Journal of Architectural Research and Development, 2024, Volume 8, Issue 2
http://ojs.bbwpublisher.com/index.php/JARD
Online ISSN: 2208-3537
Print ISSN: 2208-3529

Discussion on Construction Technology of Subway Tunnel Expansion under Bridge Foundation

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Abstract: As the urban populations grow, the number and size of subway construction projects are increasing while also meeting higher construction standards. So, subway construction projects must have a better understanding of construction technology. This article focuses on the construction technology of the subway tunnel expansion under the bridge foundation. By analyzing the engineering characteristics of the bridge foundation and using a project as an example, this article provides a detailed discussion of the construction process of tunnel expansion under a bridge foundation. This article aims to serve as a reference for subway tunnel construction in China to ensure the key points of construction technology are understood, thus improving construction quality and laying a solid technical foundation for the sustainable development of urban rail engineering.

Keywords: Subway tunnel; Bridge foundation underpass expansion; Construction technology; Steel truss support construction

Online publication: March 27, 2024

1. Introduction

Urban subway projects can benefit from expanding the construction technology of building tunnels under bridges. This method allows the subway line to cross the tunnel safely without dismantling or affecting the existing bridge structure, ensuring traffic continuity and normal operation of urban functions. However, the construction department must grasp the construction technology well when constructing the tunnel under a bridge. Poor construction quality can lead to economic losses from rework and security risks for other subway lines [1]. Therefore, exploring the construction technology of the subway tunnel under a bridge is essential. This will help with the understanding of the technical points to utilize the advantages of the expanded bridge foundation and ensure that the project meets the design requirements.

2. Characteristics of subway tunnel underpass and expanded bridge foundation engineering

Expanding the subway tunnel under the bridge foundation is a special underground engineering construction method. Its engineering characteristics include complex technology, high construction difficulty, safety risks, and environmental risks.

2.1. Technical complexity

Expanding the subway tunnel under the foundation bridge requires precise design and construction of the underground tunnel without damaging the bridge structure and its load-bearing capacity [2]. This process involves a detailed analysis of soil mechanical properties, bridge structural stability, groundwater flow characteristics, and so on to ensure safety and stability during construction and usage. The mutual influence of bridge foundation and subway tunnel construction must be comprehensively considered in the design stage.

2.2. High construction difficulty

The high difficulty of construction is reflected in the engineering operation stage, which requires precise construction technology and strict engineering monitoring. At the same time, the construction department needs to reinforce and support the bridge structure to ensure structural safety during the construction process. In addition, indicators such as surface settlement and bridge displacement must be strictly monitored during construction to avoid disasters [3].

2.3. High safety risks

Since the construction of underpass tunnels and bridges is often located in the general city center, the safety requirements for the project are extremely high. The construction department needs to establish a comprehensive risk assessment and management system while having an in-depth grasp of construction technology to avoid safety risks during the construction stage that can cause serious harm to the construction department and the public [4].

2.4. High environmental risks

Since expanding subway underpass tunnels under bridges are usually located in central areas of cities, minimizing environmental impact is an important aspect. During the construction phase, the construction department must comprehensively consider the control of noise, vibration, and dust pollution and apply necessary environmental protection measures to reduce interference to the lives of surrounding residents and urban traffic operations [5].

3. Research on construction technology of subway tunnel expansion under bridge foundation

To objectively grasp the key points of construction technology application of subway tunnel underpass and bridge foundation, this article takes the construction of the first phase tunnel project of subway line 2 under a bridge foundation in a certain city as an example and studies the application of construction technology in each step from the perspective of the entire construction cycle.

3.1. Project overview

In the first phase project of subway line 2, the expansion of the tunnel under the bridge foundation section is the key target of the line construction project. The engineering project includes a 2.4 km long underground tunnel with a 120 m length passing underneath the bridge, and the minimum clear height of the tunnel is 5.6 m. Before construction, the engineers conducted a detailed assessment and reinforcement plan design on the existing structure of the bridge. The carbon fiber reinforcement and external prestressing technology were proposed to ensure that the bearing capacity of the bridge would not be affected during construction.

3.2. Selection of drilling methods

When selecting engineering drilling methods, a comparison was made between rotary drilling rig and punched pile construction with full consideration of construction safety, technical feasibility, construction efficiency, and protection of the existing bridge structure.

First, rotary drilling rig construction tools have significant advantages over punched pile construction. The rotary drilling rig is equipped with an advanced automated control system that can accurately control the position and status of the drilling tools during the drilling process to ensure construction accuracy. This project is designed as a φ120 cm large-diameter cast-in-place pile, which has high requirements for construction equipment stability and drilling accuracy. The rotary drilling rig has fast drilling speed and higher stability and accuracy than punching pile construction. The construction interference with rotary drilling rigs is also lower, which can significantly reduce environmental interference, especially in dense urban areas [6].

Secondly, based on the analysis of the angle of soil liquefaction during construction, the rotary drilling rig will not cause significant liquefaction during the drilling process compared with punching piles, as liquefaction can significantly reduce the stability of the surrounding soil. During the expansion of the subway tunnel, the bridge stability is directly related to the structural load-bearing capacity and service life. The soil structure around the bridge foundation may become loose due to repeated impacts of punched piles during construction which affects the overall structural stability.

Third, rotary drilling rig construction can effectively reduce the use of mud, reduce pollution to the groundwater environment, and ease the difficulty of mud treatment at the construction site when compared with punch pile construction.

After comprehensively considering multiple factors, the project decided to use a rotary drilling rig to construct bored piles, thereby effectively ensuring the safety and stability of the bridge structure while reducing the impact on the environment [7].

3.3. Foundation pit excavation

As for the foundation pit excavation for the subway tunnel expansion, the construction strategy of trench excavation along the center line of the tunnel and symmetrical segmental brushing was adopted after analyzing the geological conditions and construction environment to reduce the impact of the construction process on the structural stability of the tunnel.

The symmetrical step-by-step excavation method is designed to reduce the amount of soil during each excavation operation, avoid large-scale ground settlement caused by large-scale excavation construction, prevent reverse arching of the overlying soil of the tunnel, and reduce the resulting subway tunnel deformation and destruction.

During the specific construction phase, two light excavators are deployed to operate along the center line of the tunnel. Manual excavation is used under certain special conditions when necessary to ensure the effectiveness of the tunneling. When the foundation pit reaches the predetermined depth, roofing protection measures for the subway tunnel anti-floating structure are deployed to ensure the structural safety of the tunnel.

Once the roofing construction is completed, the excavation progress of the foundation pit can be continued in symmetrical sections along the transverse direction of the tunnel [8].

3.4. Steel truss support construction

Considering the geographical constraints brought by the underground regional power pipeline corridor and the existing subway structure, the traditional center column support solution cannot be used for the foundation pit support. Therefore, a stable structure composed of steel pipe supports and steel truss support systems is proposed. In this plan, the steel pipe supports are used to reinforce the foundation pit effectively through an optimized mechanical layout, and the installation of steel trusses is to further improve the spatial stability and load-bearing capacity of the overall support system.

In the early stages of construction, the welding method for the steel pallet and crown beam structure is used to firmly fix the steel pallet to the steel plate pre-embedded in the crown beam, thereby improving the initial stability of the support system. During the steel pipe construction stage, two crawlers with a load capacity of 80 t are used to accurately hoist the pre-assembled φ600 mm single steel pipe support with a wall thickness of 14 mm to the designated position for installation. After the support installation is completed, φ299 mm steel pipes with a wall thickness of 6mm are used as the horizontal connection structure that is welded to connect adjacent steel pipe supports into a group to form a whole support.

The overall steel truss structure in support design is composed of two main steel pipe supports and connecting steel pipes to ensure that the load can be transferred and dispersed to the entire support system and enhance the overall stability of the foundation pit. The distribution of horizontal and vertical support forces is optimized based on the principles of structural mechanics, thereby reducing the stress concentration at specific parts caused by concentrated loads and improving the bearing capacity and deformation control capabilities of the entire support structure when receiving uneven loads [9].

3.5. Anti-floating anchor construction

During the anti-floating anchor construction stage of this project, anchors with a diameter of φ 32 mm, a spacing of 100 cm, and a single length of 12 m are selected to penetrate deep into the soil layer that can provide sufficient anchoring force. Four top-pressing reinforced concrete slabs were designed for the bottom of the foundation pit, and 5 anchor rods were set at both ends of each reinforced concrete slab, totaling 40 anchors, to further achieve resistance to the upward buoyancy force. At the same time, the hole diameter is controlled at φ80 mm to maintain the anchoring force of the anchor rod. A 42.5 R grade ordinary Portland cement with ≤0.45 water-cement ratio was used for the grouting process.

3.6. Reinforced concrete plate construction

Based on comprehensive consideration of the size of the existing tunnel structure and the required buoyancy resistance threshold, the designed length of the reinforced concrete pressure plate is 11,500 mm, the width is 5,000 mm, and the thickness is 500 mm. A horizontal and vertical steel network layout with a diameter of Φ25 mm and a spacing of 100 mm was adopted to maximize the pressure plate bending strength and efficiency. In addition, the Φ14 mm diameter tie bars are arranged in a 300 mm spacing grid pattern to increase the overall crack resistance and stability of the pressure plate [10].

3.7. Main structure construction

The main construction of this project is divided into three parts. The first is the section across the power pipeline corridor, the second is the section across the subway tunnel, and the third part is the reinforcement of the bridges.

For the first and second project parts, the bottom plate is first constructed. Then, the side wall construction, bracing replacement, and roof construction are performed to provide a foundation for the entire tunnel structure. This foundation stabilizes the tunnel contour and provides lateral support. The purpose of replacing bracing is to ensure safety and structural stability during roof construction. Finally, the roof of the tunnel structure is closed to complete the construction process. The main construction project ultimately formed a structure in which the tunnel structure and the reinforced concrete plate are mutually dependent. This constructed structure would jointly bear forces to ensure that the structure has high stability and safety under various external environmental pressures.

This project uses carbon fiber reinforcement and external prestressing technology to reinforce the bridge. Carbon fiber-reinforced materials are widely used in engineering projects to improve the bearing capacity of components and extend their service life with their excellent mechanical properties, corrosion resistance, and lightweight. Carbon fiber-reinforced polymer is used to reinforce tunnel structure, which can effectively improve the structural stress performance and ensure that the stress caused by tunnel excavation will not be redistributed during the construction process, damaging the structural integrity and load-bearing capacity of the bridge. External prestressing technology increases the stress-bearing capacity of components by applying prestressing force on the outside of the structure. This technology is particularly effective in bridge reinforcement, especially when it is necessary to maintain the normal use of the bridge during construction. The introduction of prestressing can increase the initial support force of the bridge and improve the stress state, thus reducing the adverse effects caused by tunnel construction.

The existing bridge structure was first evaluated to determine the optimal reinforcement position and the amount and distribution of prestress needed. Second, the bridge surface is cleaned to prepare for the fitting of carbon fiber-reinforced materials. Third, the carbon fiber-reinforced polymer material is fitted with appropriate adhesives and precise construction techniques to ensure the right combination of carbon fiber on the structural surface. Fourth, external prestressed rigging is installed in key areas of the structure with a predetermined degree of prestress applied.

3.8. Bridge deformation control technology

Since there are a large number of pipelines and building foundations around the tunnel of the project, the old pile foundation pile that affected the tunnel construction was removed and the bridge cap beams were reinforced. During the construction stage of the new pile foundation, wall-protecting mud was used to improve stability during the drilling phase.

First, the foundations were reinforced with concrete cast-in-place piles during the removal of old bridge piles. The length of the piles were 26 m and 30 m, with a diameter of 0.8 m each. A 150 t crawler crane with a 150 kW vibratory hammering operation was used during the removal phase. During the construction period, the disturbance to the soil around the pile foundation was minimized. The removed pile foundations were backfilled by filling the soil with a certain proportion of fly ash and lime added and compacted evenly.

Secondly, concrete support columns were poured between the cap beams and platforms before the pile foundations were removed to avoid changes in the stress-bearing system of the cap beams during the demolition, improvement, and capping stages. Longitudinal reinforcements were inserted into a depth of ≥30 cm to maintain the bridge stability after removing the pile foundation.

Third, wall-protecting mud was poured into the borehole during the construction of the new pile foundation to ensure that the hole wall was in a highly stable state during the drilling phase.

4. Conclusion

During the subway tunnel expansion construction under a bridge foundation, adopting correct and effective construction techniques is a key element in ensuring the stability of the bridge and the project construction quality. Therefore, this paper conducted a detailed study of the construction technology of tunnel expansion under a bridge foundation. The research results of this article can be used as a reference for future subway tunnel construction projects to ensure the rationality of the technology and key technical points used. Factors such as the actual needs of the construction project and the construction environment should be considered to ensure that the construction plan is highly consistent with the project. Hence, this will further improve the effectiveness of construction technology, improve the flexibility of its application, and meet engineering construction requirements to the maximum extent possible.

Disclosure statement

The author declares no conflict of interest.

References

[1] Ma C, 2023, Analysis of Deformation Control Technology in Constructing Large-Diameter Shield Tunnels Passing through Subway Tunnels. Jiangxi Building Materials, 2023(05): 339–341.

[2] Yu Q, 2022, Key Technologies for Bridge Pile Foundation Construction near Existing Lines. Transportation World, 2022(30): 55–57.

[3] Liang XB, 2019, Analysis of Construction Technology of Subway Tunnel Through Enlarged Foundation Bridge. Engineering Construction and Design, 2019(23): 197–199.

[4] Zhang Y, 2023, Analysis of Common Problems and Quality Control Countermeasures in Bridge and Tunnel Construction. Transportation Manager World, 2023(32): 109–111.

[5] Ji DP, Sun XC, Han TL, 2023, Research on Safety Assessment and Monitoring Technology for Bridge and Tunnel Construction. Transportation Manager World, 2023(31): 80–82.

[6] Xiao Y, 2023, Research on Reinforcement Technology and Construction Technology of Highway Tunnel Bridges. China Construction, 2023(09): 137–139.

[7] Li ZM, Kong DJ, Ying H, et al., 2023, Protection Measures and Impact Analysis of Subway Shield Tunnels Passing Through Bridges. Journal of Jiangsu Vocational and Technical College of Architecture, 23(1): 7–13.

[8] Yu JP, 2020, Analysis of Construction Technology of Expanded Foundation for Shield Tunnel Passing Through Bridge. China Construction, 2020(27): 237–238.

[9] Sun ZW, 2022, Construction Technology for Large-Diameter, Long-Distance Curved Pipe Jacking to Penetrate Subway Tunnels at Close Range. Municipal Technology, 40(9): 137–141 + 148.

[10] Li YF, 2022, Research on Construction Technology of New Subway Tunnels Passing Under Existing Subway. Modern Engineering Science and Technology, 1(4): 50–53.