Study on stability of portal section of High Slope Tunnel Based on numerical analysis

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Abstract — Due to the complexity of the portal section of high slope tunnel, unsafe accidents are prone to occur. Because of its convenience and accuracy, numerical simulation method is often used in tunnel stability analysis. In this paper, the excavation process of the slope and tunnel at the entrance of the tunnel is simulated by using the finite element software MIDAS-GTS, taking the No.6 tunnel project of the Kovi-Agvida E60 Highway Line in Georgia as an example. According to the results of numerical calculation, although the excavation volume of the slope is large, the displacement is small and the stability is good; the deformation of the surrounding rock of the tunnel is stable, and the displacement of the supporting structure is small, and the maximum displacement is about 20 mm, which is located at the vault. Therefore, the monitoring work should be done well and the support can be strengthened properly during the construction.

1. INTRODUCTION

In the construction of highway tunnels, the unsymmetrical pressure, shallow buried and high slope often appear at the entrance of the tunnel which is prone to unsafe accidents. Therefore, it is necessary to make a more accurate stability analysis of the tunnel portal section and take timely prevention and treatment.

At present, many scholars have carried out in-depth research on the stability of tunnel portal section. Zhang et al. [1] used the unbalanced thrust method to calculate the soil stability coefficient of the Loess Tunnel Portal high slope on Zhengzhou-Xi’an Passenger Dedicated Line, and put forward the optimization design scheme of the slope. Fang et al. [2] calculated the slope stability coefficient of Chading tunnel portal section of Guanwu highway, found that the tunnel construction had a great impact on the slope, and put forward relevant protection measures. Xiang et al. [3] used Marc software to analyze the variation law of stress and plastic zone during the construction of tunnel in strongly weathered rock mass. Da [4] Based on Xiangshan tunnel project, simulated the excavation process of slope and tunnel,
analyzed the potential slip surface position of slope, and proposed a reasonable reinforcement scheme. Zhu [5] studied the construction technology of portal section of shallow buried unsymmetrical pressure tunnel with collapse body, and analyzed the support effect of different pre reinforcement methods.

In this paper, based on the No.6 tunnel of E60 highway in Georgia, MIDAS-GTS finite element analysis software was used to simulate the construction process of No.6 tunnel in Tbilisi portal section. The stability of tunnel portal section is analyzed comprehensively from the aspects of slope, surrounding rock and support.

### TABLE 1. MODEL MATERIAL PARAMETERS.

| Material type                  | Unit weight (kN/m³) | Elastic modulus (GPa) | Poisson's ratio | Cohesion (kPa) | Internal friction angle |
|-------------------------------|--------------------|-----------------------|-----------------|----------------|------------------------|
| Rock mass                     | 25                 | 1.5                   | 0.3             | 80             | 45                     |
| Initial lining and Sprayed concrete | 25                 | 3                     | 0.2             | -              | -                      |
| Secondary lining and Portal structure | 25                 | 3.15                  | 0.2             | -              | -                      |

### 2. NUMERICAL SIMULATION

The supporting project of this paper is No. 6 tunnel along the Kovi-agvida E60 highway route in Georgia, which is located in the Transcaucasia block. The starting and ending pile numbers of TUN-3006-TA are 82 + 00.00 ~ 84 + 80.00, with a total length of 280 m, the maximum buried depth is 86.1 m, and the minimum buried depth is 11.81 m. They are represented by porphyry complex, including porphyry, porphyry breccia, layered tuff, etc. their main characteristics are hard, and the surrounding rock class is III ~ IV. Through engineering geological investigation, drilling and related tests, combined with experience, the relevant geomechanical parameters of rock mass are comprehensively considered and selected. The model material parameters are shown in Tab. 1.

According to the geological data of Tbilisi portal of No.6 tunnel in Georgia, the geometric model of surrounding rock mass and tunnel is established. The rock mass and portal structure around the tunnel are simulated by three-dimensional solid elements. The shotcrete and lining of the tunnel are made of two-dimensional plate elements. The isotropic Mohr Coulomb elastic-plastic model is selected for rock mass, and the isotropic elastic model without considering material nonlinearity is used for structural material [6]. The tunnel is 12.9 m wide and 10.95 m high. The specific geometry of tunnel section is shown in Fig. 1. C30 concrete with a thickness of 20 cm is used for shotcrete of initial lining; C35 concrete is used for secondary lining and portal structure, and the thickness of secondary lining with different thickness is adopted for different section types and positions.

According to the determined parameters, the geometric model is established, and the model elements are meshed appropriately according to the calculation requirements. The model is divided into 191422 elements and 110354 nodes. The axis view of the model meshing is shown in Fig. 2. In the process of geometric modeling, attention should be paid to the size of the model, and the distance from the model boundary to the tunnel boundary should not be less than 3 times the tunnel diameter [7]. Set the constraints on the established model boundary, that is, to set the constraints on the displacement and rotation in the model, including the X direction of the left and right sides of the model, the Y direction of the front and rear sides, and the XYZ direction of the bottom.

According to the actual excavation and construction process, the full face excavation method is adopted for excavation, and the footage is set according to different cross-section types to set the construction stage. The command of "passivation" and "activation" is used to simulate the excavation of rock mass and the construction of supporting structure [8].
3. NUMERICAL RESULTS ANALYSIS

3.1 Slope Analysis
According to the cloud chart of slope displacement change in Fig. 3, the horizontal displacement of the slope is small, which gradually increases from the minimum 0.65 mm at the top of the slope to 4.00 mm. It reaches the maximum near the intersection of the slope bottom and the step surface. The vertical displacement of the slope is mainly under the action of the self-weight of the rock mass and in-situ stress, and the subsidence decreases gradually from bottom to top, and the uplift appears near the surface of the step. After the excavation of the slope, the final vertical displacement is controlled, and the maximum value is 15.79 mm. Clearly, the effect of slope reinforcement measures is obvious. The horizontal and vertical displacements of the slope are effectively controlled.
3.2 Tunnel Analysis

After excavation, the maximum displacement in Z direction is 20 mm, and the vertical displacement cloud chart is shown in Fig. 4. Since the maximum deformation of the vault and invert is the middle point of the cross-section, the middle point of the section in a certain step after the tunnel excavation is selected to analyze the displacement changes during the excavation process. Step 30 is selected for left tunnel and step 28 is selected for right tunnel. According to the calculation results, the displacement change in the process of tunnel excavation is shown in Fig. 5.

The left and right tunnels start construction at the same time. Due to the different buried depth, the tunnel deformation is slightly different, but the overall deformation trend is the same. It can be seen from Fig. 5 that from the beginning of excavation to the research point, the displacement of this part is small because the construction site is still a certain distance from the research point. With the advance of the construction stage, the construction position is gradually close to the research point, and the displacement increases gradually. Then the excavation of the next section is carried out, and the initial support of the research section is carried out at the same time. At this time, the displacement of the research point is obviously reduced. After the completion of all excavation and initial lining, the secondary lining construction is carried out, and the final displacement gradually tends to be stable, which shows that the support effect is obvious and the deformation of surrounding rock is reasonably controlled.
According to the displacement data of vault, arch waist and invert at key points of the tunnel, the deformation law of rock mass around the tunnel is that the vault sinks, the sidewalls are expanded, and the invert slightly rises. The maximum displacement is about 20 mm, which is located at the vault of the last excavation stage.
The construction of the initial lining should be timely. The initial lining of each section shall be carried out simultaneously with the excavation of the next section. After the completion of the initial lining construction, the vertical displacement of the initial lining of the tunnel along the longitudinal depth of the tunnel can be obtained, as shown in Fig. 6. It can be seen that the vault displacement of tunnels decreases gradually with the increase of tunnel longitudinal depth, and finally tends to be stable. The maximum vertical displacement of the vault of the initial lining of the left tunnel is 7.5 mm, which is stable around -2 mm at the end of the tunnel excavation; the maximum vertical displacement of the vault of the initial lining of the right tunnel is 3.3 mm, which is stable around -1 mm at the end of the tunnel excavation.

According to the results of tunnel excavation, the vertical displacement of the vault and invert of the secondary lining along the longitudinal depth of the tunnel is shown in Fig. 7. It can be seen that the displacement of the second lining vault of the tunnel tends to be stable gradually with the increase of the longitudinal depth of the tunnel, while the displacement of the invert remains basically unchanged, and slightly decreases on the whole. The vertical displacement of the invert of the left tunnel in the longitudinal depth direction is about 12 mm, which decreases slightly; the vertical displacement of the vault decreases from 7 mm with the increase of the longitudinal depth of the tunnel and stabilizes around -2 mm at the end of the tunnel. The vertical displacement of the invert of the right tunnel in the longitudinal depth direction is about 9 mm, which decreases slightly; the vertical displacement of the vault decreases from 3 mm with the increase of the longitudinal depth of the tunnel and stabilizes around -1 mm at the end of the tunnel.

The results show that the secondary lining of tunnels has small displacement and finally tends to be stable, which indicates that the secondary lining effect of the tunnel is good and the supporting structure is stable.

4. CONCLUSIONS
In this paper, MIDAS-GTS is used to analyze Tbilisi portal of No.6 tunnel of Kovi-agvida E60 highway in Georgia, and the following conclusions are drawn:

- The excavation volume of the slope of the tunnel portal is large, but the maximum displacement of the slope is small, the effect of the slope support effect is good, and the slope is basically stable.
- The vault of the tunnel is sinking, the sidewalls are expanded and the invert is slightly uplifted. The displacement of tunnel lining is small and tends to be stable, and the supporting effect is good.
- The maximum displacement of the tunnel is about 20 mm, which is located at the vault of the last excavation section. Although the tunnel displacement is small, the stress of the tunnel vault is more complex. Therefore, it is necessary to do a good job of monitoring during the construction process and pay attention to the situation of key parts at any time.

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