Analysis on Deformation and Stability of Tunnel Anchor Excavation under Broken Rock Mass

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Abstract: Based on the concrete engineering support of the tunnel anchor of the Dadu River Bridge on the Sichuan-Tibet Railway, the geological background of broken rock mass, extremely developed joints and fissures, and poor self-stability of surrounding rock within the range of side anchors in Chengdu, a three-dimensional elastoplastic numerical calculation method is used. The current engineering geological conditions and the tunnel anchor design plan are to establish a three-dimensional fine numerical simulation model of the Chengdu side tunnel anchor that comprehensively considers rock mass unloading, stratum classification, and anchor tunnel excavation and support structure. The "excavation-support" process in each construction footage is simulated to realize the three-dimensional calculation of the dynamic construction and support of anchor tunnels, and to study the surrounding rock deformation, stress and plastic zone distribution changes during the excavation process. Comprehensive analysis found that the deformation of surrounding rock during excavation shows that it develops toward the empty surface, and the displacement distribution is obviously affected by the distribution of ground stress and rock formation. The greater the buried depth, the greater the deformation of the surrounding rock.

1. Introduction
The Sichuan-Tibet Railway is located in the southeast of the Qinghai-Tibet Plateau and is an important part of the Tibet Autonomous Region's external transportation channel. The geological conditions of the section from Ya'an to Linzhi are extremely complicated, and the survey, design, and construction are difficult. The Dadu River Bridge is located in the section from Ya'an to Kangding, on both sides of the Chengdu bank and Lhasa bank. Among them, the anchor surrounding rock of the Chengdu Bank Tunnel is broken, mainly grade V cataclastic rock, with well-developed joints and fissures. Large deformation and collapse risks are prone to occur during the construction process, and construction safety risks are high. The Lhasa'an Tunnel has good geological conditions for the anchoring surrounding rock, and the construction safety risk is relatively small. The minimum clear distance between the anchor and the railway tunnel of the Chengdu bank is 16.762m, and the impact of the crossing group of tunnels is greater than that of the Lhasa bank. Therefore, the Chengdu bank is selected for numerical simulation.
analysis of excavation to determine the mutual influence of the construction of the group of tunnels and analyze the deformation of the surrounding rock.

In the numerical simulation process, all external and internal forces are concentrated on the three-dimensional grid nodes by discretizing the three-dimensional medium, and then the law of motion of the continuum medium is transformed into Newton's law on discrete nodes, and the derivative of time and space adopts finite space and time. The linear variation of the interval is approximated by finite difference, and the static problem is solved as a dynamic problem, so that the inertia term in the equation of motion is used as a means to achieve the desired static balance.

2. Modeling and numerical simulation

2.1. Tunnel anchor modeling
The established 3D numerical calculation model of tunnel anchors in Chengdu section is shown in Figure 1. The centerline of the tunnel is selected as the X-axis, and the direction of the river valley is positive, and the range is 350m; the Y-axis is perpendicular to the direction of the tunnel axis, and the direction upstream is positive, and the range is 250m; the z-axis is the vertical direction, and upward is positive, and the range is from The elevation is 1500m to the surface. The model is meshed with a combination of tetrahedron and hexahedron. The entire model is divided into approximately 380,000 elements and approximately 160,000 nodes. The boundary conditions of the calculation model adopt the three-way constraint on the bottom surface, the normal constraint on the side surface, and the free surface mode.

The rock mass adopts an ideal elastoplastic model with Mohr-Coulomb criterion as the yield function. The initial in-situ stress field considers the effect of tectonic stress in the anchorage area, and the lateral pressure coefficient is used to simulate the initial in-situ stress field with a coefficient value of 1.05.

2.2. Stress changes of surrounding rock
On the basis of the established three-dimensional fine simulation model of the Chengdu side tunnel anchor, input the corresponding physical and mechanical parameters with the selected constitutive model, simulate the distribution law of the initial ground stress field considering the horizontal lateral pressure coefficient, and clear the displacement. An initial state of the tunnel anchor project area with initial stress but no initial displacement is obtained. Take each construction footage (2m) cycle as the unit, simulate the "excavation-support" process in each construction footage, and repeat the above steps continuously to simulate the gradual advancement process of the tunnel face, and the main cable section, saddle Three-dimensional calculations are carried out for the dynamic construction and support process of the anchor tunnels of the chamber section, the front anchor chamber section, the anchor plug body and the rear anchor chamber section, and the stress change characteristics of the surrounding rock during the construction and excavation are studied and analyzed.
The initial in-situ stress is shown in Figure 2. The stress is concentrated in the valley area. The closer the valley is, the more significant the horizontal tectonic effect is. And as the buried depth increases, the direction of the maximum principal stress is almost vertical. The stress field near the cataclastic rock section is locally different, and there is a certain stress concentration and relaxation phenomenon. The magnitude of the maximum principal stress in the anchor hole area is about 0~7.5MPa, and the magnitude of the minimum principal stress is about 0~4MPa, all of which are under compression.

The stress analysis of surrounding rock after the completion of the simulation excavation is shown in Figure 3. After the construction of the cavern is completed, stress relaxation occurs within a certain depth around the cave, the tangential stress of the surrounding rock increases, the radial stress decreases, and the void surface The nearby rock mass changes from a three-dimensional stress state to a near-plane stress state, that is, the minimum principal stress is gradually perpendicular to the free surface and the maximum principal stress is gradually parallel to the free surface. In the stress adjustment zone, the maximum principal stress increases or decreases, the minimum principal stress decreases, and tensile stress appears locally. The maximum principal stress value of the surrounding rock in the anchor cave area is between -0.5~14MPa, and the minimum principal stress is between 0.8~4MPa. The stress concentration area is mainly located at the top arch and bottom of the cavern; the maximum tensile stress is about 0.8MPa.
Figure 3. Distribution characteristics of the secondary stress field in the surrounding rock of the tunnel anchor after excavation (central section of the anchor tunnel)

2.3. Deformation and displacement of surrounding rock

Figure 4 shows the distribution of the total displacement of the surrounding rock of the anchor tunnel after the construction is completed. It can be found that the deformation of the surrounding rock generally shows the characteristic of developing toward the empty surface. With the formation of the side wall, the vault of the cavern is gradually subsidence; in general, the magnitude and distribution of displacement are obviously affected by the magnitude of the in-situ stress and the distribution of rock layers. The area where the excavation deformation of the surrounding rock of the anchor tunnel is more significant is mainly concentrated in the cataclastic rock (fracture zone) distribution area, the greater the buried depth the greater the deformation of surrounding rock.

In the initial excavation stage of the anchor tunnel, the deformation of the top arch is the main body, but as the tunnel is excavated and the tunnel faces forward, the displacement of the side wall becomes the main body of the deformation. Generally, the deformation of the side wall of the surrounding rock is greater than the deformation of the bottom plate and the top arch. After the excavation is completed, the maximum deformation of the surrounding rock of the anchor tunnel in the Chengdu side tunnel is about 181.1mm, concentrated in the anchor plug body near the side wall of the rear anchor chamber. The specific deformation values are shown in Table 1.

Table 1. Surrounding rock deformation values of different sections of tunnel anchors (mm)

| Location            | Deformation value range | Maximum deformation/location |
|---------------------|-------------------------|------------------------------|
| Main cable passing section | 5.0~20.0                | 45.0/Bottom plate            |
| Saddle section      | 5.0~8.0                 | 20.0/Bottom plate            |
| Front anchor room   | 10.0~50.0               | 99.0/Bottom plate            |
| Anchor plug body segment | 20.0~150.0             | 180.0/Side wall              |
| Rear anchor room    | 30.0~100.0              | 181.1/Side wall              |
2.4. Distribution change of surrounding rock plastic zone

The changes in the distribution of the plastic zone are used to analyze the possible damage and failure modes of the surrounding rock after the excavation of the cavern and the distribution range and depth of the unloading yield. Figure 5 shows the distribution characteristics of the surrounding rock plastic zone of the tunnel anchor after the construction is completed.

The yield of surrounding rock is mainly shear yield. Although tensile shear yield exists locally, the scope is relatively small; at the intersection of the front anchor room and the railway tunnel, the plastic zone between the two anchor caverns and the tunnel rock column is not clearly connected. The depth of the plastic zone of the surrounding rock of the loose cable saddle is generally less than 2m; the depth of the plastic zone of the surrounding rock of the front anchorage section is generally between 1-7m; the depth of the plastic zone of the surrounding rock of the anchor plug body section is generally between 1-5m; the rear anchor room The depth of the plastic zone of surrounding rock is generally between 2-5m.
3. Summary
This paper uses the three-dimensional elastoplastic calculation method as the main research method to carry out numerical simulation research on the tunnel anchor excavation process, analyze and evaluate the stress state and deformation displacement of the surrounding rock. The article provides a certain reference for the stress and deformation of the tunnel anchor excavation under the broken rock mass, and can provide guidance and help for the follow-up support construction of the specific project based on this. The main conclusions are as follows:

(1) After tunnel anchor excavation, the surrounding rock compressive stress concentration area is mainly distributed in the cave section where the anchor plug is distributed in the catalyzed rock, located at the top and bottom of the cavern; the top arch of the rear anchor chamber also has a certain degree of stress concentration; stress relaxation areas are distributed around the hole, and the relaxation phenomenon at the side wall is the most obvious; the maximum tensile stress is about 0.8MPa.

(2) Due to the unloading effect of the surrounding rock, the shallow part of the empty surface during the formation of the secondary stress field shows that it has reached its yield strength and enters a plastic state, especially the plastic zone of the surrounding rock in the cataclastic rock distribution. The extension range is relatively large; the overall yield of the surrounding rock is dominated by shear yield.

(3) The surrounding rock excavation deformation generally develops towards the empty surface. The deformation area is mainly concentrated in the area where the broken rock mass is distributed. The larger the buried depth, the greater the deformation of the surrounding rock; the area where the excavation deformation of the surrounding rock of the anchor tunnel is more significant is mainly concentrated Where the anchor plug body is close to the side wall of the rear anchor room section, this position is also a larger buried depth of the cataclastic rock. During construction, key monitoring and effective control are required. During the construction, great attention should be paid to formulate the plan to deal with the collapse and large deformation of the cataclastic rock cave section. In the construction process, the support structure scheme can be adjusted in time according to the feedback geological conditions and monitoring measurement.

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