Study on the Evaluation of Surrounding Rock Stability and the Criterion of Limit Displacement of Fractured Stratum Tunnel

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Abstract. Displacement of fracture formation for highway tunnel surrounding rock stability and limit the problem of value, of deep buried tunnel by FLAC3D and the plane model is established, through strength subtraction, get tunnel vault subsidence and peripheral convergence value, secondly, based on the presence of fault cases surrounding rock ultimate shear strain analysis, it is concluded that with the loss of the reduction factor, tunnel inverted arch and arch foot site first achieve ultimate strain value and the limits of tunnel surrounding rock integrity buckling safety factor is 1.40, the fracture formation of tunnel surrounding rock stability safety factor than under the condition of no fault, lower limit displacement value than under the condition of no fault.

1. Introduction

As the number of tunnel projects in our country is increasing, the length of tunnel construction is getting longer and longer, the span of the tunnel is getting larger and larger, the geological conditions encountered are becoming more and more complicated, and the difficulty of construction is also increasing. Therefore, during the excavation and construction of tunnels and other underground projects, it is inevitable to encounter a variety of bad geology, such as swelling rock mass, loess layer, karst caves, fault fracture zone., among these bad geology , the influence of fault fracture zone on the stability of tunnel surrounding rock is more common, and it has always been an important concealed structure considered in the stability study of tunnel engineering.

Verruijt A, Booker J R [1] proposed the vertical displacement formula of tunnel elliptic deformation based on Poisson's ratio. Wei-I. Chou and Antonio Bobet [2] concluded through long-term observation of land subsidence that most of the land subsidence occurs within three or four radius of the tunnel. Sotirios S. Vardakos et al. [3] studied the mechanical characteristics of TBM tunnelling method and the variation law of surface settlement through UDEC discrete element simulation. Attewell [4] predicted the maximum settlement volume at the center of the tunnel while pointing out the influencing factors of the settlement trough. Vermeer P A[5] et al. pointed out the important influence of the first excavation and simulated the gradual excavation of the tunnel under two working conditions. Chen Xianguo [6] specifically studied and analyzed the tunnel structure, rock mass instability process, mechanism and its influencing factors, discussed the rock mass instability phenomenon, and studied the instability...
phenomenon of the huge tunnel system through the joint analysis of different disciplines. Liu Bo [7] used Midas to simulate three-dimensional tunnel excavation, evaluated the stability of surrounding rock according to displacement and rate, and verified the correctness of the conclusion through comparative analysis. Zhang Guomao [8] analyzed and studied the mechanism and influencing factors of surface deformation and optimized the support methods and parameters in the construction process. Ling Jianming et al. [9] established the unloading damage analysis theory to analyze the stability of tunnel surrounding rock by studying the significant time effect of surrounding rock damage and applying it to Qingdao metro to achieve good results. Lu Chunyang [10] combined with the strength reduction method of Qingdao Metro Line 3 to analyze the stability of the tunnel, and optimized the support based on the safety factor.

In the study of fault tunnel, the domestic and foreign scholars have focused on about the fault of the stability analysis of surrounding rock of the tunnel and tunnel monitoring measurement, the displacement of surrounding rock stability evaluation and the limit values of standard research is less, therefore, in this paper, based on the analysis of the existing research situation, through 3 d numerical simulation analysis method, displacement of surrounding rock stability evaluation and limit standard values are put forward.

2. Establishment of numerical analysis model

2.1 Calculation and analysis of working conditions and mechanical parameters selection
Fracture formation tend to lower levels of surrounding rock and high ground stress, calculation of rock mechanics parameters determination shall be carried out in accordance with the V level of surrounding rock, assuming that horizontal stress in the vertical stress of surrounding rock of level 2 times, calculated by strength reduction method still numerical limit analysis, the rate of reduction factor in accordance with the value of 0.05, closer to the damage rate of encryption, and value range of 1.0 ~ calculation convergence, surrounding rock mechanics parameter values are shown in table 2, at 100 m tunnel buried deep calculation and analysis, for example, under the condition of buried depth calculation method for the other in accordance with this.

| Surrounding rock level | Severe (KN/m³) | Deformation modulus (GPa) | Poisson's ratio | Internal friction angle (°) | Cohesion (MPa) |
|------------------------|----------------|--------------------------|----------------|--------------------------|---------------|
| I                      | >26.5          | >33                      | <0.2           | >60                      | >2.1          |
| II                     | 20~33          | 0.2~0.25                 | 50~60          | 1.5~2.1                  |
| III                    | 26.5~24.5      | 6~20                     | 0.25~0.3       | 39~50                    | 0.7~1.5       |
| IV                     | 24.5~22.5      | 1.3~6                    | 0.3~0.35       | 27~39                    | 0.2~0.7       |
| V                      | 17~22.5        | <1.3                     | 0.35~0.45      | 20~27                    | 0.05~0.2      |
| VI                     | 15~17          | <1.0                     | 0.45~0.5       | <20                      | <0.2          |

In order to obtain the ultimate displacement under the condition of Grade V surrounding rock through numerical limit analysis, the most unfavorable condition of Grade V surrounding rock is calculated, that is, the low value of deformation and strength under the condition of Grade V surrounding rock is used for calculation. The calculation parameters of surrounding rock are taken as The values are shown in Table 2 below.
Table 2. Values of mechanical parameters of surrounding rock

| Surrounding rock level | Severe \((\text{KN/m}^3)\) | Deformation modulus \((\text{GPa})\) | Poisson's ratio \(\mu\) | Internal friction angle \(\phi\) | Cohesion \((\text{MPa})\) |
|------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| V                      | 17              | 0.9             | 0.45            | 20              | 0.05            |

The mechanical parameters of the support structure are selected. The surrounding rock in the fault fracture zone is poor. Generally, the initial support design is relatively strong. The initial support adopts 30cm thick C25 shotcrete. The initial support adopts the elasto-plastic model for the mechanical parameter values shown in Table 3.

Table 3. Value table of initial support mechanical parameters

| The Serial Number | The Parameter Name        | Symbol | Unit   | The Values |
|-------------------|---------------------------|--------|--------|------------|
| 1                 | Modulus of Elasticity     | \(E_c\) | GPa    | 22.95      |
| 2                 | Poisson's Ratio           | \(\mu_c\) | /      | 0.2        |
| 3                 | Cohesive Force            | \(C_c\) | MPa    | 2.57       |
| 4                 | Angle of Internal Friction| \(\phi_c\) | °      | 55.76      |
| 5                 | Severe                    | \(\gamma_c\) | KN/m³  | 22         |

2.2. Calculation model establishment

The calculation adopts the stratum structure method, and establishes the calculation and analysis plane model with the help of FLAC3D software. The left and right sides and top and bottom boundaries of the deep buried tunnel model are taken as 3~5 times the diameter of the hole, so the calculation model size is 120m (width) * 120m (height) * 1m (length), the front and back, left and right, and bottom of the model adopt displacement constraint boundary conditions, and the surrounding rock at the top is converted into a load applied to the top of the model, with a value of 0.95 MPa. According to the design data, the grade V surrounding rock section is constructed by the full-face method, and the calculation is carried out by the two-step method for excavation. The calculation model is shown in Figure 1.

![Figure 1. Numerical calculation analysis model](image-url)
3. Analysis of calculation results
In order to clearly and intuitively display the change law of surrounding rock deformation with the strength reduction coefficient, obtain the limit value of the tunnel surrounding rock vault settlement and surrounding convergence, and extract the tunnel vault settlement and surrounding convergence value when the strength reduction coefficient is not as shown in the figure. 2 shown.

![Figure 2. The law of deformation of tunnel surrounding rock along with strength reduction coefficient](image)

The comparative analysis of the ultimate shear strain of tunnel surrounding rock with or without faults under different reduction factors is shown in the following figure:

|          | No fault | Faulted |
|----------|----------|---------|
| K=1.0    | ![Screenshot](image) | ![Screenshot](image) |
| K=1.2    | ![Screenshot](image) | ![Screenshot](image) |
It can be seen from Figure 3 that as the reduction factor decreases, the tunnel invert and arch toe parts first reach the ultimate strain value, and the surrounding rock partially cracks, loosens or spalls, and then as the reduction factor further increases, the ultimate strain is reached. The area gradually increases and gradually extends to the arch. When the reduction factor is equal to 1.40, the ultimate strain area of the surrounding rock on the tunnel side is connected, and the surrounding rock and supporting structure of the tunnel are in a critical state of overall instability, and its instability failure mode because the failure of the vault and the bottom of the inverted arch drives the failure of the side wall, and finally leads to the overall collapse and collapse. Due to the influence of horizontal tectonic stress, the instability and failure shape of the surrounding rock under the condition of no fault is compared and analyzed. The two are completely opposite, under the condition of no fault. It is horizontally flat, and vertically flat under fault conditions. At the same time, it can be seen from Figure 2 that under the calculation conditions of the fractured strata, with the continuous increase of the reduction coefficient, the deformation of the...
tunnel surrounding rock and supporting structure gradually increases. When the reduction coefficient is less than 1.40, the surrounding rock The deformation of the supporting structure increases linearly with the change of the reduction coefficient. When the reduction coefficient is equal to 1.40, the curve change rate has an inflection point, and the curve slope of the surrounding rock and supporting structure changes with the increase of the reduction coefficient Gradually increase, the risk of instability and collapse of the surrounding rock increases, which is basically consistent with the results of the ultimate strain analysis. Therefore, the deformation value of the surrounding rock and supporting structure when the reduction factor is equal to 1.40 can be used as the tunnel construction safety The monitored limit displacement values, the limit displacement values of the dome settlement and the surrounding convergence are 43.406mm and 70.903mm, respectively, and the limit safety factor for the overall instability of the tunnel surrounding rock is 1.40, as shown in Table 4.

Table 4. Value table of limit displacement of tunnel in fractured stratum

| Surrounding rock level | Buried depth (m) | Stress ratio | Safety factor | Absolute value of limit displacement (mm) | Relative limit displacement (%) |
|------------------------|------------------|--------------|---------------|------------------------------------------|---------------------------------|
|                        |                  |              |               | Vault settlement                         | Peripheral convergence          |
| V                      | 100              | 2.0          | 1.40          | 43.406                                   | 79.903                          |

4. Conclusion

As the reduction factor decreases, the invert and arch toe parts of the tunnel first reach the ultimate strain value, and the surrounding rock partially cracks, loosens or spalls. As the reduction factor increases, the area reaching the ultimate strain gradually increases, gradually The arch is extended and finally reaches the critical instability state of the tunnel surrounding rock and supporting structure.

When the reduction factor is 1.40, the ultimate strain area of the surrounding rock on the tunnel side is connected, and the surrounding rock and supporting structure of the tunnel are in a critical state of overall instability, that is, the ultimate safety factor for the overall instability of the surrounding rock of the tunnel is 1.40.

When the reduction factor is 1.40, the deformation value of the surrounding rock and supporting structure can be used as the limit displacement value of the tunnel construction safety monitoring. The limit displacement values of the dome settlement and surrounding convergence are 43.406mm and 70.903mm, respectively.

By comparing and analyzing the calculation results with and without faults, the stability of the tunnel surrounding rock in the fractured stratum is lower than the safety factor under the condition of no fault, and the limit displacement value is larger than that under the condition of no fault.

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