Cause analysis of water and mud inrush in fault fracture zone of deep tunnel and its treatment measures

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Abstract. A water conveyance tunnel of a hydropower station encountered the disaster of water inrush and mud inrush in the fault fracture zone, which caused the filling collapse in the fault fracture zone on the face of the tunnel, which seriously threatened the safety construction of the workers and affected the construction period. Based on the comprehensive analysis of the influencing factors of water and mud inrush in the fault fracture zone of the tunnel, this paper makes a preliminary analysis of the water and mud inrush in the tunnel, and puts forward the comprehensive treatment measures for the construction of the collapse section. Through the field engineering practice, this disposal measures passed the collapse section smoothly. The research results can be used for reference to the cause analysis of water and mud inrush in the fault fracture zone of similar tunnels and the construction method in the collapse section.

1. Introduction

In recent years, with the in-depth implementation of the strategy of "one country and one belt" and the strategy of developing the western region, a large number of water conservancy and hydropower projects and transportation projects have been started [1]-[2]. Yunnan Province, as the radiation center of China facing south Asia and Southeast Asia, is speeding up the construction of "five networks", in which the construction of road network and water network is stepping into the "fast lane", a large number of infrastructure construction projects of traffic and water conservancy projects are being carried out closely, accompanied by a large number of traffic hydraulic tunnels are speeding up the construction[3]-[4]. However, due to the more and more complex conditions of the tunnel site, when the tunnel passes through the fault fracture zone, it will often encounter a large water and mud inrush disaster, which will cause damage to facilities and equipment, even will cause heavy casualties and forced to change the line, seriously affecting the local economic and social development. Therefore, it is of great engineering significance and social benefit to study the water and mud inrush of tunnel through the fault fracture zone [5]-[6]. Based on the analysis of the main influencing factors of water and mud inrush in the fault fracture zone, this paper analyzes the causes of water and mud inrush in the fault fracture zone, and puts forward the corresponding engineering treatment measures for the collapse of the fault fracture zone.
2. Project profile
The first phase of water resources comprehensive utilization project of a hydropower station is located in the Jinsha River Valley area of Heqing County, Yunnan Province, which consists of 15 tunnels. The total length of the water conveyance tunnel studied is 4158.9m. It is a non pressure water conveyance tunnel, which is lined with C25 reinforced concrete. The surrounding rock of the entrance and exit section is classified as class IV and V. The tunnel body is mainly composed of class III surrounding rock with 20%-30% of class IV and V surrounding rock. The net section size of the tunnel (width×height) is 1.50m×2.233m, which belongs to the small section water conveyance tunnel. The gate tunnel type is adopted, and the design flow is 1.9m³/s.

3. Water and mud inrush in fault broken zone during tunnel construction
At about 6:30 on December 25, 2013, during the drilling and blasting construction at No.0+365.500 of the tunnel, there was a sudden surge (the water inflow was about 5.0m³/s when it first occurred), the flow was about 1.1m³/s after the water inflow was stable, and a large amount of broken rock slag was mixed in the water inflow. On December 28, 2013, the daily water output began to decrease, and on December 29, 2013, the daily water output decreased to 0.25m³/s. According to the on-site inspection, 80% of the space between the stake 0+270.300 and the original face of the tunnel has been filled by the rock slag produced by the water gushing from the fault fracture zone, and then the slag is discharged under the condition of ensuring safety. On January 12, 2014, the slag was discharged to the original face of pile No.0+365.500. During the slag removal process, it was found that the constant and balanced stone slag gushed out from the vault, which was difficult to pass through normally. The water inrush on site is shown in Figure 1 and Figure 2.

![Fig. 1 Photos of water inrush in the tunnel](image1)
![Fig. 2 Water inrush from the tunnel accumulates at the Entrance](image2)

4. Analysis on the main influencing factors and causes of water and mud inrush in the fault fracture zone of the tunnel
4.1. Engineering geological factors
(1) landform
The water diversion tunnel is excavated through the fault fracture zone, high mountains and valleys, depressions and other catchment structures, which are often the collection area of atmospheric precipitation and surface runoff. A large amount of surface water is transferred to the underground, which improves the groundwater level, and is one of the important factors causing the water and mud inrush disaster of the tunnel.

(2) Formation lithology
The stratum lithology where the water conveyance tunnel passes through is mainly basalt, breccia basalt with limestone lentils, and the lower part is lower Permian limestone. The fault fillings are mainly fault gouge, silty fine sand, breccia and gravel, which have strong water conductivity. In the stratum rich in groundwater, water rich faults are often formed. Once the excavation is exposed, it can cause water and mud inrush disaster.

3) Fault structure
The internal structure of the fault is complex and variable, and the content of filling medium with different particle size is also different, which has an important impact on the permeability characteristics of the fault, and then affects the water and mud inrush when the tunnel passes through the fault. In this case, the evolution process of water inrush and mud inrush in tunnel is relatively complex, the internal fissures are developed, and the groundwater is active, which is easy to cause water inrush and mud inrush in tunnel.

4.2. Hydrogeological factors
(1) Weather conditions
The climate characteristics of the study area are dry in winter and spring, rainy in summer and autumn. The rainy season is from late May to late October, with an average annual precipitation of 600mm. The underground and surface water systems are complex, and the fault fracture zone is connected with the surface water system. In the rainy season, it is revealed that the water pressure in the fault fracture zone is higher, which is more likely to cause water and mud inrush disasters during the tunnel construction in the rainy season.

(2) Hydrographic features
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4.3. Construction effect
Due to the influence of blasting disturbance, drilling and blasting excavation is more likely to cause the loosening of water isolation damping structure and the loosening of filling medium inside the fault, and then water and mud inrush will occur under the action of high ground stress and high permeability disturbance.

4.4. Preliminary analysis on the cause of water and mud inrush in the fault fracture zone of the tunnel
According to the geological survey data, the lithology revealed by the excavation in the tunnel, the occurrence of the thickness of the fault fracture zone, the integrity of the rock mass, and the gushing matter, combined with the development characteristics of the surface fissures in the water and mud inrush section, the causes of the water and mud inrush in this tunnel are comprehensively analyzed as follows: When the tunnel is excavated to no.0+365.500, which encounters the fault fracture zone. Because the fracture in the fault fracture zone is very developed, which is a good channel for water storage and water diversion, and is conducive to the migration of groundwater and soil particles. The fracture in the fault zone is filled with a lot of fault gouge, fine sand, breccia and broken stone, which become the basic material source of water and mud inrush [7]. When the tunnel excavation reveals the fault fissures, it destroys the original groundwater balance system, and the fillings erode and lose particles under the action of high stress and high-pressure seepage, which eventually leads to the transformation process of filling material from water resistance to seepage conduction, from weak seepage to strong seepage, to the formation of a surge channel, thus a large number of groundwater carrying mud, sand and gravel flows into the tunnel. It is the cause of water gushing and mud bursting in the tunnel.
5. Treatment measures of tunnel collapse caused by water and mud inrush

The collapse of the fault fracture zone caused by the outburst disaster at the site resulted in the formation of a large number of debris and rock slag at the face, as shown in Figure 3. A large number of loose rock slag will continue to fall in the process of normal tunneling, so it is necessary to take engineering treatment measures to successfully pass.

![Fig. 3 Rock slag on tunnel face](image)

According to the actual situation of water and mud inrush in the tunnel and the actual situation of tunnel passing through fault fracture zone at home and abroad, the following treatment measures are proposed. The treatment measures for tunnel surge collapse section is shown in Figure 4.

![Fig. 4 Treatment measures for tunnel surge collapse section](image)

1. In the first step, the outer section steel support construction shall be carried out first. The steel support shall be i18 I-beam with a spacing of 40cm. The steel supports shall be connected by Φ25 steel bars with a spacing of 50cm. Each steel support shall be arranged with Φ22, L=1.8m foot lock and mortar anchor bolts.
2. In the second step, C15 concrete with a thickness of 50cm shall be poured on the surface of the initial muck as the cover plate for the next stage of consolidation grouting.
3. In the third step, the first stage of consolidation grouting shall be carried out. According to the hole
forming conditions, the grouting shall be carried out gradually from the outside to the inside in I–III sequence. The consolidation grouting hole diameter is 75cm, the hole depth is 6m each time. The grouting shall be carried out with clean water slurry, the water cement ratio of the slurry is 0.45:1 ~ 0.65:1, and the grouting pressure shall be controlled within 0.2~0.5MPa. The construction of the drainage hole shall be carried out at the same time according to the actual situation. 4. The fourth step is to carry out the consolidation grouting construction of the outer part of the second stage grouting cover plate. According to the hole forming conditions, the grouting will be carried out gradually in I–III sequence. The rows are arranged in a quincunx shape, with an aperture of 75cm and a hole depth of 9m. 5. The fifth step is to carry out the construction of the outer anchor bolt. 6. The sixth step is the construction of self-propelled advance anchor. The self-propelled anchor adopts Φ25, L=4.5m, spacing 10cm, and the overlapping length of each row of anchor is 1.5m. 7. Remove the grouting cover plate concrete in step 7. 8. In the eighth step, slag out and concrete pouring of bottom slab cushion shall be carried out immediately every 0.5m forward. The parameters of steel support are the same as those in the first step. The steel mesh shall be Φ6.5 with a spacing of 5cm, and the shotcrete shall be C20 with a thickness of 18cm. 9. The ninth step is to carry out the secondary grouting cover plate internal consolidation grouting construction. According to the hole forming conditions, the grouting is carried out while the consolidation grouting is carried out. The grouting is divided into I–III sequence cyclic grouting. Each row is arranged in a quincunx shape, with an aperture of 75cm and a hole depth of 9m. 10. Follow up steps: first stage consolidation grouting→self-propelled advance anchor bolt→slag discharge→cushion concrete pouring→steel support construction→shoetcreting construction→second stage consolidation grouting→anchor bolt construction, which is cyclic construction.

6. Conclusion
(1) when the tunnel is excavated to no.0+365.500, a large-scale water and mud inrush disaster occurs near the fault fracture zone. When the tunnel excavation reveals the fracture of the fault, the original groundwater balance system is destroyed, and the filling medium is eroded and particles are lost under the action of high stress and high pressure seepage, which eventually causes the karst pipeline to experience from water resistance to seepage conduction, from weak seepage to strong seepage, until the formation of outburst. In the process of seepage transformation, a large number of ground water carrying mud, sand and gravel flow into the tunnel, which is the reason for the formation of water inrush and mud inrush in the tunnel.

(2) According to the causes of water inrush and mud inrush, combined with the on-site inrush and collapse situation, a comprehensive treatment scheme is proposed, which is steel support construction→first stage consolidation grouting→self-propelled advance anchor bolt→slag discharge→cushion concrete pouring→steel support construction→shoetcreting construction→second stage consolidation grouting→anchor bolt construction. The field engineering practice shows that the method is effective in crossing the tunnel fault rupture zone.

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