Slope Stability Analysis

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Abstract. Excavation construction can have an impact on the stability of the mountain and even form new landslide disasters. Based on the construction of a highway tunnel entrance in a certain mountainous area, the stability of the slope was analyzed, and numerical simulation analysis was conducted on different treatment schemes. By analyzing the stability of the tunnel entrance slope under several engineering slope treatment states, including a slope thickness of 1m, a slope thickness of 1.5m, and a slope thickness of 2m, the maximum vertical displacement of the slope was minimized when the slope unloading scheme with a slope thickness of 1.5m was adopted. Taking into account the quantity and cost of slope excavation, an optimal treatment plan has been developed, which has important guiding significance for the construction of slopes at tunnel entrances in mountainous areas.

Keywords: slope; Stability; analysis;

1 INTRODUCTION

During the construction of highways in mountainous and hilly areas, excavation, filling, and tunnel entrance slopes often occur, making slope stability a major engineering geological issue in the construction of highways in such areas. The landslide instability and failure of slopes is an important geological hazard, especially the instability of tunnel entrance slopes can cause local environmental damage.

The highway tunnel in a mountainous area of Hubei Province is located in the remaining veins of Qinling Mountains and Daba Mountain, and the tunnel is spread in an east-west direction, with a length of 322m on the left and a maximum buried depth of about 57m, and a length of 311m on the right and a maximum buried depth of about 69m. The width of the tunnel is about 12m, the height is about 10m, and the surrounding rock grade of the tunnel entrance section is V. level, and it is planned to set up a 5m open hole at the entrance and 20m ahead of the pipe shed support.

During the excavation and leveling process of the tunnel entrance, the uphill slope of the mountain slides and the surface cracks and deforms, seriously affecting the construction of the tunnel entrance section. Analyze the stability of tunnel slopes based on the actual engineering geological conditions, construction characteristics, and environmental conditions of the tunnel entrance[1]. Compare and select the un-

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loading plans for the slope of the tunnel entrance to determine the safety and reliability of their construction.

2 FACTORS AFFECTING THE STABILITY OF TUNNEL OPENINGS AND FAILURE MODES

The construction of the tunnel entrance section and the stability of the slope interact with each other. The excavation of the entrance section has disrupted the natural balance of the mountain, and further reduced the support at the foot of the mountain during tunnel construction, resulting in increased deformation of the side and front slopes during tunnel construction; At the same time, the deformation of the slope increases the pressure on the support structure of the entrance section, resulting in unfavorable stress on the support structure[2].

2.1 Factors Affecting the Stability of Tunnel Slopes

There are various basic factors that affect the stability of slopes. For tunnel slopes, the first step is to start from the geological structure and mechanical characteristics of the tunnel, and then combine specific engineering and natural factors to comprehensively analyze the characteristics and relationships of each factor. In general, the rock layers in the area where the slope is located are not of only one type, but are composed of two or more types of rock layers. Slope rock layers can be divided into hard rock and soft rock according to their compressive strength. Hard rock has good self stabilization performance, and the design slope can be steep, while soft rock is prone to instability and failure under steep slope conditions.

2.2 Failure Modes of Tunnel Slopes

There are many different failure modes for tunnel slopes of rock and soil slopes. The failure modes of tunnel slopes can be divided into planar sliding failure, wedge-shaped failure, collapse failure, local collapse failure, and pile collapse failure [3].

3 CHARACTERISTICS OF LANDSLIDES AT TUNNEL ENTRANCES

During the excavation and leveling process of the tunnel entrance, the mountain slope slides and the surface cracks and deforms, seriously affecting the construction of the tunnel entrance section. The landslide area is mainly divided into three platforms from bottom to top. The first level platform has an elevation of about 275m, the second level platform has an elevation of about 289m, and the third level platform has an elevation of about 298m. The landslide body is in a "dustpan" shape on the plane, with a main sliding direction of 75 °. The elevation of the rear edge of the landslide is 312m, the elevation of the front edge is 275 m, and the height difference between the front and rear edges is 37 m, leaning towards the eastern gully.

3.1 Characteristics of Sliding Body and Sliding Bed

The material composition of the landslide body is mainly Quaternary residual slope gravel soil, brown yellow, mainly composed of gravel soil. The gravel is composed of strongly weathered schist fragments, slightly dense to medium dense, with a soil to rock ratio of 2:8. The particle size of the gravel is generally 2-5cm, with a small amount exceeding 20cm. Among them, the soil to rock ratio of K3 and K4 boreholes is 6:4, with a high content of silty clay and a plastic shape. The thickness of this layer is 3.95-8.80m.The material composition of the sliding bed is schist, gray green, dark gray, with a metamorphic structure and sheet-like structure. The main mineral components are mica and quartz, and can be divided into strong weathering zone and medium weathering zone according to the degree of rock weathering.

3.2 Sliding Surface Characteristics

Based on the analysis of the material composition and deformation characteristics of the landslide body, the landslide is a soil landslide, and the sliding surface is the interface between soil and rock. The overall inclination angle of the sliding surface is 18 °, and the cohesive soil content at the soil rock interface is relatively high, presenting a soft plastic state. After encountering resistance, groundwater is soaked and softened to soften the soil. The rock mechanics test results of the tunnel entrance measured on site are shown in Table 1.

Table 1. Rock Mechanics Test Results at Tunnel Exit

sampling position	Natural moisture content/%	Natural density/(g/cm3)	Dry density/(g/cm3)	Cohesion force/(kPa)	Internal friction angle/(°)	Soil type
Left roof of tunnel entrance	14.8	2.02	1.760	68.08	26.53	Clay

4 SLOPE STABILITY ANALYSIS

The tunnel slope adopts the cutting and load reduction method, which reduces the overweight part of the sliding body in the sliding section caused by the landslide, reduces the sliding force of the sliding body, and makes the landslide tend to be stable.

4.1 Slope Stability Analysis Method

Calculate the slope stability coefficient using the strength reduction method. By continuously increasing the reduction factor and repeatedly analyzing the slope until it reaches the critical failure state, the obtained stability safety factor is [4].

4.2 Model Establishment and Selection of Calculation Parameters

The geological parameters used in the model simulation are shown in Table 2.

Table 2. Geological Parameters Table

index Soil quality	Density /(g/cm^3)	Deformation modulus/GPa	Poisson's ratio	shear strength	
				Cohesive force Cm/kPa	internal friction angle φ M/(°)
Surface gravel soil	23.0	3.55	0.40	5	16.8
Strongly weathered rock layers	26.0	7.94	0.32	175	31.5
Moderately weathered schist	27.0	12.0	0.28	300	38

When simulating, the entire model is divided into surface gravel soil layer, middle strongly weathered rock layer, and lower moderately weathered rock layer[5]. The surface gravel soil layer of the slope adopts an elastic model with a thickness of 6m; The strongly weathered rock layer is 6m, and the moderately weathered rock layer is 24m. Throughout the modeling process, solid elements are applied to simulate the entire slope structure[6].

4.3 Analysis Of Numerical Simulation Calculation Results

The stability coefficients of the tunnel entrance slope under natural conditions, excavation at the foot of the slope, and various engineering slope treatment states were obtained through numerical simulation, as detailed in Table 3.

Table 3. Calculation Results of Slope Stability Coefficient

Working conditions	Natural conditions	Cutting the slope at the foot of the slope	Cut the slope surface by 1m	Cut the slope surface by 1.5m	Cut the slope surface by 2m
safety factor	1.08	0.89	1.42	1.48	1.57

As the thickness of the cut slope increases, the safety factor of slope stability continues to increase, and the stability of the slope gradually strengthens.

The maximum vertical displacement of the slope under different working conditions was obtained through numerical simulation calculation, and the results are shown in Table 4.

Table 4. Maximum vertical displacement of slopes under different working conditions

Working conditions	Natural conditions	Cutting the slope at the foot of the slope	Cutting the slope surface by 1m	Cut the slope surface by 1.5m	Cut the slope surface by 2m
Vertical displacement/cm	19.55	21.54	2.53	1.54	1.68

The numerical simulation analysis method was used to calculate the stability of the slope. The calculation results showed that under natural conditions, the stability coefficient of the slope was 1.08, and the slope was in a limit equilibrium state, but also in a dangerous state at times; When excavating at the foot of the slope, the safety factor for the stability of the entrance slope is 0.98. It is obvious that the slope has been damaged and the entrance slope has started to slide; By using the slope cutting and load reduction method, the slope is cut. As the thickness of the cut increases, the safety factor of slope stability continues to increase, and the stability of the slope gradually strengthens. As the thickness of the slope cutting increases, the shear failure area of the slope gradually decreases, and the entire slope area becomes stable. The part where the failure occurs also gradually becomes self stable. The slope cutting unloading plan is beneficial for improving the stability of the slope, and the thickness of the slope cutting has an impact on the internal failure area of the slope[7].

Based on the analysis of the slope stability coefficient, the maximum vertical displacement of the slope is minimized when using the slope unloading scheme with a slope cutting thickness of 1.5m.

5 CONCLUSION

In engineering practice, it is necessary to analyze the stability of tunnel slopes based on the actual engineering geological conditions, construction characteristics, and environmental conditions at the tunnel entrance. After considering the quantity and cost of slope cutting earthwork, and comparing three slope cutting schemes, a slope cutting unloading scheme with a slope cutting thickness of 1.5m was adopted. The maximum vertical displacement of the slope was the smallest, and the effect was the best. Further research is needed to consider the impact of both water and slope protection reinforcement forms on stability.

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