Study on Mechanical Characteristics of Support Structure in Tunnel Entrance Section under Mechanized Construction

Hongyan Guo, Dengzhi Tang, Chengrui Yao, Xiaolong Zhang

1 China Merchants Chongqing Communication Research & Design Institute Co., Ltd, Chongqing, 400067, China
2 Yunnan infrastructure investment Co., Ltd, Kunming, Yunnan, 650000, China
3 School of Civil Engineering, Chongqing Jiaotong University, Chongqing, 400074, China

* Corresponding author’s e-mail: guohongyan@cmhk.com

Abstract. In view of the mechanical characteristics of the support structure under the mechanized construction conditions of the shallow buried section of the tunnel entrance, numerical simulation methods are used to compare and analyze the different cycle footage and the different tunnel face depth before and after the tunnel face reinforcement been carried out when the shallow buried section of the tunnel entrance is constructed by the micro-step method. The results of the study show that the primary support and pipe shed force increases with the increase in the depth of the tunnel face (buried depth), and decreases with the increase of the cyclic footage; When the fiberglass bolt is used to reinforce the face, the axial tensile stress of the fiberglass bolt can reach 18kN; Without reinforcement of the tunnel face, the primary support of the arch at the entrance of the tunnel is vulnerable to cause tensile damage; After the tunnel face is reinforced, the tensile stress of the primary support is significantly reduced.

1. Introduction
With the development of human economy and technology, the tunnel construction, which used to excavate by manual drilling and blasting, is developing towards mechanized construction[1]. However, the tunnel entrance is often shallow and the surrounding rock conditions are poor. During construction, the method of partial excavation is generally used. This conflicts with the large-section or full-section construction required by the mechanized construction of the tunnel. Therefore, how to adapt to the requirements of mechanized large-section construction of tunnels through changes in construction methods and technologies at the shallow buried section of the entrance has become the key to fully promote the tunnel mechanical construction technology.

Wang Mingnian et al.[2], aiming at the imperfect technology of advanced support in mechanized large-section excavation of tunnels in soft surrounding rocks, derived the formula for calculating the stability coefficient K value of the tunnel face under four kinds of advanced support measures. Mei Yuan et al. [3] proposed a tunnel construction method combining mechanized construction equipment and division excavation method, which can greatly improve the speed of tunnel construction in loess area. Zhang Tao[4], in view of the low adaptability of mechanized construction in the soft surrounding rock section of the tunnel, combined with the traditional step method construction method, proposed the improvement measures of expanding the upper half tunnel face area to adapt to large-scale mechanized construction equipment. Ma Chunde et al. [5] proposed a blasting technique with the reserved smooth
blasting layer suitable for large-section tunnel excavation, aiming at the problem that traditional smooth blasting can hardly avoid the over excavation and under excavation of tunnel section outline, which provides technical support for the improvement of tunnel mechanized excavation quality. By optimizing blasting parameters, Li Qiyue et al. [6] reduced the over excavation and under excavation phenomenon of tunnel section outline and damage to surrounding rocks caused by blasting vibration, and promoted the development of mechanized rapid drilling and blasting technology in tunnels. Li Kang et al. [7] studied the mechanical characters of the tunnel support structure under the condition of mechanized full section excavation by using the method of field monitoring and measurement. Wu Song et al. [8] studied the progressive failure mechanism of shallow buried large-section tunnels with the excavation process through model tests and field monitoring measurements. Wang Wei et al. [9] analyzed the deformation law of surrounding rocks in shallow buried soft rock section of tunnel entrance during construction by means of on-site monitoring and measurement and numerical simulation, and put forward safety measures for shallow buried section of tunnel entrance based on the research results. Dong Peng et al. [10] used distributed optical fiber to monitor the settlement of the overlying layer of the shallow buried tunnel. This monitoring technology can obtain the spatial and temporal evolution characteristics of the overall deformation of the rock and soil mass overlying the tunnel, and can be used to improve the monitoring accuracy of the mechanized construction of the tunnel.

To sum up, most of the current research focuses on the adaptability of mechanized tunnel construction, the optimization of the support system of the mechanized tunnel construction, and the deformation mode and failure mechanism of the surrounding rock in the large section of the shallow buried section of the tunnel entrance. The research on the mechanical characteristics of the supporting structure under the condition of mechanized large-section construction is still slightly insufficient. Therefore, it is necessary to conduct research on this.

2. Project Overview

The length of the supporting project tunnel is about 5.4km, and the maximum buried depth of the tunnel is about 642m. According to geological surveys and drilling reveals, there are many types of stratum lithology distributed in the proposed tunnel area, from top to bottom there are mainly Quaternary strata (Q4) and the fourth section of the Cambrian Gongyanghe Group (∈gn4), The third section of the Cambrian Gongyanghe Group (∈gn3), the second section of the Cambrian Gongyanghe Group (∈gn2), the first section of the Cambrian Gongyanghe Group (∈gn1). There are no adverse geological effects or special geotechnical distribution in the tunnel area. During tunnel construction, the thickness of the covering layer at the entrance of the tunnel is generally 10~25m. The slope of the entrance of the tunnel has a steep topographic gradient, and the construction safety risk is greater.

3. Establishment of numerical analysis model

3.1. Numerical analysis model and calculation conditions

According to the design data, when the general construction method is adopted, the shallow buried section of the tunnel entrance is generally designed with pipe shed support. In order to adapt to mechanized excavation, the construction and excavation method of micro-steps needs to be adopted, and the stability of the tunnel face and reinforcement measures are needed to be studied. The numerical model is shown in Figure 1. The calculation conditions include: the cyclic footage is 0.6m, 1.2m, 1.8m and 2.4m in the order of no tunnel face reinforcement measures, and the cyclic footage is 0.6m, 1.2m, 1.8m and 2.4m in the order of tunnel face reinforcement measures.
3.2. Corresponding parameters for numerical analysis
According to the general situation of the supporting project, the surrounding rock level of the shallow buried section of the tunnel entrance is V2, and the surrounding rock and lining structure parameters, which are shown in Table 1, are selected according to the "Highway Tunnel Design Rules" (JTG/T D70-2010).

| Materials       | Young's modulus (GPa) | Poisson's ratio | Density (kN/m³) | Frictional angle (°) | Cohesion (MPa) |
|----------------|-----------------------|-----------------|-----------------|----------------------|----------------|
| Surrounding rock| 1.15                  | 0.42            | 1750            | 21                   | 0.085          |
| Primary support | 22.95                 | 0.2             | 22              | 50                   | 0.2            |

4. Research on mechanical characteristics of supporting structure

4.1. Without reinforcement of the tunnel face
In order to facilitate the comparative analysis of the influence of different cyclic footage on the mechanical behavior of the support structure, the maximum principal tensile stress value, the maximum principal compressive stress value and the maximum compressive stress value of the pipe shed of the tunnel under different working conditions were extracted, and each characteristic value was studied. The change rule with the cycle footage is shown in Figure 2~Figure 4. Firstly, it can be seen from Figure 2 that the maximum principal tensile stress of the primary support increases with the increase of the tunnel face footage, and decreases with the continuous increase of the cyclic footage. The larger the cyclic footage, the smaller the slope of the curve. Secondly, it can be seen from Figure 3 that the maximum principal compressive stress of the primary support increases with the increase of the depth of the tunnel face. The larger the cyclic footage, the smaller the slope of the curve. Overall, primary support tunnel with pipe shed stress constraints as footage (depth) increases, decreases with the increase of cyclical footage, constraints the reason for this is that it increases penetration, buried depth increases, the supporting structure and pipe shed stress is bound to increase, in addition, the greater the cyclical footage, surrounding rock stress release time is longer, the remnants of the surrounding rock stress is small, which leads to the primary support and the pipe shed stress decreases.
4.2. Under the condition of the tunnel face reinforcement

In order to facilitate comparative analysis, the typical characteristic values of the initial support before and after reinforcement of the tunnel face and the force of the pipe shed under different working conditions are extracted and drawn into histograms, as shown in Figure 5 to Figure 11.

It can be seen from Figure 5 that when the shallow buried section of the opening is constructed with micro-steps and the tunnel face is reinforced with fiberglass anchors, when the tunnel face is at both ends of the pipe shed, the maximum axial tension of the fiberglass anchor reaches the maximum. When the tunnel face is in the middle of the pipe shed, the maximum axial tension of the fiberglass anchor is relatively minimum, about 15 kN. Considering a certain safety factor (take 2.0), the pullout force of the fiberglass anchor is recommended to be 36 kN.

From Figure 6 to Figure 11, due to the effect of reinforcement of the fiberglass bolt, constraints is strengthened, surrounding rock stress release to pipe shed, lead to the pipe shed stress increases, due to the transfer function of pipe shed force, supporting the main tensile stress, the early main compressive stress did not have obvious change, when circulating footage of 1.8 m, at the beginning of the principal tensile stress decreases slightly, is advantageous to the structure in the process of the construction structure safety; When the cyclic footage is 2.4 m, the primary compressive stress of primary support increases slightly, which is less than the designed compressive strength of shotcrete, satisfying the...
requirements of construction safety. The cyclic footage is 1.8m and 2.4m, and the stress of the pipe shed increases greatly, but it is less than the design strength of the pipe shed material, which meets the safety of construction.

In general, from the perspective of structural forces, except when the cyclic footage is 1.8m and the tunnel face footage is 28.8 m, the sprayed concrete on the top of the primary arch near the casing arch reaches the tensile design strength of the concrete (but less than the limit tensile strength), the stress of the primary support and the pipe shed under other working conditions is less than the design strength of the material, that is to say, through the reinforcement of the tunnel face, both types of circular footage can meet the safety of structural construction.
5. Conclusion

In this paper, through the numerical analysis method, the mechanical characteristics of tunnel support structure before and after tunnel face reinforcement with different cyclic footage (0.6 m, 1.2 m, 1.8 m and 2.4 m) and face footage (7.2 m, 14.4 m, 21.6 m and 28.8 m) are compared and analysed. The conclusions are as follows.

The stress on the primary support and pipe roof of the tunnel increases with the increase in the depth of the tunnel face (buried depth), and decreases with the increase in the cyclic footage.

When fiberglass anchors are used to reinforce the tunnel face, the axial tensile stress of the fiberglass anchors can reach 18kN. To ensure the safety of construction, the pull-out force of the fiberglass anchors is recommended to be 36 kN.

In the case of no tunnel face reinforcement, the primary support of the arch of the tunnel entrance is likely to cause tensile damage; after reinforcement of the tunnel face, the tensile stress of the initial support is significantly reduced, indicating that the tunnel face reinforcement can improve the safety of tunnel mechanized construction.
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