Discussion on the Treatment of Karst Water of Jinmen Tunnel During Construction

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Abstract. Jinmen tunnel passes through the environmental nature reserve. In the process of construction, many karst caves are exposed and a large amount of water gushes from karst are encountered several times. During the treatment of water inrush, the source and characteristics of water inrush are explored, and several treatment measures such as "advance curtain grouting", "diameter backward grouting" and "anti water pressure lining" are taken. The engineering practice shows that the treatment technology of karst water inrush adopted by the project is practical and effective, which has certain reference significance for the tunnel construction under the condition of rich karst water inrush.

1. Preface

In the construction process of karst tunnel, due to the existence of high-pressure water-rich karst, water gushing accidents often occur. If not handled properly, it will affect the construction safety and project progress, and even cause the deterioration of the surface environment and the operation environment in the tunnel. In the past, when encountering the water gushing phenomenon of karst tunnel, most of the water is mainly discharged from the construction area [1]-[4]. Similar treatment will lead to the loss of karst water, resulting in high-level water shortage, affecting the reserves of drinking water in high-level areas. In addition, when the karst water is rich in carbonate or sulfate, the drainage in the tunnel will erode the tunnel structure and consume its service life [5]. Therefore, in the treatment process of tunnel karst water, it is necessary to comprehensively consider various technical means to ensure the safe construction of the tunnel in the Karst Section and its affected zone.

In order to protect the groundwater resources in the environmental nature reserve, the Jinmen tunnel adopts many treatment technologies, such as "advanced curtain grouting", "back-grouting", "anti-hydraulic lining" and "combination of blocking and drainage", which realizes the effective protection of the natural environment and provides reliable guarantee for the construction and structural safety of the tunnel.

2. Engineering Survey

The overall landform of the Jinmen tunnel site is tectonic denudation type. The tunnel is 6492m long and the maximum buried depth is nearly 500m.

The tunnel site belongs to the landform of low mountains and hills, with developed vegetation, large longitudinal gradient, and numerous scarps. The upper part of the slope is covered by thin eluvial Deluvial red clay and silty clay. The entrance of the tunnel passes through the Xueshanzhang anticline,
mainly composed of sandstone, shale and mudstone; due to the geological tectonic movement, the fissures in the axis of the anticline are developed, the rock mass is broken, and the groundwater is mainly bedrock fissure water, which is rich in groundwater. The outlet is mainly limestone mixed with marlstone, with obvious surface erosion, karst funnel, depression and falling water hole everywhere; the groundwater is mainly karst water, obviously affected by the season, and the spring flow in the field investigation changes and fluctuates with the season.

3. Typical Karst Water Inflow
Due to the development of karst fissures in the tunnel site area, multiple karst caves and fissures of different sizes are exposed during excavation, as shown in Figure 1.

In the process of tunnel construction, karst water gushing with different scales has been encountered for many times. The buried depth of ZK200+920~ZK200+985 tunnel is about 130m~160m, which is a geophysical anomaly area. After several days of rain, there is a large amount of water gushing on the face of the tunnel and the initial wall, as shown in Figure 2.

4. Special hydrological investigation

4.1. Water inflow observation inside and outside the tunnel
According to the observation statistics, the karst water inflow in the tunnel is closely related to the rainfall outside the tunnel and the rainfall time, as shown in Table 1.

| Stake No | Weather          | Water inflow description                      | Water inflow |
|----------|------------------|-----------------------------------------------|--------------|
| 1        | Moderate~ heavy rain | Water gushing at left arch waist and arch foot | 40,000m³/d   |
| 2        | Heavy rain       | Water inrush from excavation face and back side | 100,000m³/d |
| 3        | Heavy rain       | Water gushing from excavation face            | 130,000m³/d |
| 4        | Cloudy           | Femoral fissure water                         | 12,000m³/d  |

The large-scale water inrush in the tunnel occurs in rainy days. The water inrush begins to appear in the tunnel 2~4 hours after the rain, and disappears 3~5 hours after the rain. In limestone section, the surface karst fissures are developed, and the surface water flows through karst fissures, ground funnels and falling water holes, infiltrates and converges, then transfers along the horizontal karst pipeline, and finally converges at the low-lying place for drainage. The karst spring 540m away from the south side of the tunnel exit is the final drainage outlet (as shown in Fig. 3 and Fig. 4). According to the field survey, the water volume of the karst spring outlet during the tunnel water inflow is far greater than that in the tunnel [6] [7].
4.2. Underground river pipeline connection test

By the limestone section ZK200+920~ZK200+985 at the exit of the tunnel, it passes through the underground river. It is speculated that the underground river is located at the tunnel arch about 5 ~ 8m. When the tunnel is excavated to this place, the karst fissures on the surrounding rock wall develop; after several days of rainfall, a large amount of groundwater flows into the tunnel.

In order to further explore the flow path of underground river and the relationship between the tunnel and the location of underground river, the isotopic connection hydrological test was carried out on the spot in rainy days. At the surface of the upper reaches of the speculated underground river, seven falling water holes were selected to place fluorescein sodium reagent, and seven signal receiving points were arranged at the tunnel portal and the outlet of the lower reaches of the speculated underground river. According to the connection test, No.1 receiving point has hydraulic connection with No.2 dropping point, No.3 dropping point and No.4 dropping point; Meanwhile, No.1 receiving point has hydraulic connection with No.1 dropping point during the test.

5. Treatment plan of karst water gushing

5.1. Treatment principle and plan

The treatment plan of karst groundwater gushing out is mainly determined according to the information of water gushing amount, water quality, surrounding rock geological conditions, etc. Generally, water blocking scheme and drainage scheme are adopted, the former includes pre grouting water blocking, post grouting water blocking and filling grouting water blocking, and the latter includes measures such as relying on the drainage system of the tunnel itself, culvert drainage and drain tunnel drainage. The specific operation plan is as follows:

1) Pay attention to and strengthen the geological work during the tunnel construction period, adhere to the whole process of advance geological prediction, and find out the relative position relationship between the rich water body and the tunnel and the rich water situation.
2) For sections with large water volume and high water pressure, advance curtain grouting can be used to block the section in front of the face of the tunnel, and then partial excavation schemes such as single side wall, double side wall, or upper and lower steps can be used to drive forward.

3) For the general water seepage section that has been proved, the excavation can be carried out first, and then the grouting method can be used for treatment; for the area with large local water inflow, the centralized drilling water diversion and drainage can be adopted.

4) For the pressure rich water section, reliable orifice outburst prevention device shall be adopted first to ensure the construction safety. The lining structure can be totally closed or semi closed according to the hydrogeological conditions and environmental protection requirements.

5.2. Treatment of common karst water gushing section

5.2.1. Reinforcement of surrounding rock by radial grouting
For the ordinary karst water gushing section, where there is still water flowing in the form of strands or lines after excavation, radial grouting measures shall be taken as far as possible to block the runoff channel in the fracture or strengthen the surrounding rock. The grouting range is the water outlet area and the surrounding area, and the grouting depth is 3-5m beyond the excavation outline. The number and location of grouting holes can be arranged on site according to the location of water outlet, water volume and fracture of rock stratum.

5.2.2. Advanced curtain grouting scheme
When there is a fracture zone in front of the construction face, the rock stratum is relatively weak and the water inflow is large, in order to ensure the construction safety, the advanced curtain grouting scheme is adopted [8]. The specific construction scheme is as follows:

1) Drilling: the grouting holes are arranged umbrella around the tunnel axis from the face along the excavation direction. There are 115 holes in the whole section, with the opening diameter of 115mm and the final hole diameter of 75mm. The opening section is shown in Figure 4-1.

2) Grouting: the grouting range is 6m away from the excavation line, the pressure value is taken as 1.0MPa, the grouting section length is 30m, adopt the step-by-step forward grouting, divided into three ring construction, with the length of 12m, 20m and 30m respectively, grouting once every 3m, and reserve 6m grouting rock disk until the designed grouting depth is met. The grouting sequence shall be carried out in accordance with "from the outside to the inside, from the top to the bottom, and interval grouting", and inspection holes shall be set.

3) Grouting material: cement water glass double liquid grouting is adopted, and the proportioning parameters are shown in table 4-1 below.
5.3. Tunnel cross underground river section

5.3.1. Grouting reinforcement of surrounding rock
Zk200+920~ZK200+985 section is a geophysical anomaly area. During the excavation process, karst fissures develop on the wall of surrounding rock, and a large amount of water gushes into the tunnel face. According to the special hydrological investigation and the connection test of underground river pipeline, the underground river runs under the section, and the underground river is located at the vault of the tunnel about 5~8m.

After comparison and selection of various schemes, in order to ensure the safety of tunnel construction and operation, the overall treatment principle of this section is "to keep the original underground river pipeline unblocked, and to block water outside the lining and limit drainage". The concrete construction is carried out in two steps: first, according to the characteristics of rapid setting of cement water glass double liquid slurry in the water environment, grouting and water blocking measures are taken for the surrounding rock of the tunnel vault; second, according to the characteristics of good durability of cement slurry, single liquid slurry of cement slurry is used to block the karst fissure.

5.3.2. Hydraulic lining structure
In order to minimize the impact of tunnel construction on the water slide Mountain Nature Reserve, the water pressure resistant lining structure is adopted in this section. The water pressure resistant lining structure is composed of three parts: initial support, drainage system and water pressure resistant lining. The load structure method is mainly used to check the design thickness and strength of hydraulic lining structure. Calculation parameters: lining thickness is 0.8m. In consideration of the sharing of the initial support, 80% of the load is borne by the secondary lining, and the calculation results are shown.
in Figure 10.

According to the above calculation, the internal force of the hydraulic lining structure is obtained, and the reinforcement of the section is checked by the probability limit state method. The calculation results show that the design parameters of lining structure under hydrostatic pressure are reasonable, which can meet the requirements of serviceability limit state and crack durability design.

5.3.3. Design of waterproof and drainage system

The waterproof and drainage system of the anti-water pressure and waterproof support structure is composed of grouting water stop reinforcing ring, full section waterproof layer between the primary support and the secondary lining, anti-water pressure and waterproof secondary lining, circular blind pipe and construction joint water stop belt. After the cement water glass double liquid slurry grouting treatment for the water gushing section of the tunnel, the grouting reinforcement circle is formed to effectively fill the karst fissure and block the karst water, which is the first waterproof system.

Subsequently, a waterproof layer is arranged in the whole ring between the primary support and the second lining, with non-woven fabric and waterproof board as the main waterproof layer material to prevent karst water from infiltrating into the tunnel structure system, which is the second waterproof system.

Back stick type waterstop shall be set at circumferential and longitudinal construction joints to ensure the sealing of waterproof layer. 80cm thick C30 reinforced concrete secondary lining, which is the third waterproof system. Finally, a circular blind pipe and a horizontal drain pipe are arranged along the longitudinal spacing of 2m to guide a small amount of seepage to the drainage ditch and discharge the tunnel in a limited amount.

6. Summary

1) Water inrush in karst tunnel is a more complex and dangerous problem, so it is necessary to strengthen geological prediction and monitoring in advance, so as to achieve early detection and treatment. In the formulation of the treatment plan for water inrush, find out the causes of water inrush in the tunnel, analyze the law of water inrush, and reasonably select the treatment plan for karst water under the principles of economy, science, environmental protection and long-term.

2) For tunnel engineering similar to underground river crossing, the main channel of underground river shall be mainly dredged, and the main channel of underground river shall not be blocked; the original karst channel shall be fully protected and maintained to minimize the disturbance to underground water system and ensure the stability of water network system and geological structure.

3) In view of the underground river water gushing section under the tunnel, firstly, cement water glass double liquid slurry is used for rapid grouting and water plugging to meet the safety requirements of construction driving; secondly, cement slurry single liquid slurry is used to block the karst fissure to form the surrounding rock reinforcement ring, to enhance the durability and make it play the role of bearing water pressure, so as to ensure the operation safety.

4) The safety excavation under the condition of rich water and complex karst water inrush is realized by adopting the steel flower diameter grouting reinforcement, advanced curtain grouting water blocking
and water pressure resistant lining structure. The comprehensive measures have important reference value for the same type of engineering.

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