figure 4. Dynamic simulation model of bogie.

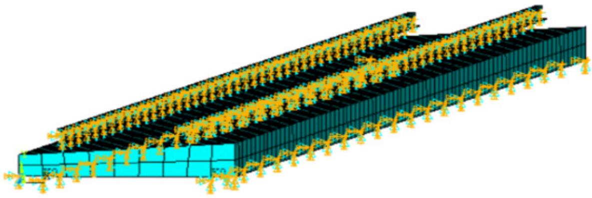

Figure 5. Floating slab tracks with flat base.

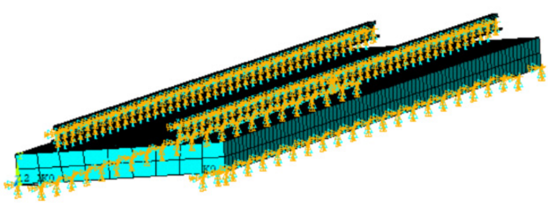

Figure 6. Floating slab tracks with inclined base.

Table 1. Main calculation parameters [8].

	Element type	Parameter	Value	Unit
Fastening	Combin14	Stiffness	3.9×10^{7}	N/m
		Damping	4×10^{4}	N·s/m
		Spacing	0.6	m
Spring damper	Combin14	Stiffness	6.67×10^{6}	N/m
		Damping	4×10^{4}	N·s/m
		Spacing	1.2	m
Rail	Beam188	Density	7830	kg/m^3
		Elasticity modulus	2.1×10^{11}	N/m^2
Slab	Solid45	Density	2500	kg/m^3
		Elasticity modulus	3.25×10^{10}	N/m^2

2.3ANSYS finite element model of the tunnel

In this part, ANSYS is used to build two-dimensional tunnel models with flat and inclined base. As the superelevation is provided by the tunnel base in " integrated assembly " method, the superelevation values of the inclined base are 60mm, 90mm and 120mm respectively. The tunnel section is simulated with the Plane182 and the concrete uses the C55. Take the middle section of the tunnel as the research object, the reaction values from Model 2.2 are applied to the tunnel wall for transient dynamic analysis and compare the vibration levels of the tunnel wall nodes.

3. Modal analysis of the floating slab track

The maximum value of vibration is caused by the resonance of the wheel and the floating slab track. Therefore, the resonance frequency is determined by the train speed and the floating plate modal frequency for this paper. Based on the Model 2.2, the first 10 order modal frequencies of floating slab track with flat and inclined base are analysed by Block Lanczos method provided by ANSYS. The first 10 order modal frequencies of the track with different superelevation are given in the Table 2 (h represents the superelevation value). It can be seen that there is no significant influence on modal frequency as the base form and superelevation change, i.e., in the case of the same train speed, the position of the resonant frequency in the frequency domain is roughly the same.

Table 2. The first 10 order modal frequencies of floating slab track with flat and inclined base.

Order	h=60mm		h=90mm		h=120mm	
	Flat	Inclined	Flat	Inclined	Flat	Inclined
1	7.9099	7.9405	7.8718	7.9405	7.8182	7.9405
2	13.491	13.523	13.451	13.521	13.399	13.519
3	18.178	18.194	18.155	18.191	18.126	18.189
4	20.860	20.703	21.053	20.701	21.320	20.699
5	22.260	22.275	22.241	22.273	22.214	22.272
6	24.511	24.500	24.518	24.496	24.525	24.494

7	25.472	25.556	25.368	25.556	25.230	25.556
8	30.313	30.237	30.403	30.233	30.532	30.231
9	32.263	32.023	32.558	32.020	32.969	32.018
10	37.215	37.072	37.389	37.067	37.634	37.065

4. Reaction force analysis of the steel spring

The reaction force at the bottom of the steel spring is equivalent to the force transferred from the floating slab track to the tunnel, which is of great significance to study the vibration level of tunnel wall nodes. Based on the finite element in Model 2.2, the vertical and horizontal reaction forces parallel to the rail cross-section are taken as the research objects. The following conclusions are drawn through reaction force values of the same curve with different superelevation at different speeds:

(1) The vertical reaction forces on the inside and outside of the curve with different base forms are approximately the same when superelevation value is the same. As the length of the article is limited, only the vertical reaction with superelevation value of 120mm is showed in Figure 7 to Figure 9 (v represents the train speed). With the increase of train speed, the vertical reaction force on the inside of the curve decreases gradually, while the vertical reaction on the outside increases gradually, and finally exceeds the inside. In this process, base forms have little influence on the vertical reaction.

(2) The horizontal reaction forces on the inside and outside of the curve with flat base have the same change rules as the vertical reaction value changes with the train speed, as shown in Figure 10. However, the simulation results of the inside and outside with inclined base are much lower than those of the flat base, which means it can be ignored.

The conclusions above show that the base form has little influence on the vertical reaction force, by contrast, it has a significant effect on the horizontal reaction forces.

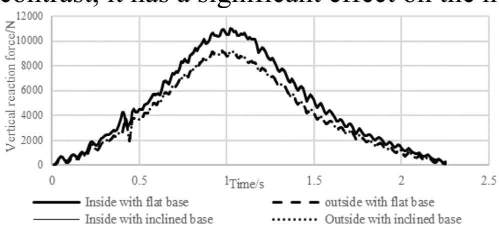

Figure 7. Vertical reaction force with a speed of 40km/h.

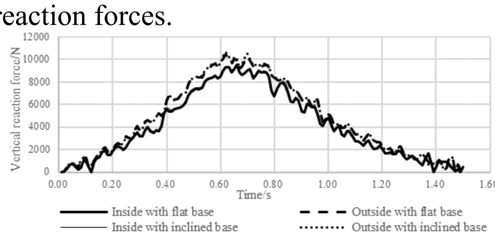

Figure 8. Vertical reaction force with a speed of 60km/h.

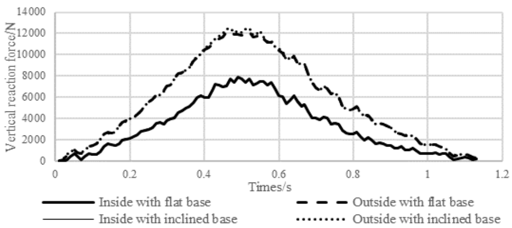

Figure 9. Vertical reaction force with a speed of 80km/h.

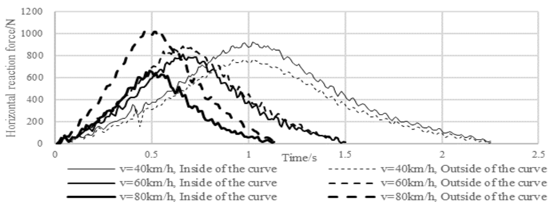

Figure 10. Horizontal reaction force at different speeds with flat base.

5. Vibration level analysis of the tunnel wall nodes

5.1Comparison of vibration levels

In view of the vertical acceleration caused by subway operation is much larger than the horizontal acceleration, vertical acceleration should be taken as the main analysis object when evaluating the environmental vibration [9]. In the first place, this paper gets the vertical displacement and acceleration response of tunnel wall nodes in the time domain by Model 2.3, and then the acceleration response in frequency domain is obtained by fast Fourier transform (FFT), finally divide the centre frequency by 1/3 octave to evaluate the impact on the environment [10].

As the propagation distance increases, the high-frequency component of vibration acceleration will decay rapidly, while the low-frequency component will decay slowly, so the low-frequency component has a greater impact on the environment. Therefore, this paper will focus on the vertical vibration level of 0-50Hz. From the comparison, the vertical vibration level of tunnel wall nodes has the same change rule with different superelevation:

(1) Taking the superelevation value of 120mm as an example (as shown in Figure 11), comparing the vibration level of tunnel wall nodes of 2.5m away from the base, it is found that the vibration level around the base frequency of the floating slab track reaches the peak value and the faster the speed is, the higher the peak value reaches, which has the same trend with the peak value of the reaction force in the previous section. Moreover, the vibration level of tunnel wall nodes with inclined tunnel base is larger than that of the flat tunnel base at the same speed.

(2) Taking the train speed of 40km/h as an example, Figure 12 shows that the larger the superelevation value is, the greater the difference value of vibration levels between the flat and inclined base becomes, which also indicates that the vibration reduction performance of the "integrated assembly" is lower than that of the traditional construction method.

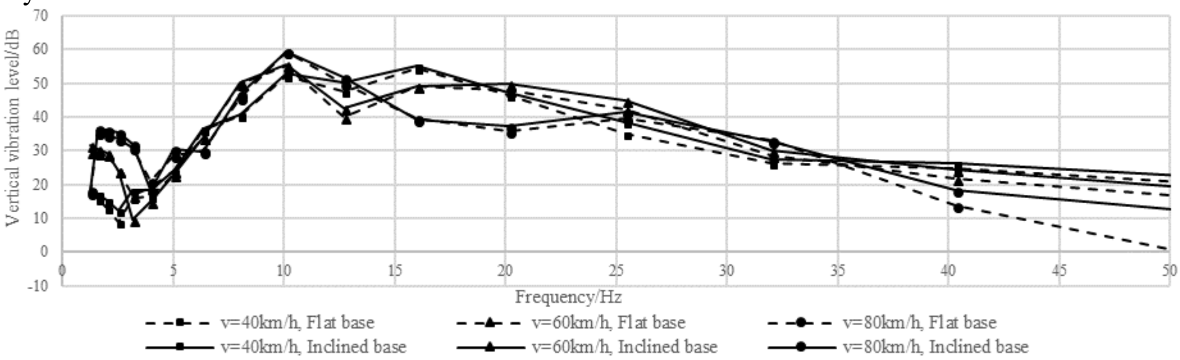

Figure 11. The vertical vibration levels of different speeds and different tunnel base forms.

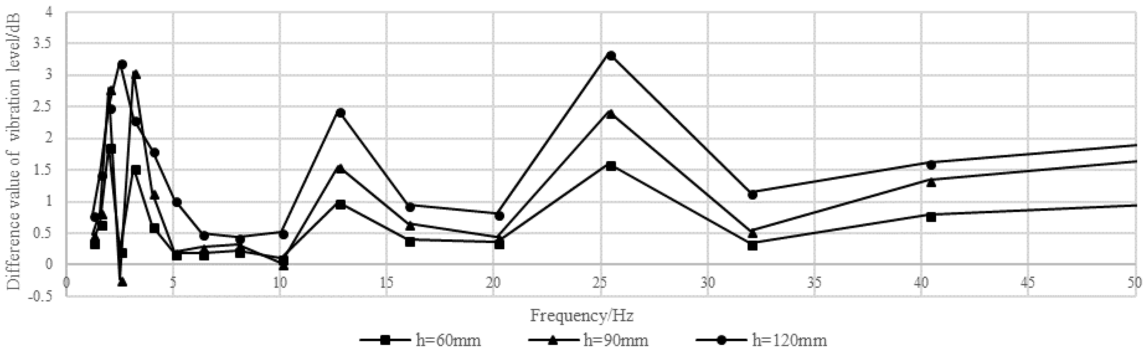

Figure 12. The difference value of vibration levels with different tunnel base forms.

5.2The reason and solution for the larger vibration level of the inclined base

In order to find out the reason why the inclined base ("integrated assembly") has larger vibration levels than flat base (traditional method), this section will use the corresponding reaction forces previously for analysis. Taking the superelevation value and train speed of 120mm and 80km/h respectively as an example and taking the vertical vibration level of tunnel wall nodes of 2.5m away from the base as the research object, compare the vibration levels of the flat base model applying the vertical force and the horizontal force with the same model only applying the vertical force, the results show that they are very close, which indicates the horizontal force has little effect on the vertical vibration level;

comparing the vibration levels of the flat base model applying the vertical force with the inclined base model applying the corresponding vertical force, it is found that the vibration level of the inclined base is larger than that of the flat base, which means the main reason for this phenomenon is the vertical force applying on different forms of the tunnel base (as shown in Figure 13). In addition, the analysis of other tunnel wall nodes is also carried out and the results are the same as the above conclusions.

In order to reduce the difference value of vibration levels between flat and inclined base, it could be considered that the superelevation value required can be respectively provided by the prefabricated floating slab and tunnel base. Taking the superelevation value and train speed of 120mm and 80km/h respectively as an example and taking the vertical vibration level of tunnel wall nodes of 2.5m away from the base as the research object, the tunnel bases are respectively assigned a superelevation value of 120 mm (i.e., previous inclined base), 90 mm, 60 mm, 30 mm, 0 mm (i.e., flat base), and the remaining superelevation values are provided by the upper surface of the prefabricated floating slab. Figure 14 shows the vertical vibration level of the tunnel wall node, which indicates that the larger the superelevation provided by the tunnel base is, the larger the vibration level becomes (h′ represents the superelevation value that the tunnel base provides). Therefore, the tunnel base and the prefabricated floating slab could respectively provide 30mm and 90mm (i.e., placing floating slabs with the flat base on the inclined tunnel base). In the curve with the superelevation value less than 30mm (such as the transition curve section), the floating slab track with inclined base can still be adopted, otherwise the upper surface of the floating slab can be appropriately adjusted as appropriate, which means that on the one hand, the" integrated assembly" method can be still adopted, on the other hand, it can avoid the problem that the vibration level of tunnel wall nodes is relatively larger when the superelevation value is completely provided by the tunnel base.

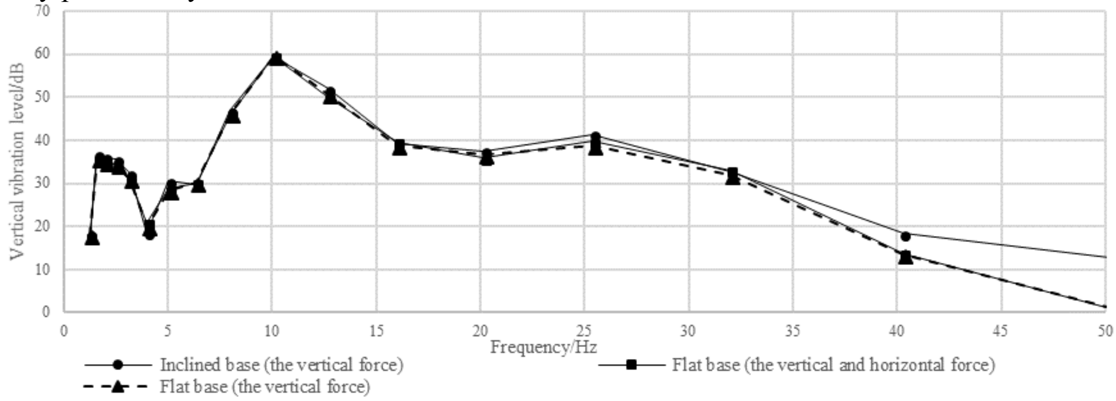

Figure 13. The vertical vibration levels of the node under different load schemes and tunnel base forms.

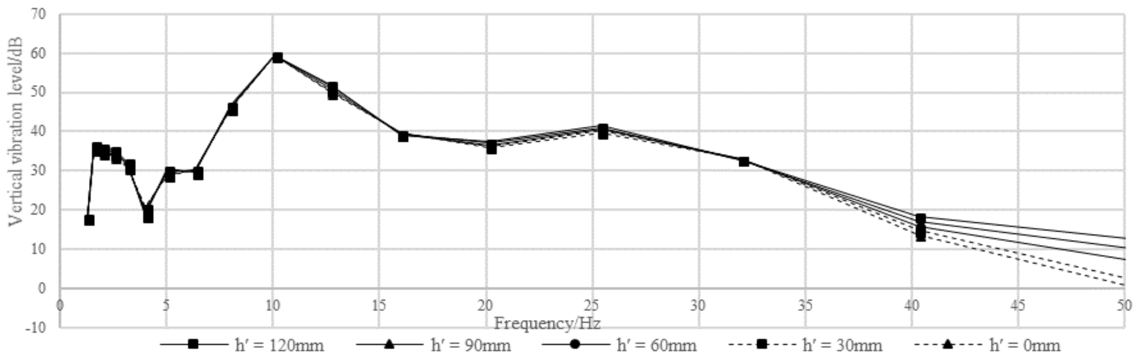

Figure 14. The vertical vibration levels of the node when the tunnel base provides different h′values.

6. Conclusion

This study compares the vibration reduction effect of the floating slab track of different base forms caused by different construction methods. The obtained results indicate that the vibration level of tunnel wall nodes corresponding to the inclined slab base is larger than those of the flat base at the same speed, moreover, the larger the superelevation value is, the greater the difference value of vibration levels between the flat and inclined base becomes.

The proposed method that the superelevation value required can be respectively provided by the prefabricated floating slab and tunnel base is an effective procedure to improve the vibration damping performance of the floating slab track with the incline base, which will be helpful to achieve better damping effect for the" integrated assembly" method.

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