Numerical simulation of slope failure treatment of a tunnel portal section based on MIDAS GTS

Yetao Wang⁰, Guanyu Zhu²,³*, Linbo Ding⁴, Dequan Zhuang⁴, Wenwen Ba⁴

¹ China Road and Bridge Corporation, Beijing, 100011, China
² School of Civil Engineering, Xian University of Architecture and Technology, Xi’an, Shaanxi, 710055, China
³ Shaanxi Key Laboratory of Geotechnical and Underground Space Engineering, Xi’an, Shaanxi, 710055, China
* e-mail: 1547129969@qq.com

Abstract — In order to ensure the safety of tunnel construction, a retaining structure is needed to control landslides and reinforce tunnels in slope failure areas. Numerical simulation is used to study the interaction mechanism between tunnel excavation and slope displacement under the reinforcement of the "upper retaining" anti-slide pile. The results show that: the "upper retaining type" anti-slide pile as the supporting structure has a significant effect on the control of tunnel deformation in the slope failure section; the displacement deformation of the tunnel vault is consistent with that of the anti-slide pile, which indicates that the anti-slide pile retaining structure based on the "tunnel landslide system" can significantly improve the stress of the tunnel structure and is conducive to the safety of the tunnel structure and stability of the slope.

1. INTRODUCTION
In recent years, “the belt and road initiatives” has been pushed forward and developed. The infrastructure construction in foreign countries has entered the peak period. There are many mountain tunnels under construction. Many of them are faced with many engineering problems such as shallow buried, partial pressure and poor rock grade in the process of construction. In addition, because the possible development range of the failure under the action of natural environment factors is not fully estimated in the route selection and exploration, or the failure body develops into the tunnel due to the tunnel excavation, many tunnels are still set in the possible development range of ancient landslide mass and thick talus deposit. With the long-term adjustment of the stress in the slope, under the influence of the environmental geological conditions and human factors, the landslide will creep, which will lead to the mountain pressure acting on the tunnel, causing the tunnel lining deformation and cracking. In order to prevent such accidents, it is particularly important to change the technical scheme according to the actual working conditions of the tunnel.

This paper is based on the construction of a shallow buried and unsymmetrical pressure tunnel exit near the landslide talus deposit section of F3 Expressway in Georgia. Before the construction of the tunnel, it is found that the actual engineering geological conditions are not consistent with the in-situ survey. Based on the concept of interaction between tunnel and landslide [1], the expert group was organized for a consultation to accurately understand the deformation mechanism of tunnel landslide and the potential risks in tunnel construction engineering. In the process of construction, effective
measures are adopted, such as "upper retaining type" anti-slide pile to treat the slope accumulation at the tunnel entrance, counter pressure grouting treatment for eccentric pressure section and timely construction of secondary lining at the portal section are adopted to strengthen the tunnel structure. On this basis, Midas GTS is applied through the finite element numerical simulation, the tunnel slope under the new support system is simulated, which proves the feasibility of the support model based on the interaction between tunnel and landslide; reveals the stress-strain distribution law of anti-slide pile in the process of tunnel excavation, confirms the rationality of deformation mechanism analysis, and provides an important basis for further exploring the setting mode of protection engineering.

2. **ENGINEERING GEOLOGICAL CONDITIONS**

Tunnel 8 in Georgia is located in the khevi argveta section of E60 highway in the middle of Georgia block, between the greater Caucasus in the north and the small Caucasus in the south. It is a two-way single lane with shallowly buried bias in the portal section, and it is within the possible influence range of landslide accumulation. The spacing of the tunnel is 15m. In the original design scheme, the length of the left line of the tunnel is 1150m, the length of the right line of the tunnel is 1200m, and the maximum buried depth is 141m. The tunnel site is mainly composed of intrusive igneous rocks dominated by pink-gray granite, quartz porphyry and metamorphic rocks dominated by quartz gneiss. A large number of faults were found along the tunnel. The surface layer of the tunnel crossing the existing line is silty clay with a depth of 1-4m.

There is no surface water in the tunnel area. The surface water is mainly supplied by atmospheric precipitation, and the discharge mode is mainly transpiration. The surface water near the tunnel area is Dzirula River, with pure water quality and no corrosivity. The tunnel is located above the Dzirula River, and the elevation of the tunnel is about 10-30m higher than the water surface. The Dzirula river has no impact on tunnel construction.

In the rainy season, the phreatic water gushes out along the soil rock interface and joint fissure development section. The groundwater in this area is mainly supplied by atmospheric precipitation, and the water quantity varies significantly with seasons. The precipitation in the rainy season is larger than that in the dry season.

3. **DESIGN, CONSTRUCTION AND DEFORMATION MONITORING**

3.1 **tunnel design**

The tunnel 8 in Georgia is designed according to the principle of the ADECO-RS method. Professor Lunardi studied the relationship between the formation and location of bearing arch effect of the tunnel surrounding rock and the characteristics and magnitude of medium response caused by tunnel excavation. It is considered that the deformation of core surrounding rock (extrusion deformation and convergence deformation) in front of the tunnel face is closely related to tunnel deformation (convergence deformation) The stiffness of the core surrounding rock plays a decisive role in the long-term and short-term stability of the tunnel. Appropriate measures can be taken to strengthen the core surrounding rock as the key to control the deformation of surrounding rock [2]. According to the stress-strain behavior of the working face and the core surrounding rock in front of the construction face, Professor Lunardi divides the strata into three types: A, B and C. For different parts, different supporting measures (radial deformation restraint measures and pre deformation restraint measures) are adopted to achieve complete stability of the tunnel.

The tunnel 8 in Georgia belongs to the class B stratum and belongs to the short-term stable face type. In the process of tunnel construction, the composite lining is adopted, with wet shotcrete (steel mesh), steel arch as initial support and large pipe shed as auxiliary measures to reinforce the core surrounding rock and improve the rigidity of core surrounding rock to ensure the stability of the tunnel. In addition to guiding the construction of primary support and secondary mold lining, the monitoring and measurement of the extrusion deformation of the face and its core surrounding rock are more important.
According to the terrain and geological conditions of the portal, combined with the requirements of engineering construction safety and environmental protection, the end wall type portal is adopted at the exit of No.8 tunnel in Georgia. The slope surface of the original terrain shall be kept as far as possible for the excavation of the portal, so as to reduce the damage to the natural environment caused by the slope excavation. After the completion of tunnel construction, the road surface and pedestrian crossing tunnel of the tunnel adopt cement concrete pavement.

3.2 slope support design

According to the drilling data and field investigation, the landslide mass is mainly composed of bedrock weathering crust and residual slope soil. The material composition is mainly slope gravel soil and silty clay. The soil is in a hard plastic state, and the completely weathered rock has completed the weathering. It is hard and soft rock. The distribution of coarse and fine particles in landslides is uneven, and some of them are sub-circular. According to the material composition and structural form of landslide mass, it belongs to the accumulation landslide.

When the tunnel passes through the influence area of the accumulation slope, it often brings difficulties to the tunnel construction, especially for the unstable accumulation slope with huge volume, the principle of slope treatment first and then tunnel entry shall be followed to ensure the construction safety. In this paper, based on the background of the slope treatment project near the talus deposit of No.8 tunnel in Georgia, the retaining structure is used to treat the landslide and reinforce the tunnel.

In view of the three typical reinforcement methods [3-4], which are commonly used at present, i.e. "upper retaining type" and "upper retaining type", after comprehensive comparison, the upper retaining type is adopted to reinforce the slope. The pile tunnel spacing of anti-slide pile is 1.5m, the length is 18m, and the pile body material is reinforced concrete. The calculated landslide thrust behind the pile is \( t = 732.74 \text{kN/m} \), the landslide resistance in front of the pile is 732.74\text{kN/m}, the distribution of landslide thrust is rectangular, and the distribution of landslide resistance is rectangular. The support method of slope adopts bolt mesh shotcreting.

4. CALCULATION MODEL

4.1 model size

According to the terrain and geological conditions of the exit section of the Georgia tunnel, taking DK10 + 775-DK11 + 25 section as the research object, a three-dimensional numerical analysis model is established. According to the relevant principles of elastic mechanics and rock mechanics, it can be seen that the influence area of tunnel excavation on the stress state of surrounding rock is three times the width of tunnel excavation outside the contour line of tunnel excavation. According to the actual situation of strata and mountains, the size of the model is about 200m in the horizontal direction (x-axis direction), 97.6m in the direction of the tunnel axis (Y-axis direction), and 56m in the vertical direction (Z-axis direction)[5]. In the static state of the vertical simulation, only the influence of tunnel excavation on the slope under the condition of self-weight is considered, and the effect of tectonic stress is not considered. Therefore, the model boundary is set as horizontal constraint, and the ground boundary is set as horizontal and vertical constraints.

4.2 physical and mechanical parameters

| Material          | constitutive model | Unit type | E (kPa) | \( \gamma \) (kN/m\(^3\)) | \( \nu \) | C (kPa) | \( \phi \) (°) |
|-------------------|--------------------|-----------|---------|-----------------|------|--------|-------------|
| Silty clay        | M-C solid          |           | 48000   | 19.5            | 0.25 | 34     | 19          |
| Gravel and sand   | M-C solid          |           | 173000  | 20              | 0.3  | 0      | 39          |
4.3 analysis of numerical calculation results

The numerical simulation calculation is carried out according to the excavation of the left and right lines at the same time, and the cyclic footage is 2.4m. The slope stability before and after the tunnel construction is analyzed. In the process of numerical simulation, the stress-strain analysis of the tunnel is studied and compared with the actual monitoring data.

4.3.1 Natural state simulation of slope

The simulation results of the natural state of the slope are shown in Fig. 1. The calculation shows that the vertical displacement of the slope is mainly in the natural state. The displacement of the shallow layer larger, and decreases with the increase of depth. After the slope reaches equilibrium under the self-weight stress, the deformation of the slope occurs. The displacement is mainly shallow displacement, and the distribution is relatively uniform, which indicates that the slope has good...
integrity. The calculated safety factor of the slope is 1.42, and there is no through the plastic zone, so it can be judged that the slope is in a stable state.

4.3.2 Influence of tunnel excavation on slope

Tunnel excavation (cyclic footage of 2.4 m) produces a new free surface, which changes the stress state of the slope and deforms the slope. The relationship between tunnel excavation and slope strain can be directly shown by drawing the strain curve of the tunnel vault and anti-slide pile compared with the actual monitoring data.

Figure 2. Displacement curve graph.
With the excavation of the tunnel, the vault of the tunnel in AT and TA directions are all subject to displacement settlement. Due to the support function of the "push up" anti-slide pile, there is no obvious displacement change during the excavation of the TA tunnel. After that, with the excavation of the AT tunnel, the stress redistributes and the slope deforms beyond the influence scope of the anti-slide pile. The deformation of the tunnel and anti-slide pile are consistent. The slope displacement of sliding mass moves to the AT direction of the tunnel portal. The cloud chart of slope plastic area is shown in the figure below.

![Figure 3. Plastic strain analysis of surrounding rock](image)

4.4 deformation mechanism analysis:
In the natural state, the slope in this area is basically stable. The tunnel is located at the steep slope of the mountain and is shallowly buried near the mountain. Due to the unsymmetrical terrain with thin overburden, it is difficult to form a bearing arch at the exit of the tunnel, which is easy to cause geological failures such as collapse, sliding and tunnel face collapse during construction. The tunnel is located in the influence range of the accumulation slope, and the blasting excavation aggravates the disturbance effect on the slope, which is easy to accelerate the creep of the slope.

In the process of tunnel excavation, the displacement deformation of the tunnel vault is consistent with that of the anti-slide pile tip, and the maximum displacement is 17mm. Within the influence range of anti-slide pile, the deformation of vault caused by tunnel excavation is small. After exceeding the influence range, the displacement deformation increases obviously. Finally, the deformation of the tunnel vault decreases outside the influence range of accumulation landslide.

5. CONCLUSION
Based on the complexity of the deformation mechanism of tunnel and slope in a shallowly buried tunnel construction project, it is proposed that in order to avoid the damage of landslide sliding to
tunnel structure, anti-slide pile and pre-stressed anchor cable can be used to pre-strengthen the slope to form a cooperative stress structure system, which is very economic and efficient to ensure the safety of tunnel structure.

The tunnel excavation makes the slope produce a new free surface, which changes the stress state of the slope. The stress of the slope further acts on the tunnel lining and causes the tunnel lining to deform. The deformation of the tunnel vault is consistent with that of the anti-slide pile, and the relationship between tunnel excavation and slope deformation is demonstrated from the side. Therefore, it is effective to solve this kind of deformation mechanism problem by using "the tunnel slope system" collaborative analysis method.

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