Discussion on The Design of Water Blocking and Drainage Limit of Water-rich Mountain Tunnel in Ecologically Fragile Area

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Abstract. In mountainous areas with abundant groundwater and high water pressure, the design of waterproof and drainage is the most important part of the whole tunnel construction process. Improper treatment of groundwater will not only damage the local ecological environment, but also bring hidden danger to the safety of tunnel structure, especially in the ecologically fragile area. The tunnel project under construction in the East Tianshan Mountain is located in the high-altitude mountain area. The surface is the national forest protection area, and the vegetation is perennial. Once a large amount of groundwater is lost, the surface ecology will be damaged and hard to recover in a short time. In this paper, the existing design of mountain tunnel waterproof and drainage is summarized, and its advantages and disadvantages are analyzed. Based on the previous research, the concept of waterproofing and drainage design suitable for the East Tianshan tunnel is proposed: "one block, two rows and Three Preventions". "One block" is a circle of grouting outside the tunnel to block most of the groundwater. "Two rows" is to set two layers of drainage pipe network between shotcrete and waterproof layer and between waterproof layer and lining. "Three proofing" is to use three layers of waterproofing: shotcrete layer, special waterproof layer and lining concrete. Layers of fortification can minimize the interference to groundwater and ensure the safety of tunnel structure.

1. Introduction
China has a vast mountain area, accounting for about two-thirds of the country's total area, and is mostly distributed in the western region. Geological conditions in mountainous areas are complex, faults are clustered, groundwater is abundant and water pressure is high. The construction of tunnels in such an environment is a major test for the safety of the lining structure during construction and operation. Therefore, the waterproofing and drainage design of the mountain tunnel is a top priority. Prior to the 1990s, China’s tunnels adopted a “total drainage” design, and all groundwater was drained so that the tunnel lining could hardly bear the water pressure to ensure the safety of the tunnel structure. However, this approach severely disrupted the ecological balance of groundwater near the tunnel area. Especially in the western regions where water resources are severely scarce, once the water ecology is destroyed, it will be difficult to recover. For example, since the construction of the Geleshan Tunnel on the Yuhuai Railway started in April 2001, there have been 39 large exploratory holes, with a maximum single hole inflow of 14,400m³/d and a maximum water pressure of 2.2MPa. With the continuation of the tunnel drainage, a large amount of well water and spring water on the surface showed a significant drop in
water level or a decrease in flow or even exhaustion, which seriously affected the living environment of the tunnel area [1-2]. After the 90's, after recognizing the serious disadvantages of the "full drainage" design, it switched to the "full closure" design and blocked all groundwater outside the lining through engineering measures such as grouting and reinforcement, which greatly protected the ecological environment of the tunnel area. However, it caused the lining to withstand a lot of hydrostatic pressure, and the problems of tunnel leakage and cracking followed, which seriously affected the tunnel operation. For example, the Yuanliangshan Tunnel adopts a "full plugging" design. The maximum water pressure is 4.5 MPa, and the tunnel lining appears leakage and cracking, which causes the ground to collapse.

In dealing with the contradiction of reducing the pressure of lining water and protecting the ecology of groundwater, these two types of water-proof and drainage designs have gone to extremes. For this reason, the design method of “blocking water and limiting drainage” has emerged, and domestic and foreign scholars have also done a lot of research: Wang Xiuying et al. [3] proposed “mainly blocking and limiting discharge” when studying the related issues of karst tunnel water drainage. Water-proof and drainage design, water blocking by grouting of surrounding rocks, self-waterproofing of sturdy structural materials, partition drainage, and waterproofing system behind the waterproof board. Li Cangsong et al. [4] proposed field ground test and numerical simulation to fully consider the ecological environment and geological conditions around the tunnel site, and proposed suitable groundwater treatment methods for different tunnel engineering profiles. Guo Jia [5] applied theoretical derivation and numerical simulation to study the water drainage system of Xiangjiang Tunnel, and proposed to follow the principle of water prevention and drainage based on "mainly blocking and limited discharge", adopting appropriate water blocking measures and setting up multiple waterproofing lines to surround the rock. Leakage water is blocked outside the lining. Relying on the Zhongliangshan Tunnel Project, Jiang Jin [6] studied the mountain tunnel located in the high-pressure and water-rich area. The water-blocking and drainage-reducing type of drainage and drainage affected the internal force characteristics of the lining structure. The results were obtained: Both the grouting circle and the initial support have achieved the goal of water plugging. Setting drainage system outside the lining structure can significantly reduce the lining water load. The biggest influence on the water load outside the lining is the tunnel drainage.

The East Tianshan Tunnel is located above the Hami Tianshan in Xinjiang, and its ecological environment is extremely fragile. Based on previous studies, this paper analyzes the hydrogeological characteristics of groundwater recharge, runoff, and drainage in the tunnel area and their relationship with surface vegetation water retention and storage systems, and discusses how to apply the design concept of "water blocking and drainage" East Tianshan Tunnel, construction of environmentally friendly tunnel project.

2. Project Overview
The East Tianshan Tunnel is the key project of the PPP construction project of the Barikun-Hami Highway on the G575 line. The G575 line highway construction project is located in Hami region, starting from Balikun Kazak Autonomous County on the north slope of the East Tianshan Mountain in the north and reaching Hami City on the south slope of the East Tianshan Mountain in the south. It is the strategic support point for building the "Silk Road Economic Belt", the need to promote the economic and social modernization of Xinjiang Autonomous Region, and an important part of the national highway network planning.

The tunnel is a separated tunnel with a total length of 11.9km. The standard of two-way four lane first-class highway is adopted and the design speed is 80km/h. The overall axis direction of the tunnel is about 42°, running through the north and south of Tianshan Mountain. The tunnel entrance is located at the downstream side of songshutang ski resort to the north of Tianshan Mountain, and the exit is located at the north side of hulugou to the south of Tianshan Mountain. The elevation of the tunnel area is 2040m-3375m, which belongs to the mountainous area of high and middle school. The slope of the tunnel entrance to the north of Tianshan Mountain is relatively gentle, and the surface is a national forest reserve mainly composed of spruce and Siberian larch, as shown in Fig1. Spruce is resistant to shade,
cold, cool and humid climate, fertile and deep, well drained micro acid sandy soil, slow growth, and belongs to shallow root tree species. Therefore, the ecological environment of tunnel area is fragile, and it will be difficult to recover if it is damaged.

![Fig. 1 Surface environment at the entrance to the tunnel](image)

**3. Hydrogeological conditions in the tunnel area**

The surface of the tunnel is perennial vegetation, and the ecology is fragile. Once damaged, it is difficult to recover. When the tunnel passes through the water-rich stratum, the groundwater is drained in order to ensure the excavation and safety, which may cause inestimable damage to the surface ecological environment. Investigation and analysis of the distribution of surface water systems, groundwater recharge, runoff, drainage, and surface vegetation water retention and storage systems.

**3.1. Surface water system distribution in Balikun-Yiwu Basin**

Rivers: There are 66 large and small rivers in the Bayi Basin, with a total runoff of 31,977,000 cubic meters. There are mainly 20 rivers with a flow of more than 5 million cubic meters, distributed in Moqin Wula Mountain, the southern slope of Balikun Mountain, and the northern slope of Balikun Mountain. Four rivers with a flow of more than 10 million cubic meters are distributed in Hongshankou, Daheigou, Yiwu Valley in Yiwu Valley, and Tulgan Ditch in Yanchi. From April to May, the ice and snow melting period of the river accounts for 10.9-20.6% of the total annual runoff. June to August is the flood period, accounting for 34.26-76.4% of the total annual runoff. The period from September to March of the following year is the flat water period, accounting for 5.3-32.2% of the total annual runoff. There are a total of 44 rivers in Balikun, with an annual total runoff of 17.0626 million cubic meters, of which there are 26 on the northern slope of Balikun Mountain and an annual total of 12.512 million cubic meters. There are 18 on the southern slope of Mochinwula Mountain and an annual total runoff of 4514.6 Million cubic meters.

Lakes: The water area of Lake Balikun is about 87 square kilometers, and the water depth is only 0.1 to 0.2 meters. It is a salt water lake and the final destination of surface water and groundwater in the Balikun Basin. The area of Lake Tolle Coole is about 28.9 square kilometers. The lake's water supply is ice and snow melt, glaciers, and atmospheric precipitation in Harric and Mochinwura Mountains. Lake Incule is a collection of groundwater and floods. The average water depth is 1.5 meters, the deepest is about 5 meters, the water area is about 0.59 square kilometers, and the water is bitter and salty.

Glaciers: The glaciers are distributed in Barikun Mountain and Hallik Mountain in southern Yiwu. There are 57 glaciers in Balikun Mountain, with an area of 29.94 square kilometers and a total reserve of 1.1532 cubic kilometers. Harrick Mountain has 122 glaciers, with a total area of about 125.89 square kilometers and a total reserve of 7.0177 cubic kilometers.

Reservoir: There are a total of 24 reservoirs in the area, with a designed total storage capacity of 74.504 million cubic meters. Among them, there are a total of 18 Balikun counties with a total designed storage capacity of 5574.61 million cubic meters.
3.2. Characteristics of groundwater in the mountainous area of Balikun Basin

3.2.1. Groundwater type

According to the existence conditions and hydraulic properties of groundwater, the mountain aquifer system can be divided into frozen layer water and bedrock fissure water aquifer.

(1) Frozen water

Frozen layer water is distributed in the alpine frozen soil areas above 3000-3200 meters in the mountains of Balikun and Mochinwula. According to the lithological characteristics of the aquifer, this type of groundwater can be divided into frozen rock water of loose rocks and frozen rock water of bedrocks.

Loose rock-type frozen layer water: Sporadically distributed in the glacial valleys of rivers in the eastern part of Balikun Mountain. The aquifer lithology is mainly glacial rock, moraine block gravel, boulder soil, and a small amount of ice water sand gravel. This type of groundwater has sufficient replenishment sources, not only good water quality, but also abundant water. The flow of a single spring is generally greater than 1 liter / second, and the maximum is 5-10 liter / second.

Bedrock-type frozen layer water: mainly distributed in the watershed of the Balikun Mountain, followed by parts of the mountainous area on the south slope of the Moqinwula Mountain. Liters / second, with a maximum of 10 liters / second. Due to the large and continuous replenishment of glacial snow melting water in this area, groundwater is relatively abundant and the water quality is good.

(2) Bedrock fissure water

Layered bedrock fissure water: it is rich in water (single spring flow > 1.0l/s), distributed in the middle mountain area to the south of Luobao spring in Balikun mountain, the south mountain area of Suji mountain, the northeast of Qianshan Township and the southeast mountain area of komenzi. The aquifer lithology is mainly tuff and sandstone. The water yield is medium (single spring flow is 0.1-1.0l/s), which is distributed in the middle mountain area of the south slope of mochin Wula mountain, the middle mountain area to the north of jianyaogou Daliugou, weiweiweigou dazigou and the middle mountain area of Balikun mountain. The aquifer lithology is tuff, sandstone, etc. The water rich property is weak (single spring flow rate <0.1 liters / second), which is distributed in the middle and low mountainous area and xiaojiashan area on the west side of the basin. The aquifer lithology is mainly tuff and sandstone.

Massive bedrock fissure water: it is rich in water (single spring flow rate> 1.0 liter / second), in the underground water system of Lake Balikun, it is only distributed in the area of Shuangdunzi and south of Qianshan Township, with small distribution area. The lithology is mainly granite. Medium water-rich (single spring flow rate 0.1-1.0 liters / second), distributed in Daliugou-Qiangougou of Mochinwula Mountain and Xihegou-Donghegou of Barikun Mountain in Zhongshan District, and Jianshanzi and Suji Mountains Around. The aquifer lithology is all granite. Weak water richness (single spring flow rate <0.1 liters / second), distributed in the Zhongshan District in the Heigou-Damaquangou area in the east of Balikun, east of Hongjingzi in the northwestern part of the basin and in Xiaojiashan. The lithology of the aquifer is granite.

3.2.2. Groundwater recharge, runoff and drainage methods

The sources of replenishment of fissure water in the bedrock of mountainous areas are mainly infiltration replenishment of alpine glaciers, snow and seasonal snowmelt water and precipitation. The altitude of Balikun Mountain is 2892-4500m, and modern glaciers and perennial snow cover are distributed in the high mountain area. It is one of the recharge sources of bedrock fissure water in the Balikun Mountains, but its main source is atmospheric precipitation. The annual precipitation of Barikun Mountain is 200-500mm, and the annual water of Mochinwula Mountain is 50-200mm. In addition to glaciers, ice and snow melts, precipitation, etc., in addition to directly infiltrating the bedrock fissure water, it also gathers into rivers in the gully. During the downstream runoff process, it continuously infiltrates and replenishes the bedrock fissure water. In addition, the backflow of spring water from the mountain area Rock fissure water also has a certain recharge effect.
Groundwater drainage in mountainous areas is mainly surface runoff. Glacial snowmelt water, atmospheric precipitation, and bedrock fissure water are collected into surface runoff and discharged downstream, part of which infiltrate the bedrock fissure water, and the other part of the mountain pass to supply groundwater in the plain area. Secondly, spring water is also another drainage way of bedrock fissure water. Due to the deep cutting of Balikun Mountain and Moqinwula Mountain, the bedrock fissure water comes out of the dew spring along the steep slope or contact, and converges into perennial surface runoff and enters. The flood plain in front of the mountain supplies groundwater in the plain area. In addition, bedrock fissure water is also discharged to the plain area in the form of lateral runoff.

4. "One Block, Two Rows and Three Preventions" waterproof and drainage design of water-rich mountain tunnel

During the construction of mountain tunnel in this ecologically fragile area, the use of "drainage based" waterproof and drainage design in the stratum with rich groundwater will damage the ecosystem in the tunnel area. Therefore, based on the previous research and following the waterproof and drainage design concept of "blocking based, limited discharge", we put forward the waterproof and drainage design concept of "one block, two rows and Three Preventions". "One block" is a circle of grouting outside the tunnel to block most of the groundwater. "Two rows" is to set two layers of drainage pipe network between shotcrete and waterproof layer and between waterproof layer and lining. "Three preventions " is to use three layers of waterproofing: shotcrete layer, special waterproof layer and lining concrete.

4.1. Waterproof ability of grouting reinforcement ring
Grouting can reduce the water seepage of tunnel by reducing the permeability coefficient of surrounding rock, so as to reduce the water pressure behind the lining. However, because of the randomness of the surrounding rock fracture, the blindness of grouting flow and the limited impermeability of the slurry, the grouting reinforcement ring cannot completely block the seepage of groundwater, it only can extend the seepage path and improve the seepage resistance[7].

4.2. Water resistance of sprayed concrete
Zhang Junru[8-9] researched the impermeability of shotcrete. The research shows that the impermeability of shotcrete cannot be equivalent to the lining concrete. From the aspect of mix design, it is required that the shotcrete has certain impermeability Unrealistic; on the other hand, due to the unevenness of the surrounding rock of the tunnel, the loosening of dangerous rocks, and the difficulty of tight filling of the shotcrete and the surrounding rock, the design effect of shotcrete is greatly affected by the site construction. We do not consider the waterproofing capabilities of tunnel sprayed concrete.

4.3. Waterproof ability of waterproof board
There are many types of waterproof boards. Currently, PVC, EVA, HDPE, LDPE, etc. are used more in engineering. The waterproof layer of plastic board should choose polymer waterproof material. The width should be 2～4m, and the thickness should not be less than 1.5mm. It has good puncture resistance, flexibility, durability, corrosion resistance, and impermeability. According to the "Technical Specifications for Waterproofing of Underground Engineering" (GB 50108-2008) [10], the physical and mechanical properties of the waterproof board meet the requirements of Table 1.
Table 1 Main performance indexes of plastic waterproof board

| Performance | Ethylene-vinyl acetate copolymer | Ethylene-asphalt blend polymer | Polyvinyl chloride | High density polyethylene |
|-------------|----------------------------------|-------------------------------|-------------------|--------------------------|
| Tensile Strength (MPa) | ≥16 | ≥14 | ≥10 | ≥16 |
| Elongation at break (%) | ≥550 | ≥500 | ≥200 | ≥550 |
| Impervious, 120min, (MPa) | ≥0.3 | ≥0.3 | ≥0.3 | ≥0.3 |
| Low-temperature bendability | -35°C | -35°C | -20°C | -35°C |
| Heat treatment dimensional change rate (%) | ≤2.0 | ≤2.5 | ≤2.0 | ≤2.0 |

The impermeability of the waterproof board specified in the specification is 0.3 MPa, which does not mean that the waterproof line can be impervious to water pressure of 0.3 MPa. According to the "wooden barrel theory", as for the waterproof line of the waterproof panel, how much water pressure the waterproof panel can withstand depends on the ability of the welds between the waterproof panels to resist the water pressure. In the construction site, the inflation method is used to monitor the water pressure of the welds. After inspection, it is found that the water pressure resistance of the tunnel waterproof plate welds is generally less than 0.2MPa, which means that when the external water pressure is greater than 0.2MPa, water will flow from the waterproof plate welds to the back of the lining and directly act on the lining instead of it only acts on the lining instead of it.

5. Conclusions and discussion

A Based on the detailed investigation of the type, supply, runoff and discharge mode of groundwater in the tunnel area, combined with the design principle of "water blocking and drainage limiting", the design concept of "one blocking, two drainage and three prevention" is proposed for the characteristics of the East Tianshan tunnel in the ecologically fragile area. During the construction period, through pre-grouting and radial grouting in advance, a water blocking circle is formed around the contour line of the tunnel excavation, and most of the groundwater is blocked outside the grouting circle. Then through shotcreting, waterproof board and secondary lining with waterproof concrete, layer by layer fortification, to minimize the interference caused by the project construction to the groundwater environment, protect the surface ecological environment, at the same time, it can reduce the leakage and cracking of the tunnel, and extend the service life of the tunnel.

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