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Field Test of Concrete Impermeability of Side Wall of Lakeside Highway Tunnel

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Abstract: The impermeability of concrete of the exterior wall of the underground tunnel in water-rich stratum is a key concern of engineers. Taking the Aixihu highway tunnel in Nanchang city as an example, the impermeability of the concrete in the side wall of the highway tunnel is tested, through multiple tests, such as the embedded steel pipe, water injection, and field observation. The results show that, under the action of 2mpa of water pressure, no water flow permeates from the side wall of the concrete tunnel, indicating that the impermeable performance of concrete tunnel in this section meets the engineering requirements, and hoping that this research can be used as a reference for other similar projects.

Keywords: Water-rich layer; Concrete impermeability; Field test; Aixihu highway tunnel

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1. Introduction

For the construction of underground transportation projects in cities, many underground tunnels unavoidably need to pass through water-rich strata such as rivers, and lakes, therefore, ensuring the impermeability of the exterior walls of underground tunnels, has become a key concern for engineers [1-5]. A study conducted by Guo Yufeng et al., [6] analyzed the steady of seepage field of the underwater double-line parallel tunnel, and discussed the influence of the tunnel spacing, buried depth, and the relative size on the tunnel seepage. Further, Lin Lihua [7] optimized the drainage design, during the construction of Xiamen Haicang undersea tunnel, to improve the drainage effect, and anti-seepage capacity of the tunnel. Wang Hao et al., [8] used FLAC 3D, to establish a three-dimensional numerical model of the lakeside tunnel, further, compared the impermeability of the concrete with different impermeable layer thickness. Mao Zhixun and Tuo Shousheng [9] optimized the mix design of waterproof concrete, and improved the construction process, by conducting on-site construction analysis of the outer support formwork of the pull bolt to ensure the self-waterproof effect. Further, Yang Qixin et al., [10,11] analyzed the main reason for the waterproof failure for most of tunnel structures, which was mainly caused by the construction technology, and accuracy of the waterproof roll material, further proposed that, the waterproof method of spraying film for underground engineering. Next, Wang Tonghua et al., [12] summarized the hazards of groundwater leakage in the tunnel engineering, elaborated the causes, and conditions of leakage, and proposed a treatment method to prevent the leakage during the construction at each stage. By taking Longtan tunnel, and Baiyun Tunnel as an example, Ding Hao et al., [13] adopt model test, and other methods, and summarized a comprehensive water prevention and drainage system, consist of grouting water plugging, support, and waterproof. Further, Wang Jianyu [14] took the seepage effect of groundwater as the initial point, proposed that that comprehensive plugging structure should be adopted for municipal tunnels with a shallow burial depth. Meanwhile, Wu Qiliang [15] studied the tunnel waterproof scheme from the aspects of feasibility, scientific, and economy based on the practice of open-cut lake-bottom tunnel engineering. Study by Lu Ming [16] further, proposed the design optimization measures of all-inclusive, and joint waterproof for the waterproof problems existing in the open-cut tunnel. Lastly, Zhang Guojun [17] studied the optimization of the waterproof performance of an open-cut tunnel structure with high water level by taking Xianghu tunnel Nanchang as an example.

This paper takes the tunnel project of Aixihu railway in Nanchang city as the research background. The project is located on Nanchang Jingdong Avenue, and Torch Street intersection (pile K0 + 321), the Torch along the street east across central Moxa Sihu, walk to the east of the lake along the Moxa Sihu 2 line, after the eastern avenue all the way in innovation with Ashton Sihu 2 intersection before grounding, and the project end point is located at the junction of innovation all the way with Moxa Sihu 2 (pile K2 + 985). The total length of the tunnel project is about 2664m, mainly including a 2380m long of highway tunnel (including 4 ramps), and embedded metro Line 3 east extension structure. The groundwater at the site of the project, is connected with the surface water system of Ganjiang river, and is surrounded by water from lakes on the three sides. The soil layer is made of a strong permeability coarse sand, and gravel sand, and the permeability coefficient reache 110 m/d (according to Jingdong Avenue Station pumping test). If the sealing effect of the external wall of the tunnel is poor, problems such as surge, and leakage will be encountered in the process of construction, and operation, subsequently, will affect the function of the [6]. Therefore, field test of anti-seepage of the exterior wall of the highway tunnel was conducted on a section of Aixihu tunnel.

2. Field test of tunnel wall seepage resistance

The principle of the test scheme is described as follows: the embedded steel pipes with holes are bundled on the reinforcement cage of the main structure of the highway tunnel, and then poured into the outer wall of the tunnel, as shown in **Figure 1**. For the tunnel walls, after all the casting is completed, and the main structure of the concrete become completely frozen, the concrete permeability instrument is used, to embed the pipes inside the water injection pressure, and injection location at the same time. Further, the infrared camera observation was placed on the tunnel wall, to determine whether there is any water seepage from the tunnel wall during the temperature change, and to determine whether the waterproof measures of the tunnel meet the standard requirements.

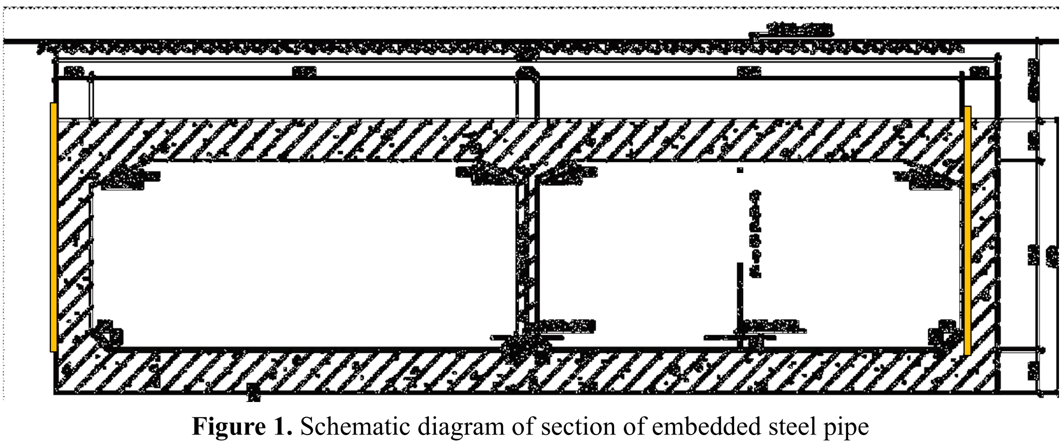


Figure 1. Schematic diagram of section of embedded steel pipe

3. The embed pipe

The concrete on the side wall of the highway tunnel in the second phase of Aixi Lake Project is 800mm in thickness, 7250mm in high, and 5650mm of internal clearance. Therefore, two steel pipes with an outer diameter of 95mm, and an inner diameter of 88mm with a length of 4m are designed for embedded steel pipes. Further, the two steel pipes are connected through nut sleeves, to form a steel pipe with a length of 8m, therefore, it is necessary to cut the thread, and matching screw sleeve at the connecting end of the embedded steel pipe, with one end closed down, while the other end open up.

Figure 2 shows the drilling design drawing of the embedded steel pipe with a total length of 8000mm, the outer diameter is 95mm with the thickness of 3.5mm. Further, the side of the embedded steel pipe facing the tunnel interior, is designed with 6 groups of holes with a diameter of 8mm (only the group with the deepest buried depth was used in the actual test). The distribution of the length in each group is 700mm with the spacing of each group is 300mm. In addition, there are 15 rows of holes in each group with the spacing of each row is about 50mm, and the specific hole layout is shown in **Figure 3**, meanwhile, the 1-1 section is shown in **Figure 5.3a** representing the layout of the first row of holes in each group. There are 7 holes in the first row of each group, and the included angle between the adjacent two holes, and the center of the string is 30°. As shown in **Figure 5.3a**, there are total of 6 holes in the second row of each group. The drilling positions are staggered with the first row, and the angle is formed between the two adjacent holes in the same row with the center of the string is 30°.

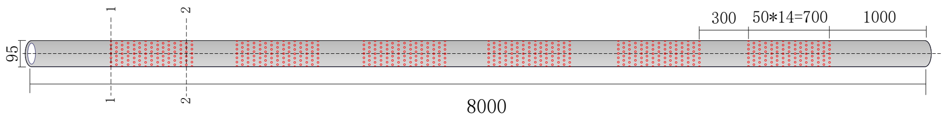
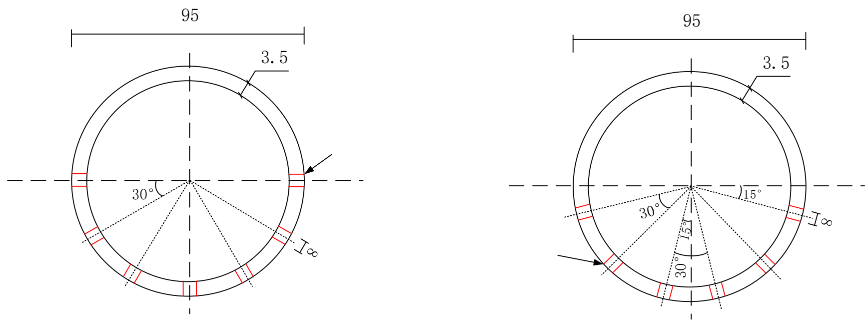


Figure 2. Overall schematic diagram of embedded steel pipe



(a) Cross section 1-1 in **Figure 2** (b) Cross section 2-2 in **Figure 2**

Figure 3. Schematic diagram of hole layout of embedded steel pipe

In order to prevent the concrete from entering the steel pipe from the holes in the steel pipe, during the pouring of the concrete for the outer wall of the tunnel, the parts with drilled holes are wrapped on the outer side of the embedded steel pipe with gauze bandages, and rubber gaskets before binding the steel pipe to the reinforcement cage. Medical gauze is used to wrap all the holes on the embedded steel pipe, to ensure that the gauze is not easily fall off from the embedded steel pipe, the gauze is fixed in the middle of each row of holes with tie wires, and further rubber rings are used to ensure the strengthen of the fixation at the both ends of each group of the holes, as shown in **Figure 4**.

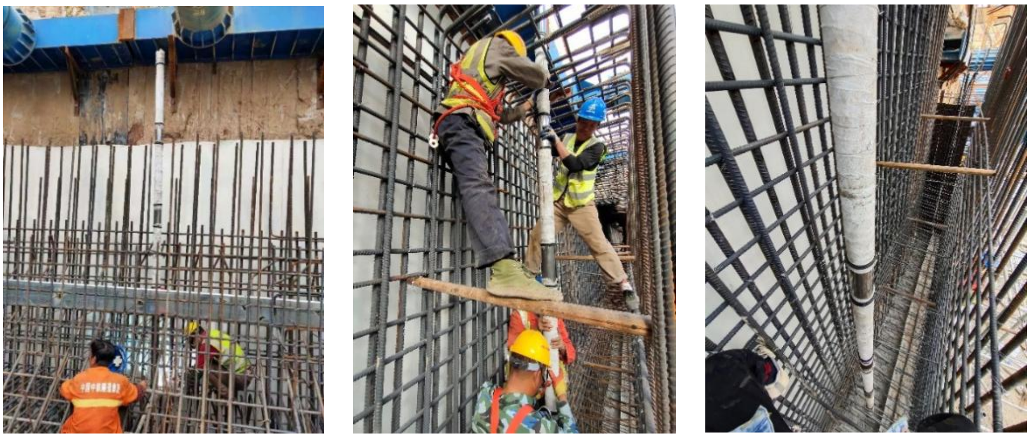
The highway tunnel of the second phase of the Aixi Lake Project, is divided into three sections of construction stage as shown below:

(1) The reinforcement cage binding, and casting of the tunnel bottom
(2) The reinforcement cage binding and casting of the tunnel side wall
(3) The reinforcement cage binding and casting of the tunnel roof

The reinforcement cage is bound to the tunnel bottom, and the embedded steel pipe is bounded on the reinforcement cage, because the embedded steel pipe is composed of two sections, firstly, the first section is tied to the bottom reinforcement cage.

The end of the first section of the embedded steel pipe is tied with a closed opening down to the reinforcement cage, and the side with the holes on the embedded steel pipe is ensured to face the tunnel. To ensure that the position of the embedded steel pipe is offset during concrete pouring, welding is also required for reinforcement, as shown in **Figure 5a**. After the bottom slab is poured, the reinforcement cage on the tunnel side wall is bound. Lastly, the second section of embedded steel pipe is connected to the installed first section of the embedded steel pipe, and the two sections of embedded steel pipe should be connected by threaded bushings, as shown in **Figure 5b** and **Figure 5c**. After the two sections of embedded the steel pipe is installed, subsequently the test is started after completed the pouring of the main structure of the tunnel.

Figure 4. Gauze bundling



(a) (b) (c)

Figure 5. Installation of the embedded steel pipe

4. Water injection pressure

For the water injection pressure test, the concrete impermeable meter was used for water injection, and pressure, to provide stable water pressure during the testing of the impermeable performance of the concrete materials. The main characteristic of the impermeable meter is that, the pressure value is displayed on the pressure display meter through the sensor, and it can initiate the automatic pressure boost based on the fixed water pressure, thereby, automatically complete the test. **Figure 6** shows the physical drawing of the concrete impermeable meter. The maximum working pressure of the concrete impermeable meter is 4Mpa with 380V power supply is provided before use it. Before initiation of the test, the water tank of the instrument is filled with enough water, further the instrument is connected to the oil pipe, and the bowl packer. Among them, the leather bowl packer is used, because it is a self-sealing packer, which seals the oil sleeve annulus by interference with the leather bowl, and the inner wall of the casing. The leather bowl expands the sealing annulus under difference pressure of the embedded steel pipe, as shown in **Figure 7**. A single set of bowl packer, can hold a large difference pressure in one direction, therefore, two groups of bowl packers with an external diameter of 90mm was used in this test, which are assembled on the opposite side to each other. The key part of the bowl packer is the cone bowl, which is made of rubber, and vulcanized on a metal framework, is connected to embedded steel pipe with other tools. After the tool is lowered according to the design position, it is sealed by compressing between the leather bowl, and the inner wall of the embedded steel pipe, and further unsealed by lifting the leather bowl packer directly. In addition, the tube with the bowl packer, is one meter long, and can be assembled according to the size of the embedded steel pipe.

Figure 6. Concrete impermeable meter

Figure 7. Single set of bowl packer

5. Observation of the test results

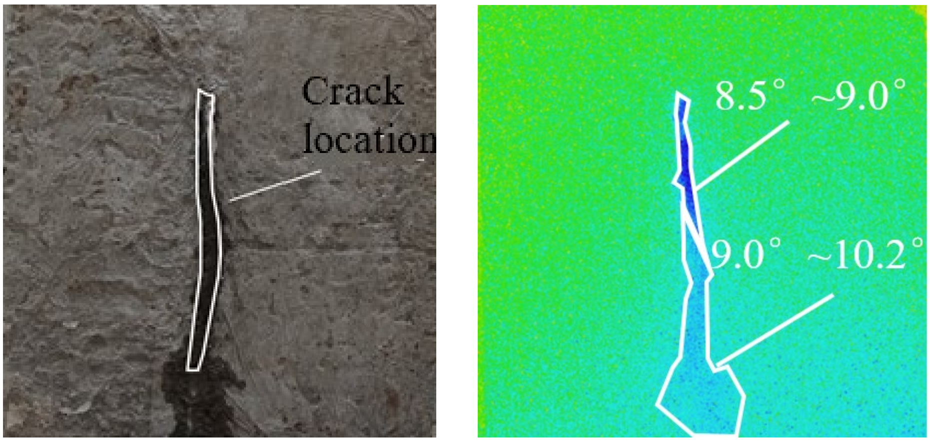
During the water injection, and pressure test, after the water injection pressure of concrete impermeable meter reaches the fixed water pressure, and once the water pressure become stable, an infrared camera is used to observe the concrete surface, and the side of the tunnel wall at the test position inside the tunnel. At present, scholars have carried out research on the application of the infrared thermal image detection technology in civil engineering [18-20]. The Japanese Avio R550 infrared thermal imager (**Figure 8**) was used for the observation. The imager can record 32,000 temperature data while taking the photos, subsequently, draw the infrared thermal images from the temperature data. The temperature measurement range, from 40°C to 650°C, and the sensitivity is about 0.25°C.

The camera was fixed on the concrete surface of the test position, to determine whether there is any water penetrating, through the concrete wall by observing the surface temperature of the concrete. If the temperature remains the same, it means there is no water infiltration, in contrast, if the temperature drops, meaning that the concrete is permeated. Additionally, if there are high temperature drops, it will generate a high range of cooling, further the water permeated through the concrete is greater, meaning that the impermeability of the surface concrete is bad. The total observation time is about two hours, and if the concrete surface temperature did not change, water pressure of 1MPa was further increased, and the test result was further observed.

Figure 8. Avio R550 series thermal imaging camera

6. Analysis of test results

Before the field test, Avio R550 infrared thermal imager was used for a trial observation. **Figure 9a** and **Figure 9b** are both the ordinary photos, and the infrared thermal image of the temperature field of 3mm wide penetrating the crack concrete test block under the water seepage taken by Avio R550. The temperature field of the infrared thermal image shows as dark blue above the crack, with the temperature ranging from 8.5° to 9.0°. The temperature below the crack gradually changes from dark blue to light blue, with the temperature increasing from 9.0° to 10.2°, indicating that it is feasible to determine the concrete seepage by observing the wall temperature with the infrared thermal imager.



(a) Common image (b) Infrared thermal image temperature field

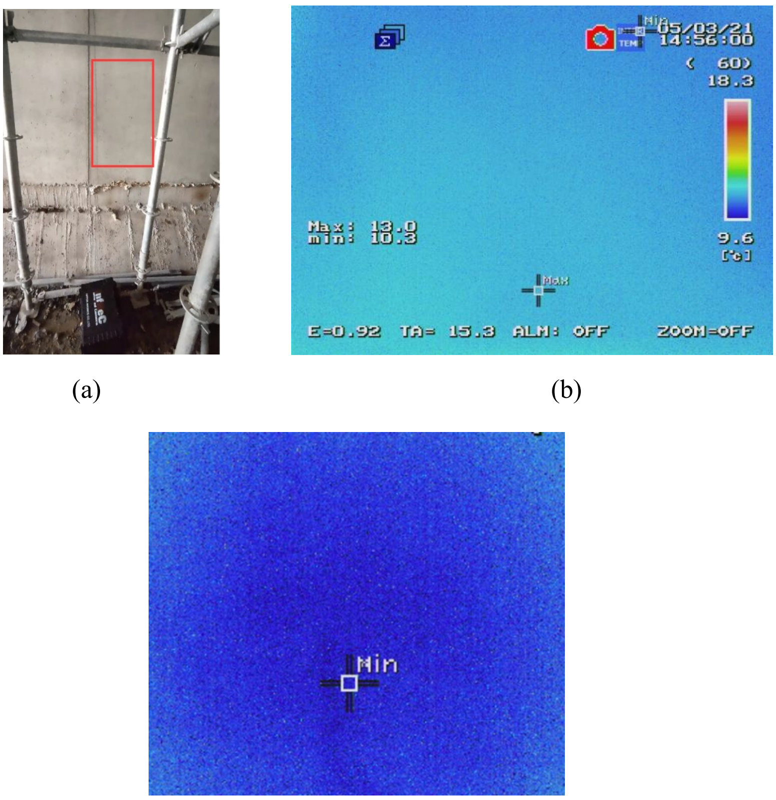
Figure 9. The ordinary photos (a), and infrared thermography (b) of concrete test block with 3mm crack under the water seepage

After pouring, and maintenance of the tunnel roof, field tests were conducted, as shown in **Figure 10**. In the test, the pressure water injection was conducted on the deepest boreholes of the embedded steel pipe, while infrared camera was used to carry out the whole observation in the corresponding position inside the tunnel.

In this test, the distance between the deepest holes in the embedded steel pipe, and the top surface of the tunnel roof is about 5400mm-6100mm with the center point is around 5750mm. Since the distance between the top surface of the tunnel roof, and the ground surface is about1300mm, considering the groundwater level is usually less than 500mm on the ground surface, the distance between the top surface of the tunnel roof, and the ground water level is 800mm, therefore, the water pressure at the location of the above holes is about 62Pa-69Pa, and 65.5Pa at the center point, considering the safety factor, and water pressure loss, the water pressure on the concrete impermeable meter was fixed to 1MPa.

A concrete impermeability tester was used for the water injection, and compression. **Figure 11a**, shows the schematic diagram of the tunnel side wall position during the testing. The water pressure was continued at 1Mpa for two hours. It can be seen from **Figure 11b** that, there is no temperature change in the concrete surface at the corresponding position inside the tunnel under the condition of 1Mpa test water pressure. Therefore, the water pressure was increased to 2Mpa, and further maintained for an additional two hours. The observation results were shown in **Figure 11c**. The figure shows that, under the action of 2Mpa test water pressure, there is still no temperature change in the concrete surface at the corresponding position in the tunnel. Indicating that with the increasing of injection pressure from 1MPa to 2MPa, there is no water leakage in tunnel inner wall, meaning that under the test condition, the water cannot flow through the concrete side wall into the tunnel, further suggesting that the concrete side wall of the highway tunnel has a good impermeability.

Figure 10. Field test diagram of anti-seepage of highway tunnel exterior wall



(a) (b)

(c)

Figure 11. Anti-seepage test results of tunnel exterior wall

7. Conclusions and Recommendations

In paper experiment, the impermeability of highway tunnel side wall in the Nanchang Aixihu tunnel project is studied. Through the test steps of embedded steel pipe, water injection, and field observation, the results show that under the action of 2mpa test water pressure of the concrete impermeability meter, the concrete tunnel side wall does not have water penetration, indicating that the impermeability of the concrete wall meets the engineering requirements, further, the field test can provide references for this project, and other projects with detailed working method.

Due to the complex operation of the field test, not sufficient control tests have been carried out, therefore, more similar tests should be performed following this work.

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Disclosure statement

The author declares no conflict of interest.

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