Research on Stress Monitoring Index of Hydraulic Tunnel Lining Based on Numerical Simulation

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Abstract. In order to study the lining stress index of hydraulic tunnel, this paper mainly analyzes the safety monitoring data of a hydraulic tunnel, uses ANSYS finite element software for modeling, uses Flac3D software for numerical calculation, and uses numerical analysis method to develop hydraulic tunnel G1 -18 Stress monitoring indicators for lining of section. The results show that the actual measured value is basically within the control range of the data calculation value. When determining the monitoring index of the steel bar stress, the result of the numerical calculation can be used as the index, but the monitoring index of the top steel bar meter should use the maximum monitoring value as the index.

1. Introduction

The regional structural water shortage in our country is becoming more and more obvious with the development of society. People adjust the flow of water resources and construct inter-basin water transfer projects with large investment and large benefits, such as hydraulic tunnels, to transfer water from the water-rich area to the lack of water resources. To solve this problem. The destruction of a hydraulic tunnel is a process from gradual change to abrupt change. At the beginning, some local defects may appear in the tunnel. When these defects develop to a certain degree, the safety performance of the tunnel deteriorates rapidly, causing damage. Therefore, if the safety monitoring data of the tunnel can be collected in time, and the safety performance of the tunnel can be analyzed and evaluated, and the problems are dealt with or strengthened in time, the destruction can be avoided. Monitoring indicators, as the most important safety evaluation criteria, are the key indicators for evaluating and monitoring the safety of water conveyance tunnels, and the basis for establishing a tunnel prediction and early warning system. It can not only quickly determine the safety status of the tunnel, but also allow managers to monitor the safe operation of the water delivery tunnel based on evidence. many scholars have made useful explorations in the safety monitoring indicators of hydraulic tunnels[1-6].

2. Project Overview

The length of a hydraulic tunnel project is 90km, the geological conditions and rock structure are complex, and the maximum depth of the tunnel is 1000m. In section 33+810~34+880, the lithology of the surrounding rock is Cretaceous intrusive potash granite, hard rock, slightly weathered to fresh rock, which is located outside the potash granite rock plant. The impact is not very large, the rock mass integrity is poor, the rock mass is mostly inlaid structure, the surrounding rock type in this section is type IIIa. It is speculated that the cave chamber is mainly dry to wet, with local dripping. The section selected for modeling this time is buried at a depth of 300m, the section number is G1-18, the pile
number is 33+916, and the surrounding rock type is class IIIa surrounding rock. The geological profile is shown in figure 1.

![Geological profile](image)

**Figure 1. Geological profile.**

3. **Finite element analysis of tunnel lining structure**

3.1. **Basic assumptions and parameter selection**

When using the finite element method to establish the tunnel and surrounding rock model, it needs to be simplified and assumed to a certain extent: ① The rock around the tunnel is a single wall rock; ② The initial stress of the surrounding rock only considers the self-weight stress; ③ The rock is an ideal elastic material, following the Moore-Coulomb yield criterion.

In this calculation section, the surrounding rock parameters are taken from the parameters given by the geological survey, see table 1

| Section position | Surrounding rock category | Coefficient of friction | Cohesion (MPa) | Deformation modulus (Gpa) | Poisson's ratio | density (g/cm³) |
|------------------|---------------------------|-------------------------|----------------|--------------------------|----------------|----------------|
| 33+916           | IIIa                      | 1                       | 1.1            | 15                       | 0.25           | 2.6            |

3.2. **Model building**

In this model, the hydraulic cross section is in the shape of a horseshoe, the height of the hair hole is up to 8.2m, and the burial depth is 300m. Because the finite element method discretizes in a limited area, in order to avoid excessive errors due to discretization, a large enough calculation range must be taken. Therefore, according to the general calculation range convention, the calculation range is not less than the rock engineering contour size 3 to 4 times. According to the basic dimensions of the tunnel, the center of the tunnel is used as the center position in the entire model. The horizontal and vertical length ranges from -30m to 30m, and the longitudinal depth is 30m.

Considering the influence of the burial depth of the cave on the boundary conditions, the constraining boundary conditions of the model are: constraining the horizontal displacement of the model in the horizontal direction, the longitudinal displacement of the front and rear, and the displacement of the bottom, and applying a downward load of 12 MPa on the model.

The meshing adopts Sweep in ANSYS to divide the solid model. The intersecting entities need to be completely divided into single entities. Grid division is also based on the principle of small to large, first to the smallest entity grid division, from small to large, in order to ensure that the grid one-to-one correspondence. In the process of grid division, there is a grid concentration situation. After
investigation, it was found that when two entities are performing Boolean operations, due to the problem of software calculation accuracy, two coincident lines will be generated at the same position. Using the Merge command, the two coincident straight lines are merged, and the entity is meshed to obtain a continuous corresponding mesh without grid concentration. After building the model, import Flac3D as shown in figure 2. Establish a three-dimensional stratum model and use solid elements to simulate lining. In stratum analysis, the surrounding rock parameters obtained by geological survey are used as the analysis data to ensure that the stress of the lining can be truly analyzed.

The tunnel lining is affected by the surrounding rock pressure and the groundwater pressure. Figure 4 is the horizontal displacement map of the lining. It can be clearly seen in the figure that under the external pressure load, the lining on both sides produces inward displacement values of 2.97mm and 2.91mm respectively. The vertical displacement of the lining is shown in figure 5. The top lining produces a settlement with a larger settlement value of 5.41mm, and the bottom lining produces a bulge phenomenon with a displacement value of 4.84mm.
It can be seen from figure 6 that the bottom of the lining has the greatest horizontal force, reaching 8.18MPa. Since the external load increases with the increase of the burial depth, the horizontal stress distribution is the smallest on both sides, and the top load of the lining is smaller than the top load, but it is much higher than the lining on both sides of the tunnel. It can be clearly seen from figures 7 that the stress of the tunnel lining on both sides has reached the maximum stress of 11.75 MPa due to the gravity of the upper surrounding rock. Combined with the horizontal element stress, the stress on the lining on both sides of the tunnel is the maximum value in the overall lining.

4. Preparation of stress index of tunnel lining

The layout of G1-18 monitoring section reinforcement gauge for a project is shown in figure 8. Through the analysis of the monitoring data, the change trend of steel bar stress with time is obtained, as shown in figure 9 to figure 12.
The steel stress process line graph can be used to analyze the stress change trend of the concrete. The stress of the steel bar is basically not affected by the temperature change. The pressure of the outer ring concrete after hardening begins to gradually increase after being hardened. The inner ring concrete is stressed except for the top, the values are smaller. The monitoring data values of the four measuring points outside 01, 03, 05 and 07 are compared with the numerically calculated stress values. The results are shown in Table 2.

| Left side lining (MPa) | Top (MPa) | Right side lining (MPa) | Bottom (MPa) |
|------------------------|-----------|-------------------------|--------------|
| Rebar measurement      | 10.36     | 12.42                   | 11.63        |
| Numerically calculated value | 11.75   | 8.01                    | 11.75        |
|                        |           |                         | 8.18         |

It can be seen from the comparison that in the numerical calculation results, the theoretical calculation values of the concrete on the left, right, top and bottom are basically the same, because the load distribution, that is, the stress of the lining structure is symmetrical in the model analysis. However, from the actual observation data, the stress of the lining structure is not symmetrical, the stress values on the left and right sides are quite different, and the stress value on the top is significantly greater than the bottom, indicating that the stress state of the rocks around the tunnel is...
not evenly distributed. From the comparison results, the actual measured value is basically within the control range of the data calculation value. When determining the monitoring index of the steel bar stress, the result of the numerical calculation can be used as the index, but the monitoring index of the top steel bar meter should use the maximum monitoring value as the index. With the increase of monitoring data, the monitoring indicators for long-term observations need to be adjusted, combined with statistical analysis methods to modify the monitoring indicators.

5. Conclusion

(1) In this paper, the model is established by Ansys software, and Flac3D software is used to calculate, and the stress of the tunnel lining under the combined action of surrounding rock pressure and groundwater pressure is obtained, and the stress-strain diagram is obtained. Provide a reference for the design of the actual engineering support structure.

(2) It can be seen from the displacement change diagram that the vertical displacement of the tunnel lining is much greater than the horizontal displacement. The vertical displacement at the top of the lining is larger than the vertical displacement at the bottom of the lining, and uneven deformation will occur. In addition, due to the non-uniformity of the surrounding rock stress state, the horizontal displacement of the left lining of the tunnel is greater than that of the right lining. It is appropriate to monitor and strengthen the lining on both sides, top and bottom of the tunnel to prevent damage.

(3) In the numerical calculation results, the theoretical calculation values of the concrete on the left, right, top, and bottom are basically the same, because the load distribution, that is, the stress of the lining structure is symmetrical when the model is analyzed. However, from the actual observation data, the stress of the lining structure is not symmetrical, the stress values on the left and right sides are quite different, and the stress value on the top is significantly greater than the bottom, indicating that the stress state of the rocks around the tunnel is not evenly distributed. The actual measured value is basically within the control range of the data calculation value. When determining the monitoring index of the steel bar stress, the result of the numerical calculation can be used as the index, but the monitoring index of the top steel bar meter should use the maximum monitoring value as the index.

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