Research on Settlement Control of Double-line Shield Tunneling Underneath Existing Expressway

Shangang Wang[a], Jinzhu Zhu[b*], Guojiao Wen[c] and Wen Liu[d]

CCCC Wuhan Zhixing International Engineering Consulting Co., Ltd., Wuhan, 430074, China

[a]1689324983@qq.com, [b*]2014523087@qq.com, [c]1412181898@qq.com, [d]379047775@qq.com

Abstract. Shield construction in composite strata can easily lead to face collapse and instability, which in severe cases may cause significant settlement and deformation of existing highway subgrades, affecting the service life of highways. Therefore, this paper proposes corresponding control methods from the perspective of maintaining excavation face stability: using ground-penetrating radar to detect unfavorable geological factors before undercrossing, optimizing construction parameters during undercrossing based on data from test excavation sections; during undercrossing, monitoring the shield machine posture through VMT guidance system, dynamically adjusting the composition of soil conditioning agents, and using inert slurry to control segment posture. These methods can achieve minimal disturbance to the surrounding environment. Practical results demonstrate that the control measures proposed in this paper are of significant importance for ensuring the structural stability of existing highways and can provide reference for similar shield undercrossing projects.

Keywords: Double line shield tunneling, Underpass construction, expressway, settlement control.

1 Introduction

1.1 A Subsection Sample

In recent years, with the rapid development of cities and the increasing scale of rail transit construction, shield tunneling underneath highways has become increasingly common. Ensuring the structural safety of highways during construction has become a key issue that requires special attention.

To reduce the impact of shield tunnel construction on existing highways, many scholars have conducted research on this issue. Wang Jinhua et al. [1] used FLAC3D to simulate the deformation characteristics of highways caused by shield construction under soft-over-hard stratum conditions. Wang Chao et al. [2] considered the effects of the intersection angle between the tunnel and highway, uplift deviation angle, and tunnel slope angle to establish a settlement prediction model for highways. Chengyong Cao et al. [3] summarized optimization methods for twin-shield tunneling underneath highways

A. Mallik et al. (eds.), *Proceedings of the 2025 6th International Conference on Management Science and Engineering Management (ICMSEM 2025)*, Atlantis Highlights in Economics, Business and Management 4,
https://doi.org/10.2991/978-94-6463-845-5_5

through comprehensive analysis. H. Katebi et al. [4]studied the effects of ground stratification, surface building specifications, and tunnel depth on lining loads. Ryan A. Ramirez [5]used Persistent Scatterer Interferometric Synthetic Aperture Radar (PS-InSAR) technology and Sentinel-1B SAR data to analyze tunnel-related ground surface deformation. Yuxiang Li et al. [6] predicted highway subgrade settlement caused by shield construction by introducing soil loss rate correction coefficients and settlement trough width correction coefficients. Wang Naiyong [7] simulated the effects of tunnel excavation on road surfaces and cut slopes using FLAC, with results showing that during oblique undercrossing construction, road surface settlement exhibits three-dimensional asymmetric distribution characteristics.

From the above literature, it can be observed that existing research has mainly focused on three aspects: summarizing highway settlement deformation patterns, optimizing shield construction parameters, and proposing ground reinforcement measures, while there are fewer studies on the impact of excavation face stability on highways.

2 Project Overview

2.1 Project Introduction

Guangzhou Rail Transit Line 12 section between Luntou Station and Guanzhou Station uses a 6700mm diameter dual-mode shield machine for tunnel excavation. The South Ring Expressway main line subgrade is designed with 6 lanes in both directions, with a width of 33.5m and a design speed of 120Km/h.

2.2 Geological and Hydrological Conditions of the Undercrossing Section

The special geotechnical conditions in the section where the shield tunnel passes under the ring expressway mainly consist of fill, soft soil (mucky soil), weathered rock, and residual soil. The soft soil layer is of marine-continental interaction facies with poor mechanical properties, which adversely affects foundation stability and settlement control. The groundwater at the site primarily consists of phreatic water and bedrock fissure water, with a relatively shallow overall water table.

3 Face Stability Control

3.1 Pre-undercrossing Control Measures

Geological Radar Detection of Adverse Factors. Before undercrossing, the project conducted geological radar scanning to understand the geological conditions beneath the ring expressway, identifying drainage pipes and water-bearing strata under the subgrade, and implementing countermeasures in advance. However, the VMT automatic guidance system is prone to fluctuations in measurement accuracy and system delays under complex geological conditions, thereby limiting its real-time monitoring performance. Future improvements can be achieved by incorporating geology-adaptive algorithms, real-time error compensation methods, and transfer learning techniques to enhance system stability and cross-regional adaptability.

Test Section Excavation to Guide Construction Parameters. According to geological survey results, the geological conditions of the undercrossing section were basically consistent with those of the section before undercrossing. Therefore, based on the surface settlement monitoring values (front, middle, and rear of the face) and segment settlement monitoring values from the 30-ring test excavation section, the preset excavation parameters for the undercrossing section were determined, as shown in Table 1.

Table 1. Preset Parameters for Undercrossing the Ring Expressway in the Lun-Guan Interval

Parameter Name	Parameter Value	Parameter Name	Parameter Value
Upper earth pressure (kPa)	110-150	Synchronous grouting volume (m^3)	6-7
Cutter head rotation speed (r/min)	<1.5	Synchronous grouting pressure (MPa)	<0.5
Excavation speed (mm/min)	<30	Cutter head torque (kN·m)	3000-4000
Thrust (kN)	<15000	Soil discharge volume (m^3)	60-67

3.2 Control Measures During Undercrossing

Real-time Monitoring and Control of Excavation Posture. The soil in the undercrossing section was relatively soft, making the shield machine's posture prone to deviation and change. During construction, the VMT automatic guidance system was equipped to monitor the shield machine's tunneling posture. This system enabled real-time determination of deviations in the shield tunneling axis.

Dynamic Optimization and Adjustment of Muck Conditioning Parameters. Silty clay existed within the range where the shield tunnel passed under the South Ring Expressway, and cutter head clogging could easily cause excavation face instability. To address this issue, preliminary soil conditioning was performed using foam and water. The foam solution concentration was 3%, with a foaming ratio of 10-15, and a foam injection rate (FIR) between 30-40%. The foam dilution injection amount was 1200-1600L in completely to strongly weathered rock layers and residual soil layers, and 2000-2500L in silty clay layers. The variations in soil conditioning parameters are shown in Figure 1.

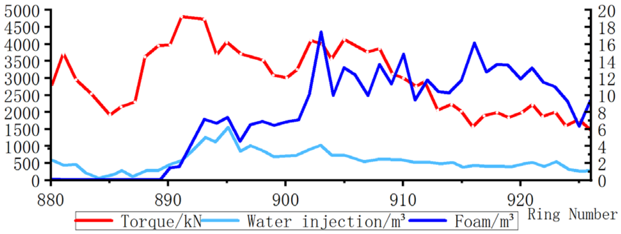


Fig. 1. Variation chart of muck conditioning parameters

From the above figure and analysis of the actual composition of on-site muck, it can be seen that when excavation reached around Ring 884, cutter head mud caking occurred due to changes in stratum structure. However, by promptly adjusting the conditioning agent composition, the cutter head torque quickly returned to normal levels.

Inert Grout Injection to Control Segment Posture. When constructing in soft-over-hard strata, segments risk floating upward, which can affect stratum stability. During construction, inert grout was formed by mixing cement, fly ash, sand, and bentonite in specific proportions, and a control measure of greater grouting volume in the upper part than the lower part was adopted to control segment posture.

4 Construction Site Monitoring

4.1 Earth Pressure Monitoring

Figure 2 shows the earth chamber pressure variation curve during shield undercrossing of the expressway. From the figure, it can be seen that the earth chamber pressure varied between 110-176 kPa, with actual pressure higher than static earth pressure. Since the Southern Ring Expressway has an isosceles trapezoidal cross-section with lower pressure at the slope bottom and the expressway surface at the highest point, the upper overburden is relatively thick, resulting in a high theoretical earth pressure value of 158 kPa.

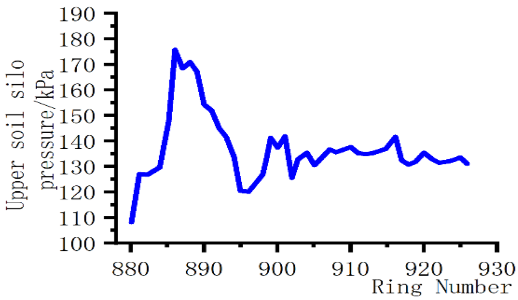


Fig. 2. Variation chart of upper earth pressure during shield excavationFigure

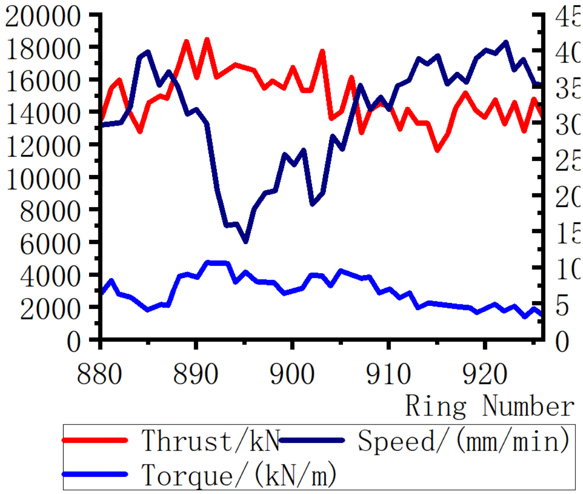


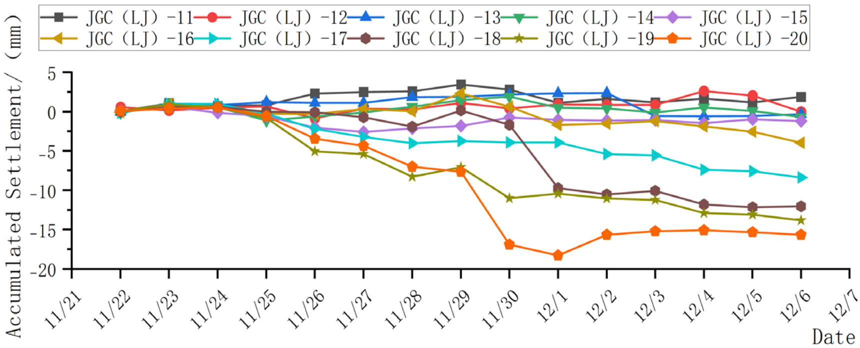
Fig. 3. Variation chart of excavation parameters

4.2 Excavation Parameter Monitoring

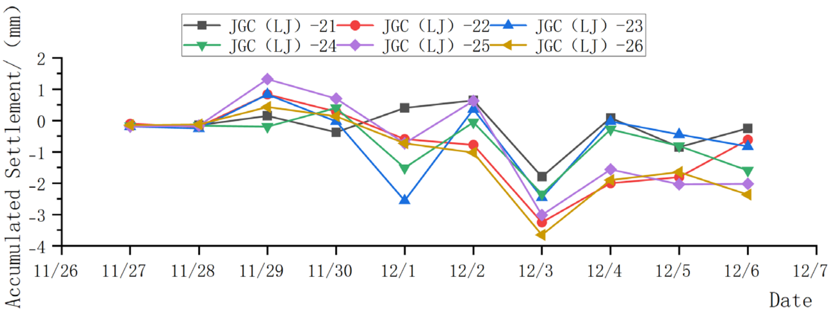
Figure 3 shows the monitoring value variation chart of shield machine thrust, torque, and speed. From the figure, it can be seen that when excavation reached Ring 884, torque rapidly increased and excavation speed rapidly decreased due to cutter head mud caking. The situation was subsequently normalized through muck conditioning.

4.3 Road Surface Settlement Monitoring

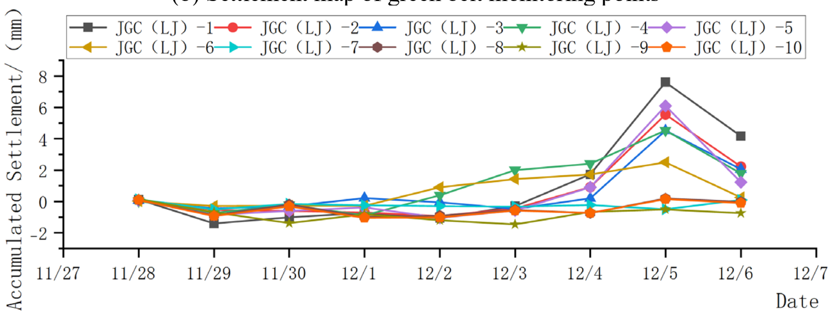
To intuitively represent the degree of disturbance impact during undercrossing, the structural condition of the Southern Ring Expressway surface and surrounding ancillary facilities was monitored during construction. The monitoring results are shown in Figure 4.



(a) Settlement map of front monitoring point



(b) Settlement map of green belt monitoring points



(c) Settlement map of rear monitoring point

Fig. 4. Variation chart of Southern Ring Expressway monitoring data

From the monitoring data (a), it can be observed that changes in the stratum structure caused clogging of the cutter head, increasing the disturbance effect on the excavation face. Subsequently, by optimizing the composition of soil conditioning agents, the clogging problem was resolved. The final maximum cumulative settlement was maintained at around 15mm, within the allowable range. The settlement in the central median strip of the South Ring Road was mostly maintained within 4mm, with the main settlement occurring after the shield tail passed through. This was caused by ground loss due to the tail void, which could be mitigated through secondary grouting and other measures to lift the ground, ultimately maintaining the settlement value at around 2mm. The ground surface behind the South Ring Road showed uplift, with a maximum of 8mm, which was related to the relatively high earth pressure during excavation.

5 Conclusion

Based on actual engineering practice results and the research content of this paper, the following conclusions are drawn:

(1) Changes in stratum structure from mucky soil to silty clay can cause cutter head clogging, increasing torque and the disturbance effect on the soil mass, leading to instability and failure of the excavation face.

(2) Measures such as determining adverse geological factors through ground-penetrating radar detection, optimizing tunneling parameters for the undercrossing section based on test section excavation guidance, controlling shield machine posture, soil conditioning, and inert slurry grouting can reduce the disturbance effect on the excavation face during construction.

(3) During the construction process, monitoring results of earth pressure, thrust, and torque can reflect the basic conditions of the excavation face, while monitoring results of the expressway and its auxiliary facilities can directly indicate the degree of impact.

References

1. Wang Jinhua, Xu Changjie, Wang Yulin, et al. (2023) Research on deformation patterns and control technology of shield tunneling adjacent to bridges and undercrossing roads . Highway, 68(1): 7.
2. Wang Chao, Shan Shengbiao. (2023)Research on ground settlement prediction model for double-line shield tunnel obliquely undercrossing existing airport expressway . China Safety Science and Technology, 19(1): 10.
3. Chengyong Cao, Chenghua Shi, (2018)Mingfeng Lei, et al. Deformation characteristics and countermeasures of shallow and large-span tunnel under-crossing the existing highway in soft soil: a case study . KSCE Journal of Civil Engineering , 22: 3170-3181.
4. Katebi, H., et al. (2015)"Assessment the influence of ground stratification, tunnel and surface buildings specifications on shield tunnel lining loads (by FEM)." Tunnelling and Underground Space Technology 49: 67-78.
5. Ramirez, Ryan A., et al. (2022)"Monitoring of construction-induced urban ground deformations using Sentinel-1 PS-InSAR: The case study of tunneling in Dangjin, Korea." *International Journal of Applied Earth Observation and Geoinformation* 108: 102721.
6. Yuxiang Li, Juncen Lin, Songhong Yan, et al. (2022)Modification of the Peck Formula for a Double-Track Shield Tunnel under Expressway Subgrade . Symmetry, 14(9): 1904.
7. Wang Naiyong. Impact of double-line shield tunnel obliquely undercrossing on expressway . Science Technology and Engineering, 21(32): 13919-13925(2021).