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Analysis of surrounding rock deformation in large section tunnel with different control technology crossing fault zone

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Abstract: *Aiming at solving the deformation of surrounding rockmass when large-section tunnels pass through faults, the construction method of No. 2 Cajianweishan tunnel of Shugang Passage in Haicang is optimized, and the original design method and optimization method for the construction process are simulated numerically by FLAC3D. The deformation of surrounding rock caused by construction under above two methods during tunnel excavation is compared and analyzed. The results show that the deformation is almost equal in above two construction methods when crossing the fault, but the optimized construction method can provide enough working space when excavating the No.2 and No.4 heading and effectively avoid the problem of pass of construction vehicles due to the setting of the inverted arch trestle. Considering the construction schedule, it is more advantageous to adopt the optimized construction method in the fault zone. The study can provide a reference for the tunnel engineering with similar geological conditions in the future.*

Keywords: *tunnel construction; large section tunnels; faults; numerical simulation; scheme optimization*

1. Introduction

Fault is one of the common and typical unfavorable geology in the construction process of tunnel. When a large-section tunnel passes through the fault, the stress concentration of the surrounding rockmass and support system is more obvious, which can cause the structural stability and safety of the tunnel greatly reduce. A large number of scholars have carried out research in this field[1-6]. Zhang et al.[7] took the Sichuan-Tibet railway tunnel as the background, and proposed strengthening deformation joints and developing flexible joint structures to deal with the problems of tunnels crossing the deep and large active fault zone. An et al. [8] conducted numerical analysis on concrete linings with different materials in the fault, and analyzed the displacement, stress and safety factor of the secondary lining. Zou [9] carried out numerical simulations on various construction methods, and obtained the optimal construction parameters for crossing the fault fracture zone. It can be seen that it would be a great idea to reduce the single excavation area and increase the support strength to ensure that the tunnel passes through the fault fracture zone in practical engineering. However, for different geological conditions and construction conditions, the evolution laws of rockmass deformation and displacement are quite different, especially in the actual construction of large-section tunnels. Therefore, it is necessary to take into account the stability of surrounding rock and construction efficiency.

This paper analyzes and evaluates the surrounding rockmass deformation of the Caijianweishan 2# tunnel of Haicang Shugang Channel in the fault section and the rationality of optimizing the construction method is discussed, aiming at providing reference for similar projects in the future.

2. Project introduction

The Haicang Shugang Passage is generally east-west, with a length of 326.883m (K3+580~K6+840.883), and it has to pass through multiple fault fracture zones. The three-lane tunnel in the fault zone of ZK3+775~ZHK3+855 is selected as the research object (Fig. 2). This tunnel is 16m wide and 11.32m high. It is mainly V-grade surrounding rock, and the surrounding area of the tunnel is moderately weathered granite, the rock mass quality is relatively between complete to fragmented degree. The fault greatly reduces the stability of the surrounding rock, and may cause instability damage and water inrush disasters.

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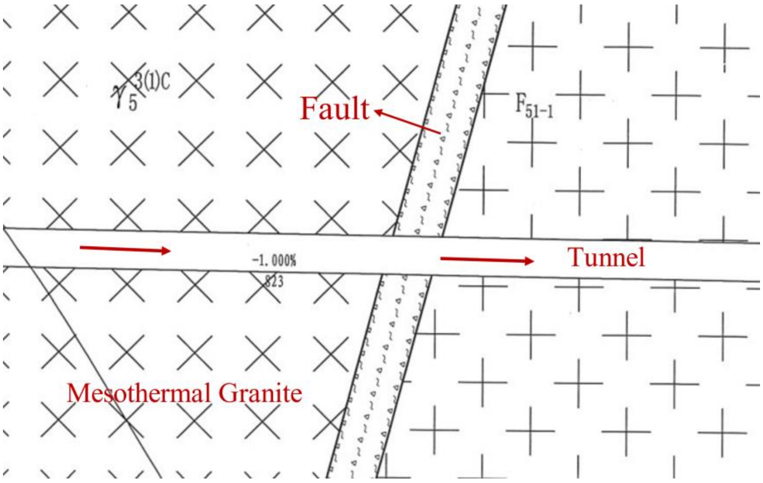
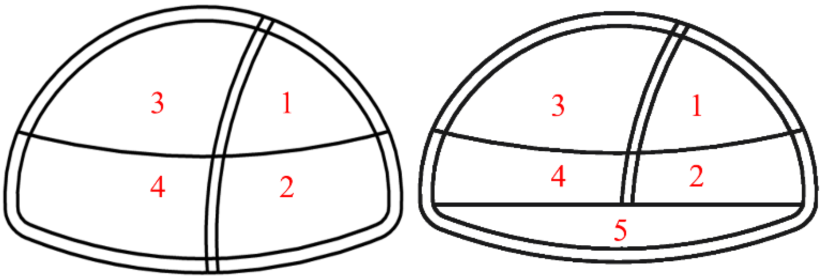


Figure 1: The fault location map of the geological longitudinal section of the left line of the tunnel

3. Work methodically and supporting method

According to the geological survey and design data, the tunnel intersects with the fault obliquely with a length of 10m. The tunnel passes through the flat inferred layer developed in this section. The rock mass in the fault zone is broken and the stability of the surrounding rock is poor. The original design adopts construction method 1 to pass through the fault zone. However, due to the existing of the inverted arch of the tunnel, the excavation of guide pit 1 and guide pit 3 would be directly affected. Moreover, when the middle next door is connected to the bottom of the inverted arch, the work efficiency of pit 3 is further reduced because two inverted arch trestle bridges need to be used before and after the single-sided pilot pit., And the working space is small, and the safety hazards such as vehicle entry and exit are relatively large. Therefore, the original construction method is optimized, and the partition wall in the optimized construction method 2 no longer falls to the bottom. The schematic diagrams of the two construction methods are shown in Figure 2.



(a)Work method 1 *(b)Work method 2*

Figure 2: Schematic diagram of different construction methods

Since the next door no longer falls to the bottom in Work Method 2, the relevant technical means would be adopted to achieve the purpose of reinforcement, and the main scheme is shown as follows:

(1) Add two locking anchors(Φ42*3.5mm and 4m long) to each section of the arches , which can initially support the vaults of the left and right pilot pits to reinforce the initial support of the steel arches.

(2) On the basis of the original design of 2 locking foot anchor pipes (Φ42*3.5mm), the arch foot of the side wall of the lower step is increased by two.

(3) The connection between the back arch and the foot of the side wall is changed from the designed bottom smooth connection method to the side connection method to reduce the disturbance to the foot of the side wall during the back arch excavation.

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4. Numerical simulation

4.1 Building the model

The numerical model was built withthe large-scale finite-difference software FLAC3D and the whole process of tunnel excavation in the fractured section of the fault was simulated[10]. In this paper, the weakened assignment method was used to simulate tunnel excavation in fault fracture zones. According to St. Venant's principle, the model length x width x height is 135m ×80m × 50m. The solid units were adopted in the surrounding rockmass, middle liner and secondary lining all adopt, the Mohr-Coulomb principal structure model was adopted in the surrounding rock and secondary lining adopt, and the elastic principal structure model was adopted in the middle liner. The steel arch frame adopts the principle of equivalent compressive stiffness, and the elastic modulus of the steel arch frame is converted to the corresponding support according to the formula (1). The shell structural unit and cable structural unit were adopted in the initial lining and the anchor, respectively adopts, the locking foot anchor pipe adopts pile structural unit, and the excavation process is realized by giving empty unit (null).[11-12]

$$E = E_0 + S_g \times E_g / S_c \tag{1}$$

E : Elastic modulus of concrete after conversion

E_0 : Elastic modulus of original concrete

S_g : Section area of steel arch frame

E_g : Elastic modulus of steel products

S_c : Elastic modulus of concrete

According to the ground investigation report combined with relevant specifications, the main mechanical parameters were obtained as shown in Table 1.

Table 1: Mechanical parameters of the surrounding rock

Items	Density /kg m-3	Modulus of elasticity /GPa	Poisson's ratio	Cohesion /MPa	Angle of internal friction /(°)
Medium weathered Granite	2680	7	0.26	4	44.5
Fracture Zone	2400	4	0.3	0.28	38

4.2 Simulate the construction process

In the finite difference software FLAC3D, set each calculation step to simulate an excavation footage, and each excavation footage is 2m. There are 100 calculation steps in construction method 1. After 7 steps of No. 1 heading excavation, No. 2 heading excavation. After 5 steps of No. 3 guide pit, No. 2 guide pit is excavated. After 8 steps of simultaneous excavation of No. 1, No. 2 and No. 3 guide pits, No. 4 guide pits were excavated immediately. No. 1 heading is 14m ahead of No. 2 heading, No 2 heading is 10m ahead of No 3 heading, and No 3 heading is 16m ahead of No. 4 heading. There are 125 steps in construction method 2, and the excavation sequence is the same as that of CD method.

4.3 Placement of monitoring points

In order to better analyze and compare the results of the numerical simulation, a 50m survey line was set at the top, bottom and foot of the tunnel to monitor the vertical and horizontal displacements of the tunnel. The monitoring interval is 2m in the tunnel depth, and the location of the tunnel envelope measurement line is arranged as shown in Figure 3.

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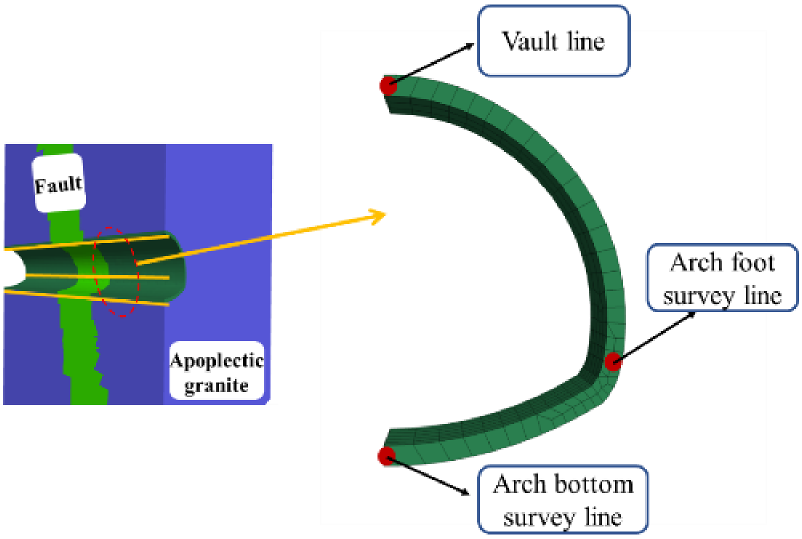
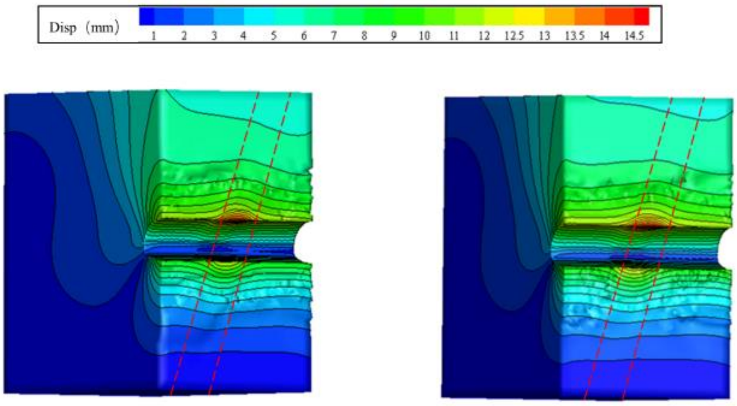


Figure 3: The location of the tunnel surrounding rock mass survey line

5. Numerical simulation results and comparison

5.1 Analysis of deformation

Due to the continuous excavation of the tunnel face, the displacement of the rock around the tunnel increases continuously, and gradually stabilizes with the increase of calculation steps. After the tunnel excavation is completed, the displacement cloud diagrams of the two working conditions are shown in Figure 4.



(a) Work method 1 (b) Work method 2

Figure 4: Deformation field of the surrounding rock of the tunnel for both methods

It can be seen from Figure 4 that the overall displacement of the tunnel is small when the tunnel passes through this section,, and the surrounding rock is basically in a relatively stable state. However, due to the existence of the fault, the deformation at the vault of the fault is the largest, followed by the center line at the bottom of the tunnel. Therefore, in the construction process, the main attention should be paid to monitoring the settlement and deformation of the vault at the fault and adopting support measures according to the actual situation. On the whole, the disturbance to the rock above the tunnel in working condition 1 is smaller than that in working condition 2, but it is not obvious. In order to compare the deformation characteristics of the two construction methods after the tunnel is excavated, the longitudinal displacement diagram of the bottom of the vault and the horizontal displacement diagram of the arch foot are drawn according to the survey lines arranged as shown in Figure 5.

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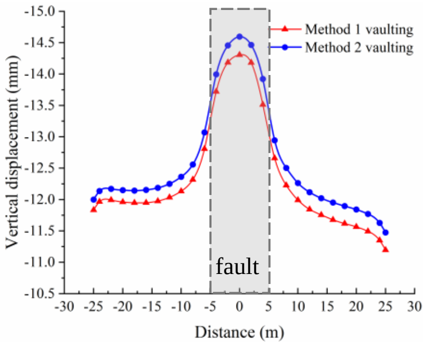
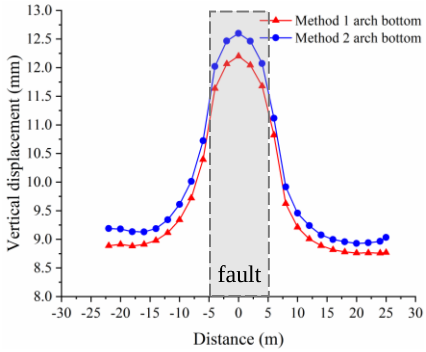
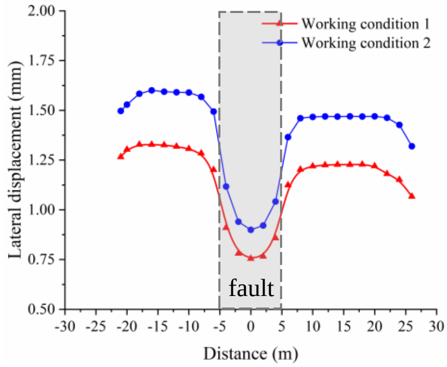


(a) Vertical displacement of arch top



(b) Vertical displacement of arch bottom



(c) Lateral displacement of arch foot

Figure 5: Comparison of deformation of main measurement lines in the tunnel

It can be seen from Figure 5(a) that the vertical displacement of the vault in construction method 1 is smaller than the displacement value generated by construction method 2 on the same section, and the maximum vertical displacement of the two construction methods is generated at the center of the fault. The maximum vertical displacement is 14.38mm, and the maximum vertical displacement of construction method 2 is 14.68mm, a difference of 0.3mm. Outside the fault, the vertical displacement of the vault in construction method 1 is about 0.2 mm smaller than that in construction method 2. When the tunnel was excavated 8m before the fault, the displacement of the tunnel vault began to increase significantly. Therefore, we should it is necessary to carry out monitoring of the rock mass in front of the fault during the construction, so as to provide an indication for the subsequent construction in the fault. In Figure 5(b), the maximum displacement of the arch bottom of the two working methods occurs at the center of the fault, and the fault affects the deformation of the surrounding rock 10m before and after the tunnel excavation. The maximum vertical displacement of the arch bottom in the two working conditions is 0.4 mm. In Fig. 5(c), in the normal section, the horizontal displacement of the arch foot is relatively stable and kept at about 1.25mm. When entering the fault, the displacement value decreases. Comparing the horizontal displacement of the arch foot in the fault with the horizontal displacement of the ordinary section, the horizontal displacement of the fault is about 0.5mm smaller than the horizontal displacement of the ordinary section. Although the deformation values generated by the two construction methods on the survey line are different, the difference is not large and the deformation distribution law is roughly the same. In the actual measurement, the maximum vertical displacement of the tunnel vault is 15.6mm. Compared with the actual measurement, the simulation value of the two methods is slightly smaller than the actual measurement value, but the obtained simulation values all meet the control value of the surrounding rock deformation of 40mm in the specification.

By comparing the deformation of construction method 1 and construction method 2, it can be seen that the deformation state of the surrounding rock near the fault is basically same for the two construction methods, but construction method 2 can greatly improve the construction efficiency, shorten the construction period and reduce the construction cost.

5.2 Analysis of deformation

In order to investigate the stress state of the surrounding rock with different construction methods , the cloud diagram of maximum principal stress (Fig. 6) and minimum principal stress (Fig. 7) after tunnel excavation are drawn respectively. As can be seen in the figure, the tunnel stress state is

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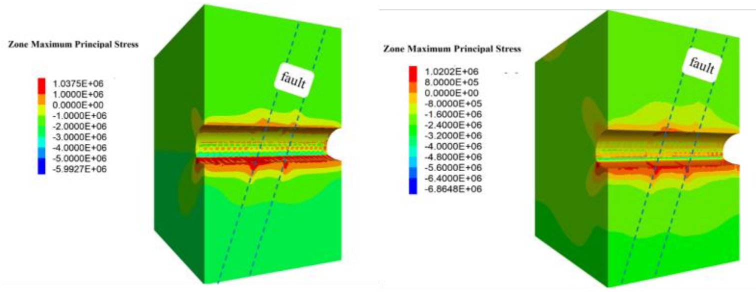
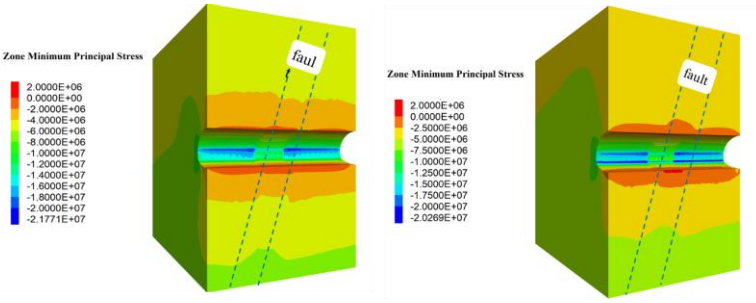
relatively stable before entering the fault, and the maximum principal stress appears at the vault and bottom of the fault boundary, indicating that the stress is concentrated in the hard rock part at the intersection of the tunnel and the fault. When different construction methods are used, the magnitude of stress is different. In contrast, the tensile stress at the arch bottom under condition 2 is smaller and more uniform. At the fault boundary, the maximum principal stress of the two construction methods is roughly equal, and the minimum principal stress of the construction method 1 decreases by 0.3MPa compared with the construction method 2.



(a)Work method 1 (b)Work method 2

Figure 6: Cloud diagram of maximum principal stress



(a)Work method 1 (b)Work method 2

Figure 7: Cloud diagram of minimum principal stress

6. Conclusion

This paper conducts numerical simulations on the two construction methods adopted when the tunnel crosses the fault, taking Caijianweishan 2# tunnel as the engineering background. And the deformation distribution law of the surrounding rock of the large-span tunnel crossing the fault was analyzed. The conclusions are as follows.

(1) During the construction of tunnel in the fault broken zone, the deformation of the tunnel has begun to increase before the excavation to the fault, and corresponding monitoring methods should be adopted. According to the monitoring data obtained before the tunnel face reaches the fault, the corresponding judgment is made on the deformation in the fault zone to ensure the safety of construction.

(2) According to the numerical simulation results, the displacement of the central vault of the tunnel fault is the largest. Therefore, more attention should be paid to the support of the vault of the tunnel fault broken zone, during the construction.

(3) When the long-span tunnel passes through the fault fracture zone, construction methods 1 and 2 used for construction, both can meet the requirements of the specification and play a better role in stabilizing the deformation and stress state of the surrounding rock.

(4) Construction method 1 is only 0.3mm smaller in displacement than construction method 2, which is basically negligible. Since the middle partition of working condition 2 is not connected to the bottom of the inverted arch, the efficiency is greatly improved during construction. Therefore, when the vault subsidence and surrounding convergence monitoring data in the case of monitoring and measuring the allowable value range of deformation, construction method 2 can be adopted to cross the fault fracture zone.

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