Simulation Study on Surrounding Rock Deformation of Strongly Weathered Sandstone Tunnel Supported by Pipe Shed

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Abstract. Strongly weathered sandstone belongs to the category of soft rock and is easily deformed and damaged during tunnel excavation. In order to explore the control effect of the pipe shed advanced support on the deformation of the strongly weathered sandstone tunnel. This paper uses FLAC3D software to simulate the excavation and support of strongly weathered sandstone, and compares the deformation before and after the support. Through analysis and research, it is found that the pipe roof support has greatly improved the amount of deformation and horizontal convergence of the tunnel vault. The dome subsidence and horizontal convergence are reduced from 162mm and 126mm to 19mm and 13mm respectively, and the reduction is 143mm and 113mm respectively. It can provide experience for similar projects in the future.

1. Introduction

The strongly weathered sandstone distributed in the central and western regions of my country has low strength and extremely poor stability. It is extremely prone to damages such as wall rock deformation and collapse, which brings difficulties to tunnel construction. Cuiying Zhou, Huanjun Bi, Nan Li, Wanxiang Lei, Yang Sun\textsuperscript{[1-5]} have done a lot of research on the strength, deformation mechanism, excavation method and support measures of strongly weathered sandstone. However, with the continuous development of science and technology, there is still a lot of research space in its deformation mechanism and supporting measures.

In order to explore the failure law of the large deformation of the surrounding rock of the strongly weathered sandstone, and study the reasonable excavation method and support system. In this paper, a tunnel on a certain expressway in Ningxia is used as the engineering support, combined with the actual project, and the tunnel excavation and support will be simulated through FLAC3D. Based on the results, explore its dome subsidence and horizontal convergence under the pipe roof advanced support, and...
compare the change with the displacement before the unsupported. This paper is based on this research to further enrich the theoretical research and construction technology of highway tunnels in strongly weathered sandstone formations.

2. FLAC3D Overview

2.1. Introduction to FLAC3D
FLAC3D is a numerical simulation software developed by Itasca in the United States. It is a three-dimensional finite difference software. FLAC3D includes 11 material constitutive models (empty element model, three elastic models, seven plastic models), 5 calculation modes (static, dynamic, creep, seepage, temperature) and multiple boundary conditions. It forms a three-dimensional grid through the unit polyhedral structural unit to fit the actual structure. When building the model, a calculation model is composed of a number of three-dimensional unit bodies, and each unit body is divided into four-node tetrahedrons during calculation. The tetrahedron transmits stress and strain to other tetrahedrons through four nodes. When a force is applied to a node, the force affects the surrounding nodes. The software calculates the displacement through the equation of motion, and then converts the three-dimensional problem into a two-dimensional problem to find the strain through Gaussian integration, and finally obtains the stress through the constitutive equation. In general, a hybrid discrete method is used to decompose the three-dimensional element into several tetrahedral elements. With the application of external force, the material deforms, and at the same time the mesh also changes. [6]

3. Establishment of Pipe Shed Support Model and Analysis of Results
The tunnel traverses the strongly weathered sandstone stratum, the surrounding rock is grade V. The rock layers from top to bottom are silty clay, loess, fully weathered sandstone, strongly weathered sandstone, sandy mudstone, moderately weathered mudstone, moderately weathered calcareous mudstone with marl [7]. The tunnel section is a circular section, the radius of the tunnel is 5m, and the buried depth is 25m. When building a model, the size of the model is best between 3D and 5D. The left and right sides of the model are each 50m, the total height of the model is 60m, and the width of the model is 10m. A three-dimensional model can be established through the data, as shown in Figure 1.

![Figure 1](image)

Figure 1: Tunnel model diagram

3.1. Parameter selection
The surrounding rock conditions are based on the actual project, so the specific parameters of each rock layer are shown in Table 1.

| Rock formation | Elastic modulus | Shear modulus | Cohesion (kPa) | Internal friction angle | Density (kg/m³) |
|----------------|-----------------|---------------|---------------|-------------------------|----------------|
| Silty clay     | 1.80e7          | 1.20e7        | 1.87e4        | 22                      | 1500           |
| Loess          | 8.01e8          | 3.00e7        | 2.15e4        | 25                      | 1600           |
The pipe shed support has a significant effect in controlling the deformation of the tunnel, so the pipe shed advanced support is selected for the initial support. The secondary lining mainly adopts C30 shotcrete as the main supporting measure. They work together to form a composite lining. The specific parameters are shown in Table 2.

|                         | Elastic Modulus | Shear Modulus | Poisson's ratio | Density |
|-------------------------|-----------------|---------------|-----------------|---------|
| Initial support         | 4.3e10          | -             | 0.35            | 2700    |
| Secondary lining        | 5.0e10          | 4.01e10       | -               | 2700    |

3.2. Comparative analysis of deformation

3.2.1. Overall deformation analysis

Figure 2 and Figure 3 are the overall displacement diagrams of the model before support and after pipe shed support. It can be seen from the figure that a certain degree of deformation has taken place on the ground, vault top, arch bottom, and both sides of the tunnel. The overall deformation is symmetrical along the tunnel direction. The largest deformation position before the support is the vault, which reaches about 171mm. The rock layer above the vault gradually decreases as the depth of the surrounding rock decreases. The maximum subsidence on the ground is 120mm-130mm. The deformation of the surrounding rock of the tunnel is greatly reduced after the support. After the support, the maximum deformation of the tunnel is about 20mm, which is about 151mm lower. The maximum deformation of the ground is about 12mm-14mm, which is about 108mm-116mm down.

3.2.2. Vault subsidence analysis

Figure 4 and Figure 5 Vertical displacement changes before and after support. It can be seen from the figure that the vertical displacement and deformation are symmetrical. When no support is provided, the maximum deformation of the arch top and arch bottom is about 162mm and 45mm respectively. After the support, the maximum deformation of the tunnel vault and arch bottom is about 19mm and 20mm. The deformation of the ground surface has also been reduced from 100mm-120mm to 7mm-10mm.

3.2.3. Horizontal convergence analysis

Figure 6 and Figure 7 reflect the horizontal displacement changes of the tunnel model before and after the support. From the figure, it can be seen that the tunnel support has undergone a certain deformation to the inside of the tunnel before and after. In other words, the left side of the tunnel is displaced to the right and the right side of the tunnel is displaced to the left. The maximum deformation is about 126mm and 13mm respectively, which is reduced by about 113mm. The deformation of the ground surface is reduced from 50mm-75mm to 5mm-7.5mm.
Figure. 2 Overall deformation before support

Figure. 3 Overall displacement diagram after support

Figure. 4 Settlement displacement diagram of vault before support
4. Conclusion
The deformation of the tunnel under the pipe roof support was simulated by FLAC3D, and the following
conclusions can be drawn from the simulation and analysis results:

(1) When the strong weathered sandstone tunnel is not supported, the deformation of the tunnel is symmetrical along the tunnel direction. The vault and the left and right sides of the tunnel are deformed greatly, and at the same time cause large settlements on the ground. After the tunnel is supported by the pipe shed, the deformation of the surrounding rock is significantly reduced, especially the deformation of the vault and the left and right sides of the tunnel.

(2) The following conclusions can be obtained through comparative analysis before and after support. After taking measures, the amount of dome subsidence has been improved by about 88.3%, and the amount of horizontal convergence has been improved by about 89.7%. The improvement of arch bottom deformation is relatively small, about 55.6%.

Through the above analysis, it can be seen that the pipe roof support has a great effect in controlling deformation. The research results provide experience and theoretical support for similar projects in the future. It also laid the foundation for more in-depth theoretical research in the future.

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