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Waterproofing Technology of Underground Subway Tunnels

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Abstract: The waterproof construction of subway tunnels is a crucial and challenging aspect of subway tunnel engineering. Mastering excellent waterproof construction technology is essential to ensure that the construction meets design requirements and guarantees the safe operation of subway lines. This paper focuses on discussing waterproof construction technology for subway station tunnels. By analyzing the main methods and techniques of underground tunnel construction, as well as the key techniques and difficulties of waterproofing construction, this paper examines the waterproofing construction project of Guangzhou Metro Culture Park Station as a case study. It analyzes the methods, quality management practices, and safety management strategies applied in the project. This paper serves as a reference for tunnel engineering design and construction units in our country, offering insights into effective waterproof construction techniques for subway tunnels.

Keywords: Concealed tunnel; Waterproof construction; Quality management; Safety management

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1. Introduction

The waterproofing construction of underground tunnels in subway stations is directly related to the durability, safety, and integrity of the underground structure. It plays a crucial role in preventing underground water from penetrating the tunnel, thereby ensuring a safe operating environment for subway operations [1]. Therefore, it is important to discuss the waterproofing construction technology of subway tunnels to ensure the safe operation of the subway, reduce maintenance costs, and maintain the long-term stability of urban underground space.

2. Main methods and techniques of waterproofing construction of subway tunnels in subway stations

2.1. Diaphragm wall

As a foundation pit support and waterproof structure, the diaphragm wall plays a central role in preventing the intrusion of groundwater into the subway system. Leveraging its high-strength and high-density characteristics, the diaphragm wall forms a robust waterproof barrier. This is achieved by installing a reinforced concrete wall into the deep soil during the construction process. Consequently, it effectively controls the groundwater level, ensuring a dry environment during operation and meeting watertightness requirements in the final operational stage.

2.2. Shotcrete waterproofing

In concealed tunnel construction, shotcrete waterproofing involves high-pressure spraying of concrete mixed with waterproofing additives directly onto the tunnel surface. This process creates a strong and durable waterproof layer on the tunnel [2]. Shotcrete technology is highly adaptable, allowing adjustments in spraying technique, compactness, and layer thickness based on the specific conditions of the construction site. This flexibility ensures effective waterproofing treatment tailored to different parts of the tunnel.

2.3. Polyurethane waterproof coating

Polyurethane waterproofing coating technology is widely employed for waterproofing in concealed tunnel construction at subway stations. This technology leverages the excellent elasticity and adhesion properties of polyurethane. When applied, the polyurethane forms a continuous, seamless waterproof film that adheres closely to the underlying surface, effectively blocking water infiltration.

2.4. Construction technology of polymer waterproof rolling material

Polymer waterproof coil technology utilizes materials such as polyvinyl chloride (PVC) and ethylene propylene diene monomer (EPDM) during the waterproof construction stage. These polymer materials offer excellent mechanical properties, chemical resistance, and dimensional stability. Additionally, the waterproofing effect of polymer waterproof rolls is minimally impacted by surface changes and long-term loads. This technology provides reliable protection for underground structures during the construction of subway tunnels.

2.5. Other new waterproofing methods

In addition to the above four kinds of waterproofing engineering technologies commonly used in underground tunnels in subway stations, the common waterproofing technologies in tunnel construction in the past also include grouting waterproofing, curtain grouting, and all-inclusive flexible waterproofing layer.

2.5.1. Grouting

Grouting waterproofing technology is primarily employed to seal and reinforce cracks and loose zones in the surrounding rock of tunnels, thereby reducing water penetration. Typically, the grouting material consists of cement-based, chemical, or other expansion materials. Depending on the characteristics and permeability of the rock, the material ratios must be adjusted to achieve optimal effectiveness [3].

2.5.2. Curtain grouting

Curtain grouting waterproof technology is a technology that forms a closed curtain with parallel grouting pores during tunnel construction, which is mainly used to deal with the whole seal and reinforcement of surrounding rock. By injecting grouting materials containing special chemical compositions such as expanded organic polymers, an impermeable barrier can be formed in the tunnel to isolate the groundwater path [4].

2.5.3. All-inclusive flexible waterproof layer

The all-inclusive flexible waterproofing layer utilizes highly elastic and extensible materials, such as modified bitumen, to thoroughly cover the tunnel structure's surface. This method creates a continuous, seamless waterproofing layer. Its high adaptability allows it to conform closely to the tunnel body, effectively managing the impact of geological changes and structural displacement. This ensures that the waterproof layer remains effective over time.

3. Key technologies and difficulties of waterproofing construction of subway tunnels

3.1. Groundwater treatment and control technology

Groundwater treatment and control technology is central to the waterproofing construction of underground tunnels in subway stations. It is crucial for ensuring project safety and the reliability of subsequent subway line operations [5]. The key aspects of groundwater treatment and control involve the reasonable design and implementation of groundwater reduction measures, exclusion measures, and protective measures. These strategies aim to reduce water pressure during both the construction and service periods of the underground structure, preventing the erosive effects of water and soil on the structure.

During concealed excavation, the complexity and uncertainty of groundwater dynamics pose significant challenges for groundwater treatment and control. Factors such as seasonal rainfall, geological structure, and nearby underground hydrological works influence groundwater levels and flow characteristics. Therefore, the waterproofing construction stage of concealed tunnels in subway stations necessitates that technical units conduct comprehensive hydrogeological investigations and establish precise groundwater flow models before construction begins. This preparation ensures effective groundwater management throughout the project [6].

3.2. Tunnel wall treatment and protection techniques

Tunnel wall treatment and protection technology involves strengthening, sealing, and protective measures for tunnel walls to ensure their waterproof performance and structural safety. The key elements of this technology are the structural design, material selection, construction process, and subsequent maintenance strategy of the tunnel wall [7].

In this technical field, the primary challenges during the construction stage stem from the complexity of geological conditions, the variability of the underground environment, and the continuous impact of mechanical stress, chemical corrosion, and other factors on the tunnel wall. To address these issues, the technical unit must first conduct detailed geological predictions and designs prior to construction. This involves accurate structural design of the tunnel wall based on comprehensive geological data and selecting suitable waterproofing and reinforcing materials, such as concrete injection and special waterproofing coatings [8]. Additionally, the construction unit can utilize a new technology—automatic shotcrete—which ensures the uniformity and continuity of the tunnel wall's waterproof layer, thereby minimizing the uncertainties associated with human factors.

3.3. Tunnel joints and cracks treatment technology

Tunnel joints and crack treatment technology are vital in the waterproofing construction of subway tunnels at subway stations. Its objective is to prevent joints and cracks in the tunnel structure from becoming pathways for water seepage, thereby preserving the integrity of the waterproof structure. Key technologies for addressing tunnel joints and cracks include accurately identifying their nature, selecting suitable filling and sealing materials, and executing precise construction techniques. Additionally, ongoing monitoring and maintenance during later stages of construction are essential for ensuring long-term effectiveness.

During the construction of subway tunnels, addressing tunnel joints and cracks poses challenges due to their irregularity and potential for movement. In concealed tunnel projects, factors like geological conditions, construction processes, and material expansion and contraction can lead to changes in the movement of cracks and joints. This variability presents a significant challenge for waterproofing treatments. Additionally, joints and cracks may experience secondary cracking or expansion under different environmental conditions. To address these challenges, the construction unit must systematically assess cracks and unsealing, considering factors such as width, depth, extension, and movement patterns. This assessment provides a basis for decision-making in subsequent construction phases [9]. Furthermore, the construction unit should strategically reserve deformation joints and pre-install them in areas expected to undergo structural deformation. Using telescopic sealing materials in these joints can effectively mitigate the impact of structural deformation on the treatment of joints and cracks.

3.4. Tunnel leakage detection and repair technology

Tunnel leakage detection and repair technology is a crucial part of the waterproofing construction of subway tunnels in subway stations, which is used to ensure the reliability and effectiveness of the long-term waterproofing performance of tunnels. The key technology of the process is to accurately identify the leakage point, the reasonable use of geo-radar technology, and infrared thermal imaging technology to determine the extent of leakage, and take appropriate repair methods.

During the construction of waterproof subway tunnels, the technical challenges of leakage detection and repair stem from the complex environmental conditions and the various patterns of leakage within the tunnels. These factors often make it difficult for the construction unit to pinpoint the exact source of leakage, particularly in cases of small-scale micro-leakage or hidden leaks within the structure. To address these challenges, the construction unit should utilize high-precision detection technology, such as acoustic wave detection, infrared thermal imaging, and electronic leakage monitoring. These advanced technologies enhance the accuracy of identifying tunnel leakage, enabling the rapid localization of leakage points. Additionally, localized pressure and injection management techniques can be implemented during construction. This involves applying localized pressure compression or chemical grouting to detect leakage points using materials like intumescent substances or fast-drying cement. This approach swiftly seals the leaks and restores the continuity of the tunnel's waterproof layer.

4. Quality control and safety management of waterproofing of subway tunnels

4.1. Quality control system

Establishing a robust quality control system is essential for enhancing the quality of waterproofing construction in underground tunnels. Firstly, the quality control system should establish clear quality standards and inspection criteria based on relevant regulations and engineering specifications. Independent quality control procedures should be developed accordingly. In terms of material selection, strict adherence to national standards and industry certifications for waterproof and moisture-proof materials is imperative. Additionally, materials should undergo rigorous on-site inspection to ensure quality.

Secondly, during the construction process, the construction unit must implement comprehensive supervision and management, including rigorous inspections at every stage. Real-time monitoring of construction quality using professional instruments by the quality inspection department is crucial. Moreover, a responsibility system should be established within the project team and construction units to delineate quality responsibilities for each position. Key nodes such as joint processing and leakage points require meticulous inspection and repair to ensure construction quality aligns with design and specification requirements.

4.2. Quality inspection and acceptance criteria

Establishing stringent and scientifically sound quality inspection and acceptance standards is essential to ensure that construction quality aligns with design requirements.

During the quality inspection stage, materials must adhere to the requirements outlined in the "Test Method for Building Waterproof Materials Engineering Requirements" (T/CWA 302-2023) document. A comprehensive performance and environmental adaptability assessment should also be conducted. Regarding construction quality, the construction unit should meticulously verify process parameters such as thickness, flatness, and joint sealing at key points during each stage of tunnel waterproof layer construction. This verification should be performed according to the "Urban Rail Transit Engineering Project Code" (GB 55033-2022) and the "Waterproof Engineering Quality Acceptance Code" (GB50208-2011). Detailed testing processes and acceptance procedures should be specified for testing and acceptance procedures. During the acceptance stage, leakage detection, detection frequency, and evaluation criteria should be strictly implemented. Responsibilities and acceptance standards should be clearly defined to ensure adherence to quality standards.

4.4. Safety management measures

Safety management measures for waterproofing construction in subway tunnels are crucial for project progress and personnel safety. These measures must adhere to standards such as the "Safety Inspection Standards for Building Construction" (GB 50300-2013) and the "Technical Specification for Safety Control of Urban Railway Transportation Projects" (GB/T50839-2013).

Before construction, a comprehensive risk assessment should be conducted, potential dangers identified, and corresponding emergency plans formulated.

Secondly, safety education and training should be strictly carried out to ensure that construction personnel fully understand the operating procedures and emergency response methods.

Third, a professional safety team should be established, and members of the safety team should be strictly selected, specializing in the daily construction phase of safety inspection, supervision, and guidance work. Inspection contents should include the wearing of protective equipment, the status of construction machinery and tools, and the safety management level of the construction site.

5. Case analysis

5.1. Project overview

Guangzhou Metro Culture Park Station is an interchange station for Metro Line 6 and Line 8. The main interface of the station is a three-layer underground reinforced concrete structure with a foundation pit of 23 m, which takes the form of open excavation. The standard section width of the foundation pit is 21.7 m. Among them, Line 8 adopts the combination of open excavation and underground excavation, the right line of the station is open excavation, the platform layer of the left line is underground excavation, and the construction stage of the underground part adopts the construction form of shallow buried and underground excavation combined with spray anchoring.

5.2. Waterproof construction strategy

In the underground tunnel construction of Guangzhou Metro Culture Park station, a waterproofing method combining shotcrete with polymer waterproofing coils was employed. Initially, the tunnel excavation face is supported, and a solid base is applied to the shotcrete. The shotcrete construction utilizes the wet spraying method. During the early stages, the concrete ratio was meticulously designed by the engineering team and underwent testing to ensure that the spraying quality met load-bearing and waterproofing requirements. Ultimately, it was determined that the concrete ratio would be designed at the C25 strength level, with the water-cement ratio controlled within 0.45. This involved the use of Portland cement, fine aggregate, admixture, and water to form a waterproof layer on the surface of the tunnel surrounding rock through wet spraying technology, with a targeted thickness of approximately 25 cm. After wet spraying the concrete, a quality inspection was conducted to verify the thickness, compactness, and adhesion firmness. Subsequently, after the foundation was trimmed and smoothed, the construction of a PVC polymer waterproof coil commences according to the prescribed process. During the laying process, all overlapping edges adhered to technical procedures, undergoing hot air gun welding to ensure an overlap width of no less than 10 cm.

5.3. Quality management measures

To ensure the quality of waterproof construction, a comprehensive quality management system was established by the Guangzhou Metro Culture Park Station concealed tunnel project team in collaboration with the construction unit. The specific measures adopted are as follows:

(1) Design review and optimization

The waterproof design scheme undergoes thorough review and optimization before construction, ensuring its scientific, rational, and feasible nature.

(2) Shotcrete ratio inspection

Quality inspectors meticulously control the shotcrete ratio, conducting material selection and ratio tests according to design standards to ensure the concrete's water resistance and structural strength.

(3) Coil quality control

Strict adherence to national and industry standards is enforced for the use of PVC polymer waterproof coil, with rigorous quality inspections conducted at the entrance, encompassing tensile strength, elongation, and welding performance.

(4) Construction process supervision

Quality inspection personnel perform real-time monitoring of key construction process steps, testing parameters such as slump, layer thickness, and surface smoothness during shotcrete construction. Additionally, strict monitoring of PVC waterproof coil laying and welding quality is upheld.

(5) Quality inspection and assessment

Upon completion of construction, a comprehensive inspection is conducted, including penetration tests, tensile tests, and joint inspections, ensuring the overall effectiveness of waterproofing.

5.4. Safety management measures

During the project implementation stage, on-site safety management should be strictly enforced by the project team and the construction unit. Firstly, safety education and skills training are provided to all construction personnel to ensure their familiarity with safety regulations and emergency plans. Secondly, clear safety signs should be set up at the site, with strict enforcement of workers wearing protective equipment and proper isolation of the construction area by the construction unit. Finally, regular safety risk identification and assessment of potential risk points should be conducted by the project team, serving as the basis for formulating specific preventive measures. Emphasis should be placed on safety supervision and inspection of major construction nodes and special operations to ensure compliance with safety requirements during construction operations.

6. Conclusion

This paper discusses the waterproofing technology of concealed subway tunnels. It begins by providing an in-depth overview of the primary methods and techniques employed in waterproofing such tunnels, along with an examination of key techniques and challenges. Using the Guangzhou Metro Culture Park Station project as a case study, the paper then delves into the specific waterproofing methods applied in the project, alongside discussions on quality and safety management. Notably, the Guangzhou Metro Culture Park concealed tunnel waterproofing construction project has yielded significant achievements. Through the combined use of shotcrete and PVC polymer waterproof coil, the tunnel has achieved long-term stable waterproofing performance without any leakage issues. Furthermore, strict adherence to design requirements and industry standards throughout all project procedures has ensured that the project quality aligns with predetermined standards. Lastly, effective safety measures and risk control mechanisms have resulted in the absence of safety accidents during the project's construction phase.

Disclosure statement

The authors declare no conflict of interest.

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