

# Research on Plugging Technology of Underwater Shield Tunnel During Operation Period

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**Abstract:** With the development of urban rail transit technology, subways can quickly spread across the country's major first-tier cities. In 2019, Zhengzhou Metro Line 5 was officially put into operation. During its normal operation, due to the complex underground hydrogeological conditions and the reduced blocking efficiency of the segment system, the segment leakage in the section was serious. Under the pressure and corrosion of the external groundwater, the self-waterproofing system and the sealing gasket fail, and the uneven settlement between the segments causes misalignment. The resulting drips, leaks and wet stains affect the safety of the electrical equipment in the tunnel and the normal operation of the train. Therefore, it is necessary to deeply discuss the plugging process at the water seepage site, and propose treatment measures for water leakage at segment joints, segment bolt holes and segment secondary grouting holes. The results show that the modified epoxy resin grouting material can quickly repair the leakage point of shield segment, and can provide a reasonable reference for the treatment of shield tunnel water leakage in the later operating period.

**Keywords:** Slip casting; Leak stoppage; Leakage of water; segment.

## 1. Research Background

With the increase of subway tunnel operation time, the leakage situation in the tunnel is gradually prominent. Water leakage will cause serious harm to the subway tunnel. For the tunnel itself and its interior, water leakage will affect the stability of the tunnel structure and traffic safety. For the equipment attached to the tunnel, leakage will accelerate the corrosion of the equipment, resulting in equipment failure and shortened life [1][2]. On the outside of the tunnel, leakage can pose a long-term threat to the surface buildings and underground pipelines [3]. Qing [4] showed through his research that excessive fault level was the main cause of water leakage caused by the failure of waterproof measures of shield tunnel. Liu [5] used theoretical analysis, accelerated corrosion degradation test, similar model test, numerical simulation and other methods to conduct a comprehensive and systematic study on the evolution mechanism of the structural performance of shield tunnel under the action of erosion environment from the four levels of environment, material, component and structure, and the research results were aimed at ensuring the safety of shield tunnel lining structure under the action of erosion environment during the whole life cycle. Full-service performance plays an important guiding role [6]. Huang [7] discussed the properties and characteristics of treatment materials such as acrylate, high elastic polyurethane sealant and hand-scraped polyurea, as well as their application methods and application scope in deformation joint leakage treatment engineering. Xiao [8], in order to facilitate the unified reference, investigated and analyzed the development process of various shield tunnel segment joints waterproofing in China. According to the characteristics of shield tunnel segment joints waterproofing system, he proposed the generation system division method, and elaborated the structural characteristics and main application scope of each generation system.

Previous studies only existed in the first generation of single-channel EPDM sealant joint waterproofing system and

the second generation of "one main and one auxiliary" joint waterproofing system formed by EPDM + water-expanded elastomer. However, due to the complexity of underwater tunnel geological environment, tunnel structure and operating environment, The causes of leakage are complicated, which leads to different plugging techniques for different leakage sites. Therefore, the use of the third generation joint waterproof system with double EPDM rubber gasket as the main body is very necessary.

## 2. Overview of Hydrogeology of Zhengzhou Metro Line 5

This paper takes Yuji Garden Station - Shakou Road of Zhengzhou Metro Line 5 as the construction background. Shakou Station is located at the intersection of Shakou Road, Huanghe Road, Jinshui District, Zhengzhou City, Henan Province, China. The station was put into operation on May 20, 2019, and passes through Zhengzhou Metro Line 5. On July 20, 2021, Shakou Road Station was suspended due to the "7.20 Zhengzhou rainstorm" and resumed operation in September. The section is constructed by shield tunneling method. There are no major pipelines in this section. The location plan is shown in Figure 1.

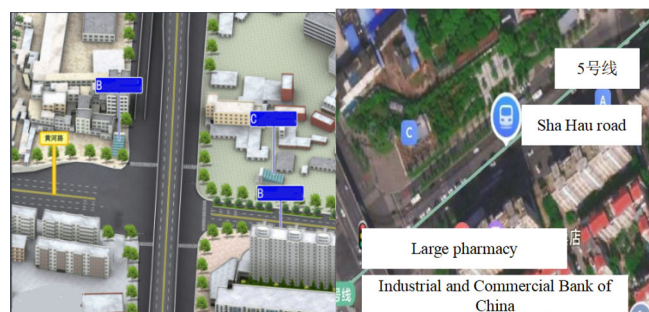


Figure 1. Surface position map

The elevation of this section is 102.77-104.50m, the site is

flat and open, and the terrain of Huanghe Road under the Beijing-Guangzhou Railway Box Bridge is low, the elevation is 96.86-101.64m, and the landform of the proposed site belongs to the foremountain alluvial flood plain.) The engineering geological zone is B zone.

The geomorphic unit of Area B is the foremountain alluvial and diluvial plain landform, and the inner layer of the site is mainly quaternary in the depth range of 30-40m: the strata are sandy powder, clay powder and silty clay, and are intermixed with fine sand. The zoning range is from Jianshe West Road station south to Tongbai Road, West Railway Station Road, Huanghe Road Nanyang Road Station east: mileage (KO+000~K3+130, K38+650K40+227), the ground elevation is between 101.97m~119.13m. The engineering geological zone of this section is B zone. According to the regional hydrogeological data and the field drilling, the groundwater type in this area is mainly the pore port water of the quaternary unconsolidated layer. The lithology of the quaternary porous aquifer is dominated by clay, silty clay and fine sand. During the investigation, the initial groundwater level buried depth is 11.50 "18.00m, and the stable water level buried depth is 11.10~17.40m(elevation 85.4090.00m), with a variation of 1.02.0m. At present, the groundwater in this area is affected by the mining in Zhengzhou City, and the change of groundwater level is controlled artificially. According to the survey site, the highest groundwater depth in recent 3 to 5 years is 9.0015.00m(89.0092.0m), and the highest groundwater depth in history is 2.50~9.30m(95.00m). The profile is shown in Figure 2.

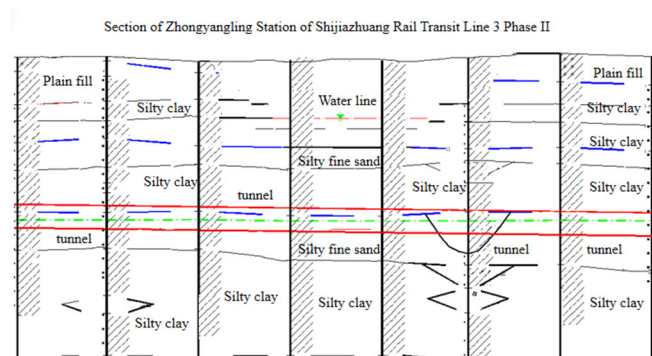


Figure 2. Geological profile of the left line

### 3. Brief Description of Materials design

#### (1) Hydrophilic polyurethane plugging agent

Hydrophilic polyurethane plugging agent is a new kind of polymer plugging material, which is composed of polyurethane elastomer material and hydrophilic material. It has good fluidity and curing speed, can quickly plug leakage, and is widely used in construction engineering, water conservancy engineering, transportation and other fields[9].

Main features:

Hydrophilic: The molecular structure of the plugging agent contains a large number of hydrophilic groups, which can react quickly with water to form a strong bond.

② Fluidity: The plugging agent has good fluidity during the construction process, and can easily penetrate into the gaps and defects to form a solid bond

③ Fast curing: hydrophilic polyurethane plugging agent can cure quickly, usually within 20 minutes to complete the curing, shortening the construction time

④ High strength: hydrophilic polyurethane has high strength and hardness after curing, and can withstand greater pressure and other harsh environments.



Figure 3. The hydrophilic polyurethane plugging agent

#### (2) Hydrophobic polyurethane plugging agent

Hydrophobic polyurethane plugging agent is similar to hydrophilic polyurethane plugging agent, it is also a kind of polymer plugging material, the main difference is that the proportion of hydrophilic groups and hydrophobic groups in the molecular structure of the plugging agent is different[10].

Compared with hydrophilic polyurethane plugging agent, the advantage of hydrophobic polyurethane plugging agent is that it is not easy to react with water, so it has better stability in water and can be soaked underwater for a long time without deformation and deterioration. In addition, the solubility of hydrophobic polyurethane plugging agent in oily substances is poor, so it can effectively prevent the penetration of grease and other substances, so as to better prevent leakage. It should be noted that the hydrophobic polyurethane plugging agent may not be as suitable as the hydrophilic polyurethane plugging agent in some cases, such as under high pressure, high temperature and other conditions, so the actual application needs to be selected according to the specific situation.



Figure 4. Hydrophobic polyurethane plugging agent

(3) Construction equipment

Water stop nail, electric hammer, high pressure filling machine, bucket, flashlight, rubber gloves, wrench, expansion ladder, work clothes and safety hat, etc. Figure 5, 6,7.



Figure 5. Electric hammer



Figure 6. Water stop nail



Figure 7. Grouting machine

#### 4. Pipe Leakage Plugging Method

(1) Pipe joint leakage treatment measures

For the part where the water leakage is large, the corresponding engineering treatment measures are as follows:

1) Through the tunnel special drainage pump (FIG. 8,9,10), detect the water displacement within the set time, calculate the leakage water, and select the appropriate diameter of the drainage plastic pipe with closure valve for drainage.



Figure 8. Pump pumping



Figure 9. Drainage



Figure 10. Joint leakage

Treatment, while using "wedge + hemp + one component ultrafast reaction polyurethane" seal around the pipe[11][12][13]; 2) Selection of slurry. Double slurry or oil-soluble polyurethane slurry can be used for grouting at the back of adjacent concrete segment walls, and oil-soluble polyurethane slurry can be used for grouting at the assembled joint of steel pipe segments, and the failed elastic rubber gasket or water baffle in the assembled joint of steel pipe segments can be filled to restore the original sealing effect [14]. 3) grouting pressure. With low pressure as the appropriate, the grouting pressure behind the wall is not more than 0.3MPa, and the grouting pressure of the steel pipe piece assembly joint is not more than 0.5MPa, so that the slurry can be slowly and fully filled into the steel pipe piece assembly joint. 4) Grouting sequence. Priority should be given to the wall grouting of the surrounding concrete segments, and then according to the number of grouting pipes buried at the joint of the steel pipe segments, grouting should be carried out in turn. 5) Grouting termination conditions. Grouting can be stopped when the grouting pressure behind the wall is greater than 0.3MPa, the grouting pressure of the steel pipe piece assembly joint is greater than 0.5MPa, or the surrounding steel pipe piece assembly joint oozes slurry for 3 minutes. The grouting amount behind the wall of each concrete segment shall not exceed 100kg.

(2) Pipe seepage treatment measures

The treatment process and specific operation steps of the pipe segment water seepage treatment measures are as follows: basic cleaning → finding the leakage point → foundation plugging treatment → drilling → grouting plugging → painting closed waterproof coating → painting flexible waterproof coating → Observing the plugging effect → laying waterproof coil → on-site cleaning and recovery → Observing and accepting[15].(1) Clean the base and expose the working base. Including the removal of all objects within the leakage area that impede construction and the clearance of the construction site. (2) Carefully observe the concrete surface, cracks and leakage, analyze and find out the water leakage path, find the leakage point, and determine the scope of the foundation plugging, drilling location and spacing. (3) Clean the foreign residue at the concrete joint of the segment, and apply special plugging materials on the joint surface to make the segment joint a closed space. This process can ensure the penetration range of grouting materials and ensure the grouting pressure[16].The operation sequence is as follows: First, the escalator is set up, the first construction worker goes to the water hanging trace, finds the main outlet position, and then the electric hammer is inclined to punch the depth of the oblique hole next to the water outlet, while the other construction worker deploys the required plugging agent on the ground and pours the plugging agent into the high-pressure grouting machine[17][18].When the two tasks are completed, the construction personnel on the escalator drive the water stop nail into the borehole (as shown in Figure 11,12), and then tighten the water stop nail with a wrench. Because the rubber at the end of the water stop nail begins to compress vertically under the action of thread advancement, while the surrounding area expands, the water stop nail is fixed in the borehole. Then the end of the grouting machine is connected to the water stop nail to start grouting, and the speed of grouting should be adjusted according to the reaction of the hanging water trace. Generally, some continuous injection is first, and then the situation is observed, and the injected slurry will be filled according to the pores and joints

inside. This time, the side wall of the platform is a more serious situation, and the slurry has been left from the top flow channel to the bottom (as shown in Figure 13).

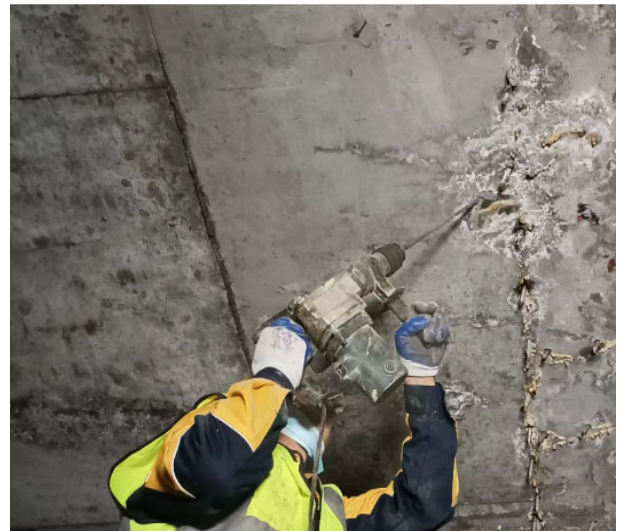


Figure 11. Plate top drilling

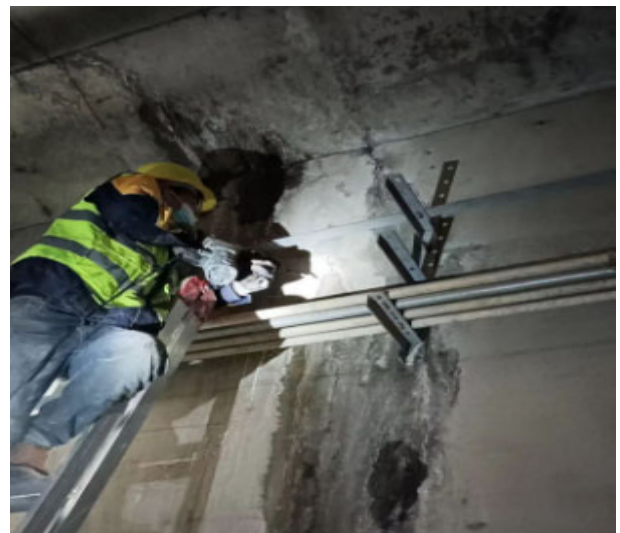


Figure 12. Platform drilling

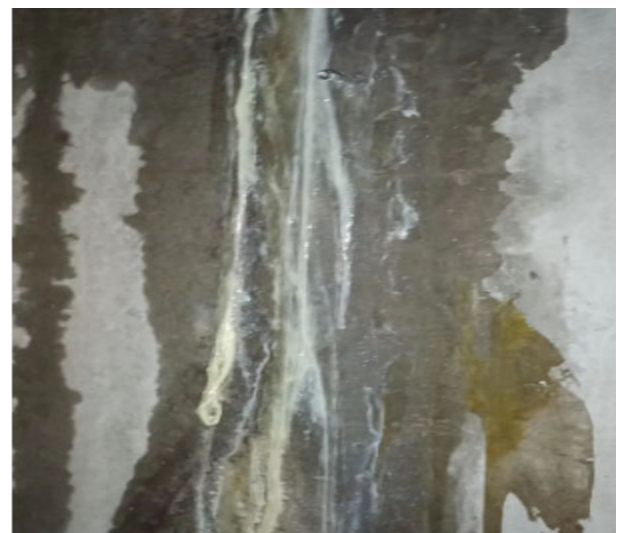


Figure 13. Grouting effect

(3) Treatment measures for the leakage of secondary grouting holes of segments

The secondary grouting hole leakage adopts the original hole grouting scheme, and the "central grouting + peripheral sealing" scheme is adopted. The grouting material is made of cement slurry and water glass. The ratio of grouting body is determined by field test considering the geological condition and ground settlement law of the tunnel site[19][20]. (2) Through grouting, the cavity behind the segment is completely filled with slurry, and the water sac is gradually reduced until it is basically eliminated, thus achieving the purpose of waterproof[21].(3) After the end of grouting, each grouting hole should be sealed and inspected twice to prevent water leakage in the later stage. If the acceptance is qualified and the effect is good, measures can be taken to permanently block the grouting hole. The grouting holes are shown in Figure 14.



Figure 14. Grouting hole

(4) Transient plugging agent

In the transient plugging agent is a powdery substance similar to cement as shown in Figure 16,17. When using, chisel the water part properly, as shown in Figure 18. Add water with this product, mix it well and knead it into a material mass slightly smaller than the size of the water leak. Stop for a while and squeeze the material mass into the water leak when it feels hard, press it with your hand or a suitable tool, and then block the water leakage instantly. To deal with diffuse seepage, repeated scraping and coating construction can gradually plug the capillary leakage hole. 3. When the water amount is large, absorbent materials such as gauze and tissue paper can be used to wrap the product according to the size of the water leak, plug it into the water leak, and then press the appropriate tool for a certain time to block the water leak. 4. After the water leakage is blocked, a layer of "anti-seepage plugging agent" with a thickness greater than 5mm on the surface of the trowel is used for anti-seepage protection. 5, before plugging, the leakage mouth around the need to use "anti-seepage plugging agent" for waterproof treatment, such as a certain strength and then plugging, to prevent the construction of water may leak from other parts around the leakage mouth. 6, after the construction is completed, check the construction part if it is too dry, it should be moisturized for 2 to 3 days .Finally, observe the construction effect to ensure that there is no leakage, as shown in Figure 18.



Figure 16. Instantaneous plugging agent



Figure 17. Powder form



Figure 18. Clearing debris



**Figure 19.** Effect observation

## 5. Conclusion

Based on the water leakage case of Zhengzhou Metro Line 5, this paper introduces in detail the flow of the 3rd generation joint waterproof system with double EPDM rubber gasket as the main body, determines the cause of water leakage through investigation, and puts forward the corresponding water leakage treatment measures. At the same time, with the breakthrough of new materials, new structures, new processes and other aspects of the entire waterproof system, the fourth generation of new joint waterproof system will be produced. In the research and development of new joint waterproof system, it is suggested to conduct in-depth research on the characteristics of underwater shield tunnel, combine with specific projects to achieve application transformation of research results, after repeated verification, it can be considered to be included in the standard specification, and further promote the rapid development of large-scale underwater shield tunnel construction in China. However, water leakage treatment measures only apply to the treatment scheme after water leakage occurs in the shield tunnel. In order to avoid a wide range of water leakage in the tunnel and reduce unnecessary plugging measures, quality testing should be carried out during the construction period and even during segment production to meet the qualified requirements and then put into use..

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