

Stability Analysis of Interaction between Portal Slope and Shallow Buried Super Large Section Tunnel

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Abstract

In order to describe the interaction effect between tunnel excavation and uphill slope, taking Baishi No.2 tunnel as the engineering background, the numerical simulation method is used to reveal the interaction mechanism between tunnel excavation and uphill slope. The results show that (1) The safety factor of the stability of the slope at the entrance of the tunnel is significantly improved after brushing and strengthening. Then, with the excavation of the tunnel, the deformation of the slope gradually increases. After the excavation is completed, the safety factor of the slope gradually decreases to 1.52, but the slope is still in a stable state ;(2) After brush reinforcement, the pile-board structure improves the anti-sliding force of the slope and makes it in a stable state, which inhibits the influence of the sliding force of the slope on the deformation of the surrounding rock and the supporting structure, and the reinforcement effect is remarkable. The research results can provide reference for slope protection and reinforcement and tunnel stability construction.

Keywords

Uphill; Tunnel; Numerical Simulation; Stability.

1. Introduction

The surrounding rock of the super-large section loess tunnel portal is weak, and the self-bearing capacity is low. It is difficult to form a bearing arch. During the excavation process, tunnel collapse and slope instability accidents are prone to occur under the action of the uphill slope, which endangers the safety of personnel. Therefore, it is particularly necessary to study the interaction mechanism between the two. The research results can provide favorable support for the design of the uphill slope and tunnel support structure.

In the study of the interaction between tunnel and slope, Yin Chuan et al. [1] studied the deformation characteristics and stress mechanism of tunnel-landslide orthogonal mode, summarized six failure modes of tunnel structure under tunnel-landslide interaction, and put forward corresponding control technology for landslide. Shao Zhushan et al.[2][5] studied the safety factor of slope stability and the variation of stress and deformation of surrounding rock and supporting structure under different reinforcement measures by numerical simulation and model test, verified the influence of tunnel excavation on slope, and evaluated the reinforcement effect of different schemes. Liu Chuanli et al. [6] studied the stability of the landslide-tunnel oblique system by taking a tunnel exit section as an example, proposed a set of on-site treatment measures, and evaluated the treatment effect and the safety of the tunnel structure through numerical simulation. Based on the actual project, Tao et al.[7]-[10] carried out numerical simulation on the front slope of tunnel entrance, and compared with the field monitoring results, and analyzed the stress and deformation variation law of tunnel and front slope under different excavation and support conditions..

In summary, the interaction between the tunnel entrance and the uphill slope is mainly reflected in two aspects : on the one hand, the tunnel excavation leads to the reduction of the

anti-sliding force of the slope, which makes the uphill slope tend to be unstable ; on the other hand, the sliding force of the upward slope increases the stress and deformation of the surrounding rock and supporting structure of the tunnel. The excavation of Baishi No.2 tunnel portal is faced with extreme conditions such as shallow buried bias and broken surrounding rock, and the deformation of surrounding rock and uphill slope is difficult to control. At present, there is still a lack of understanding of the interaction mechanism between portal excavation and uphill slope under such shallow buried and super-large span conditions, and there are few relevant research data. Based on this, this paper takes the Baishi No.2 tunnel as the engineering background, discusses the interaction mechanism between the excavation of the super-long-span tunnel and the slope, so as to demonstrate the necessity of the slope protection at the entrance. The research results can not only verify the rationality of the tunnel support design, but also provide a reference for the subsequent use of sheet-pile wall to protect the slope.

2. Project Profile

2.1. General Geology

The Baishi No.2 tunnel is shallowly buried. The span of the tunnel exit end is 18.65 m, the height is 14.75 m, the excavation area of the section is 220.75 m², and the original terrain slope of the exit end is between 60° and 75°. After the load reduction of the brush side, a second-stage uphill slope with a slope angle of 45° is formed above the tunnel entrance. The first-stage uphill slope is 8 m high, the second-stage uphill slope is 10 m high, and the middle platform is 2 m wide. In addition, the surface layer of the tunnel is mainly composed of sandy loess, accompanied by a small amount of construction waste, and the bottom layer is mainly coarse gravel soil. Within the scope of the project, it is mainly the foundation of convenience roadbed and houses. It is easy to produce uneven settlement during the construction process, which affects the safety of tunnel construction.

2.2. Tunnel Construction Scheme

The double-side heading method is widely used in weak surrounding rock because of its small excavation surface and fast support. The tunnel of this project is shallow and the surrounding rock is weak. The advanced pipe roof + double-side guide pit method is used for excavation. The cycle footage is 1 m, and the step length is 4 m. The whole process adopts parallel circulation operation.

The tunnel adopts a composite lining structure, and the advance support is arranged with a circular spacing of 0.4 m in the 140° range of the arch of the Φ159 advance large pipe shed. The primary support is composed of I25a steel arch+C25 concrete+Φ22 mortar bolt+Φ8 steel mesh. The steel arch spacing is 0.5 m, the spray mixing thickness is 0.31 m, the bolt length is 4 m, the spacing is 1.2m (ring) * 1m (longitudinal), and the steel mesh spacing is 0.2 m. The secondary lining is composed of waterproof layer and reinforced concrete with a design thickness of 0.7 m. The composite protection form of temporary spray anchor and skeleton slope protection is adopted on the slope surface of the entrance. The temporary spray anchor adopts C25 concrete and Φ8 steel mesh. The spray mixing thickness is 0.15 m, and the steel mesh spacing is 0.25 m. The pile plate wall is added at the entrance to stabilize the slope.

3. Establishment of Numerical Model

3.1. Model Introducing

In this paper, the Baishi No.2 super-large section tunnel is taken as the engineering background, and the three-dimensional finite element model of the tunnel and the slope is established by using the finite element software for numerical calculation. The Z direction of the model is the direction of tunnel excavation, the X direction is the vertical excavation direction, and the Y

direction is the vertical direction. The maximum buried depth of the tunnel is 20 m. In order to eliminate the influence of boundary conditions, the width of the left and right sides of the model is 120 m, the longitudinal excavation length is 60 m, the bottom boundary is 55 m from the bottom of the tunnel, and the upper boundary is determined according to the buried depth.

The boundary conditions of the model are as follows : X-direction constraints are applied to the left and right sides, Z-direction constraints are applied to the front and back boundaries, the bottom is fixed constraints, and the remaining surfaces are free surfaces. The model applies gravity load in the Y direction. The parameters of surrounding rock are obtained by geological data and laboratory test of undisturbed soil. The parameters of pile plate are determined by design. The parameters of shotcrete anchor and supporting structure are determined by reduction.

4. Analysis of the Influence of Tunnel Excavation on the Stability of the Slope Occlusion

4.1. Analysis of Tunnel Excavation on the Stability of the Slope

In order to evaluate the influence of tunnel excavation on the slope, the deformation analysis of the top of the first and second grade slope is studied. Therefore, the deformation changes of the top of the slope under six excavation conditions are extracted to analyze the stability of the slope. The working conditions are shown in table 1, and the deformation curve of the slope is shown in figure 1 and figure 2.

Table 1. Working Condition Description table

Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
Excavation of the left upper heading is 5 m	Excavation of the left upper heading is 10m	Excavation of the left upper heading is 20m	Excavation of the left upper heading is 30m	Excavation of the left upper heading is completed	All excavation is completed

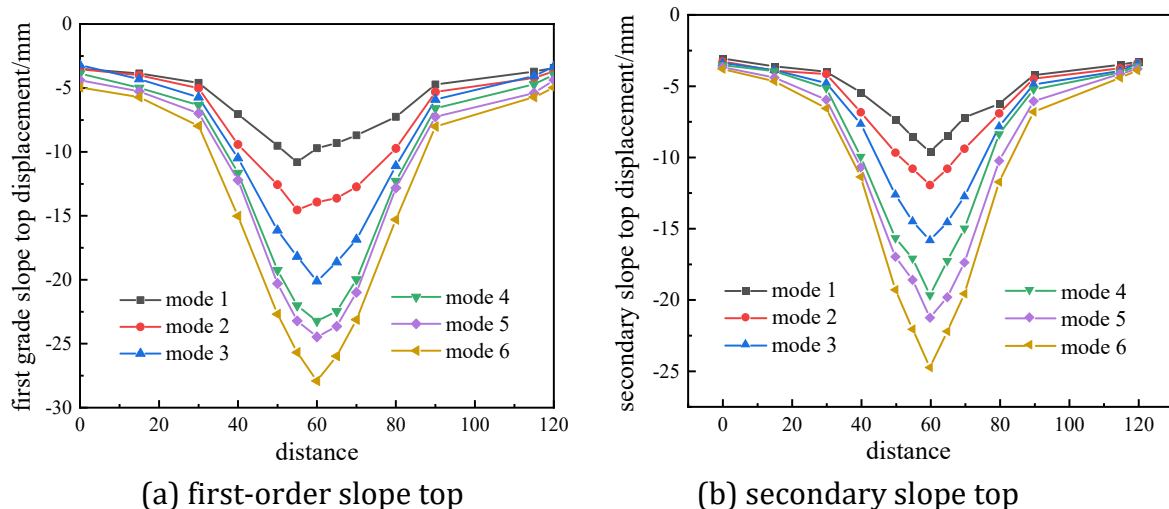


Figure 1. Vertical deformation of slope top

It can be seen from Figure 1 that the deformation law of the surface at different positions is basically consistent. On the whole, with the continuous removal of the soil on the tunnel face, the vertical deformation of the slope top increases to varying degrees, and the settlement rate near the tunnel axis is the fastest, and the greater the buried depth of the tunnel, the smaller the impact on the deformation of the slope. With the progress of excavation, the maximum

vertical deformation of the first-stage slope top increases from 9.7 mm under working condition 1 to 27.9 mm under working condition 6, with an increase of 187.6%. The maximum vertical deformation of the top of the secondary slope increases from 9.6 mm under working condition 1 to 24.8 mm under working condition 6, with an increase of 158.3%. The data show that tunnel excavation has an impact on the stability of the slope

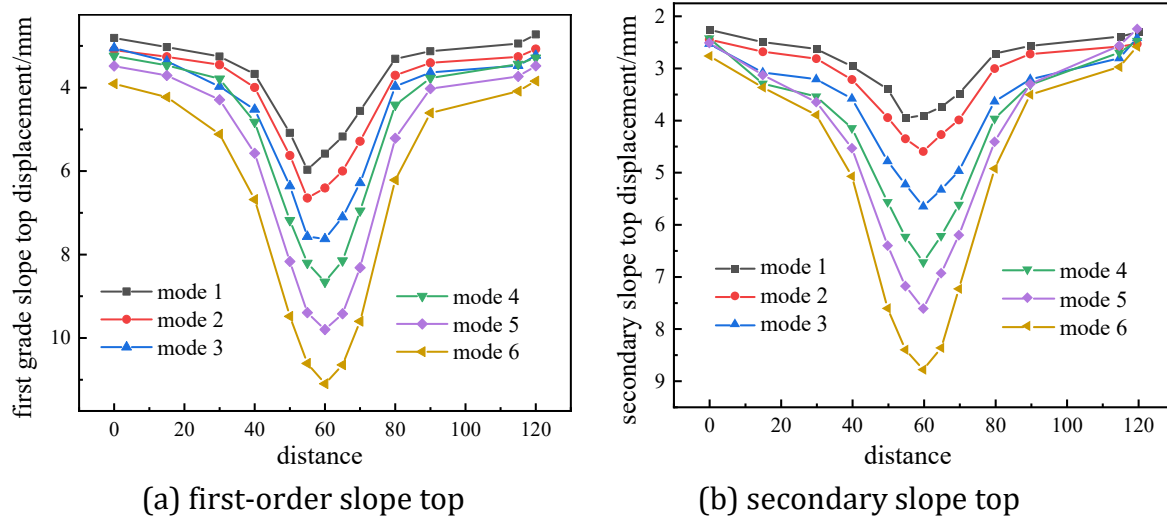


Figure 2. Horizontal deformation of slope top

It can be seen from Figure 2 that the horizontal deformation law of the front slope is consistent with the vertical deformation. The horizontal displacement near the tunnel axis has the fastest growth rate. The farther away from the axis, the slower the speed, the greater the buried depth of the tunnel, and the smaller the horizontal deformation. After the excavation is completed, the horizontal deformation of the first-stage front slope increases from 5.6 mm to 11.1 mm, with an increase of 98.2%. The horizontal deformation of the second-stage slope increased from 3.9 mm to 8.8 mm, with an increase of 125.6%.

Therefore, according to the above-mentioned deformation law of the slope, the tunnel has a significant impact on the deformation of the slope. During the excavation process, the supporting structure should be closed in time and strengthened monitoring. In addition, the safety factor of the slope after brushing reinforcement is 1.56, and the safety factor is increased to 1.77 after the pipe shed is erected. With the removal of the soil on the tunnel face, the anti-sliding force of the slope decreases, the deformation gradually increases, and the safety factor of the slope stability begins to decrease continuously until the excavation is completed. The safety factor is reduced to 1.52, which is 2.56% lower than 1.56, but the slope is still in a stable state, indicating that the excavation of the tunnel under the condition of slope reinforcement can significantly reduce its instability probability.

5. Analysis of the Stability of the Tunnel and the Supporting Structure of the Slope

After the slope of the tunnel entrance is brushed, the stress of the slope is redistributed and the safety factor is reduced. If not reinforced, in the process of tunnel excavation, the slope is likely to be unstable, affecting the stability of surrounding rock and lining structure. Therefore, it is very important to study the stability of tunnel surrounding rock and supporting structure before and after slope reinforcement. The following will compare and analyze the deformation of surrounding rock and supporting structure caused by tunnel excavation before and after slope reinforcement, and verify the influence of slope on tunnel and supporting structure.

5.1. Surrounding Rock Deformation Analysis

The horizontal displacement cloud diagram of the surrounding rock of the 30 m section from the portal before and after the reinforcement of the slope is shown in Fig.3. It can be seen that the horizontal displacement of surrounding rock mainly occurs at both sides of the side wall and the arch foot of the inverted arch. The maximum displacements of the left and right side walls before the reinforcement of the inverted slope are 13.8mm and 11.2mm respectively, and 10.6mm and 8.7mm respectively after the reinforcement, which are reduced by 23.4% and 22.7%. It shows that the slope reinforcement effectively restrains the lateral deformation of the surrounding rock, makes the slope in a compressive state, ensures the strength and integrity of the rock mass, and reduces the deformation of the surrounding rock under the self-bearing capacity.

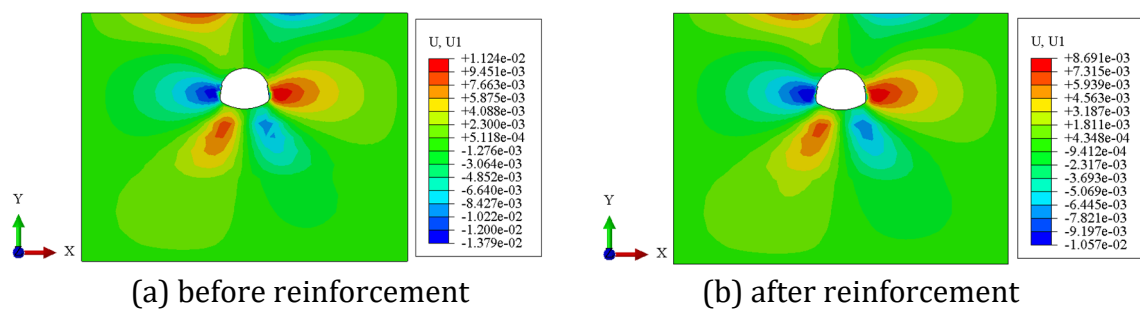


Figure 3. Horizontal displacement of surrounding rock

5.2. Stability Analysis of Secondary Lining

After the initial support deformation of the tunnel excavation is stable, the secondary lining is applied. At this time, the deformation and stress of the secondary lining change very little, and all parts are in a stable state. In order to study the influence of the sliding force of the slope on the stability of the secondary lining in the later stage, the vertical deformation of the secondary lining is analyzed when the tunnel is excavated in two states.

According to the settlement curve of the secondary lining vault, it can be found that the maximum settlement of the secondary lining vault is 13.53 mm before the excavation of the slope reinforcement, and the maximum settlement is 4.91 mm after the excavation of the reinforcement, which is reduced by 63.7%. The effect is obvious, which further indicates that the slope has an impact on the stability of the secondary lining, and then verifies the necessity of the brush reinforcement of the slope..

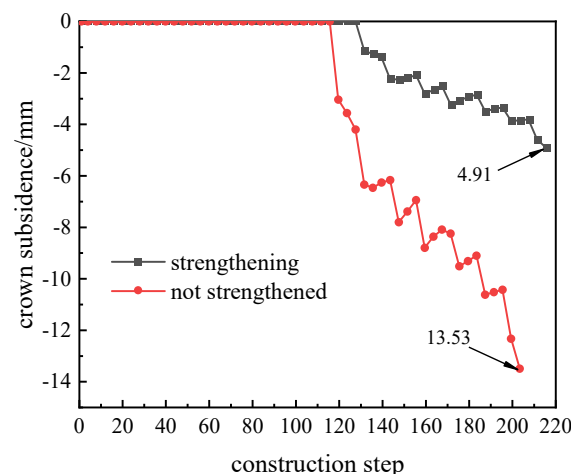


Figure 4. Secondary lining vault settlement duration curve

In summary, whether the slope is reinforced or not is very important to the stability of the surrounding rock and supporting structure of the tunnel. Although the reinforcement cannot completely eliminate the influence of the slope on the tunnel, it can reduce its force to a certain extent, and then improve the safety factor of the tunnel. Therefore, it is necessary to reinforce the slope before tunnel excavation.

6. Conclusion

Based on the Baishi No.2 tunnel project, this paper studies the interaction mechanism between the slope and the tunnel support structure during the excavation of the tunnel portal by numerical simulation. The main conclusions are as follows:

- (1) With the excavation of the tunnel, the vertical deformation and horizontal deformation of the first and second slopes of the slope are increased. After the excavation is completed, the safety factor of the slope is reduced to 1.52, but the slope is still in a stable state.
- (2) When the tunnel is excavated before and after the reinforcement of the slope, the deformation of the surrounding rock and the secondary lining is reduced, and the values are within a reasonable range. The influence of the sliding force of the slope on the stability of the tunnel surrounding rock and its supporting structure. In order to ensure the smooth excavation, it is necessary to brush the slope before excavation.

References

- [1] C Yin, J F Wang , W J Zhou, et al. Discussion on deformation characteristics and control technology of tunnel orthogonal crossing landslide [J]. Railway Construction, 2021,61 (06) : 59-64.
- [2] J.Z S Shao, F Cui, C L Li, et al. Study on influencing factors and treatment technology of silty clay tunnel slope stability [J].Journal of Railway Science and Engineering, 2020,17 (08) : 2055-2064.
- [3] H G Wu, T Yang, H M Ma , etc. Study on pre-reinforcement mechanism and model test of tunnel-landslide system [J]. Journal of Rock Mechanics and Engineering, 2014,33 (S2) : 3531-3538.
- [4] J F Lv, J M Du , Z J Luo, et al. Study on the stability and supporting parameters of high and steep slope of Yankou Highway Tunnel [J].Modern Tunnel Technology, 2020,57 (05) : 116-124.
- [5] D L Liu. The influence of tunnel excavation on slope stability [J]. Railway Construction, 2018,58 (07) : 68-71.
- [6] C L Liu , J J Tong. Case analysis and comprehensive treatment of stability of landslide-tunnel oblique system-Taking the exit section of Chunping No.2 Tunnel on Daguang-Yongshan Expressway in Yunnan Province as an example [J].Tunnel Construction (Chinese and English), 2022,42 (S2) : 161-167.
- [7] Z Tao, M Qun. Numerical Analysis And Research of Entrance Slope of Shallow Buried Karst Tunnel[J].IOP Conference Series: Earth and Environmental Science,2020,455012176-012176.
- [8] D Song , X Liu,Chen Z , et al.Influence of Tunnel Excavation on the Stability of a Bedded Rock Slope: A Case Study on the Mountainous Area in Southern Anhui, China[J].KSCE Journal of Civil Engineering,2020,25(publish):1-10.
- [9] M Wu , Y Xi, H Guo. Strength Reduction Method Based Study on Tunnel Excavation Effect on Front Slope Stability[J].IOP Conference Series: Materials Science and Engineering,2020,741012007-012007.
- [10] W X Du, T Y Gao .On the Stability and Control Technology of the Side Slope of the Tunnel Entrance [J]. Applied Mechanics and Materials, 2014,2916(488-489):737-740.