Feasibility study on construction of highway tunnel with large cross section in red beds geology

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Abstract. This paper is based on the Shanchongqing Tunnel of Yishi Expressway in Yunnan Province and takes numerical simulation to analyze the feasibility of using the three-step method to construct a three-lane large section tunnel in red beds. Through the research, it is found that the maximum displacement and settlement of the vault is -10.72mm, and the uplift value of the tunnel invert is 9.49mm; the maximum horizontal displacement of the arch waist on the left is 11.03mm, and the minimum horizontal displacement of the arch on the right is -12.52mm; the top displacement settlement extreme value is -10.72mm, the uplift value of the tunnel invert is 9.49mm, the maximum horizontal displacement value of the left arch waist is 11.03mm, and the minimum horizontal displacement value of the right arch waist is -12.52mm; the maximum axis of the left tunnel anchor rod The force is 41.82Mpa, and the maximum axial force of the bolt support structure of the right hole is 43.72Mpa. Therefore, through empirical comparison, these values meet the stability requirements of the tunnel. Comprehensively, the three-step method is feasible in the excavation of large-section V-level surrounding rock in red geology.

1. Introduction

With the development of social economy and production, traveling convenient and speedy have become people's simplest wishes. In the new era, people are not only constantly eager to increase travel speed and improve travel quality, but also require straight lines, gentle slopes, and spacious roads. An effective way is the construction of road tunnels, it can shorten the distance, reduce travel time, increase transportation capacity, reduce traffic accidents, and play a vital role in other aspects. Among them, because the red layer has the characteristics of large interlayer properties, poor interlayer bonding, low mudstone strength and softening in contact with water, and prominent slope stability problems, these are the most difficult points in tunnel construction.

In the construction of expressways, the construction of large-section highway tunnels is a very important part. Through the construction of large-section highway tunnels, the capacity of highways can be better improved, and the traffic pressure can be relieved. Due to its large span and excavation section, the structural force is more complex, and engineering disasters such as large deformation of surrounding rock, collapse, cracking and destruction of the lining structure often occur. Therefore, choosing a suitable construction plan is directly related to the safety of tunnel construction and the durability of the structure[1]. Bandin relied on the Sparvo twin tunnels in Italy, introduced in detail the safety engineering
system developed for the excavation of the Sparvo twin tunnels with EPB-TBM, and expounded the construction plan when EPB-TBM excavated large-section tunnels in high-pressure rock masses[2]. Majid relied on the Sabzkuh tunnel in the mountainous area of southwestern Iran and studied the influence of the electronic stability control system on the response and stability of the tunnel based on the three-dimensional finite difference method and the finite element method. The results of the study show that the tunnel face is stable when the tunnel is excavated by the full-face method[3].

As a sedimentary rock, the red beds are usually composed of sandstone, siltstone and shale. Due to the presence of iron oxide, the red beds are mainly red. Usually, these red sedimentary strata partially contain thin layers of conglomerate, marl, limestone or some combination of these sedimentary rocks[4]. Red beds have poor diagenesis, some of which are semi-cemented and low in strength. Generally speaking, it belongs to the soft rock type. It is a complex rock mass with varying thicknesses between soft and hard bottom layers with a large difference in elastic modulus, widely concerned by related scholars[5]. Su Peisen found that because the surrounding rock of the tunnel is relatively weak, the tunnel construction has a greater impact on the deformation of the surrounding rock. About twice the tunnel diameter in the longitudinal direction and double the tunnel diameter in the transverse direction are the strong disturbance areas for construction, and the support should be strengthened during construction. And after the construction of the CRD method, the measured surrounding rock deformation stabilized after about 20 days of tunnel excavation, while the surrounding rock pressure, steel arch and initial lining force were all increased in the first 10 days after tunnel excavation, and then gradually stabilized[6].

In general, due to the complex forces on the surrounding rock of large-section tunnels, and the low strength of the red-bed soft rock, it is easy to soften, swell and disintegrate under the action of water. Therefore, it is rarely about research and engineering examples of large-section tunnels in red-bed geology. This paper is based on the Shanchongqing tunnel project of Yishi Expressway in Yunnan Province, and adopts a numerical simulation method to carry out research on the whole process of red-bed geological large-section tunnel construction, which can also provide experience and reference for similar projects in the future.

2. Materials and methods

2.1 Research and analysis on engineering geology of Shanchongqing tunnel

Through the collection of on-site survey data, the development of geological structures in the target area and the distribution characteristics of stratum lithology, hydrogeological conditions and the development of adverse geological processes are ascertained. Using the method of laboratory tests, the mechanical properties of the red-bed soft rock based on the compressive strength, tensile strength characteristics, deformation and failure characteristics of the dry state with different moisture contents are studied and analyzed. Considering that the red-bed soft rock is softened due to hydration and weathering, the strength of the surrounding rock is reduced to a certain extent.

2.2 Numerical simulation of the whole construction process of the three-step method

According to the "Design Rules for Highway Tunnels (JTG/T D70-2010)" and the physical parameters of soft rock on site, the physical and mechanical parameters of the V-level surrounding rock section and the supporting structure parameters are selected. The initial support is made of steel arch frame shotcrete. The elastic modulus of the steel arch frame is converted to shotcrete to obtain the elastic modulus of the initial tunnel support based on the principle of equivalent stiffness.

Considering the geology and lithology of the tunnel, the constitutive model of the rock mass is determined to be the Mohr-Coulomb constitutive model; the anchor rod is simulated by implanted truss elements, and the constitutive model is elastic. The spray-mixing structure is simulated in the form of plate elements. The constitutive model is the same as that of the anchor rod. The specific spray-mixing thickness is simulated according to actual engineering conditions. Midas GTS NX finite element software is used to simulate and establish a three-dimensional finite element numerical model. The
model and material parameters are shown in the figure 1-2 and table 1.

![Finite element model of surrounding rock](image)

**Table 1. Model material parameters**

| Model material   | Unit weight (KN/m³) | Elasticity modulus (kPa) | Poisson's ratio | Cohesive force | Internal friction angle (°) | Thickness (m) |
|------------------|---------------------|--------------------------|-----------------|----------------|-----------------------------|---------------|
| Red sandstone    | 19                  | 1.6×10⁶                  | 0.38            | 150            | 25                          | /             |
| Pneumatically placed concrete | 24                | 3.125×10⁷                | 0.2             | /              | /                           | 0.3           |
| Anchor rod       | 78.5                | 2.1×10⁷                  | 0.3             | /              | /                           | /             |
| Partition wall   | 25                  | 2.1×10⁷                  | 0.2             | /              | /                           | /             |

Finally, the numerical simulation results are used to analyze whether the three-step method can be applied to the excavation of large-section tunnels in red beds.

3. **Results & Discussion**

3.1. **Vertical displacement analysis**

The vertical displacement cloud diagram of V-level surrounding rock excavation with three steps method is shown in the figure 2-3. As the rock masses of the right and left tunnels are symmetrical, their deformation laws are similar. For the right tunnel of the tunnel, the top displacement and settlement extreme value of the three-step method is -10.72 mm, and the uplift value of the tunnel invert is 9.49 mm. From the overall view of the displacement and deformation of the right tunnel, the settlement value of the three-step method vault is slightly larger than the invert heave value. For the left tunnel of the tunnel, the top displacement and settlement extreme value of the three-step method is -10.67 mm, and the uplift value of the tunnel invert is 9.22 mm.

![Tunnel vertical displacement](image)

![Vault displacement](image)

3.2. **Horizontal displacement analysis**

The horizontal displacement of the left and right holes of the tunnel and the horizontal displacement of the arch waist are shown in Figure 4-5. Compared with the right tunnel of the tunnel, the excavation of
the left tunnel disturbs the original surrounding rock and redistributes the stress. When the left tunnel is excavated, the left and right arches have large horizontal displacements and move to the left respectively. Extend the side arch and the right shoulder. The maximum horizontal displacement value of the arch waist on the left side of the tunnel excavated by the three-step method is 11.03mm, and the minimum horizontal displacement value of the arch waist on the right side is -12.52mm. It can be seen from the time history curve at the arch waist that the surrounding rock has undergone several phase changes and the deformation rate is relatively large.

3.3. Spray mix and anchor rod analysis

For the spray-mixed structure of the tunnel, the maximum principal stress appears at the position of the tunnel vault and the value is 4.72MPa. This value is small because the three-step method has fewer blocks and fewer processes, so that the surrounding rock stress can be released in a short time. The minimum principal stress is -9.32MPa, and it mainly appears at the arch foot of the upper step. The reason is that during the excavation of the three steps, the rock mass around the upper step of the tunnel is disturbed, the original three-dimensional stress balance is broken, and the stress is heavy. The distribution causes the greatest pressure on the arch. The maximum positive bending moment of the spray-mixed structure is 27.4kN•m, the maximum negative bending moment is -62kN•m, this value is small, and the arch waist and arch toe of the left and right tunnels are areas of sudden bending moments, because attention should be paid to strengthen the support and monitoring. It can be seen in figure 6-8.

Anchor rod is an important measure in the initial support of the tunnel. Therefore, in order to more accurately understand the impact of the three-step method on the tunnel, the anchor axial force cloud diagram of the tunnel interruption is selected for analysis. It can be seen in figure 9. The maximum axial force of the anchor rod appears at the arch waist position of the left and right holes of the tunnel and is symmetrical. The maximum axial force of the anchor rod support for the left hole is 41.82Mpa, and the maximum axial force of the anchor rod support structure for the right hole is 43.72Mpa. Because the left and right holes are far apart, the maximum position of the anchor rod axial force is basically the same, and the maximum axial force value Almost the same.
4. Conclusions

Relying on the Shanchongqing Tunnel of the Yishi Expressway Project in Kunming City, Yunnan Province, using the method of finite element numerical simulation and the conclusion is as follows:

(1) According to the numerical simulation results of the V-level surrounding rock section of the Shanchongqing Tunnel, the three-step method excavated the sprayed concrete structure of the tunnel with lower stress and bending moment, but the horizontal convergence and dome settlement are larger. Considering the construction progress and economic cost, it is recommended that the three-step method be used for the construction of the V-level surrounding rock section of Shanchongqing Tunnel.

(2) It can be observed that the stress of the surrounding rock in the left tunnel of the tunnel is greater than that of the right tunnel, and the area where the maximum axial force of the anchor bolts and the bending moment of the left and right tunnels change suddenly is concentrated at the intersection of the arch waist and arch toe. Therefore, during construction, attention should be paid to the deformation of the vault and waist of the left tunnel, and monitoring should be strengthened.

(3) Because the three-step method has a large construction space and is convenient for mechanized construction, it can work in parallel with multiple working surfaces and has high work efficiency. Compared with the previous red bed geology using CRD method to excavate, it avoids the unsafe factors caused by the removal of temporary supports and the force conversion, and it is more economical. On the whole, the three-step method can be used for the excavation of the V-level surrounding rock of the large section of the red bed geology.

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