Analysis on excavation stability of tunnel portal with different design methods

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Abstract—The stability of tunnel portal has its particularity. Due to the influence of natural or human factors, it is easy to produce cracking, landslide, collapse and other diseases. Taking the No.5 highway tunnel of F3 bid in Georgia as the background, using the finite element analysis software MIDAS-GTS to establish a three-dimensional model to simulate the tunnel construction process. The tunnel portal adopts two design schemes of micro pile wall support and bolt mesh shotcrete support. Through the analysis and comparison of the transverse and vertical displacement and stress field characteristics of surrounding rock caused by two schemes of tunnel excavation, the influence of tunnel excavation on the stability of tunnel portal is studied. The numerical results show that the maximum transverse and longitudinal displacements of surrounding rock are 3.55mm and 8.73mm respectively, and the maximum tensile stress is 1.91mpa. Compared with the micro pile wall support design, the bolt mesh shotcrete support scheme is more feasible. The conclusion has a certain guiding role for the construction of highway tunnels in mountain areas.

1.INTRODUCTION
With the rapid development of global economy and the need of traffic construction, more and more tunnels are built in mountain areas. Improper treatment of tunnel portal may cause tunnel collapse and threaten the overall stability of the tunnel [1-3]. Wenlin Xiong carried out three-dimensional dynamic numerical simulation on the entrance slope of tunnel, and obtained that the shear deformation of tunnel slope is the most obvious on the slope surface, and the part with the worst stability in the process of tunnel excavation is the front part of slope body [4].

This paper first summarizes the project of No.5 highway tunnel in F3 bid section of Georgia, and then uses the finite element analysis software MIDAS-GTS to establish the 3-D finite element model of tunnel exit section [5-6].
2. ENGINEERING BACKGROUND

The tunnel is a double track tunnel. The starting and ending mileage of the tunnel is DK6+438 ~ DK7+305, with a total design length of 867m. The maximum buried depth of the tunnel is 27.3m, the minimum buried depth is 1m, the clearance span of the tunnel is 39.21m, and the distance between left and right tunnels is 10.31m. The geological map of tunnel portal section is shown in Figure 1.

3. THREE-DIMENSIONAL NUMERICAL SIMULATION

3.1. Introduction of portal design scheme

At the entrance of the tunnel, the original design planned a 240 mm diameter, 0.50 m spacing micro pile wall support, with 168.3 mm diameter and 10 mm thick section steel reinforcement; now the design uses 32 mm diameter solid circular section bolt and 20 cm thick C30 concrete to form anchor mesh shotcrete slope support.

3.2. Parameter setting

In MIDAS-GTS finite element model, Mohr Coulomb constitutive model is adopted for rock mass, elastic constitutive type is adopted for tunnel shotcrete and other supporting structures. Parameter settings of tunnel geotechnical parameters and materials under natural state are shown in Table 1.

| Material name  | Constitutive type | Unit type      | $E$ (kPa) | $\gamma$ (kN/m3) | $\nu$ | $c$ (kPa) | $\phi$ (°) |
|----------------|-------------------|----------------|----------|------------------|------|-----------|------------|
| Geotechnical   | Mohr Coulomb      | Entity         | $1.0\times 10^6$ | 25               | 0.25 | 100       | 54         |
| Portal         | Elastic           | Entity         | $3.15\times 10^6$ | 25               | 0.2  | -         | -          |
| Pile           | Elastic           | Embedded beam  | $2.8\times 10^6$  | 23               | 0.2  | -         | -          |
| Bolt           | Elastic           | Embedded beam  | $2.0\times 10^6$  | 77               | 0.3  | -         | -          |
| Shotcrete (C30)| Elastic           | Plate element  | $3.0\times 10^6$  | 24               | 0.2  | -         | -          |
| Invert (C35)   | Elastic           | Plate element  | $3.15\times 10^6$ | 25               | 0.2  | -         | -          |
| Vault (C35)    | Elastic           | Plate element  | $3.15\times 10^6$ | 25               | 0.2  | -         | -          |

3.3. Establishment of calculation model

Establishing 3D model of tunnel portal section by Midas-GTS software. The calculation models with the length of 140m, 130m and 90m are established along the transverse direction (x-axis direction, the length of the tunnel is 3 times of the tunnel diameter in the x-axis direction), the longitudinal direction (y-axis, the tunnel excavation direction is the negative axis direction), and the vertical (Z-direction). The
comparison of the overall finite element mesh models of the two portal support design schemes is shown in Figure 2, and the rock and soil are divided into $4 \times 4$ grids; the local finite element mesh model of the tunnel is shown in Figure 3, and the tunnel lining is divided into $1 \times 1$ grids.

![Figure 2. Comparison of two models of portal support design scheme.](image)

3.4 Construction stage arrangement

For the design of micro-pile wall support, the simulated construction process of the tunnel is to first excavate the side slope of the tunnel entrance. The slope is divided into four levels along the $z$-axis from top to bottom. After the excavation is completed, the diameter is 240mm and the spacing is the 0.50m micro-pile forms a micro-pile wall support and is reinforced with a profile steel with a diameter of 168.3mm and a thickness of 10mm; for the design scheme of bolt mesh shotcrete support, the construction process of the tunnel is simulated. Firstly, the slope is excavated three times from top to bottom along the Z axis, after a part of the excavation is completed, the support of each level of excavation side and upside slope will be carried out. The support method is C30 concrete sprayed and a solid circular section with a diameter of 32mm the anchor rod and the hanging net sprayed C30 concrete with a thickness of 20cm form the anchor net sprayed slope support. The purpose of supporting the slope is to prevent the rock mass from falling off or collapsing. After the support construction, it can bear the force together with the
rock and soil to reduce the deformation of the rock and soil. After the slope support is completed, the concrete support at the entrance is broken according to the design requirements of the entrance, and the open tunnel construction is carried out before the tunnel excavation.

Subsequently, the tunnel was excavated. The tunnel excavation and support construction stages of the two portal support schemes are the same. The left and right tunnels were excavated for the first time, with an excavation footage of 6m, followed by changes in the properties of the openings of the first excavation section, which were transformed into concrete structures. Followed by the temporary support for the first excavation, the thickness of the support layer is 0.2m, and the support method is sprayed with C30 concrete to prevent large deformation of the rock and soil due to the large size of the first excavation, and then the concrete opening of the tunnel Section of construction. According to the selected section type, an excavator is used to excavate the entire tunnel with a 3m footage, and C30 concrete is used for initial support to prevent the tunnel from collapsing due to the decrease in stability during the excavation process. Finally, after entering the tunnel for a certain distance, use C35 concrete to support the tunnel a second time and initially support the invert. The thickness of the invert support layer is 0.8m, and the thickness of the vault support layer is 0.65m. In order to avoid the inverted arch uplift due to the extrusion of rock and soil on both sides in the process of tunnel excavation.

4. NUMERICAL SIMULATION RESULTS AND ANALYSIS

4.1. Comparison of displacement and deformation of surrounding rock

Because the front slope of the tunnel entrance is gentle, the displacement along the excavation direction of the tunnel, i.e. the y-axis direction, is not considered. After the completion of numerical simulation, the analysis results of horizontal displacement and vertical displacement of surrounding rock under the condition of tunnel excavation with 100m in two kinds of portal support design schemes are intercepted (Figure 4-7).

Figure 4. Horizontal displacement of surrounding rock of micro pile wall.

Figure 5. Horizontal displacement of surrounding rock of bolt mesh shotcrete.
It can be seen from figure 4 to figure 7 that the maximum horizontal displacement of surrounding rock in the design of micro pile wall support is 6.99mm, and the maximum longitudinal vertical displacement is 21.45mm; the maximum horizontal displacement of surrounding rock in the design of bolt mesh shotcrete support is 3.55mm, and the maximum longitudinal vertical displacement is 8.73mm.

Through a more detailed comparison, it is found that the maximum displacement occurs at the slope in front of the portal, and the actual displacement and deformation of the slope are very small. Comprehensive analysis of bolt mesh shotcrete support design can effectively control the horizontal and vertical displacement of surrounding rock, and ensure the stability of surrounding rock displacement.

4.2. Comparison of stress characteristics of surrounding rock

The analysis of stress distribution characteristics of surrounding rock plays an important role in stability. The spatial distribution characteristics and stress state of the stress field will change due to the excavation of the tunnel, and some parts will form stress reduction areas and stress concentration areas. In order to achieve a new equilibrium state, the surrounding rock will be adjusted by deformation and other means. After the completion of numerical simulation, the first principal stress nephogram of surrounding rock of two kinds of portal support design schemes under the condition of tunnel excavation entering 100m is obtained (Figure 8-9).
Through the comparison and analysis of the calculation results of the model, it can be seen that, the maximum tensile stress of mountain surrounding rock caused by tunnel excavation is 2.36MPa, the maximum compressive stress is 673.37kPa; The maximum tensile stress caused by tunnel excavation is 1.91MPa, the maximum compressive stress is 673.24kPa. Meet the requirements of safe construction.

It should be noted that the maximum tensile stress occurs at the first excavation of the right tunnel portal. According to the geological exploration data, the maximum stress of the model is granite, and the yield strength of granite is 100-250MPa. The maximum stress in each part of the two schemes is less than the yield strength of granite. Therefore, in the construction process, the support parameters of bolt mesh shotcrete support design are far less than those of micro pile wall support design. However, the support of tunnel portal should be strengthened to prevent instability.

5. CONCLUSION
In this paper, the finite element analysis software MIDAS-GTS is used to carry out numerical simulation analysis on the construction process of No. 5 highway tunnel in F3 bid section of Georgia, and study and compare the design scheme of micro pile wall support and bolt mesh shotcrete support design scheme, the transverse and vertical displacement and stress field characteristics of surrounding rock caused by tunnel excavation are compared, and the following conclusions are drawn:

a) The maximum horizontal displacement and vertical displacement of surrounding rock by bolt mesh shotcrete design are 3.55mm and 8.73mm respectively, compared with the design of micro pile wall support, it reduces 49% and 59% respectively.

b) The maximum tensile stress of bolt mesh shotcrete support design is 1.91mpa, which is 19% less than that of micro pile wall support design, and disappears at the slope toe.

c) It shows that the horizontal and vertical displacement and stress requirements of surrounding rock are effectively controlled in the design scheme of bolt mesh shotcrete support, and the stability of surrounding rock is ensured.

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