Construction Simulation and Stress Characteristics of Large Span Tunnel Crossing Fault Fracture Zone

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Abstract. Combined with the engineering of a large span tunnel passing through the fault fracture zone, the settlement of the crown in the fault zone is studied. The stress situation of the secondary lining in the fault is analyzed. The influence zone of fault fracture zone is put forward based on the first principal stress of structure. The results show that: (1) The fault fracture zone has great influence on the settlement of the crown when the step method is used, and the settlement value is 2.14 times that of the fault free zone. (2) The fracture convergence zone will obviously postpone the convergence time of crown settlement. In this case, 2nd construction steps are delayed. (3) The fracture pressure zone will obviously increase the lateral pressure of the secondary lining structure, which is 1.3 times of that in the fault free zone. The tensile stress concentration of the secondary lining walls at the fault is 1.17 times of that without faults. (4) Based on the first principal stress of the secondary lining wall, the width of the fault is 16m, and its influence area is about 3.5 times of its own width.

1. Preface
Geological conditions in China are complex and changeable while faults and joints are very common. In the process of building a tunnel, it is often inevitable to cross the fault zone, resulting in large deformation, collapse and structural instability of the surrounding rock, which has brought many difficulties to the design and construction. And because of the nature, width, filling, water content, activity and the relationship with the space position of the tunnel, the countermeasures are relatively passive, and those problems are often treated behind the abnormal surrounding rock or structure.

At present, the structural stability of tunnels passing through fault fracture zones has been studied at home and abroad. Liu Kai [1] analyzed the mechanical characteristics of the lining in the fault fracture zone under high ground stress, and proposed the failure form and potential failure surface of the lining. Cui Guangyao [2] contrasted the fault damage of the tunnel in the normal section and the fault fracture zone. It is proposed that the wide fault fracture zone not only causes the collapse of the secondary lining, but also causes the collapse of the tunnel, while the ordinary section tunnel has only a few sections of the tunnel collapse, and there is no tunnel collapse. Based on the old Fort tunnel of Zhang Ji railway, Li Xiang [3] studied the causes of large deformation in the initial branch of the fault fracture zone, and put forward corresponding measures. Lin Yu [4] simulated the construction method of the shallow fault fracture zone of the Tong Zi cliff tunnel in Baxi railway, and put forward the conclusion that the double wall heading method is the best. Geng Ping [5] proposed that the internal force value of the tunnel located in the fracture zone is far greater than that from the distant and when the tunnel lining is far away from the fault, the internal force value of the longitudinal section is...
convergent to a stable value. Li Dewu\cite{6} and Peng Chao\cite{7} proposed that the plastic zone of the wall rock in the fault zone is larger than that of the non fault fracture zone, and the initial support and the internal force of the secondary lining increase from 10% to 30%, and the engineering treatment technology is put forward.

According to the above data, most of the current researches focus on static analysis or seismic force analysis of the built tunnel. There is a relative lack of research on the construction mechanics of the tunnel excavation in the fault fracture zone and the judgement of the influence scope of the fault. Moreover, the study of large span tunnel crossing fault fracture zone is relatively few. Therefore, this paper, relying on a large span tunnel project through a step method to cross fault fracture zone, studies the settlement of the construction process, the stress situation of the secondary lining and the influence range of the fault fracture zone, which provides some reference for the similar projects in the future.

2. Project introduction

The span of a new arch large underground station is 32.3m with a height of 19.4m. The length of the station is about 470m. The depth of the station is 50 ~ 95m and the depth of the platform is 63 ~ 107m. The grade of surrounding rock in this area is V grade. C25 shotcrete was used in initial support. The secondary lining is C35 reinforced concrete. The local holes in the underground station are in fault fracture zone, lithologic contact fracture zone, rock contact belt, joint development intensive zone and alteration zone. The rock mass is broken and the groundwater is easy to accumulate. The stability of the surrounding rock is poor. The occurrence of the fault is 236 degrees and 80 degrees. The width is about 16m. The local longitudinal section and cross section diagram are shown in Figure 1.

The tunnel construction method is the step method, and the excavation steps are shown in figures 2 and 3. The specific process is as follows: (1) the steel frame set up by the upper cycle is used as the tunnel support, 1 parts are excavated and the initial support is applied; (2) excavate 2 and 3 parts after the completeness of 1 parts and the initial support from a distant; (3) excavate 4 and 5 and conduct the initial support after the completeness of 3 part from a distance; (4) excavate 6 parts; (5) excavate 7 and 8 parts and initial support after a lag of 6 parts. (6) excavate 9 parts; (7) excavate 10 parts.

![Fig.1 Spatial relationship between the tunnel and the fault fracture zone(plan view)](image1)

![Fig.2 Plan of benching method](image2)
3. Simulation model

The finite element software ANSYS is used to simulate the tunnel and fault fracture zone. The formation structure model is used in the calculation. The total model takes 220m along the longitudinal direction. The lateral hole diameter is more than 4 times to eliminate the boundary effect. According to the relevant information, the depth of the calculation model is 85m (the maximum depth of the tunnel near the fault fracture zone is 85m). The width of the fault is 16m and the yield is 236 degrees and 80 degrees. The tunnel passes through the fault zone in the form of oblique intersection. The numerical model is shown in Figure 4. According to the design information and the relevant provisions of the code for design of railway tunnels, the calculation parameters are shown in Table 1.

The numerical model simulates the fault zone with the form of the contact zone of the weak zone. The mechanical parameters of the surrounding rock in the fault are reflected in the form of weak zones. Surface and surface contact elements Target170 and Contact174 are added at the junction between fault and normal surrounding rock. The free contact method can better simulate the interaction between the upper and lower faults. The corresponding contact surface is also added between the initial support and the secondary lining, and the type of the contact element is the same as above. The contact mode is also free contact, which can simulate the interaction force and relative slip between the initial support and the secondary lining.

The excavation of bench method is simulated by the function of life and death element of finite element, according to the corresponding order of steps. In the model, the corresponding surrounding rock is killed by unit operation to simulate the excavation, and the activation unit is used to simulate the initial support. The step method excavation model is shown in Figure 6.
Fig. 5 Contact element between primary support and the secondary lining

Fig. 6 Numerical model of benching method

Table 1 Mechanical parameters

| Physical value | Elastic Modulus (GPa) | Cohesion (MPa) | Secondary Friction Angle (°) | Poisson Ratio | Density (kg/m³) |
|----------------|-----------------------|---------------|------------------------------|--------------|----------------|
| surrounding rock | 1.04 | 0.05 | 20 | 0.45 | 2000 |
| faults zone | 0.8 | 0.045 | 20 | 0.45 | 2000 |

| Mechanical properties | Initial supporting elastic modulus | Secondary lining elastic modulus | Invert arch elastic modulus | Poisson Ratio | Density (kg/m³) |
|-----------------------|-----------------------------------|-------------------------------|---------------------------|--------------|----------------|
| b. lining | 23GPa | 32GPa | 32GPa | 0.2 | 2500 kg/m³ |

4. Result analysis

4.1 Crown settlement
Numerical model is used to analyze the settlement of the crown of the footpath when the footage reaches and does not reach the fault zone. The settlement of the crown and the curve are drawn after the steps are completed in the statistical step method. When the settlement data is not reached, the distance between the tunnel face and the fault is more than 3 times that of the secondary lining. The 50m is taken in this paper. The calculation results are shown in Figure 7 and Table 2.

Table 2 Crown settlement during excavation

| excavation step | settlement(mm) |
|-----------------|-----------------|
|                 | footage doesn’t reach fault zone | footage reach fault zone |
| 1               | 14.68           | 24.61           |
| 2               | 31.34           | 48.56           |
| 3               | 37.43           | 63.13           |
| 4               | 39.70           | 75.76           |
| 5               | 40.71           | 83.33           |
According to figures 7 and 2, the maximum settlement of the crown is 42.33mm when the footage does not reach the fault zone. The settlement value tends to be stable after fourth excavation steps. When the footage reaches the fault fracture zone, the maximum settlement of the crown reaches 90.39mm, 2.14 times that of the former. The settlement value began to stabilize after sixth excavation steps. It can be seen that the influence of fault fracture zone on tunnel excavation not only increases the settlement value of the crown, but also has a great influence on the convergence rate of the settlement.

4.2 Contact pressure and structural internal force
After the secondary lining is constructed, the contact pressure between the secondary lining and the initial support and the internal force distribution of the secondary lining structure are shown in Figures 8 and 9.
Fig. 8 Contact pressure between primary lining and secondary lining. As shown in Fig. 8, the apparent lateral pressure increases in the secondary lining structure in the fault fracture zone and near the fault. The maximum contact pressure between the initial and two intersections near the fault fracture zone is 1.76 MPa. The maximum contact pressure from far away from the fault fracture zone is 1.36 MPa, which is 1.30 times of the latter. Therefore, the location of lining sidewalls can be optimized near the fault fracture zone to reduce the risk of instability of lining.

The 1st principal stress distribution near the fault fracture zone is extracted, as shown in Figure 9.

Fig. 9 The 1st principle stress of secondary lining in fault fracture zone

As shown in Figure 9, the maximum primary stress of the structure in the fault zone is 2.32 MPa, which is close to the tensile strength of the concrete, and the structure has the possibility of failure. The structure is mainly distributed in the lateral wall of the wall. Therefore, it is suggested to strengthen the support for the side wall of the lining structure near the fault fracture zone and increase the monitoring frequency [10], so as to ensure the smooth progress of the project.

4.3 The Influence Range of Fault Fracture Zone

According to the analysis of the 4.2 section, when the tunnel is in oblique relation with the fault fracture zone, the position of the side wall of the secondary lining structure is most affected by the fault. Therefore, the maximum first principal stress value of the outer side wall of the whole model
220m is extracted to analyze the influence of the fracture zone on the secondary lining structure. The relationship between the first principal stress and mileage of the measuring point is shown in Figure 10.

![Fig.10 The 1st principle stress of secondary lining-mileage curve](image)

As shown in Fig.10, the first principal stress value of the measured point increases significantly during the mileage of 100~155m. It reaches the maximum value of 1.91MPa at the center of the fault. The stress increased by about 17% compared with that without fault. Therefore, it can be considered that when the fault width is 16m, the influence range can reach 55m. It is also suggested that some measures should be taken to strengthen the support, improve the monitoring frequency [11] and deal with the abnormal situation in time.

5. Conclusions

In this paper, the actual engineering of a large span tunnel crossing fault fracture zone is studied. The crown settlement in the construction of the step method in the fault fracture zone is counted. The structural stress of the secondary lining in the fault fracture zone is analyzed. The influence scope of fault fracture zone on the secondary lining structure is also proposed. The conclusions are as follows:

(1) The fault fracture zone has great influence on the settlement value of the crown when the bench method is used. Compared with the effect of no fault condition, the settlement of the crown in the fault excavation is 2.14 times of the former.

(2) The existence of fault fracture zone delayed the convergence time of crown settlement. In this case, the settlement of the crown under the influence of the fault is stable after sixth excavation steps. The settlement of crown under the influence of no fault is stable after fourth excavation steps.

(3) At the fault fracture zone and near the fault, the lateral pressure of the secondary lining structure is obviously increased, which is 1.3 times that of the fault free zone. The fault has obvious effect on the main stress of the secondary lining structure. There is a clear concentration of tensile stress in the area. The maximum tensile stress value is 1.17 times that of the fault free zone. Therefore, it is suggested to take optimal measures for the secondary lining walls in the fault.

(4) With the first principal stress of the secondary lining wall as the criterion, the influence scope of the fault fracture zone on the structure is proposed. In the example of this paper, when the width of fault is 16m, the influence range is 55m, about 3.5 times of its own width.

The conclusions obtained in this paper can provide some reference for similar projects in the future. However, there are still many deficiencies, such as the treatment of fault fracture zones, a study of the different location relations between tunnels and faults. The influence scope of different fault width. These contents should be carried out in future research.

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