

Impact Analysis of Shield Idling Through Pre-excavated Section on Existing Tunnel Postprint

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Abstract

To address the challenge of a certain section of Wuhan Metro Line 6 tunnel undercrossing an existing station of Line 2, the advance underground excavation method was employed for the undercrossing zone. This paper presents the corresponding solutions to a series of issues encountered during shield tunneling through the advance underground excavation section, and evaluates the influence of shield idling on the existing tunnel by analyzing the rail surface settlement of Line 2 and the settlement of existing station structures during construction. Based on a specific metro tunnel project of Wuhan Rail Transit Line 6, this study systematically analyzes the advance crossing of an existing tunnel using the underground excavation method, followed by shield idling. Furthermore, the effectiveness of shield idling through the underground excavation section is investigated from the perspectives of rail surface settlement of the existing track and cumulative settlement of station structures. The project also implemented specialized dewatering and reinforcement measures to mitigate impacts on the operation of the existing line during construction, thereby providing valuable references for similar projects.

Full Text

Preamble

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Analysis of the Influence of Empty Shield Tunneling Through Pre-Excavated Sections on Existing Tunnels

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Abstract: To address the challenge of Wuhan Metro Line 6 crossing beneath an existing station of Line 2, the under-crossing section was constructed using advance mining methods. This paper introduces the solutions to a series of problems encountered during shield tunneling through the pre-excavated section, and analyzes the impact of empty shield tunneling on the existing tunnel by examining track surface settlement of Line 2 and building settlement of the existing station. Based on a metro tunnel project of Wuhan Rail Transit Line 6, this study systematically analyzes the method of advance mining through existing tunnels followed by empty shield tunneling. The effectiveness of this approach is evaluated from two perspectives: track surface settlement of the existing railway and cumulative settlement of station structures. The project also employs specialized dewatering and reinforcement schemes to minimize impacts on existing line operations during construction, providing valuable reference for similar projects.

Keywords: Shield Tunneling; Mining Method; Empty Shield Tunneling

1 Project Overview

Shield tunneling has become increasingly important in urban metro construction due to its minimal environmental impact, rapid construction speed, excellent engineering quality, safety, environmental friendliness, and wide applicability. However, with the expansion of metro networks, line intersections have become inevitable. The challenge of constructing new lines without disrupting existing operations has emerged as a critical issue.

The subject interval of Wuhan Metro Line 6 consists of a 792.1 m right line and a 781.6 m left line, both constructed using shield tunneling methods. The right line advances from the large-mileage end toward the small-mileage end, while the left line progresses in the opposite direction. The site layout is shown in [Figure 1: see original paper].

This section crosses beneath an existing station of Line 2. To avoid affecting normal operations of Line 2, a construction scheme involving advance mining followed by empty shield tunneling was adopted. Due to spatial and equipment constraints in the tunnel, advancing through the empty-push section involves more complex procedures than soil excavation, making quality control of the completed tunnel more challenging. This paper identifies the primary risks associated with shield passage through empty-push sections and proposes targeted technical measures to guide similar construction projects.

The crossing section passes beneath Line 2. To ensure uninterrupted operation of Line 2, the under-crossing section was pre-excavated to remove six uplift piles that would obstruct shield tunneling. The pre-excavated embedded section

measures 57.55 m on the right line and 71 m on the left line. The tunnel crown is buried at a depth of 18 m, with a 6.5 m clearance between the tunnel roof and the base slab of the Line 2 station. The spatial relationship between the pre-excavated tunnel and the existing Line 2 station is illustrated in [Figure 2: see original paper] and [Figure 3: see original paper].

The project site exhibits relatively flat terrain with a ground elevation of approximately 20.50 m. The geological strata and lithology are summarized in . From top to bottom, the strata consist of: fill layer and Quaternary fill layer, Grade II terrace accumulation plain, and underlying bedrock. The pre-excavated tunnel section primarily passes through 10-2 silty clay, 11 clay, and 11b silty clay layers. According to survey data, the site contains three types of groundwater: perched water, confined pore water, and bedrock fissure water. The pre-excavated tunnel section traverses water-rich confined aquifers.

The embedded tunnel section was initially constructed with only primary support and secondary lining, without waterproofing. The shield machine passes through by assembling segments in the empty-push mode. The embedded section features a 3 m wide cross-passage at the small-mileage end, with an internal diameter of 6,580 mm. Primary support consists of 350 mm thick steel-reinforced grid concrete, while the secondary lining comprises 300 mm thick C30 reinforced concrete. The large-mileage end of the embedded section is sealed by a trapezoidal C20 plain concrete wall measuring 3 m wide at the top and 9.58 m wide at the bottom. The shield machine has an outer diameter of 6,460 mm, leaving a 60 mm gap between the shield body and the mining secondary lining to facilitate passage.

Before empty shield tunneling, soil reinforcement using jet grouting must be completed at both ends of the embedded section. The initial support and secondary lining at the small-mileage cross-passage, as well as the plain concrete sealing wall at the large-mileage end, must be demolished after dewatering operations. For the left line, both ends were reinforced using $\Phi 800@500$ mm triple-pipe high-pressure jet grouting piles from the ground surface. Due to lack of surface access, the right line ends were reinforced using internal horizontal grouting.

2 Construction Difficulties and Solutions

This interval was excavated by two composite earth pressure balance shield machines (CET6400) manufactured by China Railway Equipment, launched sequentially. The construction process involves: (1) dewatering the embedded section, (2) reinforcing both ends of the pre-excavated section, (3) portal demolition, (4) empty shield tunneling through the embedded section, and (5) secondary launch. The detailed construction flow is shown in [Figure 4: see original paper].

2.1 Technical Challenges

Shield tunneling through the pre-excavated embedded section presents several construction difficulties: (1) Surface reinforcement is impossible at the small-mileage portal due to existing road conditions, requiring internal horizontal reinforcement; (2) Water and mud gushing between piles may occur during portal demolition at both ends; (3) Control of shield launch attitude and thrust force is critical; (4) During empty pushing in the embedded section, minimal resistance ahead of the shield machine may cause segment misalignment and leakage; (5) The shield machine is prone to “turning” and alignment control difficulties during empty pushing.

2.2 End Reinforcement of Embedded Section

Right Line End Horizontal Reinforcement: Since the embedded section of the right line is located directly beneath a road surface without ground construction access, internal horizontal reinforcement using $\Phi 800@600$ mm triple-pipe high-pressure jet grouting piles was implemented. Horizontal grouting was used to supplement reinforcement in blind areas. Construction holes were arranged circumferentially along the tunnel perimeter at 500 mm spacing, totaling 38 holes, as shown in [Figure 5: see original paper]. This ensured effective reinforcement of soil within 3 m outside the tunnel structure, with a 10.5 m reinforcement length at the small-mileage end and 9 m at the large-mileage end.

Left Line End Vertical Reinforcement: Both ends of the left line were reinforced using $\Phi 800@500$ mm triple-pipe high-pressure jet grouting piles from the ground surface. The first row of jet grouting piles overlapped the portal support structure by no less than 300 mm. The reinforcement range extended 3 m beyond the tunnel structure edges, with a 10.5 m length at the small-mileage end and 9 m at the large-mileage end.

2.3 Portal Demolition

The portal demolition sequence is as follows:

Small-mileage end: Remove primary support surface concrete → cut primary support steel grid → remove remaining primary support concrete → remove secondary lining surface concrete → cut secondary lining steel mesh → remove remaining secondary lining concrete → clear waste debris.

Large-mileage end: Break plain concrete wall → clear waste debris.

Portal demolition was performed manually using pneumatic picks. The portal was divided into nine sections, with demolition proceeding in numbered sequence from bottom to top and from sides to center (short piles before long piles) to facilitate personnel evacuation during emergencies. Steel pipe scaffolding was erected as a working platform before demolition. The demolition sequence is illustrated in [Figure 6: see original paper].

2.4 Shield Empty Pushing Through Embedded Section

2.4.1 Preparations Before Shield Entry Guiding Platform Construction: A 60 mm thick reinforced concrete guiding platform was cast in place with a chord length of 3,230 mm, as detailed in [Figure 7: see original paper].

Shield Machine Attitude Control: Shield machine attitude was manually resurveyed at 100 m and 50 m before reaching the embedded section to correct deviations promptly and ensure smooth entry. The final 25 m before the embedded section was designated as the approach zone, where open-mode tunneling was adopted based on geological conditions. When entering the approach zone, thrust force and advance speed were gradually reduced while increasing monitoring of excavation volume. Cutterhead rotation speed was maintained at 1.65–1.85 r/min, total thrust kept below 800 t, and advance speed limited to no more than 25 mm/min. For the final three rings before entry, advance speed was controlled within 15 mm/min and total thrust reduced to under 600 t, allowing the shield to enter the embedded section with low thrust and speed.

2.4.2 Empty Pushing in Embedded Section Based on the relationship between the cutterhead and guiding platform, the stroke of each thrust cylinder group was adjusted to maintain shield alignment along the design route. Initial advance speed was generally controlled at 15–40 mm/min, increasing to 60–85 mm/min after operators gained proficiency. Lower cylinder pressure was slightly higher than upper cylinder pressure, while dedicated personnel monitored shield advancement from the front.

Pea gravel filling was performed using a wet shotcrete machine at a rate of 6–9 m³/h. During pea gravel injection, sandbag cofferdams were constructed every 4.5 m around the cutterhead perimeter (covering the 2:00–10:00 clock positions) to prevent backflow of pea gravel and mortar. Pea gravel aggregate (5–10 mm particle size) was blown from the cutterhead front toward the rear at 0.25–0.3 MPa pressure. Non-operating personnel were prohibited from entering the work area during injection to prevent injury from flying debris.

Synchronous grouting used cement mortar with initial setting time of 8 hours and final setting time of 10.5 hours. The gel time was adjusted based on grout flow during shield advancement. Since the shield periphery was open, pressure variation was minimal, and grouting completion was controlled by volume rather than pressure—grouting ended when volume reached 80% of theoretical requirement. After installing 10 rings, secondary grouting was performed every 6 m (4 ring segments) at grouting holes to check effectiveness.

Based on segment leakage conditions, secondary grouting was performed using cement-sodium silicate double-fluid grout (ratio 1:1) at 0.2–0.3 MPa pressure and flow rate not exceeding 10 L/min. Grouting termination was controlled by pressure alone.

3 Construction Monitoring Data Analysis

To ensure operational safety of Metro Line 2, automated real-time monitoring of track surfaces was conducted using hydrostatic levelers throughout the shield passage.

3.1 Monitoring Scheme

Monitoring aimed to identify potential construction risks, analyze and respond to feedback information promptly, adjust operational parameters based on monitoring data, ensure surrounding environment safety, and guarantee smooth project execution. Theoretical monitoring items during shield crossing included surface settlement and building settlement/inclination. Monitoring point layout is shown in [Figure 8: see original paper].

During shield tunneling, track surface settlement was observed in real time. When measurements indicated anomalies or dangerous trends, immediate emergency measures were implemented, including construction suspension and preventive actions to avoid accidents.

3.2 Settlement Analysis of Line 2 Track Surface

Settlement data from monitoring points GMC01-GMC30 were analyzed from pre-crossing to post-crossing stages, covering the period from April 2 to May 16, 2015. The cumulative settlement time-history curve is shown in [Figure 9: see original paper].

Monitoring frequency was approximately once every three days. Data indicated that empty shield tunneling had minimal impact on Line 2 track surface settlement, with a maximum cumulative settlement of 0.9 mm.

3.3 Settlement Analysis of Line 2 Station Buildings

Settlement analysis was also performed for the existing Line 2 station buildings using data from the same period (April 2 to May 16, 2015). Cumulative settlement variations at each monitoring point are shown in [Figure 10: see original paper].

Monitoring frequency remained at approximately once every three days. Data demonstrated that empty shield tunneling caused minimal settlement impact on the station buildings, with a maximum cumulative settlement of -2.9 mm. This cumulative settlement remained far below warning thresholds, indicating good safety conditions.

Analysis of both track surface and station building settlements revealed that empty shield tunneling through the pre-excavated embedded section had minimal impact on the operating Line 2 tracks and station structures above.

4 Conclusions

Based on the case of Wuhan Metro Line 6 crossing beneath an existing Line 2 station using pre-excavated embedded sections, this study conducted comprehensive risk control analysis of shield tunneling beneath existing rail lines. The findings facilitate orderly construction progress and provide valuable experience for future projects, yielding the following conclusions:

- (1) Effective protection of the surrounding environment during construction, combined with technically appropriate measures tailored to actual hydrogeological conditions, provides good control of construction risks.
- (2) For structures with strict settlement control requirements, instruments with high precision capable of continuous observation should be employed. Continuous monitoring data provides effective feedback on emerging risks during construction, enabling timely responses from site personnel and preventing hazardous incidents.
- (3) Compared to ground improvement schemes, advance construction of pre-excavated embedded sections causes less ground disturbance during shield crossing, resulting in smaller impacts on existing lines and ensuring operational safety.
- (4) Shield tunneling through pre-excavated embedded sections involves higher risks due to internal reception and launching conditions. Therefore, end reinforcement quality and methods must be carefully considered, and dewatering schemes should be selected with consideration for impacts on existing rail lines.

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Note: Figure translations are in progress. See original paper for figures.

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