Risk prediction of water inrush in karst tunnels and analysis of surrounding rock stability

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Abstract. Karst tunnel construction has always been an important and difficult point in tunnel engineering. Based on the Yilai Expressway Wantan Tunnel Project, this paper analyzes the water-bearing lithofacies of the surrounding rock of the Wantan Tunnel and the karst hydrogeological conditions of the tunnel site area, and predicts the risk of tunnel water inrush disaster. Through monitoring and measurement, the existing construction technology was analyzed and the following conclusions were drawn: The surrounding rock of the Wantan Tunnel is a typical carbonate phase stratum, with a large amount of water inflow during the rainy season. There are local caves and karst pipes, and the comprehensive water inrush assessment level is III (medium risk); According to the monitoring, the displacement and deformation of each monitoring section in the tunnel changes normally, and the cumulative deformation value is less than 1/3 of the limit value. The stability of the surrounding rock is good, and the construction safety is high.

Keywords: Karst Tunnel; Risk Prediction; Monitoring And Measurement; Surrounding Rock Stability.

1. Introduction

In recent years, my country's railways, highways and other transportation industries have developed rapidly, and the number and mileage of tunnels have continued to increase. At the same time, various tunnel disease problems continue to arise, especially in karst tunnels. The adverse geological effects of karst can easily bring about geological disasters such as “mud bursts, water gushing, and collapses.” It is easy to cause deformation and instability of the surrounding rocks around the tunnel, posing a serious threat to tunnel construction and operation.[1-3] Domestic scholars have carried out a series of studies and achieved certain results. Wang Simiao used mathematical statistics theory to analyze the monitoring and measurement results of the Gaojiatun Tunnel, and found that the tunnel clearance convergence and vault settlement are positively correlated with the surrounding rock grade, time factors and construction factors, and are most correlated with the tunnel surrounding rock grade[4]. In order to study the influence of karst cavity on the stress of surrounding rock and support during tunnel construction, Zhang Yi used numerical simulation methods to analyze the stress deformation of surrounding rock, stress of surrounding rock and stress of support under different working conditions[5]. Han Jingwei’s research found that when tunnels are excavated in karst areas, the lining vaults bear greater stress while the side walls bear smaller stresses. Both the side walls and the vaults suffer from subsidence, and the displacement shows a linear growth trend. The tunnel surrounding rock There is a certain degree of reverse arching at the bottom[6]. In view of the above research experience, this article relies on the Wantan Tunnel to predict the risk of water inrush in karst tunnels, and analyzes the tunnel stability based on surrounding rock deformation factors combined with monitoring measurements.

2. Project Overview

The proposed Wantan Tunnel is located in Wantan Town, Wufeng Tujia Autonomous County, Hubei Province. It is a separate tunnel，The tunnel axis has an azimuth angle of 243.2°, a length of 1586 m, and a maximum burial depth of 303.2 m; Tunnel clearance: 10.50*5.0 m. The entrance of the cave door adopts the cut bamboo type, and the exit of the cave door adopts the end wall type.The entrance and exit of the tunnel are both on slopes, with steep slopes, mostly bushes and a few trees. Village access roads pass through the entrance and exit of the tunnel. Generally speaking, the transportation at the entrance and exit is more convenient. The tunnel area belongs to the mid-mountain landform of structural erosion and dissolution, and the domed mountain topography. The proposed tunnel runs diagonally through a steep hillside, and the entire surface of the tunnel crossing area is undulating, with a large height difference.

3. Factors affecting the stability of tunnel surrounding rock

The factors that affect the stability of tunnel surrounding rock can be summarized into two aspects: geological factors and engineering factors. Geological factors reflect the internal relationship of the stability of the cavern, while engineering factors are the external conditions that change the stable state of the cavern.

3.1 Geological factors

Since the rock mass is a combination of rock masses cut by various structural planes, the stability and strength of the rock mass are often controlled by weak structural planes. The geological factors that affect the stability of tunnel surrounding rocks are shown in Table 1 below.

Table 1 Geological factors affecting the stability of tunnel surrounding rock

Influencing Factors	Overview
The integrity or fragmentation of a rock mass	Regarding the stability and pressure of the surrounding rock, the integrity of the rock mass is more important than the solidity of the rock mass. The higher the degree of fragmentation of the surrounding rock, the worse the stability of the surrounding rock.
Surrounding rock structural plane	The occurrence, distribution and properties of weak structural surfaces, including filling conditions, properties of filling materials, etc.
Groundwater activity	The more weak structural planes there are, the worse the stability of the surrounding rock.
Physical and mechanical properties of rock mass	In hard and complete rock formations, the surrounding rock of the cavern is generally in an elastic state, with only elastic deformation or small plastic deformation. In rock formations with developed fissures, poor weak surface combination, and weak lithology, large plastic zones will appear in the surrounding rock, and great plastic deformation pressure will appear on the supporting structure.

3.2 Engineering factors

The main engineering factors that affect the stability of the cavern and the pressure of the surrounding rock include: the shape and size of the cavern, the type and stiffness of the support, the burial depth of the cavern, and the technical measures during construction.

Table 2 Engineering factors affecting the stability of tunnel surrounding rock

Influencing Factors	Overview
Hole shape and cavity size	It is generally believed that the surrounding rock pressure generated by a circular or elliptical cavern is smaller, while that of a rectangular or trapezoidal cavern is greater, because tensile stress is prone to occur at the top of a rectangular or trapezoidal cavern,

	and there are large stress concentrations at the corners on both sides. .
Type and stiffness of supporting structures	Support type, support stiffness and support time all have a certain impact on the surrounding rock pressure. After the cave is excavated, with the occurrence of radial deformation, the stress of the surrounding rock is redistributed. At the same time, with the expansion of the plastic zone, the support reaction force required by the surrounding rock also decreases. Therefore, the use of shotcrete support and flexible support structures can make full use of the self-supporting capacity of the surrounding rock and reduce the pressure of the surrounding rock. Closed supports are more rigid than unclosed supports. For caverns with bottom drum phenomenon, closed support should be used.
Burial depth or covering thickness of the cavern	For shallowly buried caverns, the surrounding rock pressure increases with depth. For deeply buried caverns, because the burial depth is directly related to the value of the lateral pressure coefficient, it is closely related to the surrounding rock stress.
Technical measures during construction	The construction method has a great influence on the stability of the cavern and the pressure of the surrounding rock.For example: the degree of loosening and fragmentation of surrounding rock caused by blasting; the sequence and method of excavation of the cave; the timeliness of support, the length of exposure time of surrounding rock, etc.

In addition to the above influencing factors, there are also other influencing factors, such as the distance between adjacent caverns, time factors, etc.

4. Tunnel engineering geology and supporting structure

4.1 Engineering geological analysis

The tunnel site area is located on the flank of the Wantan anticline, with well-exposed bedrock and a syncline structure. Affected by factors such as structure and dissolution, multiple groups of joints and fissures are developed in the surface rock mass, and no fracture structures are developed. The proportion of surrounding rock classification in the tunnel body is: Grade III surrounding rock accounts for 39%, Grade IV surrounding rock accounts for 40%, and Grade V surrounding rock accounts for 21%.

There are two main types of groundwater: (1) Loose rock pore water: It mainly exists in the Quaternary residual slope accumulation at the entrance and exit of the tunnel. It is basically a water-permeable layer, with a small distribution area, poor water volume, and weak water richness; (2) Carbonate rock cave (pipe) water: It mainly exists in the Loushanguan dolomite of the upper Cambrian system. It has very rich groundwater and complex runoff. It often appears on the surface as springs and underground rivers, and has strong water content.

The tunnel site area mainly receives vertical recharge from atmospheric rainfall, and the overall water volume is relatively abundant. Surface water drainage is relatively smooth, and the design elevation of the tunnel is higher than the surface drainage valley. The tunnel body is generally located above the stable groundwater level. Groundwater is mainly supplied by atmospheric rainfall infiltration into karst slopes and karst troughs, and flows into the Wantan River through surface and gully runoff. The front section of the Wantan Tunnel intersects with the karst pipeline at the south outlet of Xiaofengchi Trough Valley at approximately X83+440. The elevation of the karst pipeline is expected to be 24 m above the designed tunnel top elevation. During the dry season, the water volume is small and the impact is small, but during the wet season, the water volume is huge. If a raid occurs, it will cause a huge water inrush and mud burst disaster. The groundwater level in the latter section is low during the dry season, but it cannot be ruled out that the underground river channel between the Xiaofengchi South Dissipation Port (See Fig 1)and Hengdukou Village will be invaded during the wet season. The karst development is weak to moderate, and the water-bearing medium is mainly fissures and small-scale dissolution. The disappearance experiment (See Fig 2) shows that there are many karst channels along the tunnel. During the tunnel construction process, water seepage is the main problem, and large dissolution fissures may be encountered locally. Water gushing occurs.

Fig 1 Xiaofengchi South Water Discharge Outlet (Sun)

Fig 2 Fluorescein sodium administration

4.2 Lining structure design

The tunnel lining section design mainly adopts composite structure. The surrounding rock of levels IV and V adopts the design with inverted arches, while the design of level III and above adopts the design without inverts. Design and construction are carried out in accordance with the principles of the New Austrian Method, which requires the use of smooth blasting technology during the construction process to reduce disturbance to the surrounding rock and strictly control over- and under-excavation. Composite lining consists of anchor rods, shotcrete or reinforced mesh shotcrete, steel supports as the initial support system, and reinforced concrete as the secondary support, which together form a permanent load-bearing structure. In order to fully utilize the bearing capacity of the surrounding rock and lining, auxiliary construction measures such as grouting can be used to reinforce the surrounding rock. During the construction process, surrounding rock monitoring and measurement should be carried out, and the measurement information should be processed and fed back to further adjust the support parameters. The tunnel waterproofing and drainage design follows the principles of "limited emissions, combined with drainage prevention, adapting measures to local conditions, and comprehensive management" to ensure that the tunnel is basically dry and ensures the normal use of structures and equipment and driving safety [5-7].

4.3 Evaluation of surrounding rock stability

According to the special regional hydrogeological survey, the karst pipeline may intersect with the line, and there are two karst caves along the tunnel, which are greatly affected by karst. The groundwater is well developed, there is a water outlet on the surface, and the water volume is sufficient during the wet season. The risk of mud intrusion in the tunnel is high, and it is rated as Level III (medium risk). During tunnel construction, special attention should be paid to the prevention and control of tunnel mud and water inrush disasters. Strengthen advance geological forecasting work, focusing on prevention and combining blockage relief. Excavate in time, support in time, and provide advanced support.

5. Tunnel site monitoring and measurement

5.1 Observation inside and outside the cave

After each blasting or initial spraying of the tunnel tunnel face, the geological conditions of the surrounding rock should be described and recorded through naked eye observation, geological compass and geological hammer inspection. Including: lithology, rock formation occurrence, fissures, groundwater conditions, surrounding rock integrity and stability. Determine whether the surrounding rock grade is consistent with the design. If necessary, take photos to observe the support effect.

5.2 Tunnel peripheral displacement and vault subsidence

The measurement of peripheral displacement and vault subsidence is one of the most basic main measurement items. Each measuring point should be installed as soon as possible close to the tunnel face and within a range not affected by blasting. The initial reading should be taken within 12 hours after each excavation, and no later than 24 hours before the next cycle of excavation. The layout of measuring points is comprehensively determined based on the construction method, geological conditions, location of the measurement section, tunnel burial depth and other conditions. When the geological conditions are good and full-section excavation is adopted, a horizontal measurement line can be set up for the surrounding displacement. When using the step method for excavation, a horizontal survey line can be set for each step. The vault subsidence measurement and peripheral displacement measurement points are arranged in the same section, and a monitoring point is buried in the center of the vault in each measurement section. Data collection is the same as peripheral displacement measurement. Taking two of the sections as examples, the results are as follows:
(1) ZK84+080 section

The monitoring conditions of this section are: the cumulative settlement of the tunnel vault is 15.0mm, the cumulative displacement of tunnel peripheral displacement monitoring point #1 is 13.5mm, the cumulative displacement of tunnel peripheral displacement monitoring point #2 is 3.2mm, and the settlement of each measuring point The relationship with time is shown in Figure 2 below.

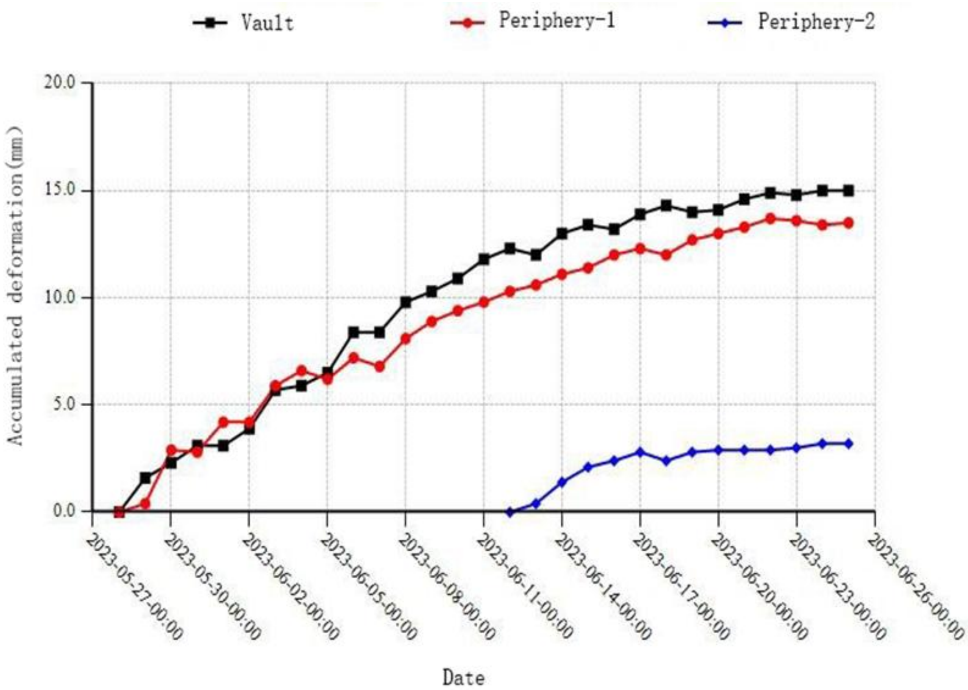

Fig 3 ZK84+080 tunnel accumulation volume and time relationship curve

（2）ZK84+980 section

The monitoring conditions of this section are: the cumulative settlement of the tunnel vault is 15.3mm, the cumulative displacement of tunnel peripheral displacement monitoring point #1 is 16.3mm, the cumulative displacement of tunnel peripheral displacement monitoring point #2 is 1.2mm, and the settlement of each measuring point The relationship with time is shown in Figure 4 below.

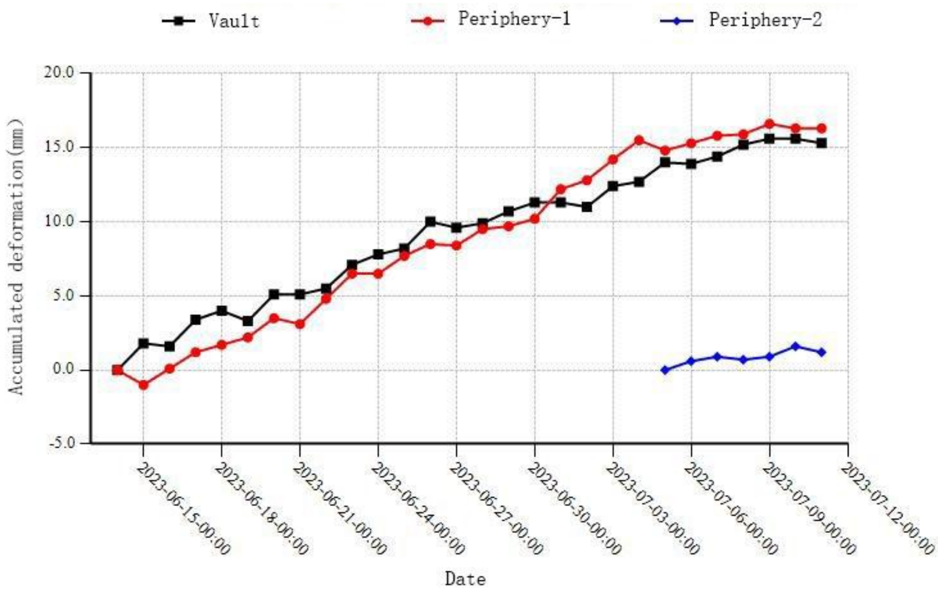

Fig 4 ZK84+980 tunnel accumulation volume and time relationship curve

To sum up, the surrounding rock at the face of the Wantan Tunnel is mainly weathered dolomite. The rock mass is gray-white, with developed fissures and partial fragmentation. There is soil between layers, the tunnel face is dry, and the overall self-stabilizing ability of the surrounding rock is poor. The displacement and deformation of each monitoring section in the cave changes normally, and the cumulative displacement value is less than 1/3 of the limit value. The surrounding rock of the tunnel has good stability and the construction process is highly safe.

6. Conclusion

This article takes the Wantan Tunnel as the engineering background, and evaluates the stability of the surrounding rock of the tunnel through the engineering geological conditions of the tunnel site area and tunnel monitoring measurement analysis:

(1) Comprehensive surface geological survey, advanced geological forecast monitoring, and underground hydrogeological analysis, the Wantan Tunnel mainly receives rainfall infiltration recharge. There are 2 karst caves developed on the tunnel path, and they intersect with the karst pipeline of the South Water Dissipation Inlet. The water inflow is relatively large in the rainy season. big. The comprehensive inrush water assessment level is III (medium risk), and it is necessary to avoid flood periods and prevent and control inrush water disasters.

(2) This tunnel is constructed using the New Austrian method, and the main tunnel uses composite lining. Tunnel waterproofing and drainage must follow the principle of "limited discharge, combined with prevention and drainage", and the tunnel construction technology conforms to the current karst tunnel construction methods. According to the monitoring measurement results, the displacement and deformation of each monitoring section in the tunnel changes normally, and the cumulative displacement value is less than 1/3 of the limit value. The surrounding rock has good stability and the construction safety is high.

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