Key Technologies of Metro Construction in Complex Geological Areas

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Abstract. In recent years, China's underground rail transit has developed rapidly, especially with the construction of urban subway tunnels, submarine traffic lanes, water conservancy and hydropower, and municipal public tunnels. The construction of underground tunnels by shield method has been widely used. However, in some complex geology, the construction of the shield method still encounters many problems, including ultra-shallow covering and connecting through the group houses. How to solve these practical engineering problems is a topic that people are very concerned about. Based on this, this paper has carried out related research work on three common problems, including the ultra-shallow soil-pressure-balanced shield lake bottom tunnelling technology, the shield tunnelling control technology for the close-crossing group buildings, and the construction technology of complex geological and extra-large subway stations. Through the review of existing cases and theoretical research, it provides references for similar construction problems in the future.

1. Introduction
With the rapid development of China's economy and the accelerating urbanization process, the ground space of medium and large-sized cities tends to be saturated, and traffic congestion has become an obstacle to the rapid development of many cities. Urban underground rail transit has the advantages of large traffic volume, low energy consumption, light pollution, high safety, and small occupied land. Its development plays a huge role in alleviating urban ground traffic congestion, improving urban traffic efficiency and improving urban modernization. At the same time, the shield construction method (SCM) has been widely used in tunnel constructions such as subway tunnels, urban highway tunnels, and crossing rivers and lakes. However, there are still some unsolved problems in this field, which needs further research.

The shield method has the advantages of strong adaptability, high degree of mechanization, small impact on the surrounding environment, high construction precision and strong durability, which is widely used in municipal infrastructure construction. However, under the conditions of complex geology and large-scale buildings, the SCM is difficult and the safety risk is high. At present, there are some cases for the construction of shield tunnels under the rivers, but most of them use mud-water shields. Due to their own characteristics, the earth-pressure balance shields are generally not used for construction under the river. However, it is impossible to change the original shield type due to partial small river when stratum is considered. In addition, the cost of shielding under a large river is huge, and some projects cannot be referenced. The risk is higher when using a soil pressure shield to cross the super shallow soil containing a large amount of bottom muddy. If the face pressure is less than the earth pressure, upper part of the shield can rise. Otherwise, the upper part of the shield will collapse. Any case
will lead to huge safety risk. At the same time, the floating phenomenon of the pipe segments in the shield tunnel is a technical problem that plagues the construction of the shield tunnel in engineering. Therefore, correcting and controlling the floating pipe segments are the key to ensure that the shield can pass through the lake without affecting the ecological landscape of the lake.

Based on the above background, this paper reviews key technologies of subway construction in complex areas, including the following three parts: technology of the ultra-shallow soil-pressure balanced shield under lake, the shield close-crossing group building construction settlement control technology, complex geological extra-large subway Station construction technology.

2. Technology of the ultra-shallow soil-pressure balanced shield under lake

Since the 1970s, the construction technology of shield tunnels has made great progress. High-performance shields such as earth pressure balance shield, mud-water balance shield and air pressure (local pressure) shield have been successively introduced, making long distance tunnels in soft soil have become a reality. However, when the shield method is used to construct tunnels under waters (rivers, rivers, lakes, and seas), the following risks and problems are still encountered: (1) top-flowing and permeable flows; (2) floating tunnel; (3) flowing sand and piping.

Under the shallow soil, there will be overburden and even damage due to improper control of the cutter head pressure, resulting in water and soil flow to the tunnel. Based on specific projects, experts summarize some excavation methods and engineering control measures.

Starting from the equilibrium state of the shield excavation surface and the anti-floating condition of the tunnel bottom, Zhang et al. studied the minimum cover soil thickness required for the shield to pass through the shallow soil at the bottom of the water and maintain the soil and the tunnel[1]. On this basis, taking the test subway section in Nanjing Line as an engineering example, the engineering measures for underwater tunnel shield construction under super-shallow soil cover are proposed. Based on a practice in Xian subway line, Yan et al developed the safety scope of the pressure in the soil bin of the shield face based on local engineering geology and hydrogeology conditions and principle of minimum support[2]. The author points out that piled up in the river and properly control the pressure of the silo can control formation deformation effectively. Based on the rigid slider upper limit method, Liu obtained the ultimate support force of surface uplift damage of shallow shield tunnel under plane strain and three-dimensional space using programming software[3]. According to the return value of the program, the author discusses the scope of the damage of stability damage. Tang analyzed the longitudinal force of the lining of complex underwater shield tunnel segments under special circumstances on the basis of two practices in Shiziyang and Xiamen[4]. Combined with the shortcomings of the longitudinal design of the shield tunnel, the equivalent continuous model under the longitudinal force is also derived and the modification of the longitudinal structure performance of the special environment and the auxiliary structure are discussed. Zhao introduced the construction method of the shield machine crossing the West Lake combined with the construction in Zhengzhou Metro Line, including the tunnelling parameter control and tube floating technology control[5].

3. Settlement control technology for shield tunnelling through group buildings

Since the low foundation strength of residential buildings as well as the diffusion of earth pressure during shield construction is sensitive to the settlement of the ground, it is extremely important for the settlement control of shield construction. A general schematic diagram is shown in Figure 1.
Taking Suzhou Subway Line 2 as an example, Liu studied and summarized the engineering countermeasures in the silt layer crossing the building group. Through strict monitoring and measurement, the construction of the shield under the existing buildings can be guaranteed[6]. Li deduced and established a method to determine pipeline safety based on measured surface settlement data[7]. In addition, the relationship between surface deformation and stress state at pipeline location is established. Based on the engineering practice of a rail transit project in Wuhan, Zhu used the finite element software FLAC3D to compare and analyze the total excavation displacement of different excavation sequences aimed at providing reasonable suggestions for the actual construction of the crossing building[8]. Xia et al. also used the finite element software FLAC3D to simulate the construction process of the shield crossing the railway station and the pile group of the building, which provides reasonable advice to actual construction[9]. Jiang analyzed a frame structure office building by the finite element software ANSYS and calculate the settlement and additional stress caused by the shield tunnel subway tunnel[10]. Ge built the three-dimensional numerical simulation model of multi-case system for ground settlement law caused by shield tunnelling through existing buildings. The results has been applied to engineering successfully[11]. Through deep analysis of the construction method of shield tunnelling through pile foundation in domestic subway construction, Liu proposed the specific measures and applicable conditions of five construction methods, including line adjustment, pile foundation underpinning, pile pulling, punching and direct crossing are proposed[12].

Through literature review, it is found that the SCM will inevitably break the original stress balance state of the rock and soil body. The elastoplastic deformation and rock loss will also cause the cavity deformation and surface settlement, which impacts greatly on the adjacent buildings and pipe networks. Since the subway is built in the urban center area, the probability of subway tunnel going through the existing buildings will increase greatly with its continuous construction. Therefore, the research on the ground settlement control technology when the tunnel shield is close to the building is of great significance.

4. Extra-large metro station construction technology under complex geological

The foundation pit protection, waterproofing of large stations, crack resistance of large concrete, as well as the organization and management during construction are the key points.

On the basis of existing design and construction practice of foundation pit practice, Yan analyzed the characteristics of various common foundation pit supporting schemes, and summarized their advantages and disadvantages[13]. Important factors affecting the selection of specific foundation pit support schemes are also pointed out. By a case in Zhengzhou, Wang compared the advantages and disadvantages of different enclosure structures combining with the local hydrogeological conditions, and finally find a reasonable support method[14]. Then, the authors employed LiZheng software to check the foundation pit engineering to ensure the rationality and reliability of the foundation pit support scheme. Based on the perspective of system engineering, Zhu constructed the subway station waterproof system. Considering the leakage of the subway station, the author analyzed its composition of the
waterproof system and structural characteristics[15]. From the failure cause of the waterproof system, the key factors in the whole construction process are found out. Hu summarized the related subway waterproof technology and proposed the classification standard[16]. On the basis, two standards of active and passive waterproofing technology are described in detail by considering their applicability. Finally, the author believed that the waterproofing of the subway should adopt the combination of active and passive waterproofing technologies comprehensively. Taking the high-speed railway station project in China as an example, Shen analyzed the application of seamless construction technology of large-volume super-long concrete structure in practical engineering cases[17]. In practice, auxiliary jumping method with seamless construction is used to replace the post-casting construction method. Meantime, the segmented construction method is proved to be a successful and feasible one (Figure 2).

Based on the cracks causes analysis in concrete structures of bridges, Xu proposed the crack control technologies, including construction in strict accordance with the construction process, and the configuration, transportation, pouring vibration of concrete, water treatment, maintenance management and other aspects of work to effectively improve the quality of bridge concrete structures to extend the service life[18]. By an empirical study of a certain excavation subway station as an example, Xia conducted an empirical study with the focus on the construction safety risk management, including identification, evaluation and response research[19]. Finally, according to the characteristics of the project, feasible and targeted risk response measures were proposed (Figure 3).

5. Conclusions
This paper reviews the key technologies of subway construction in complex geological areas with the focuses on the following three problems: the ultra-shallow soil-pressure-balanced shield lake bottom tunnelling technology, the shield close-crossing group building construction settlement control technology, and complex geological extra-large subway station construction technology. Through relevant engineering cases and theoretical research, the overall status of research has been grasped, which provides a valuable reference for solving such engineering problems.

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