Original Research Article

Construction Technology of Tunnel Consolidation Excavation in Water-rich Soft and Broken Rock Formations

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Abstract: Combined with the example of the Junchang Tunnel of Censhui Expressway in the middle and Guangxi section of Baomao Expressway, this paper briefly introduces the four major mud and water inrush disasters that occurred, and expounds the causes of the disasters. Consolidation excavation of the tunnel has made a summary of construction technology.

Keywords: Junchang tunnel; Water-rich weak broken rock formation; Curtain grouting; Consolidation excavation.

1. Introduction

With the rapid development of transportation engineering construction in our country, the proportion of tunnel engineering in the overall engineering is increasing, and complex geological conditions such as water rich, weak, and fractured rock layers encountered are also gradually increasing; China has accumulated rich work experience in tunnel collapse prevention construction, but there is still a lack of effective experience in the consolidation treatment of water rich, weak and fractured rock layers. This article summarizes the construction process of the Junchang Tunnel on the Censhui Expressway, including the technology of curtain grouting to consolidate rock layers and the measures for auxiliary reinforcement during excavation. This aims to minimize the occurrence of various disasters in future tunnel construction and ensure the safe operation of the tunnel after completion.

2. Mud and Water Inrush Disasters and Engineering Overview

2.1 Project Overview

The Censhui Expressway is an extremely important section of the north-south trunk line of China's expressway network, Baomao Expressway, with a total length of 30.7km. It is one of the highway sections with the highest bridge tunnel ratio (41.54%) in Guangxi. The Junchang Tunnel is a separated small clear distance two-way four lane extra long tunnel. The starting and ending pile numbers of the left line are DK6+450 Yao DK10+730, with a length of 4280m. The starting and ending pile numbers of the right line are CK6+475 Yao CK10+770, with a length of 4295m. The distance between the center lines of the two lanes is 29m, with a clear distance of 15m and a clearance (hole width height) of 1-10.75 meters. The remaining unfinished section is located below Shanxin Village, with a burial depth of approximately 85-105m. Belonging to the micro basin terrain, it has extremely strong water collection capacity. The surrounding rock is fully strongly weathered granite, with weak and fractured rock layers rich in water and well-developed joints and fissures. The water transmission in the area is unobstructed. (Figures 1 and 2)

2.2 Overview of Sudden Mud and Water Disasters

2.2.1 9.11 Mud and Water Inrush Disasters

On September 11, 2013, when the right entrance of Junchang Tunnel was excavated to the upper platform of CK7+837.5, there was a surge of water in the palm face, with a maximum water column height of 80cm and

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a maximum water inflow of 1195m^3/h. Two days later, the water inflow remained at 695m^3/h. After 1 day of water inrush in the tunnel, there was a collapse on the surface 790m away from the tunnel face, and the well pond had dried up. After 11 days of water inrush, there were also large collapse pits on the surface above the face, and local collapse and deformation of the initial support in the tunnel were severe, with more obvious deformation of the left tunnel initial support and a cumulative water inrush of 25 × 104m^3, with approximately 2500m^3 of mud and sand accumulation. (Figure 3)

Figure 1 Schematic diagram of unconnected section.

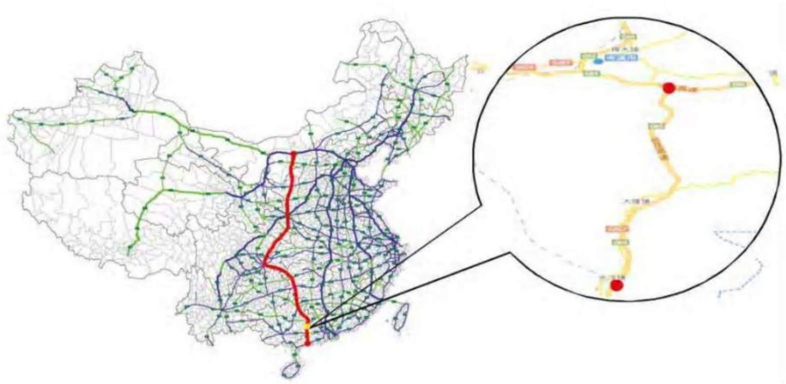

Figure 2 Schematic diagram of Baomao Expressway.

Figure 3 Surface collapse in muddy and watery areas.

2.2.2 9.19 Mud and Water Inrush Disasters

On September 19, 2014, when the left exit of the Junchang Tunnel was excavated to DK7+962.5, there was a mudslide on the face of the tunnel, which lasted for 4 hours, with a mudslide volume of about 2900 cubic meters. The palm face is buried at a depth of 100m, and a collapse pit with a diameter of 13m and a depth of 7m appears in front of the palm face surface. (Figure 4)

Figure 4 Surface collapse of Tu Ni Yao.

2.2.3 5.1 Mud and Water Inrush Disasters

On May 1, 2015, the original water and mud inrush section was treated on the upper steps of the palm face and advanced to CK7+834.5 mileage. During the initial support construction, there was a surge of water at the right arch foot of the upper step, with a diameter of about 15cm and a water inflow of about 38m3/h. After 2 hours of successful sealing, the water inflow increased and broke through the closed sand bag and palm face, increasing to 605m^3/h. After 1 day of water inrush, several rivers near the surface of Shanxin Village Committee collapsed due to water interruption. After 4 days of water inrush, deeper sinkholes reappeared at the original surface collapse caused by the geological disaster of 9.11 water inrush and mud inrush. It was not until May 9th that the right tunnel of the tunnel face was effectively sealed, and during the process, the cumulative water inflow reached 10×10^4m^3, with mud and sand accumulation of about 1000m^3. (Figure 5)

2.2.4 10.23 Mud and Water Inrush Disasters

Figure 5 Surface collapse situation of sudden mud and water gushing Yao.

On October 23, 2015, when the upper step of the left exit of the Junchang Tunnel was used to treat the original water and mud inrush section and excavated to DK7+938.5, there was another water and mud inrush on the face, which lasted for 5 hours. The maximum water inflow reached 650m^3/h, and the mud inrush was about 2500 cubic meters. A funnel-shaped collapse pit with a diameter of 8m and a depth of 10m appeared on the surface in front of the palm. (Figure 6)

3. Analysis of the Causes of Sudden Mud and Water Influx

The occurrence and evolution process of geological disasters caused by sudden mud and water inrush in the Junchang Tunnel indicate that geological disasters caused by sudden mud and water inrush in fractured rock layers of tunnels in the Fushui area are characterized by strong suddenness, fast progress of disasters, extremely serious secondary disasters, and a large impact range. By conducting on-site supplementary drilling and geophysical exploration through the system, the factors causing water inrush and mud inrush disasters in the poor geological section of fractured rock layers in the Fushui area of the Junchang Tunnel have been determined as follows:

Figure 6 Surface collapse of Tu Ni Yao.

3.1 "V" - Shaped Valley and Micro Basin Catchment Terrain

The Junchang Tunnel site is located in the middle and low mountain landform area. Due to long-term geological tectonic action and erosion by surface water, the terrain changes greatly, and the mountain volume is large, with high and steep slopes, forming a "V"-shaped valley terrain. The area is surrounded by mountains and relatively flat in the middle, forming a micro basin with strong catchment capacity and a large catchment area. The surface water has a high intensity of supplying groundwater.

3.2 Widespread Distribution of Water Channels

Through supplementary drilling, high-density electrical exploration, and other exploration work, it is shown that the geological structure of the Junchang Tunnel is a near EW trending weathered deep trough with rich water. Previously, there was magma intrusion and regional metamorphism, which developed into relatively unobstructed seepage channels in the contact zone of intrusive rocks and strata. At the same time, strongly to moderately weathered granite and weathered quartz veins also have good water conductivity, and together with the weathered interface water conductivity channels, they form water inrush and mud inrush channels, which are widely distributed.

3.3 Surface Water and Groundwater Are Extremely Abundant and Closely Related

The tunnel site area has abundant rainfall, with an average annual rainfall of about 1500mm. According to several monitoring measurements of the groundwater level above the face of the sudden mud and water influx in the Junchang Tunnel, it was found that as the water inflow increased, the groundwater level continued to decrease, leading to surface collapse. The amount of water inflow in the tunnel decreased, and the groundwater level began to rapidly rise, indicating a close connection between surface water and groundwater.

3.4 Weak and Fragmented Rock Layers with Poor Self Stability Performance

The Junchang Tunnel area is affected by geological structure and strong weathering, and the surrounding rock in the emergency rescue section is mainly composed of completely strongly weathered granite. The degree of rock fragmentation is very high, with developed joints and cracks, extremely weak and fragmented, and poor self stability and bearing capacity. After immersion in the rich water section, its strength sharply decreases and its water stability is poor.

4. Construction Technology of Rock Curtain Grouting and Consolidation

4.1 Consolidation Plan and Governance System

Due to the abundant water and high water pressure inside the tunnel during excavation, the surrounding rock has poor self stabilization ability, and may slide and collapse when encountering water, even resulting in sudden mud and water inrush disasters; Therefore, before tunnel excavation, it is necessary to pre reinforce the surrounding rock of Junchang Tunnel to improve the physical and mechanical properties of the surrounding rock, thereby enhancing the stability of the tunnel surrounding rock. Considering the special geological conditions and rock characteristics of Junchang Tunnel, as well as various considerations such as economic investment and operational safety, a comparative analysis was conducted on the ground curtain interception method, freezing method, advanced curtain grouting method inside the tunnel, long pipe shed with small conduit method, and drainage and strong excavation method. Finally, the full section curtain grouting method inside the tunnel was determined. This method can fundamentally block the hydraulic supply channel, achieve systematic reinforcement of surrounding rock, ensure the safety of tunnel construction and operation periods, and have a moderate cost and controllable construction period. Establish a comprehensive governance system that provides theoretical guidance and feasible solutions, solidifies before excavating, steadily advances, and promptly addresses any doubts during the governance process.

4.2 Full Section Curtain Grouting Construction Technology

4.2.1 Advance Geological Prediction and Horizontal Advance Drilling

The engineering geological and hydrogeological conditions of the unconnected section of the Junchang Tunnel are extremely complex. In order to further explore the structural fracture zone, weak interlayers, and underground water burial and distribution in front of the tunnel face in the unconnected section, and provide technical references for underground water sealing, surrounding rock reinforcement, and tunnel excavation, advanced geological predictions were made for the left and right tunnels in the unconnected section using methods such as transient electromagnetic method, land sonar method, and differential electrical exploration method, During the curtain grouting process, horizontal advanced drilling holes were also used for verification. (Figure 7)

Figure 7 Transient electromagnetic detection of left and right holes.

4.2.2 Selection of curtain grouting materials

In the comprehensive treatment project of sudden mud and water inrush tunnel disasters, commonly used grouting materials include cement single liquid slurry, cement water glass double liquid slurry, etc. The geological conditions and water inflow revealed through geophysical exploration and horizontal drilling are difficult to control using only the above-mentioned materials, especially when the water inflow is large. Therefore, a slurry that can quickly seal the large water inflow is needed. GT liquid is a paste like grouting material independently developed by Shandong University. It is mixed with cement slurry to form a dual liquid slurry, which has the advantages of good diffusion control, adjustable initial and final setting time, anti dispersion in dynamic water, and high early strength. It can quickly seal grouting holes with high water inflow and high water pressure.

4.2.3 Determination of Curtain Grouting Parameters

According to different geological conditions and water inrush situations, as well as multiple grouting excavation practices, the length of each grouting section in each cycle is controlled at 15-20m, and the curtain thickness is 5-8m. The effective diffusion radius of the slurry is calculated as 2m, and the distance between the final grouting holes is controlled by 1.5 times the diffusion radius of the slurry. The water inflow pressure of the emergency section of Junchang Tunnel is 0.65MPa per month, the grouting pressure is controlled within 2.5MPa for a hole depth of 0yao 6m, 4.0MPa for a hole depth of 6yao 12m, and 5.0MPa for a hole depth above 12m. In special circumstances, adjustments are made based on whether the grout stop wall cracks and the size of the single hole water output to avoid excessive deformation such as initial support, grout stop wall, and work platform cracking. The water cement ratio of cement slurry is 1:1 and 1:0.8, and the blending ratio of dual slurry is between 1:1 and 5:1.

4.2.4 Curtain Grouting, Drilling and Grouting Construction

Uniformly distribute the drilling holes on the grout stop wall, with five rings A, B, C, D, and E. The drilling is carried out in sequence from the inside out and from the bottom up. When there is no water or collapse in the same ring, grouting can be carried out through separate holes. If encountering areas with rich water and broken sections, the spacing should be reduced, and the area should be treated with emphasis. During the drilling process, control the accuracy and angle deviation of the hole position, and ensure that the orifice pipe is firmly installed. Detailed records of water inrush, borehole collapse, stuck drilling, faults, and rock changes during construction provide reference data for grouting. (Figure 8- Figure 10)

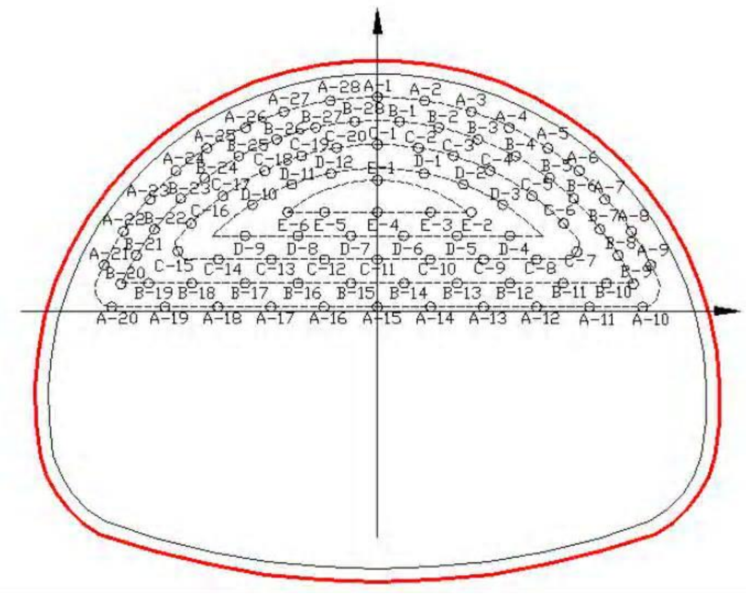

Figure 8 Schematic diagram of full section curtain grouting hole opening.

4.2.5 Testing of Curtain Grouting Effect

After the completion of full section curtain grouting, a comprehensive inspection and evaluation of the grouting effect is required before excavation to see if the excavation conditions can be met. The detection adopts methods such as transient electromagnetic detection, inspection hole observation, comparative analysis of water inflow, and drilling P-Q-t curve.

(1) The transient electromagnetic method is used to analyze and determine whether there is a water rich area in the surrounding rock of the grouting length section. If not, the grouting meets the requirements and excavation can be carried out.

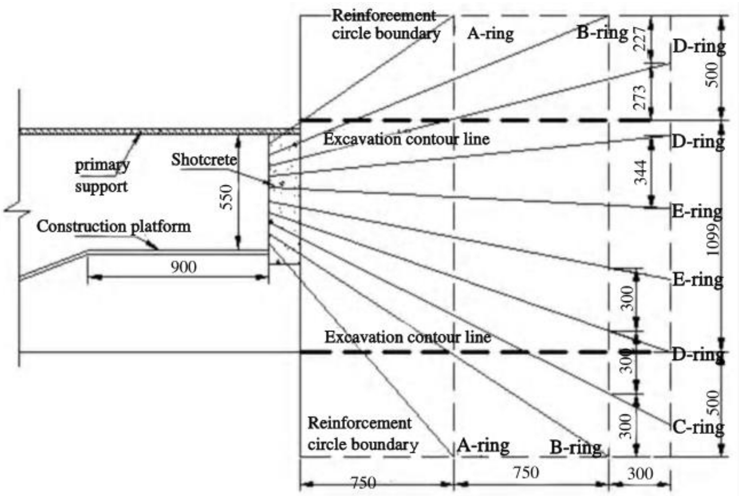

Figure 9 Schematic diagram of segmented cross-section of curtain grouting.

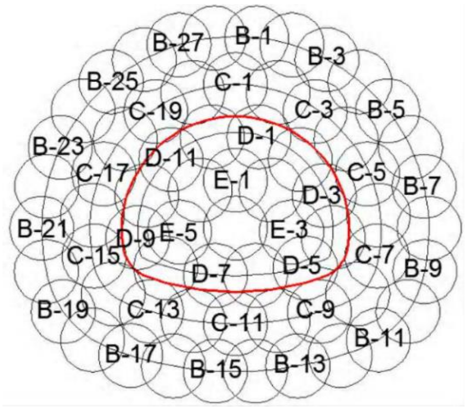

Figure 10 Schematic diagram of slurry diffusion and intersection at the final hole position of curtain grouting.

(2) The inspection hole observation method is mainly achieved by carefully observing that the inspection hole is intact, free from water, mud, and sand surges, and has not collapsed after being left for a period of time, without producing water, mud, or sand surges. This proves that the grouting effect meets the requirements and can be excavated.

(3) The standard for comparative analysis of water inflow is that the water inflow per linear meter of each hole is less than 0.20L/min · m and the water inflow per single hole is less than 3L/min. If the above two points are met, it proves that the grouting effect meets the requirements and excavation can be carried out.

(4) The drilling P-Q-t curve method is to conduct drilling and grouting tests on the designed inspection holes. By analyzing the characteristics of the P-Q-t curve of the designed inspection holes, the final grouting effect can be determined. The P-Q-t curve of the inspection holes should be steeper than the curve shape during normal grouting. After 5-10 minutes of grouting, both the grouting pressure value and the grouting flow rate Q value should reach the design final pressure value, proving that the grouting effect meets the requirements and excavation can be carried out.

5. Tunnel Excavation and Auxiliary Measures

5.1 Excavation of Tunnel Rescue Section

(1) The emergency rescue section of the tunnel is a V-class surrounding rock layer, which is rich in water and weak in fractured rock layers. Therefore, the three-step seven step method is used for excavation, and the core soil is reserved at the upper step.

(2) Excavation support is 0.5m per beam, and the initial support is made of 20 I-beam and double-layer ø12

steel mesh. C25 sprayed concrete is used to seal the ring. After excavation, concrete with a thickness of 3-5 cm should be sprayed immediately to reduce the exposure time of the surrounding rock.

(3) The excavation on the left and right sides of the middle and lower steps must be staggered, and it is strictly prohibited to be staggered. The distance between the left and right sides should be 2-3m. The inverted arch must closely follow the construction of the lower steps and quickly close to form a stable and reliable support system.

(4) Strictly control the external insertion angle of the advanced catheter when using the advanced catheter; Add a 16 channel steel longitudinal beam at the connection plate of the upper platform, and the toe of the steel frame should be placed on a solid foundation rock surface, with a 45cm long 30 channel steel pad added. It is strictly prohibited to suspend the arch (wall) foot arch or use virtual soil for backfilling treatment; The steel frame is firmly connected to the steel frame with M20 high-strength bolts, and the steel frame and locking anchor rod are welded firmly with ø22 “L” shaped steel bars.

(5) The initial support of the inverted arch shall be constructed with a length of 3m for each section, and the distance from the palm surface shall not exceed 20m.

(6) The length of each section of the secondary lining construction is 12m, and the distance from the palm surface is not more than 40m.

(7) During the construction process, arch settlement and peripheral convergence monitoring are carried out on the initial support according to the frequency of the surrounding rock.

During the construction process, timely improve the temporary waterproof and drainage system inside the tunnel before excavation. It is strictly prohibited to soak the arch (wall) feet on both sides of the tunnel with accumulated water and allow the accumulated water to flow freely on the construction site to prevent a decrease in the bearing capacity of the foundation. When the water content in the local layer of the tunnel is high, a transverse water ditch should be excavated near the bottom of the upper platform excavation face of the palm face to divert the water in front of the palm face to the drainage ditches prepared on both sides of the tunnel and discharge it outside the tunnel; When the inlet is constructed on a reverse slope, a collection pit is excavated at the end of the inverted arch to concentrate water and discharge it outside the tunnel.

5.2 Auxiliary Measures for Problems Encountered During Excavation Process

Curtain grouting has timeliness, especially during rainy seasons, where water in the rock layers outside the curtain grouting slowly seeps into the excavation face. However, during the excavation process, there may be seepage or even water seepage and collapse in the face and initial support. Therefore, other auxiliary measures need to be taken.

(1) The initial support seepage is achieved by using a small conduit radial supplementary grouting method to seal the water source channel and reinforce the surrounding rock that has already been initially supported.

(2) The initial support sinks and cracks, and ø108 steel pipe large locking feet are used to lock the arch, and grouting is used to reinforce the rock layer, with each 6m and a spacing of 0.5m.

(3) During the excavation process, there is a phenomenon of water seepage and collapse in front of the palm. After using steel mesh and sprayed concrete to seal it, it is difficult to excavate, and large machinery is also difficult to enter the borehole for grouting. Therefore, air drills are used for drilling, and other chemical grouting fluids such as Weideke are used. A small ZBQ-5/12 grouting pump is used to quickly supplement the grouting and seal the front of the palm, and then continue excavation, and so on, but cannot exceed the original excavation length.

(4) The initial support seepage and arch foot water seepage are relatively serious. Therefore, drilling drainage holes on the side of the initial support is adopted to ensure the stability and safety of the rock layer

during excavation. (Figure 11- Figure 14)

Figure 11 Radial supplementary grouting construction.

Figure 12 Construction of large lock foot drilling and grouting.

Figure 13 Weideke chemical slurry supplementary grouting.

Figure 14 Drilling drainage holes for water diversion and drainage.

6. Conclusion

The Junchang Tunnel of the Cenxi Shuiwen Expressway is located in a fully weathered granite and water rich area, with weak and fragmented rock layers and developed joint fissures, making it very difficult to treat. During the governance process, various advanced forecasts and theoretical analyses were conducted, and different grouting materials and processes were used to effectively control the Junchang Tunnel in the soft and fractured rock layers with abundant water. This article provides an in-depth summary of the causes and comprehensive treatment technologies of sudden mud and water disasters, and establishes a comprehensive treatment system of “theoretical guidance, feasible plans; solid before excavation, steady progress; suspicious points must be investigated, and timely treatment”. It has successively achieved the connection of left and right tunnels, ensuring the implementation of the overall construction plan, and providing effective construction experience for the consolidation and excavation construction of tunnels in soft and fractured rock layers with rich water in the future.

References

1. Wang Mengshu, Huang Fuming. Key issues in underwater tunnel construction [J]. Journal of Architecture Science and Engineering, 2005, 22 (4): 1-4.
2. Li Rong, Li Zhiguo. Research on grouting technology for fully weathered granite strata in underwater tunnels [J]. Modern Tunnel Technology, 2008, 45 (1): 21-29.
3. Zhang Mei, et al. Construction technology for karst fault tunnels on the Yiwan Railway [M]. Beijing: Science Press, 2010, 11.
4. Lu Chunfang. Tunnel Engineering (Typical Case of High Speed Railway Construction) [M]. Beijing: China Railway Press, 2015, 4.