Construction stability analysis of large section highway tunnel portal section based on numerical analysis

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Abstract: the entrance portal of No.8 tunnel of F3 bid section of E60 highway in Georgia is shallow buried and under unsymmetrical pressure, which leads to high risk and difficulty in tunnel construction. Tunnel 8 is designed based on ADECO-RS (analysis of controlled deformation in rock and soil). In order to understand the stability characteristics of tunnel portal in the whole section construction process and determine reasonable and feasible engineering countermeasures, the numerical simulation analysis of tunnel construction process is carried out. We not only studied the relationship between the stability of the slope at the entrance and the stability of the whole tunnel body under the actual stratum conditions, but also studied the mechanical and deformation characteristics of the surrounding rock and supporting structure of the tunnel. The numerical analysis results show that the stability characteristics of the portal slope directly affect the overall stability of the tunnel portal section; due to the disturbance of tunnel excavation, a large range of plastic zone appears at the interface of rock and soil at the portal section, resulting in large settlement deformation of vault. The collapse and deformation of the upper soil layer with poor engineering properties will cause excessive additional load on the supporting structure of the tunnel. Therefore, advance support measures should be taken to control the excessive deformation of vault. At the same time, due to the influence of asymmetric pressure, the supporting structure of the shallow buried side and the deep buried side of the tunnel appears obvious asymmetric pressure state. It is suggested to strengthen the stiffness of the shallow buried side support structure and adopt the asymmetric support structure to ensure the safety of the support structure.

1. Introduction

There are nine tunnels (no.1-9) in ubisa shorapani (F3) section of E60 Expressway in Georgia. Tunnel engineering is a complex system engineering. Personalized analysis should be carried out for different regions under different conditions to predict the potential safety and engineering quality hazards caused by adverse geological conditions, especially the portal section of the tunnel [1-2]. According to the stability of portal section, relevant experts conducted theoretical analysis [3-4], numerical simulation and on-site monitoring [5-7], and proposed targeted disposal scheme, which guided the tunnel construction.

The tunnel portal section of No.8 tunnel is shallow buried and bears asymmetric pressure. The stratum is soil rock combination stratum, and the mechanical properties of surrounding rock are poor.
The tunnel is designed based on ADECO-RS (analysis of controlled deformation in rock and soil), full section method is adopted for construction. In order to judge the stability of the tunnel portal section during the whole section construction, it is of great significance to carry out numerical simulation analysis on the stability of the tunnel portal section, the mechanical characteristics of the supporting structure and the relationship between them before construction.

2. Analysis scheme for construction stability of tunnel portal section

2.1 General situation of No.8 tunnel of E60 highway
The geographical location of the E60 highway project in Georgia is shown in Figure 1(a). The total length of tunnel 8 is 1171.0 m, the section size is 12.80 × 10.05 m, and the excavation area is 115.59 m². It belongs to the large section tunnel. The excavation section of the tunnel is shown in Figure 1(b). There are shallow buried and unsymmetrical pressure in a certain range of entrance portal of AT line. In this case, the distribution of internal force and deformation of surrounding rock and supporting structure is complex, so it is necessary to study the stability of surrounding rock and the safety of supporting structure.

![Figure 1(a). Location of E60 highway project.](image)

![Figure 1(b). Excavation section (unit: m).](image)

2.2 Numerical analysis scheme

(1) Building models
Using Midas GTS NX numerical analysis software to establish a three-dimensional finite element numerical model. The range of portal section simulated by this model is K10 + 849.000 ~ k10887.000, with a length of 38m. Considering the terrain conditions and the size of the control model, the width of the model is 65 meters. Because this model is to simulate and analyze the excavation and support process in the tunnel, the slope excavation process is not simulated. In the simulation process, the excavation step is 1.0 m, while the excavation unit is passivated, the shotcrete unit, steel rib unit and anchor rod unit are activated. The thickness of shotcrete is 0.2m, which is simulated by plate element; the steel rib is double welded IPN180, which is simulated by implantable beam element; the diameter of anchor rod is 32mm, which is simulated by implantable truss element. In order to ensure the calculation accuracy and save the calculation time, different element size control is adopted for different parts of the model: The size of the unit in the excavation area is 1 m, and that of the outer edge of the model is 2 m. The size of the middle element is between the two and gradually transits. The displacement boundary is simulated by applying normal displacement constraints around and fixed constraints on the bottom. The overall model, displacement boundary constraint and support structure element are shown in Fig. 2.

![Figure 2. Overall model, displacement boundary constraint and support structure element.](image)
Figure 2(a). Overall model of tunnel portal section. Figure 2(b). Displacement boundary constraint.

Figure 2(c). Shotcrete unit. Figure 2(d). Steel rib unit. Figure 2(e). Bolt unit.

(2) Stratum distribution and material parameters
The upper part is silty clay with a thickness of 11m to 13m. The thickness of silty clay layer is taken as 13m in the numerical model. The lower part is granite stratum. Mohr-Coulomb constitutive model is used for the upper and lower strata. The elastic constitutive model is adopted for shotcrete, steel arch and anchor rod. The geotechnical and supporting material parameters are shown in Table 1.

| Model material | Unit weight (KN/m³) | Elasticity modulus (kPa) | Poisson's ratio | Cohesive force (kPa) | Internal friction angle (°) | Thickness (m) |
|----------------|---------------------|--------------------------|----------------|----------------------|---------------------------|---------------|
| Silty clay     | 19.5                | 4.8×10⁴                  | 0.31           | 34                   | 19                        | 13            |
| Granite        | 25.1                | 3.2×10⁷                  | 0.21           | 330                  | 41                        | /             |
| Shotcrete      | 25                  | 2.1×10⁷                  | 0.2            | /                    | /                         | 0.2           |
| Steel          | 78.5                | 21×10⁷                   | 0.26           | /                    | /                         | /             |

3. Numerical simulation results and analysis

3.1 Stability of portal slope
According to figure 3 (a) and (b), the slope stability is analyzed:For the whole slope, the distribution law of effective plastic strain and maximum principal strain is basically consistent, the effective plastic strain and maximum principal strain at the interface between silty clay layer and granite stratum are large, and the strain decreases gradually from top to bottom. It is worth noting that the change is most obvious when the arch is close to the arch crown because of the stress release phenomenon in the excavation area, which makes the plastic strain and the maximum principal strain decrease.

Figure 3 (c) shows the distribution characteristics of surface deformation at the portal section after excavation. Large settlement area and uplift area appear at the vault and shallow buried side respectively, so that the tension crack zone will appear between them. Figure 3 (d) shows that after excavation, the redistribution of surrounding rock stress causes concentrated tensile stress in the upper left (marked by a rectangle) of the excavation area, which also confirms the judgment made according to figure 3 (a).
3.2 Stability of tunnel surrounding rock

It can be seen from Fig. 4 (a) and (b): the maximum settlement of vault is 19.9mm, which occurs at the place 6m away from the portal. The settlement of the vault decreases gradually after the point. The uplift value of the bottom increases gradually with the increase of the buried depth, and the maximum value is 0.179mm, which is much smaller than the settlement of the arch crown. Therefore, the key to control the deformation of the whole tunnel is to control the deformation of the vault.

It can be seen from Fig. 4 (c) and (d) that the maximum effective plastic strain and the maximum principal strain are concentrated at the stratum interface in the tunnel. Since the strength parameters of the upper stratum are much smaller than those of the lower stratum, the larger plastic strain and the maximum principal strain are concentrated on the upper side of the formation interface.
3.3 Stability of Supporting Structure

(1) Stress and deformation analysis of steel rib
Figures 5 (a) and (b) show the displacements along the X direction at the arch camber and the arch shoulder of each steel rib. The maximum bending stress and the grid joint force of steel ribs are given in Figure 5 (c) and (d). It can be seen from Fig. 8 that under the condition of shallow buried unsymmetrical compression, the deformation and stress of the steel rib are obviously asymmetric, and the deformation and stress of the shallow buried side are larger than those of the deep buried side.

(2) Deformation and stress analysis of shotcrete
As shown in Figure 6, similar to the deformation and stress characteristics of steel rib, the total deformation and maximum principal stress of shotcrete also show obvious asymmetry, and the deformation and stress of shotcrete on the shallow buried side are greater than those on the deep buried side.

(3) Analysis of deformation and stress of bolt
As shown in FIG. 7, the anchor rods at the vault are all subjected to tensile stress, which is due to the larger settlement of the soil mass at the vault; Part of the anchor rod of deep buried side spandrel and most of the anchors in the shallow buried spandrel and below produce compressive strain. The compressive strain in the bolt is analyzed: under the action of surrounding rock pressure, the shotcrete, as an elastic body, tends to deform outwards in the spandrel and some parts below, which makes the bolt compressed. Under the action of asymmetric pressure, the bolt at the shallow and deep buried sides shows asymmetry in deformation and stress. The compressive stress appears in both the shallow and deep buried sides, but there is more compression stress in the shallow buried side.
4. Conclusion and corresponding construction suggestions

Based on the actual stratum conditions, the construction stability of shallow buried portal section of No.8 tunnel of E60 highway in Georgia under asymmetric pressure is numerically simulated by using Midas GTS NX. Based on the numerical simulation analysis, the following research conclusions and construction suggestions can be drawn:

(1) The stability of portal slope of No.8 tunnel of E60 highway is closely related to the overall stability of tunnel body. The overall stability of the tunnel body can be predicted in time by monitoring the slope stability in the construction process; to ensure the overall stability of the tunnel body, attention must be paid to the protection of the slope. For the split area on the slope, it is necessary to pay attention to the protection and drainage to avoid the infiltration of rainwater and reduce the strength of the upper soil layer.

(2) Especially when the top of tunnel is close to the upper stratum, the settlement of arch crown is large. It is necessary to strengthen the protection of the tunnel roof. If necessary, advanced measures such as advanced pipe shed or advanced small pipe can be adopted to prevent the soil from loosening, collapse and even roof fall due to stress release.

(3) Due to the disturbance of tunnel excavation, a large range of plastic zone appears at the interface of rock and soil at the portal section. The stratum interface is where the plastic strain and the maximum principal strain are concentrated. It is necessary to strengthen the protection of these parts when formulating the support scheme.

(4) Under the action of asymmetric pressure, the support structure of the shallow and deep buried sides of the tunnel appears obvious asymmetric compression state. It is suggested to strengthen the stiffness of the shallow buried side support structure and adopt asymmetric supporting structure, such as thickening the shotcrete thickness at the shallow buried side, using large diameter anchor rod, increasing the cross-section area of steel arch frame.

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