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Assessment of the Service Status of the Tunnel Structure Adjacent to the Station

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Abstract. To assess the operational reliability of the tunnel structure adjacent to Metro Line 1 station during its active service, we conducted a comprehensive investigation. This investigation involved the detection and precise measurement of four significant structural concerns within the tunnel: water infiltration, segment misalignment, exposed joints, and lining fractures. We conducted a detailed analysis of the spatial distribution patterns of these structural issues along both the longitudinal and circumferential axes of the intermediate tunnel section. Additionally, we conducted an assessment of the operational condition of segment components and connecting bolts, adhering to established standards. This comprehensive approach allowed us to achieve a thorough evaluation of the overall operational condition of the tunnel.

Keywords. Tunnel service, structural deficiencies, metro infrastructure

1. Introduction

The condition of subway tunnels plays a critical role in both economic development and the daily safety of commuters. A substantial amount of research has been dedicated to evaluating tunnel conditions, with a specific focus on understanding how the deterioration of lining structures affects the tunnels' ability to bear loads [1]. Furthermore, extensive research has explored the various factors contributing to tunnel leaks, revealing that natural conditions, geological features, design and construction practices, and operational aspects can all have direct or indirect effects on leakage problems [2].

During the construction of shield tunnels, a significant number of segments have encountered issues such as cracking and detachment. These challenges have necessitated the assessment of damage levels, rates of crack propagation, and distribution patterns. Researchers have thoroughly examined the characteristics of segment structure damage under the influence of various construction-related factors [3]. The presence of cracks in the lining significantly reduces its load-bearing capacity, and external construction activities can worsen existing cracks and even lead to the formation of new ones [4].

In order to gain a comprehensive understanding of these structural problems, this study investigates the primary causes of such issues, including water infiltration,

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segment cracking, open joints, and excessive tunnel deformation. These factors were analyzed using a fault model tree, categorizing problems into three main factors: pre-design, construction, and post-operation management [5]. The overall reduction in segment stiffness due to crack presence has been further confirmed through similar model tests [6].

This research paper presents a thorough analysis of structural challenges, encompassing issues like water infiltration, segment misalignment, open joints, and lining fractures. The distribution patterns of these structural problems along both the longitudinal and circumferential axes of the intermediate tunnel section have been extensively examined. Additionally, the condition of segment components and connecting bolts has been assessed in strict accordance with existing specifications, ultimately providing a comprehensive evaluation of the tunnel's operational status.

2. Overview of Project

The tunnel is positioned within a typical soft soil region and features an internal diameter of 5.5 meters, an external diameter of 6.2 meters, and a ring width of 1.2 meters. This single-ring tunnel consists of six concrete segments constructed from C50-grade material, connected through M30 bending bolts. Specifically, the intermediate tunnel is situated between mileposts K15+621.880 and K15+813.877. It's important to note that the up line encompasses rings 475 through 315, with ring 475 representing the final ring of the up line, originating from the station tunnel. In contrast, the down line spans from Ring 1 to Ring 160, with the first ring marking the initial exit point from the station.

3. Tunnel Disease Statistics

The tolerances for segment alignment, both between tunnel segments and within a single ring, are determined in accordance with the "Shield Tunnel Construction and Acceptance Code" (GB50446-2017) [7]. These specifications stipulate a maximum permissible deviation of 15 mm for segment alignment between rings and 10 mm for alignment within a single ring. It's worth noting that the highest recorded segment alignment deviation adheres to the specified requirements for alignment between rings, remaining comfortably below the 15 mm limit. To be precise, the maximum segment alignment deviation for the up line is 10 mm, while for the down line, it slightly exceeds the prescribed specification limits at 10.5 mm.

Concerning challenges associated with water presence within the tunnel, they encompass issues such as moisture, water seepage, dripping, and, in certain instances, more severe leakage, including sediment seepage. These leakage concerns primarily manifest at the joints, with the pipe segment structure demonstrating relatively low susceptibility to leakage.

Cracks are predominantly observed on the up-line between the 440th and 330th rings, totaling 308 instances. Conversely, on the down-line, cracks are concentrated between the 35th and 145th rings, totaling 497 instances. These cracks mainly manifest on the lining vault and exhibit substantial depths in both up-line and down-line segments.

In accordance with the guidelines delineated in the "Assessment Code for Shield Tunnel Structural Integrity" (DGTJ-08-2123-2013) [8], the allowable allowance for joint openings is specified at 6 mm. After thorough inspection, it became evident that the longitudinal joints in all up-line segments displayed openings ranging from 1-2 times the allowable limit. In four rings, the maximum longitudinal joint openings were recorded up to 11 mm, with the occurrence of joint openings being particularly pronounced in the first ring segment connecting to the station, where the opening reached 10 mm. In contrast, only one ring strictly adhered to the allowable limit, while seven rings exhibited joint openings that were 1-2 times the allowable limit, and six rings showed openings that were 2-3 times the allowable limit. The most substantial opening measured up to 20 mm, surpassing the allowable limit by more than 3 times.

4. Analysis of the Distribution Patterns of Tunnel Ailments

The distribution pattern of segment cracks along the tunnel's longitudinal axis displays a noticeable trend. Specifically, there are few occurrences of cracks near the station and in the distant tunnel sections, with no significant crack-related issues. However, as we move towards the points where the tunnel narrows the most at its extremities, we observe a clustering of problems related to cracks. Throughout the entire length of the tunnel, there are structural issues related to connectivity, including water leakage, misalignment of segments, and openings at joints. Nevertheless, these structural connectivity problems become more pronounced near the tunnel's narrowing points.

Upon conducting a comprehensive analysis of the previously gathered data, it becomes evident that structural leakage issues within the tunnel primarily manifest at the joints of pipe segments, with a notable concentration of such problems occurring at the ring joints. The locations with the highest degree of misalignment between inter-ring segments consistently coincide with the arch waist position. Furthermore, the most significant observed segment misalignments within a ring primarily occur on the tunnel vault. Similarly, the most substantial openings in longitudinal segment joints are concentrated on the vault. Concerning tunnel lining cracks, those located near the points of maximum narrowing tend to appear as longitudinal cracks, and all of these are distributed along the lining vault.

5. Evaluating the Condition of Tunnel Structures

The evaluation of the structural condition of the tunnel encompasses two core aspects: the assessment of segment structures and the examination of segment connections. In accordance with the guidelines provided in the "Code for Assessment of Shield Tunnel Structural Integrity" (DGTJ-08-2123-2013) [8], a systematic categorization of the operational status of the intermediate tunnels in the impacted region has been meticulously executed, allowing for a comprehensive evaluation of the tunnel's structural soundness.

It's important to highlight, based on the results of the geological survey, that the concentration of chloride ions in the groundwater near the site consistently remains below 100 mg/L. Furthermore, the tunnel's surroundings are characterized by a moderately humid environment. In strict accordance with the specified standards [8], the environmental impact is classified as Class B. Consequently, the assessment of the component's operational condition is determined by the presence of cracks and water leakage in the pipe segments, as depicted in figure 1.

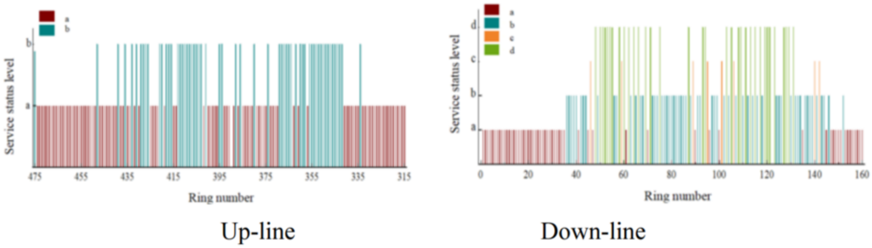

Figure 1. Evaluation of the Service Condition of Segment Structures.

Evaluating the dependability of connections within the segment structure involves considering several factors, which encompass water seepage at pipe joints, the extent of joint openings, and pipe misalignment. These variables play a pivotal role in categorizing the overall operational state of the pipe connections, aligning with well-established guidelines [8]. Figure 2 offers a comprehensive overview of the operational conditions of segment connections.

Figure 2 presents a comprehensive representation of the operational conditions of segment connections, taking into account factors such as water seepage, joint openings, and pipe misalignment. The classification system employed allows for a comprehensive assessment of the structural soundness of these connections, in accordance with the guidelines [8].

When comparing the up-line tunnels to the down-line tunnels, it becomes evident that the reliability of segment connections in the down-line tunnels is notably lower, primarily falling into the "d" classification. This distinction underscores the need for targeted maintenance and repair efforts to ensure the ongoing dependability and safety of the tunnel structure.

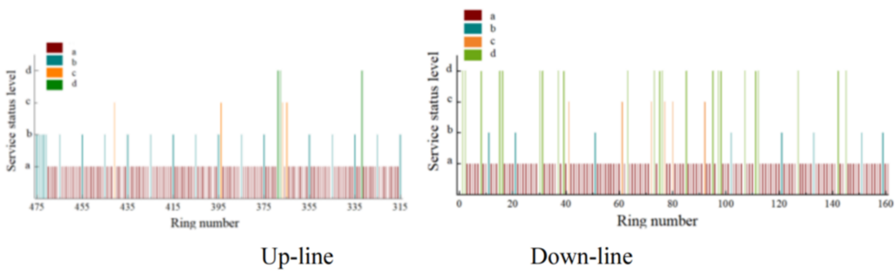

Figure 2. Assessment of the Service Condition of Segment Structure Connections.

6. Summary and Conclusions

(1) The tunnel adjacent to the station has encountered a variety of structural challenges, including issues like water seepage, segment misalignment, open joints, and cracks in the lining. Remarkably, the down-line tunnel experiences a higher frequency of

structural problems compared to the up-line tunnel, with several instances of sediment infiltration observed at the ring joints.

(2) The distribution pattern of segment cracks along the longitudinal axis of the tunnel exhibits a noticeable trend. Areas with lower levels of tunnel convergence, such as those near the station tunnel, experience minimal crack-related issues. Conversely, at points where the tunnel narrows significantly, there is a concentration of tunnel crack problems. Structural connectivity problems, including water seepage, segment misalignment, and joint openings, are scattered throughout the tunnels. Nevertheless, these structural connectivity issues become more pronounced near the tunnel's narrowing points.

(3) The most significant segment misalignments within the segment ring, the most substantial joint openings, and the occurrence of lining cracks are primarily concentrated in the region of the tunnel vault. This underscores the importance of focused inspections and maintenance efforts in this specific area.

(4) The overall service condition of the tunnel has been comprehensively assessed, considering both the segment structures and structural connections. In the case of the up-line tunnel, the service condition of components falls within categories "a" and "b," while component connections range from ratings "a" to "d." Importantly, the proportion of components and connections rated as "d" remains below 10%. In accordance with the specifications, the service condition of the up-line tunnel is classified as "iii," indicating a state of "degradation." This implies that the tunnel's functionality has been compromised and cannot be used under normal circumstances.

(5) In contrast, the down-line tunnel exhibits a broader range of service state ratings for components, spanning from "a" to "d," and a similar range for component connections. Significantly, the proportion of components and connections rated as "d" exceeds 10%. Consistent with the specifications, the service status of the down-line tunnel is designated as "iv," signifying a state of "deterioration." This suggests that while the tunnel's usability is affected, its safe operation remains intact, albeit with maintenance and repairs being imperative.

In conclusion, the comprehensive assessment of the tunnel's structural condition has identified a range of issues and emphasizes the need for targeted maintenance and repair efforts to ensure the continued safety and functionality of the tunnel, particularly in the down-line sections.

References

[1] Yong L, Gong F, Liu D, Wang S & Xuefeng S. Experimental simulation analysis of the process and failure characteristics of spalling in D-shaped tunnels under true-triaxial loading conditions. Tunnelling and Underground Space Technology. 2019.

[2] Ai Q, Yuan Y, Jiang XM, Wang H, Han CJ, Huang XC, Wang K. Pathological diagnosis of the seepage of a mountain tunnel. Tunnelling and Underground Space Technology. 2022; 128: 104657.

[3] Lu D, Sun WH, Su A & He C. Statistics and analysis of cracking disease in segment lining for shield tunnel in construction stage. Journal of Railway Engineering Society. 2018; 35: 59-66 and 87.

[4] Cai S & Ding H. Safety analysis of the secondary lining structure of existing tunnel with cracks. IOP Conference Series: Materials Science and Engineering. 2020; 741: 012061.

[5] Liu SY & Zhang XF. Fault diagnosis and maintenance countermeasures of transverse drainage pipe in subway tunnel based on fault tree analysis. International Journal of Environmental Research and Public Health. 2022; 19. 15471.

[6] Li J, Xu F, Wang T, Shi S. Research on the evolution of shield segment cracks based on acoustic emission and CMOD. Materials. 2022; 15: 5829.

[7] Zhu Y. Structural design and construction methods of long-span three-lane quasi- ellipse shield tunnel without columns. IOP Conference Series: Earth and Environmental Science. 2021; 861: 052080.

[8] Du ET, Zhou L, Fei RZ. Study on the stress and deformation characteristics of shield tunneling through mining tunnel structure. 2023; 10.20944/preprints202306.1060.v1.