Treatment technology for large deformation of tunnel passing through soft and fragmented zone

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Abstract. Large deformation is a major problem for tunnels, threatening engineering safety and increasing construction costs. In order to solve the large deformation problem of deep-buried tunnels passing through the soft and fragmented zone, relying on the Dafalang tunnel project under construction, the mechanism of the large deformation of the fracture zone tunnel is analyzed, and deformation control measures suitable for geological conditions are proposed accordingly. The large deformation of the Dafalang tunnel is the combined effect of many factors. The complex tectonic stress environment is the mechanical condition for the large deformation of the tunnel. The weak and broken surrounding rock is the material basis and internal condition of the large deformation of the tunnel. Optimizing construction parameters, grading deformation control, and combined length and short anchor rods are adopted to effectively reduce tunnel deformation and ensure construction safety and progress.

1. Introduction

The large deformation of the tunnel has always been a major problem for mountain tunnels to pass through the soft and fragmented zone. It often causes problems such as tunnel face collapse, roof collapse, initial support cracking and spalling, and arch distortion[1,2]. The tunnel was forced to undergo arch replacement construction[3], which slowed down the construction progress and threatened the safety of people and property. In Southwest China, due to its complex and changeable geological conditions and abundant groundwater, the problem of large tunnel deformation is particularly prominent.

Scholars have made a lot of useful explorations and obtained many important results for the type and classification, the mechanism and the cause of the large deformation of the surrounding rock of the tunnel in the soft and fragmented zone. Li Guoliang[4] proposed to use relative deformation and rock mass strength-stress ratio as the grading index in the design stage, and divide the large deformation of extrusion into three grades, and predict the large deformation according to the rock mass strength-stress ratio. Relying on the beam tunnel, Dai Yonghao[5] applied model tests and numerical simulation methods to analyze the rheological mechanics of the rock mass, and proposed a joint support scheme based on steel arch + anchor + steel mesh, which solved the construction support problem in weak surrounding rock sections. Yu Tianci[6] relying on the Shiziyuan tunnel project of the Chenglan Railway, comparative analysis of the support effect found: improved excavation methods, strengthened initial support, asymmetrical reserved deformation, radial grouting to strengthen surrounding rock, and long bolts to reinforce surrounding rock and strengthen monitoring and
measurement can effectively control the large deformation of soft rock tunnels. Guo Jian[7] monitored the entire construction process of the displacement of the surrounding rock of the carbonaceous slate, the internal force of the initial support and the internal force of the second lining, and explored the characteristics of the lining of the tunnel with large deformation in different construction stages.

In summary, scholars have made certain studies on the large deformation of the tunnel, but the treatment measures for the large deformation of the tunnel are also different in different sections and different lithologies, especially when passing through weak and broken zones and other unfavorable geology. The concept and method of treatment of large deformation needs to be further improved. This article combines the large deformation problems encountered by the Da Franc deep-buried tunnel through the soft and soft fracture zone, and adopts measures such as optimized construction parameters, deformation grading control, and combined length and short bolts to ensure the progress of the tunnel construction and the safety of the structure, providing a reference for similar projects in the future.

2. Project overview

2.1. Engineering design overview

Dafalang Tunnel is located in Wenshan, Yunnan. It is a separated tunnel. The tunnel is spread out in a curve. The axis direction of the entrance section of the tunnel is about 98°, and the axis direction of the exit section is about 88°. The total length of the left tunnel is 3390m, and the maximum buried depth of the tunnel is about 206.5m. The total length of the right-line tunnel is 3375m, and the maximum buried depth of the tunnel is about 195.5. It is a deep-buried super-long tunnel. The large deformation section of the Dafalang Tunnel has a span of 12.78m and a height of 10.29m. The three-step method is adopted for excavation. The excavation sequence is shown in Figure 1.

![Figure 1. schematic diagram of excavation](image1)

2.2. Geological profile

The designed elevation of the entrance of the Dafalang Tunnel is 1278.891m, the designed elevation of the tunnel exit is 1269.591m, and the relative elevation difference between the entrance and exit is 9.3m. The tunnel area is located in the southeastern region of Yunnan, which belongs to the low-medium mountain plateau landform area with large undulations.
According to the survey and design geological data, the Dafalang tunnel passes through the fracture zone at K43+100-ZK43+400, where the surrounding rock is dominated by shale and belongs to the fracture zone. Its own conditions are weak and severely affected by the structure. There is a high risk of water and mud inrush, collapse, roof fall, and large deformation of the tunnel. The longitudinal section of the tunnel geology is shown in Figure 3.

3. Overview of tunnel large deformation

3.1. Construction overview
When the tunnel is broken during construction, according to the third-party monitoring data, the monitoring sections of the left and right tunnels are at a large deformation rate, and the maximum single-day deformation of the vault is 58.4mm and 49.2mm, respectively, exceeding the warning value (5mm/d). In addition, there are missing pieces in the cave, the partial arch of the initial support is twisted, and the concrete has many cracks. Take immediate measures to control the large deformation of the tunnel. After the measures were taken, the deformation of the left and right holes of the Dafalang Tunnel was basically stable, and the excavation continued forward.

On October 7, 2020, each monitoring section of the left and right tunnels was at a relatively large deformation rate (the maximum single-day deformation was 53.9mm), which exceeded the warning value. In the cave, there are missing blocks, local arches of the initial support are twisted, and there are many cracks in the concrete. Subsequently, the deformation of the Da Franc tunnel exceeded the warning value continuously.

3.2. Tunnel large deformation mechanism
The large deformation of the soft rock in the Dafalang Tunnel is the combined effect of multiple factors. According to the survey data, a fault fracture zone developed in the tunnel site area within the construction area. The tectonic stress environment in the fracture zone is complex, and the surrounding rock stress redistributes after tunnel excavation, which further changes the stress environment, which is the mechanical condition for the large deformation of the tunnel. The survey lithology of the large deformation section of the tunnel is mainly moderately weathered shale, but the tunnel excavation reveals that it is strongly weathered argillaceous shale. Affected by faults, the surrounding rock joints and fissures are developed, and the rock mass in the fault zone is weak and broken, and the strength is low. The surrounding rock fragmentation zone is the material basis and internal conditions for the large deformation of the tunnel. The tunnel excavation revealed that the strata strata, the structural axis and the line intersect, the strata dip angle is 60°, and the flaky structure. After the tunnel is excavated, the vault to the right arch is deformed seriously, and it is prone to bending and deformation under the complex stress environment.
4. Tunnel large deformation control measures

4.1. Optimize construction parameters
In order to solve the problem of poor geological conditions in the fracture zone of the Dafalang tunnel, which led to the large deformation of the tunnel. The large deformation of the right side of the initial support for the left and right tunnels need to be replaced by the arch, according to the opening of the hole to the face of the tunnel. The direction of the machine is gradually dismantled and replaced, and the net shotcrete is reapplied. The weak and broken zone adopts three steps + temporary inverted arch construction method; strengthen the advance support, the original arch design length is 4m, grouting small pipe shed, and the length is changed to 4.5m. Strengthen the initial support of the weak and broken zone of the left and right tunnels. The original design steel arch I20b is changed to I22b, and the spacing is changed from 60cm to 50cm; the single-layer steel mesh of shotcrete is changed to double-layer steel mesh; the original design of the upper step is unilateral 2 φ42 grouting lock foot anchor pipes were changed to 4; the original design of the middle step was changed to 2 φ42 grouting lock foot anchor pipes on one side to 2 6 meters Ф76mm*6mm lock foot anchor pipes, with a downward tilt The angles are 20° and 45° respectively; the grouting pressure of the lock foot anchor pipe is controlled at 0.5-2.0 MPa. Enhance the mechanical properties of the reinforced concrete for the secondary lining in the weak fracture zone under the eccentric pressure. The distance between the main reinforcement of the secondary lining invert and the arch wall is changed from 20cm to 15cm. Strengthen the advance geological prediction and monitoring measurement of the tunnel section in the weak and fracture zone with the left and right bias.

4.2. Long and short combined anchor rod reinforcement
In the tunnel, a multi-point displacement meter is used to measure the deep displacement of the surrounding rock. The measuring rods are divided into three lengths: 0.5m, 1m, and 1.5m. The arrangement position is shown in Figure 5, and each measuring point is numbered one by one. The test of the surrounding rock loose zone shows that the displacement change trend of each measuring point of 1m, 3m, and 5m is relatively consistent, indicating that the surrounding rock loose zone is larger than the range of 5m. The original anchor rod did not extend into the elastic area of the surrounding rock for anchoring, resulting in the failure of the anchor shotcrete support of the soft rock tunnel, so the anchoring length of the anchor rod needs to be increased.

The construction technology of combining long and short bolts to control the deformation of the surrounding rock of the tunnel is a combined support method of long and short bolts. The short anchor rod in the early stage is used to limit the deformation of the shallow loose and broken surrounding rock, and form a reinforced composite arch structure with the shallow surrounding rock to jointly assume the surrounding rock deformation in the plastic zone. On the one hand, the long anchor rod controls the deformation of the deep surrounding rock; on the other hand, the reinforced composite arch structure is suspended from the deep stable rock mass. The shallow and deep surrounding rocks work together to coordinate the deformation.

Figure 5. field test layout drawing  
Figure 6. test result of surrounding rock loose zone
The combination of long and short anchor rods uses 3-4m short anchor rods and 6-8m long anchor rods. The short anchor rods can be resin (medicine-packed) anchor rods; the anchor rods longer than 6m should be hollow anchor rods. The severely deformed section where the deformation develops rapidly, the short bolt (<4m) is used for quick and convenient construction, which is used for the initial deformation control, and creates the construction time for the long bolt.

4.3. Hierarchical control of large tunnel deformation
In order to better control the deformation of the surrounding rock, quantitative analysis of the deformation of the surrounding rock in each construction stage can be carried out for hierarchical control and management of the reserved deformation, which is conducive to the connection of various construction procedures and coordinated deformation control. Propose the following classification control standards for surrounding rock deformation in each construction stage, as shown in the following table. If the surrounding rock deformation control exceeds the limit, corresponding strengthening measures should be taken in time.

| Deformation grade | Reserved deformation | Characteristic description of surrounding rock |
|-------------------|----------------------|-----------------------------------------------|
| Slightly deformation | 20cm | The strength of the surrounding rock is average, the joints and fissures are generally developed, and there is no water or wetting. |
| Moderate deformation | 40cm | The surrounding rock is weak and broken, with well-developed joints and fissures, without water or wetting. |
| Severely deformation | 60cm | The surrounding rock is weak and broken, joints and fissures are developed, and there is water or seepage or running water. |

5. Conclusion
Affected by geological conditions, large deformations often occur during the construction of tunnels in soft and fragmented zones, threatening the safety of the project. By analyzing the large deformation mechanism of the Dafalang Tunnel and putting forward corresponding treatment measures accordingly, the tunnel deformation can be effectively controlled, and the following conclusions are drawn:

(1) Relying on the Dafalang tunnel project under construction, analyzing the large deformation mechanism of the fracture zone tunnel, the results show that the large deformation of the soft rock of the Dafalang tunnel is the combined effect of multiple factors, and the complex tectonic stress environment is the mechanical condition for the large deformation of the tunnel; The weak and broken surrounding rock is the material basis and internal condition of the large deformation of the tunnel.

(2) The test of the tunnel surrounding rock loose circle shows that the displacement change trend of each measuring point of 1m, 3m, and 5m is relatively consistent, indicating that the loose zone of the surrounding rock is larger than the range of 5m. Long and short combined anchor rods are used to control the deformation of the tunnel. The length of the short anchor rod is 3-4m, and the length of the long anchor rod is 6-8m.

(3) Aiming at the large deformation of Dafalang Tunnel, the deformation control measures adapted to the geological conditions are proposed. Optimizing construction parameters, deformation grading control, combined length and short anchor rods are used to effectively reduce tunnel deformation and ensure construction safety and progress.

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