Research on water inrush and mud inrush from water-rich fault fracture zone of deep tunnel in mountainous area

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Abstract. Taking the potential risk of water and mud inrush in the construction of a water conveyance tunnel of a hydropower station as the engineering background, based on the field investigation and data collection, the whole process of tunnel construction is simulated and analyzed by using 3D finite element Midas. The results show that because the tunnel passes through the strong water rich fault fracture zone, the filling material in the fault fracture zone has obvious stress concentration under the coupling action of high stress, high pressure seepage and construction disturbance, and the displacement of the filling material has increased significantly. After the fault fracture zone is exposed, the seepage speed has increased significantly, indicating that water and mud inrush disaster has occurred here. It is suggested that when the tunnel passes through complex water-rich fault, monitoring and early warning and excavation support measures should be strengthened to prevent water and mud inrush accidents. The research results have a certain guiding role for the safe construction of the tunnel project.

1. Introduction

With the in-depth implementation of the strategy of "one country and one belt" and the strategy for the development of the western region, a large number of water conservancy and hydropower projects and transportation projects have been approved, and more and more traffic hydraulic tunnels have started construction [1-2]. However, with the continuous expansion of the construction scale of the tunnels, the geological sections in the tunnel area are becoming increasingly complex [3]. In the process of tunnel construction, geological disasters such as high ground stress, rock burst, high ground temperature, water inrush and mud inrush occur continuously [4]. The disaster of water and mud inrush from tunnels often causes damage to facilities and equipment, even causes heavy casualties, which makes the original lines of tunnels forced to change lines and seriously restricts the local economic and social development [5]. The disaster of water and mud inrush from tunnels often causes damage to facilities and equipment, even causes heavy casualties, which makes the original lines of tunnels forced to change lines and seriously restricts the local economic and social development. The disaster causing structures of water and mud inrush in tunnels are mainly divided into karst and fault types [6]. A lot of effective researches have been carried out at home and abroad, and a lot of research results have been obtained. However, for fault type, due to their complex geological conditions, there are many influencing factors of water and mud inrush. At present, the influencing factors of water and mud inrush in fault fracture zone induced by
tunnel crossing fault fracture zone are not clear, so it is of great significance to carry out the research on water and mud inrush in complex fault fracture zone [7]. In this paper, water and mud inrush from a water tunnel in a hydropower station is taken as the background to carry out relevant research.

2. General situation

The design discharge of a water conveyance tunnel in the first phase of comprehensive utilization of water resources of a hydropower station is 1.9 m$^3$/s. The average height of the underground water line is 25.45 m below the surface of the ground. The section of the tunnel is 2.0 m × 2.627 m ~ 1.5 m × 2.233 m (width height). The tunnel section is in the shape of city gate. The tunnel is lined with C25 reinforced concrete with a thickness of 0.3 m. The tunnel passes through a water rich fault fracture zone with a thickness of about 30.87 m and the fault dip angle is 36°. The surrounding rock of the upper and lower walls of the fault is grade IV, and the lithology of the fault fracture zone is poor. The main filling materials in the fault fracture zone are fault gouge, silty fine sand, breccia and broken stone.

3. Calculation model and parameters

According to the actual situation, the calculation model is established as shown in Figure 1. The calculation model is 136 m in X direction, 30 m in Y direction and 106.77 m in Z direction. The displacement boundary condition is used to constrain the horizontal displacement around the model and the fixed displacement at the bottom of the model. When the tunnel is constructed in class IV surrounding rock, the excavation step distance is 20 m, and when it meets the fault fracture zone, the excavation step distance is 3 m. M-C yield criterion is adopted. The calculated rock mass parameters are shown in Table 1. The elastic modulus of C25 concrete for tunnel lining is 10 GPa, the unit weight is 23 KN/m$^3$, and the Poisson's ratio is 0.2.

![Figure 1. Three-dimensional Computing Model](image1)

![Figure 2. Model grid division diagram](image2)
Table 1. Calculated mechanical parameters

| Lithology      | Elasticity modulus(MPa) | Poisson's ratio | Bulk density(KN/m³) | Cohesion(MPa) | Internal friction angle(°) |
|---------------|-------------------------|----------------|---------------------|---------------|---------------------------|
| III class wall rock | 5.35                    | 0.256          | 24.5               | 0.63          | 36                        |
| IV class wall rock | 1.46                    | 0.324          | 21.5               | 0.23          | 29.4                      |
| V class wall rock | 0.22                    | 0.416          | 18.5               | 0.043         | 24                        |
| Fault         | 0.10                    | 0.30           | 17.0               | 0.03          | 22                        |

4. Analysis of calculation results

4.1. Stress field analysis
In the process of tunnel excavation, the maximum compressive stress is mainly concentrated in the area near the side wall and arch foot of the tunnel; the tensile stress is mainly concentrated in the area near the arch top and bottom plate of the tunnel. After excavation of grade IV surrounding rock, the surrounding rock is relatively stable. When the excavation reaches 20m, the maximum stress is 5.25MPa. When excavating for 60m, the maximum stress is 5.98MPa. When the tunnel is about to enter the fault, the maximum stress is 7.46MPa, and the stress concentration degree and range are also expanded. After the tunnel is excavated into the fault zone, the stress concentration range of surrounding rock is further expanded, from the side wall of the tunnel to the arch foot, including the arch bottom. The rock mass around the tunnel is unloaded in a large range, the stress is loosened and the tensile stress area is extended. With the gradual release of stress, the surrounding rock will release energy in the form of expansion damage to the free face of tunnel excavation. The fracture zone of the tunnel fault will expand and develop, and at the same time, the permeability will increase, and the risk of water and mud inrush will increase greatly when the stability of the filling in the fault decreases.

4.2. Displacement field analysis
When the tunnel excavation does not enter into the fault, the change displacement of the vault and the floor is small. The extreme value of horizontal displacement is distributed on the left and right sides of the tunnel wall. During the process of tunnel excavation, the left and right sides of the tunnel wall are relatively stable before the excavation to the fault; the range of the extreme value of displacement changes after the excavation into the fault is gradually extended from both sides of the tunnel wall to the near the arch shoulder and the arch foot; the displacement changes after the excavation through the fault are relatively reduced, and the surrounding rock is more stable than the fault. In tunnel construction, there will be sudden changes when entering and passing through the fault. When entering the fault, the sudden change value will rise and change greatly. The deformation of the surrounding rock in the fault fracture zone is relatively large, so it is necessary to strengthen the monitoring and take effective engineering measures to prevent the occurrence of geological disasters such as water and mud inrush.

4.3. Seepage field analysis
In the process of tunnel construction, the total water head change of surrounding rock seepage is shown in Figure 2-5. With the tunnel construction forward, the seepage field of tunnel face changes constantly. Before the excavation, the total water head of the surrounding rock of the tunnel is distributed in layers, and the maximum variation range of the total water head around the tunnel is gradually expanded before the excavation enters the fault fracture zone. When the excavation enters into the fault, the total seepage head will suddenly change, which will cause the seepage velocity and dynamic seepage pressure to increase, and the seepage velocity at the fault will obviously increase. With the deep excavation of the
tunnel, the maximum seepage velocity of the surrounding rock near the face changes obviously. Due to the geological conditions before the excavation into the fault, the groundwater flow is relatively stable and the maximum seepage velocity is relatively gentle. Before the tunnel enters into the fault, the maximum seepage velocity increases from $1.412\times10^{-5}\text{m/s}$ to $1.732\times10^{-5}\text{m/s}$, with an increase of only 22.67%; when the tunnel enters into the fault (it is 83m from the tunnel entrance), due to the poor geological conditions of the fault and the stability of the surrounding rock, the permeability is poor, the maximum seepage velocity suddenly increases to $3.012\times10^{-5}\text{m/s}$, with an increase of 73.9%. At this time, the water and mud inrush disaster occurs in the fault fracture zone.

![Figure 3. Total seepage head distribution after 20m excavation](image3)

![Figure 4. Total seepage head distribution after 60m excavation](image4)
5. Conclusion

The fault fracture zone of the tunnel is rich in water and the fault filling material is loose and broken. When the tunnel passes through the fault fracture zone, the original balance state of ground stress at the fault is destroyed. Under the coupling action of high stress, high water pressure and construction disturbance, the stress concentration at the fault fracture zone is obvious, the displacement of surrounding rock at the fault fracture zone increases greatly, and the water head and seepage flow at the fault fracture zone are destroyed. The increase of the speed indicates that the disaster of water and mud inrush has occurred. Therefore, when the tunnel passes through the complex water rich fault fracture zone, it is necessary to strengthen the advance geological prediction, strengthen the support means and the early warning of water inrush and mud inrush during the construction, so as to prevent the major water inrush and mud inrush accidents.
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