Study on The Evaluation of Surrounding Rock Stability and Limit Displacement of High-Pressure Stratum Tunnel

Xiaolong Zhang¹, Hongyan Guo², Lianchao Ye², ³*, Dengzhi Tang ¹

¹ Yunnan infrastructure investment Co., Ltd, Kunming, Yunnan, 650000, China
² China Merchants Chongqing Communication Research & Design Institute Co., Ltd, Chongqing, 400067, China
³ School of Civil Engineering, Chongqing Jiaotong University, Chongqing, 400074, China

* Corresponding author’s e-mail: guohongyan@cmhk.com

Abstract. Aiming at the problem of the value of the stability and limit displacement of the surrounding rock of highway tunnel with high pressure, the method of numerical limit analysis is adopted, and one of the working conditions is analyzed in detail. Firstly, this paper adopts the formation structure method to calculate and establish a plane model for calculation and analysis with the help of FLAC3D software, so as to study the influence of reduction coefficient on surrounding rock deformation and its law. Secondly, by holding other variables unchanged, two different working conditions with and without high water pressure are compared and analyzed, and it is obtained that the ultimate safety factor of the integrity instability of surrounding rock of the formation tunnel with high water pressure is 1.30, and that of the integrity instability of surrounding rock of the formation tunnel without high water pressure is 1.80. Finally, the results are compared and analyzed and it is found that the stability of tunnel surrounding rocks with high pressure is lower than that without high pressure, and the limit displacement is greater than that without high pressure.

1. Introduction

With the rapid development of information and intelligent technology, making the tunnel construction safety management toward "scientific prevention and precise Shi Ce" direction, however the core of the solution to the tunnel construction security is to study the stability of the scientific and reasonable evaluation method, and developed with the intelligent monitoring and early warning and equipment during the construction process, make the tunnel construction process is scientific, reasonable, safe, reliable, the construction risk of preventable and controllable. However, as a result of underground rock mass is a kind of natural geological factors of complex geological body, has the very strong variability and randomness, cause the stability of surrounding rock of tunnel engineering research more complicated than the ground buildings, through high pressure bad geological period of performance is more outstanding, so that the lack of scientific and reasonable methods to evaluate the stability of surrounding rock and standard of monitoring and early warning system, in addition, the tunnel construction environment is complex, many interference factors, cause the development and application of the intelligent monitoring and early warning equipment is blocked, need breakthrough technology bottlenecks. In terms of using the monitoring and early warning system to forecast geological disasters, the United States is one of the early countries to enter into this field. Through comprehensive processing
of information, the United States anticipates accidents and disasters, and announces the early warning results to the public in a timely manner [1-5]. Maersk et al. [6-9] studied the current situation and comprehensive influencing factors of water inrush disaster in karst tunnel, and provided early warning standards for monitoring objects such as water pressure, water quality, surrounding rock displacement and steel arch stress, put forward three-level monitoring and early warning of water inrush disaster in karst tunnel, and developed the tunnel water inrush disaster early warning system.

Set up specifically for the tunnel in karst region, in the high water pressure real-time monitoring and early warning system is an important developing trend of disaster prevention and control technology, especially the critical warning value of research is to determine an important foundation for successful operation monitoring and early warning, but in specific to tunnel surrounding rock stability evaluation and ultimate displacement value standard to determine the above research is not enough in-depth, this paper aims to tunnel through clear health monitoring and early warning system, on the basis of function and operation of hope for the surrounding rock subjected to high water pressure condition monitoring and early warning research to offer help.

2. Project Overview

The stability of surrounding rock of tunnel engineering refers to the mechanical mechanism of deformation and instability of surrounding rock caused by stress redistribution after excavation of the tunnel. Because underground rock mass is a geological body with complicated natural geological factors and strong variability and randomness, the study on the stability of surrounding rock of tunnel engineering is more complicated than that of surface buildings, so various stability analysis methods appear in the process of practice. The stability analysis method of surrounding rock has experienced the development process of "empirical judgment - theoretical analysis - numerical calculation - numerical limit analysis", which is corresponding to the practice characteristics of tunnel engineering in different periods, people's cognition level of tunnel engineering and the development of computing technology.

3. Calculation and Analysis of Working Conditions and Mechanical Parameters Selection

As an effective means to study geotechnical problems, numerical simulation has been used more and more in civil engineering design, geotechnical stability and basic analysis of geotechnical engineering. At present, the main use of numerical method in geotechnical engineering structure are: the finite element method (FEM) and boundary element method (BEM), the finite difference method (FPM), the joint element method (JE), the block theory (BT), discontinuous deformation analysis (ODM), fast Lagrangian method (FLAC), static synchronous relaxation discrete element method (BSM), no network galerkin method (FGM) and numerical manifold method (MM), etc. Finite element method is widely used and is one of the most widely used methods at present. In the past, some scholars used numerical analysis methods to simulate the actual project and obtained some results: Shi Shiyong [10] et al. used the finite element software Ansys to simulate and analyze the influence of different positions, distances and sizes of karst caves around the tunnel on the stability of surrounding rock; Jin-shan lei [11] in a certain range of Guangzhou metro, the subway construction such as excavation background, using the finite element software MIDAS/GTS three-dimensional elastic-plastic numerical simulation research, the whole process of dynamic construction simulation under different working conditions (soil hole shape, location, size, and the distance between adjacent tunnel, etc.) the subway shield construction process of the stability of surrounding rock and the influence of the surface subsidence; Shao Zhushan et al. [10] discussed the variation of arch roof settlement with excavation time, used ABAQUS software to numerically analyze the variation trend of arch roof and surrounding displacement after tunnel excavation, and studied the influence of mechanical property parameters of surrounding rock on tunnel deformation and stability. Based on the comprehensive consideration of monitoring data and numerical results, some useful theoretical suggestions are provided for the subsequent safe tunnel construction.

This calculation adopts the formation structure method and establishes the plane model of calculation and analysis with the help of FLAC3D software. In this paper, the buried depth of the tunnel is 100m as an example for calculation and analysis. Other calculation methods are consistent with this, and we will
not list them one by one here. Surrounding rock mechanics parameters determination shall be carried out in accordance with the V level of surrounding rock, groundwater used in grouting of the lateral equivalent nodal force is calculated, the calculated vault water pressure of 0.5 MPa, with depth, the linear increase (0.01 MPa/m), the surrounding rock stability evaluation still numerical limit analysis by using the method of strength reduction, reduction coefficient of the rate of change of value in accordance with 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 1, for the numerical limit analysis for different level of surrounding rock under the condition of the limit displacement. The most unfavorable conditions of surrounding rocks at all levels were taken, that is, the low values of deformation and strength at different levels of surrounding rocks were taken for calculation. The computational parameters of surrounding rocks at all levels were shown in the table below.

Table 1. Mechanical parameters of initial support

| The Level of Surrounding Rock | Severe $\gamma$ (KN/m$^3$) | Deformation Modulus E (GPa) | Poisson's Ratio $\mu$ | Angle of Internal Friction $\psi$ (°) | Cohesive Force c (MPa) |
|------------------------------|-------------------------|----------------------------|----------------------|-----------------------------------|----------------------|
| III                          | 24.5                    | 6                         | 0.3                  | 39                                | 0.7                  |
| IV                           | 22.5                    | 1.3                       | 0.35                 | 27                                | 0.2                  |
| V                            | 17                      | 0.9                       | 0.45                 | 20                                | 0.05                 |

As for the mechanical parameters of the support structure, the surrounding rocks of the fault fracture zone are poor, and the initial support design is generally strong. The initial support adopts 30cm thick C25 shotcrete, and the mechanical parameters of the initial support using the elastic-plastic model are shown in Table 2.

Table 2. Mechanical parameters of initial support

| The Serial Number | The Parameter Name | Symbol | Unit | The Values |
|-------------------|-------------------|--------|------|------------|
| 1                 | Modulus of Elasticity | $E_e$ | GPa  | 22.95      |
| 2                 | Poisson's Ratio    | $\mu_e$ | /    | 0.2        |
| 3                 | Cohesive Force     | $C_e$  | MPa  | 2.57       |
| 4                 | Angle of Internal Friction | $\phi_e$ | °    | 55.76      |
| 5                 | Severe             | $\gamma_e$ | KN/m3 | 22         |

4. Model Building and Result Analysis

4.1. Establishment of Computational Model

Stratigraphic structure is adopted for calculation method, calculation analysis of plane model is established by means of FLAC3D, deep buried tunnel model and top boundary take 3 ~ 5 times at the bottom of the hole diameter, so the calculation model is 120 m (width) * 120 m * 1 m (long) (high), about before and after the model, and USES the displacement constraint at the bottom of the boundary conditions, the top in the conversion of surrounding rock loading on the top of the model, the value is 0.95 MPa, calculation model is shown in Figure 1.
4.2. Analysis of Calculation Results

In order to clearly and intuitively display the variation rule of surrounding rock deformation with strength reduction coefficient, the limit value of surrounding rock arch settlement and peripheral convergence is obtained, and the arch settlement and peripheral convergence value of tunnel when unstrength reduction coefficient is extracted, as shown in Figure 2.

![Figure 1. numerical calculation analysis model](image)

![Figure 2. Shows the variation pattern of surrounding rock deformation with strength reduction coefficient](image)

Under different reduction coefficients, the ultimate shear strain of surrounding rock of the tunnel with or without high water pressure is compared and analyzed as shown in the figure below:
| No High Pressure | A High Water Pressure |
|------------------|-----------------------|
| K=1.0            | K=1.0                 |
| K=1.2            | K=1.1                 |
| K=1.4            | K=1.2                 |
| K=1.6            | K=1.3                 |
The Figure 3 shows that with the loss of the reduction factor, and inverted arch tunnel wall parts achieve ultimate strain values, the first local fracture of surrounding rock, loose or flake, then with further increase of reduction factor, to achieve the ultimate strain area increases gradually, gradually to the deep and the arch vault, when the reduction coefficient equals 1.30, the ultimate strain of tunnel surrounding rock area, as well as the instability of surrounding rock and supporting structure in the whole critical state, when the reduction coefficient equals 1.30, the computational convergence, the overall buckling failure, the buckling failure mode for the sidewall and inverted arch destruction drive the vault, And that leads to the collapse of the whole thing. Due to the presence of external water pressure, the stability and safety coefficient of surrounding rocks significantly decreased. However, as the external water pressure increased with the depth, the shape of the tunnel's failure area was different from that without external water pressure. The failure area at the bottom of the invert was significantly larger than that at the arch, and the failure area was smaller at the top and larger at the bottom, which was "trapezoidal". Can be seen from Figure 3 at the same time, high pressure formation under the condition of the working condition of the calculation, with the increasing of reduction factor, deformation of tunnel surrounding rock and supporting structure gradually increases, when the reduction coefficient is less than 1.30, the deformation of surrounding rock and supporting structure with the change of the reduction factor of approximate linear growth, when the reduction coefficient equals 1.30, the curve rate of inflection point, the surrounding rock and supporting structure with the increase of reduction factor curve slope increases gradually, the change rule of surrounding rock instability increased risk of collapse, this is consistent with the analysis of the ultimate strain. Therefore, the deformation value of surrounding rock and support structure when the reduction coefficient is equal to 1.30 can be taken as the limit displacement value of tunnel construction safety monitoring; the limit displacement value of arch settlement and peripheral convergence are 31.775mm and 42.249mm respectively; the limit safety factor of tunnel surrounding rock's overall instability is 1.30, as shown in Table 3.

| The Level of Surrounding Rock | Buried Depth (m) | External Water Pressure on The Vault (MPa) | Absolute Value of Ultimate Displacement (mm) | Relative Limiting Displacement (%) |
|------------------------------|-----------------|------------------------------------------|---------------------------------------------|-----------------------------------|
|                              |                 |                                          | Safety Factor | Vault Subsidence | Peripheral Convergence | Vault Subsidence | Peripheral Convergence |
| V                            | 100             | 0.5                                      | 1.30          | 31.775          | 42.249                 | 0.397           | 0.352 |
| V                            | 100             | No High Pressure                         | 1.80          | 32.894          | 57.797                 | 0.411           | 0.482 |
5. Conclusion

Based on the numerical limit analysis, the stability evaluation standard and failure mode of surrounding rock in tunnels with high water pressure are put forward, and reasonable monitoring and early warning standards are put forward for fractured formations and high water pressure formations.

The stability of surrounding rock of the tunnel in the high pressure stratum is lower than the safety factor under the condition without high pressure, and the limit displacement value is higher than that under the condition without high pressure.

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