Study on the Limit Value of Safety Overburden Layer Thickness of Large-Span Bias Tunnel

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Abstract. The number of mountain tunnels continues to increase, the explosive demand for traffic increases, and large-span bias tunnels are increasingly appearing in actual projects. Large-span biased tunnels can cause uneven lining stress, and unreasonable thickness of the soil can cause damage to the lining. This paper relies on the Beijing-Hong Kong-Macao Expressway Guangle Expressway. It adopts three construction methods, namely, double-wall method, three-step method and CRD method. At the same time, based on different soil thickness research, it is considered in 1:1, 1:2, 1:3 Three kinds of slope effects, through the analysis of finite element numerical simulation results, the thickness limits of large-span bias tunnels under different slopes are given. The results show that the tunnel lining is under pressure within the thickness limit of the overburden. If it is too thin, it will cause the lining to be pulled and affect the stability of the tunnel. If it is too thick, it will increase the construction cost and waste. Therefore, the research on the thickness limit of large-span biased soil has a great guiding significance for design and construction.

1. Introduction

More and more highways are being built, and more and more tunnels are being built to shorten the traffic distance through the mountains. Due to the different thickness of the overlying soil above the hole, the tunnel lining structure is subjected to different tensile forces and deformations [1-2]. Therefore, under the conditions of large span and shallow buried bias, the thickness of the overburden will cause tensile damage to the tunnel structure, which seriously threatens the stability of the tunnel. In the construction process, there are no clear guidance on the thickness limit of the cover soil by the three-wall guide pit method, the CRD method and the three-step method. [3] On the one hand, it can solve the problem that the thickness of the overburden is too thin and the stability of the tunnel lining structure is insufficient. On the other hand, the proper thickness of the covering soil is beneficial to ensure the safety and economy of the tunnel during the excavation process. Therefore, studying the thickness limit of the covering soil on the tunnel and the construction method have a crucial role in the stability of the surrounding rock support structure [4-5].

At present, scholars at home and abroad have done a lot of research from theoretical analysis, numerical simulation and other aspects, mainly including: Wang Lixia and other scholars have repeatedly calculated the main influencing factors related to the thickness of the tunnel top cover soil by establishing the finite element numerical analysis model approaching to the actual problem, and
then obtained the prediction model of the safe thickness of the tunnel top cover soil by using multiple stepwise regression analysis method[6]. Based on the characteristics of the surrounding rock and the risk of water inrush of the underwater tunnel, Guo Caixia et al. Comprehensively considered the dynamic impact of the construction process, and using the numerical simulation method of particle flow, obtained the judgment basis and conditions of the covering thickness and critical value of the underwater shield tunnel [7]. Zhang Qinghe et al. Based on the Nanjing Metro test section, started with the balance state of the shield excavation face and the anti floating balance condition of the tunnel bottom, pushed the dynamic balance formula of the water and soil pressure of the excavation face and the pressure in the sealed cabin, and obtained the minimum cover thickness required for the stability of the tunnel [8]. Liu Xueyan et al. Used the method of theoretical analysis and numerical calculation to consider the adverse effect of unconsolidated slurry during the construction period, established the theoretical calculation formula of the thickness of the cover soil, and proposed that only the self weight of the cover soil and the design of anti floating and flood scouring should be considered in the tunnel during the operation period [9].

However, the above study only uses theoretical analysis and numerical simulation to get the main influencing factors related to the cover thickness of the tunnel top, and obtains the calculation formula and critical value related to the cover thickness [6], but does not take into account the limit value of the cover thickness under different construction methods and slope rates[8]. On the basis of domestic and foreign researchers, this paper adopts the finite element numerical analysis method, based on the conditions of different construction methods and three kinds of slope rates, through analyzing the influence of different construction methods, slope rates and cover thickness pull-down stress and shear stress on the tunnel lining structure, and through the comprehensive analysis of the above results, three kinds of construction methods deviation under different slope conditions are obtained Limit value range of overburden thickness of pressure tunnel [9-15].

2. engineering background introduction
Guangle expressway is the double track of Beijing Hong Kong Macao Expressway in Guangdong Province. It starts from the junction of Hunan and Guangdong in the north, and finally reaches Huashan Town, Huadu District, Guangzhou City, connecting Guangzhou Airport Expressway and Zhaohua expressway. There are 28 tunnels in the whole line, and there are 54 working areas (one is shed tunnel) in the portal project alone, with a huge construction scale. Among them, the designed three lane highway tunnel has a minimum clearance span of 16.153m, a minimum height (including inverted arch) of 10.4m, and a flat rate of 0.644 (excluding inverted arch, it is 0.516), which is a typical large-span flat tunnel. The shallow buried bias pressure of tunnel portal is serious. The surrounding rock of Guangle road portal is mainly strongly weathered shallow metamorphic sandstone and medium to slightly weathered limestone. The surrounding rock is classified as grade v. the geological conditions of surrounding rock are poor and the construction safety risk is high.

3. numerical analysis model
3.1. Calculation plan and model establishment
According to the unbalanced pressure at the tunnel entrance, the difference of tunnel construction method, slope ratio and tunnel cover thickness is considered, the construction methods are three-step method, CRD method and bilateral wall method, the slope rates are 1:1, 1:2 and 1:3 respectively. The thickness of overburden layer is 8 m, 12 m, 16 m, 20 m, 24 m, 28 m and 32 m respectively. The orthogonal combination of 63 working conditions is calculated. The purpose is to study the safety coverage thickness limit of long-span flat tunnel when three construction methods are adopted, which can be used to guide the design and construction. The method adopted is plane numerical method, and the finite element numerical analysis software is used for numerical simulation. In this paper, only 8/20/32m thickness of overlying soil is selected as an example. The numerical calculation and analysis model is shown in Figure 1.
3.2. Values of surrounding rock and support mechanics parameters

According to the design data and geological survey data of Guangle Road Tunnel, the mechanical parameters of surrounding rock calculated in this paper are calculated according to V-grade surrounding rock, as shown in Table 1 [16-17].

| Name of parameter       | Symbol | Company | value |
|-------------------------|--------|---------|-------|
| severe                  | γ      | kN/m³   | 18    |
| deformation modulus     | E      | Gpa     | 1     |
| Poisson ratio           | µ      |         | 0.39  |
| internal friction angle | ψ      |         | 20    |
| Cohesion                | c      | MPa     | 0.05  |

The effect of steel arches is considered by the equivalent method, which is to calculate the elastic modulus of steel arches into the shotcrete [18]. The calculation method is as shown in (Formula 1):

$$ E = E_0 + \frac{E_g + S_c}{S_g} $$

(1)

Among them, E is the converted concrete elastic mold; E₀ original concrete elastic mold; Sₙ is the steel arch cross-sectional area; Eₙ is the steel elastic mold; Sₙ is the concrete cross-sectional area.

When S5b support parameters are used in the calculation of initial support, the weight of shotcrete C25 is 23KN/m³, the elastic modulus is 23GPa, the weight of steel is 78.5KN/m³, the elastic modulus is 210GPa, the section area of I20a I-beam is Sₙ=35.55cm², and the elastic modulus of initial support is E=26.589GPa after conversion of formula 1.

4. Calculation results analysis

4.1. Analysis of slope impact

By recording the above numerical analysis model results, under the three-step construction conditions and the same cover thickness, the pull-down stress change diagram for different slope slopes is shown in Figure 2, and the shear stress change diagram is shown in Figure 3.
From fig.2 and fig.3, it can be seen that under the condition of three-step construction condition and the same thickness of overburden, when the slope ratio is 1:2 and 1:3, the stress of tunnel lining structure is obviously less than that when the slope ratio is 1:1, and the influence of bias pressure on tunnel is obviously reduced. When the thickness of covering soil is 8m, the tensile stress and shear stress of surrounding rock are the largest, the second is 20m, and the smallest is 32m. Therefore, the larger the slope ratio, the greater the tensile stress and shear stress of surrounding rock, the easier the deformation of surrounding rock, and the worse the safety of lining structure.

4.2. Influence of thickness of cover layer
By recording the results of the above numerical analysis model, the following figure shows the change of tensile stress and shear stress under the influence of different overburden thickness on the basis of 1:1 slope rate and three different working conditions as shown in Figure 4 and Figure 5.
Fig 4. Variation of the maximum principal tensile stress of surrounding rock under different soil thicknesses

From Fig. 4 and Fig. 5, it can be seen that on the basis of slope ratio 1:1, the changes of CRD method and bilateral wall normal tension stress are similar, and the change of three-step rule is obvious. Under the same construction method, with the increase of the thickness of overburden soil above the tunnel, the principal tensile stress of surrounding rock decreases continuously. The internal force of lining structure changes from local tension to full ring compression. The thinner the coverage on the tunnel, the worse the stability of surrounding rock and the worse the safety of lining structure. Therefore, the greater the thickness of overburden soil, the smaller the influence of eccentric pressure on surrounding rock, and the greater the shear stress on surrounding rock structure.

4.3. Analysis of the impact of construction methods

By recording the results of the above numerical analysis model, the following figure shows the variation of shear stress under the influence of different construction methods on the basis of 8m soil cover thickness and three slope rates as shown in Fig. 6 and the tensile stress as shown in Fig7.
Shear stress
Three step method CRD method double sidedrift method Construction method
Slope rate 1:1
Slope rate 1:2
Slope rate 1:3

Fig 6. Change of shear stress under different working methods

Tensile stress
Three step method CRD method double sidedrift method Construction method
Slope rate 1:1
Slope rate 1:2
Slope rate 1:3

Figure 7. Different methods of pull-down stress change diagram

It can be seen from Fig. 6 and Fig. 7 that on the basis of 8m soil cover thickness and the same slope rate, the maximum principal tensile stress of tunnel lining is under the three-step method, followed by the two-sidewall method; the maximum shear stress of tunnel lining by the two-sidewall method is the largest, followed by the CRD method and the three-step method is the smallest.

4.4. Comprehensive comparative analysis
Analyze and extract the internal force calculation results of the initial support structure of the tunnel under different working conditions. The maximum axial tension of the initial support structure of the tunnel varies with the thickness of the cover layer as shown in Figure 8~ Figure 10. The control index is that there is no tension in the internal force of initial support. When the initial support is compressed, it is considered safe. When the initial support has tensile force, the tunnel structure is considered to be insufficiently safe, and the corresponding critical overburden thickness is the safety cover thickness limit.
The thinner the overlying soil on the tunnel, the worse the stability of the surrounding rock. As the slope rate and the thickness of the overburden increase, the internal force of the lining structure will change from local tension to full ring compression. When the pressure of the whole support ring at the initial stage of the tunnel is taken as the judgment standard, the limit value of the earth cover thickness can be obtained by the method of difference value. Under the same slope condition, the limit value range of the earth cover thickness of the tunnel under the biaxial wall method is shown in Table 2.
5. Conclusion

Based on the Guangle Expressway of Beijing-Hong Kong-Macao Expressway, this paper studies the damage effect of tunnel lining structure and the limit value of overlying soil thickness above the tunnel through numerical simulation under three different construction methods, different overlying soil thickness and slope rate, and summarizes the above rules and draws the following conclusions.

1) When the slope gradient is 1:1, the internal force of the lining structure is obviously greater than that of the slope gradient is 1:2 and 1:3. The safety of the tunnel lining structure is significantly affected by bias pressure than that of the slope gradient is 1:2 and 1:3. The thinner the thickness of tunnel cover soil, the worse the stability of surrounding rock and the worse the safety of lining structure. With the increase of slope and cover thickness, the internal force of lining structure will change from local tension to full ring compression, and gradually become safe.

2) The limit values of overburden thickness of bilateral wall method, three step method and CRD method under different slope conditions are given, that is, when the slope gradient is 1:1, the minimum overburden thickness of two-sided wall method is 13m, the minimum overburden thickness of CRD method is 23m, and the minimum overburden thickness of three step method is 28m. When the slope is 1:2, 1:3, the slope becomes slower, and the limit value of covering soil thickness decreases correspondingly.

3) Although the numerical analysis method used in this paper has given the limit value range of overburden thickness of three construction methods under different slope conditions, but it can not cover all the actual engineering conditions and the actual application is less, the relevant parameters are still uncertain, and a large number of projects are needed to optimize the parameters, so as to guide the subsequent projects.

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