Study on Foam Concrete Damping Measure for Crossing High-Speed Railway tunnel

Fei Huo[1,a,*] ,Hai-Lin Liu [2,b],Li-Min Peng[3,c]

[1, 3]Central South University, Hunan Province of China

[2]China Railway Engineering Consulting Group Co.,Ltd. China

[a]atpine@163.com, [b]240321191@qq.com

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Abstract: Numerical calculations for the damping effect of foam concrete cushioning layer in crossing high-speed railway tunnel were carried out, based on the fluctuation theory using the Newmark implicit integration algorithm and he Lysmer viscous boundary condition. Then the measure's damping effects were evaluated by indicators such as the displacement, acceleration and stress response of the lining structure. Results indicated that foam concrete cushioning layer had good damping effects on the lining structure and showed significant damping effects within the thickness of 5 to 10 cm. In addition, closer to the crossing point, better the damping effects were. These results could make valuable reference for the anti-vibration design in crossing high-speed railway tunnel.

1 Introduction

With the rapid development of high-speed railway in China, crossing tunnels emerged in large numbers recently. By means of numerical simulation analysis[1-2,4-5] and field data monitoring[3], scholars at home and abroad found that lining structure's dynamic responses of the crossing tunnel under the dynamic load are more significant compared with the single tunnel[1,3,5].

Under the train vibration load, the dynamic responses of lining structure have a periodic change[6], and over time it will cause structural damage and even failure.

Nowdays, the studies on damping measures caused by train are generally limited to the single-line tunnels and subway crossing tunnels[5-7];moreover the research objects are surrounding rock and surficial constructions mainly[7-9]. However, the related researches on damping measures for crossing tunnel caused by high-speed train vibration load were relatively rare.

In this study, numerical calculations for the damping effect of foam concrete cushioning layer in crossing tunnels of high-speed railway were carried out ,based on the fluctuation theory using the Newmark implicit integration algorithm[10] and he Lysmer viscous boundary condition. Then the damping effects of this measure were evaluated hoping to make some valuable references for the anti-vibration design in crossing high-speed railway tunnel.

2 Damping Measures and the Calculation Model

2.1 Damping measures

Currently, anti-vibration and damping vibration were the two major designs in the tunneling engineering. Due to the increased internal force of the lining, the anti-vibration of improving the lining rigidity was not an ideal method. In recent years, people tented to set the damping layers to interrupt the propagation path of the vibration wave between the train and tunneling and simultaneously absorb the vibration energy. Based on that, we set up the foam concrete damping measure as follows:

Add the foam concrete damping layer between the filling layer and invert, as well as the tunnel lining and surrounding rock (refer with: Fig.1). Set three kinds of damping layers of 5cm, 10cm, 20cm for testing.

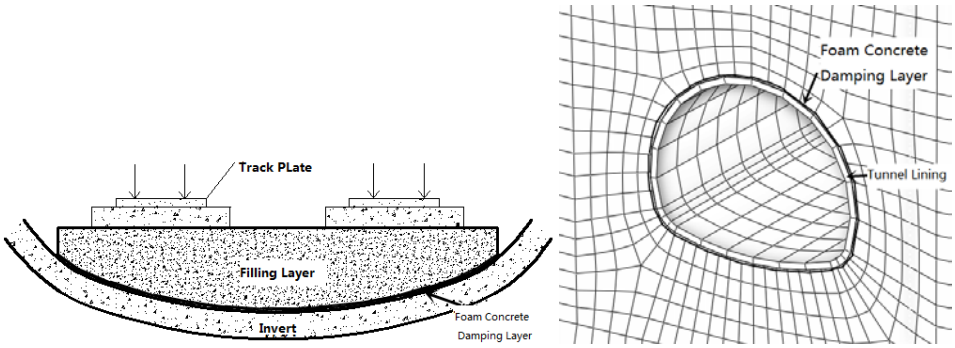


Fig.1 Foam concrete damping layer

We select the worst working conditions as the background to study the damping measures. The trains in two tunnels run in the same time at a speed of 350kph; the cross angle of two tunnel is 90 degree while the height of the rock pillar is 1m;and the surrounding rock is of V class.

2.2 Calculation model

A limited area of 100m×100m×100m was selected. The covering soil thickness of the overpass tunnel was 32m, and the foundation soil thickness of the underpass tunnel was 38m. The tunnel was double track with three-centered circular and curved wall, and its net area is 90-100 m^2. Viscous boundary conditions were applied on the side and ground boundaries.

The surrounding rock and tunnel structure was divided into eight-node solid elements and was described by the Mohr-Coulomb elastic-plastic model. Material parameters were shown in table 1 and table 2.

Table 1 Physical and mechanical parameters of the surrounding rock and concrete lining

materials	specific weight [kN/m³]	elastic modulus [Gpa]	Poisson's ratio	cohesive force [Mpa]	internal friction angle [φ°]	Dilatancy angle [θ°]
grade V surrounding rock	19.5	0.2	0.35	50	25	25
lining concrete	25	30	0.20	2.38	58.7	58.7

Table 2 parameters of foam concrete material

materials	specific weight [kN/m³]	elastic modulus [Gpa]	Poisson's ratio	cohesive force [Mpa]	internal friction angle [φ°]	Dilatancy angle [θ°]
foam concrete	8	0.34	0.1	0.5	36	36

2.3 Simulation of the train load

The train loads were simulated with the excitation function synthesizing the train axle load, hauled weight, running speed, track structure and the smoothness of the rail. Taking the movement and superposition effect of the wheel force and dispersion effect and irregularities of the track into account, we modified the existing train load formula as following.

$$P(t)=k_1k_2(P_0+P_1\sin\omega_1 t+P_2\sin\omega_2 t+P_3\sin\omega_3 t). \quad (1)$$

In the above equation, $k_1$was superposition coefficient of the adjacent rail, ranging from 1.2-1.7; $k_2$was the rail dispersion coefficient, ranging from 0.6-0.9; $P_0$was the static load of the train; P_1,P_2,P_3were the vibration loads; ω_i was the vibration angular frequency.

The simulation curve was shown in Figure.2.

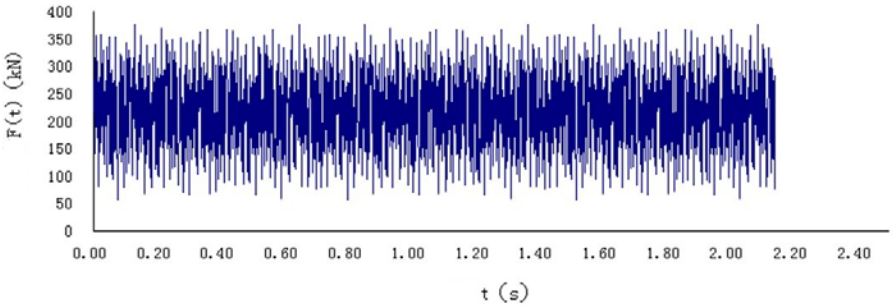
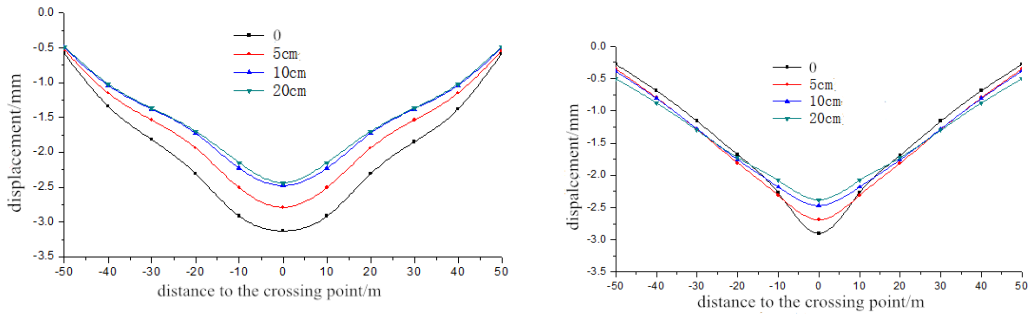


Fig.2 Time line of the train loads

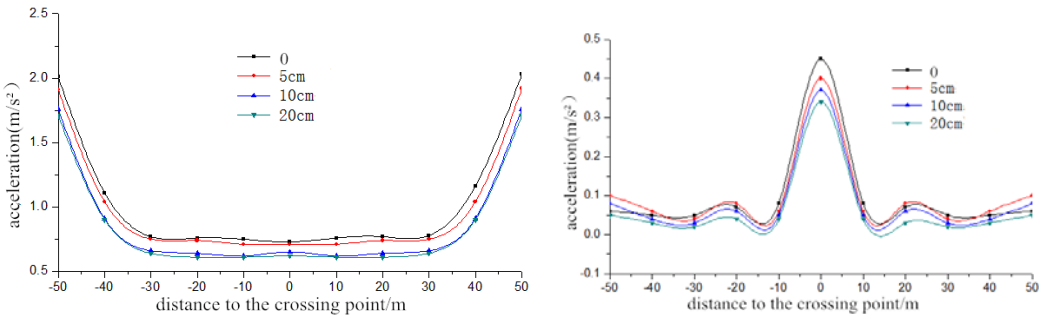
3 Results and Discussion

Taking the maximum dynamic response of the feature points in different sections as the analytic indicators, the maximum vertical displacement response of the lining with different thickness of damping layers were shown in Fig.3, the maximum vertical acceleration response were shown in Fig.4, and the maximum tensile stress response were shown in Fig.5.



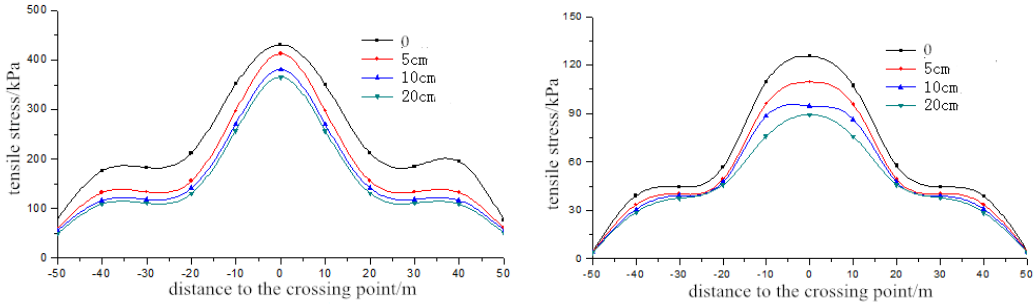
(a) bottom of the overpass tunnel (b) arch crown of the underpass tunnel

Fig.3 Maximum vertical displacement response of the lining with different thickness of damping layers



(a) bottom of the overpass tunnel (b) arch crown of the underpass tunnel

Fig.4 Maximum vertical acceleration response of the lining with different thickness of damping layers



(a) bottom of the overpass tunnel (b) arch crown of the underpass tunnel

Fig.5 Maximum tensile stress response of the lining with different thickness of damping layers

The results showed that all the vertical displacement of the overpass tunnel decreased and tend to uniform, and the nearer to the cross-point the decreasing extent is larger. The decreased vertical displacement of the overpass tunnel was 0.77mm (26.4%) at a 20cm damping layer. The decreased vertical displacement of the underpass were 0.52mm(17.9%) within the range of 10m around the cross point, however, the vertical displacement of the lining increased 10m beyond the cross point and the maximum increment was 0.5mm.

The decreased extent of vertical acceleration of the overpass tunnel was similar, the damping effect became obvious with the increased damping layer thickness. The maximum of the decrement was 0.31m/s2 with a 15.3 percent at the 20cm damping layer. The response of the underpass tunnel acceleration to the train vibration was relatively little. Adding the damping layer could reduce the response within the 10m around the cross point, the maximum decrement of the acceleration could be 0.11m/s2(24.4%) at a 20cm damping layer.

The tensile stress of the overpass tunnel reduced significantly within the calculation range, especially in the range of 30 to 40cm around the cross point with a maximum reduction of 94.48 kPa(26.9%) at a 20cm damping layer. The nearer to the cross point, the more tensile stress of the underpass tunnel decreased, and its maximum reduction was 36.18 kPa(28.9%) at a 20cm damping layer.

4 Conclusions

(1) The cushioning layer of foam concrete showed significant damping effects on the acceleration and tensile stress of the upper and lower tunnel lining structures, and the nearer to the cross-point, the damping effect were more significant. The damping layer could effectively absorb the vibration load propagation and reduce the dynamic response of the middle rock pillar.

(2)After the adding of foam concrete damping layer, the vertical displacement of the underpass tunnel increased rather than decreased in the far-away range from the cross point. Therefore, some measures should be comprehensively considered in the design of crossing tunnel to improve weak parts' structural strength.

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