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Analysis of Reinforcement Techniques for Newly Built Tunnel Defects

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Abstract: Newly built tunnels often encounter a series of defects within the first few years of operation. If not promptly addressed and reinforced, these defects threaten the tunnel's durability and stability and bring severe challenges to its safe operation. This study aims to explore reinforcement techniques for addressing defects in newly built tunnels. The research begins with an analysis of common defects found in newly built tunnels, followed by a case study of the Jinfeng Tunnel in Chongqing, examining the post-construction defects. The actual reinforcement strategies and methods employed for the tunnel are then discussed. Finally, based on the research findings, this study provides insights and references for tunnel operation and construction units in China, aiming to enhance the overall quality of tunnel engineering in the country, align with sustainable development goals, and promote further improvements at a macro level.

Keywords: Newly built tunnels; Defect treatment and reinforcement; Initial support deformation; Lining cracking

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1. Introduction

Reinforcement and treatment of defects in newly built tunnels are crucial for their long-term safety and stable operation. Effective reinforcement measures can maintain the stability and safety of the tunnel structure, preventing major accidents caused by the long-term accumulation of defects and irreversible damage to the tunnel structure. Furthermore, timely reinforcement and repair of newly built tunnels are important means to ensure their service life, improve durability, and reduce high costs caused by frequent maintenance in the later stages. Additionally, prompt treatment and reinforcement of defects in newly built tunnels can significantly enhance the comfort and sense of security for tunnel users, creating the first line of defense for the long-term sustainable operation of tunnels.

2. Analysis of common defects in newly built tunnels

2.1. Support deformation

Support deformation is a common defect in newly built tunnels. The fundamental mechanisms leading to this defect include changes in geological pressure, rock layer movement, or deviations during the construction phase. Once support deformation occurs in a newly built tunnel, it may cause the tunnel section to narrow, posing safety hazards to normal vehicle traffic and increasing stress concentration, which has a certain probability of triggering more severe structural problems.

2.2. Lining erosion and degradation

Lining erosion and degradation in newly built tunnels are usually caused by chemical erosion from groundwater, climatic factors, or inadequate material quality. Chemical erosion can significantly weaken the strength and durability of the tunnel lining, while the freeze-thaw cycles in winter can accelerate the process of deterioration. As time passes, changes in the physical and chemical properties of the lining material may damage the structural integrity.

2.3. Spalling and chipping

The causes of lining spalling and chipping in tunnels typically include material degradation, structural stress concentration, or defects left during the construction phase. Once the lining area is subjected to environmental changes or vibrations caused by frequent vehicle traffic, it is prone to small chipping or even large-scale spalling. This type of defect not only causes damage to the lining itself but also poses a safety threat to vehicles and pedestrians passing through the tunnel.

2.4. Structural cracking

Structural cracking in newly built tunnels is often caused by stress concentration, load fluctuations, or uneven foundation settlement. On the one hand, structural cracking can damage the integrity of the tunnel structure. On the other hand, the cracks formed by cracking provide channels for water and aggressive substances around the tunnel to invade, thereby accelerating the aging of the lining.

2.5. Water leakage

Water leakage, as a major defect in the field of tunnel engineering, is mostly caused by the failure of the waterproofing system, changes in groundwater levels, or structural cracking. Water leakage not only erodes the internal structure of the tunnel lining, causing a decrease in material strength but may also lead to foundation softening, resulting in uneven settlement and lining spalling. If water leakage persists, it will exacerbate defects in other structures over time, threatening the overall safe operation of the tunnel [1].

3. Project overview

To objectively understand the strategies for reinforcing and treating defects in newly built tunnels, this article takes the Jinfeng Tunnel in Chongqing, which was officially opened to the public in 2024, as an example. The Jinfeng Tunnel starts at Daishan Avenue in Bishan District and ends at Gaoxin Avenue in the High-tech Zone, with a total length of 9.20 km. It includes four casing interchanges, one tunnel, and comprehensive pipeline network ancillary projects. In 2018, the feasibility study report for the Jinfeng Tunnel was approved by the National Development and Reform Commission, and construction officially began on December 29, 2019. In September 2022, the Jinfeng Tunnel entered the construction scope of the ramp for the beltway. In May 2023, the main structure of the tunnel was completed, and in April 2024, the Jinfeng Tunnel was officially opened to the public. The designed speed of the Jinfeng Tunnel is 60 km/h, with a two-way six-lane design, and the total project investment is 5,170,368,500 yuan [2].

4. Analysis of project defects

4.1. Initial support deformation

The starting point of the Jinfeng Tunnel is located in a landslide group area. After completion of construction, before opening to the public, in October 2023, under the influence of a series of natural factors such as continuous rainfall, displacement of the sliding surface and deformation of the front stage occurred. Cracking and deformation appeared on the back of the completed anti-slide piles. Subsequently, the cracks continued to develop backward, causing many cracks to appear on the slope. According to investigations, the initial support at the entrance section of the Jinfeng Tunnel from KL0+806 to KL0+860 is deformed and intrusive, with a maximum deformation of 28 cm invading into the secondary lining.

4.2. Concrete lining cracking

Besides the initial support deformation, under the influence of the landslide, the completed secondary lining exhibited varying degrees of cracking [3]. Specifically, the cracking range of the secondary lining in the left tunnel of the Jinfeng Tunnel reached 161 m in length. Some sections showed diagonal and circumferential cracks in the secondary lining, with crack lengths concentrated between 3 m and 6 m and widths typically ranging from 1 mm to 2 mm. The cracking range of the secondary lining in the right tunnel extended up to 215 m, and some sections presented a reticulated pattern of cracks (see **Figure 1**).

Figure 1. Reticulated cracks in the secondary lining

Meanwhile, upon observation, there is a noticeable problem of staggered platforms in the secondary lining. The maximum crack width in some tunnels can reach up to 18 mm, accompanied by a 12 mm wide transverse displacement of the staggered platforms. The cracks have penetrated the entire ring from the secondary lining to the inverted arch. As shown in **Figure 2**.

Figure 2. Secondary lining cracking in Jinfeng Tunnel

4.3. Water leakage

Along with the cracking of the secondary lining in both the left and right tunnels of the Jinfeng Tunnel, water leakage has occurred in some areas. The cracks in the secondary lining have directly allowed groundwater to enter the interior of the Jinfeng Tunnel through the lining, resulting in the formation of distinct leakage zones. As shown in **Figure 3**.

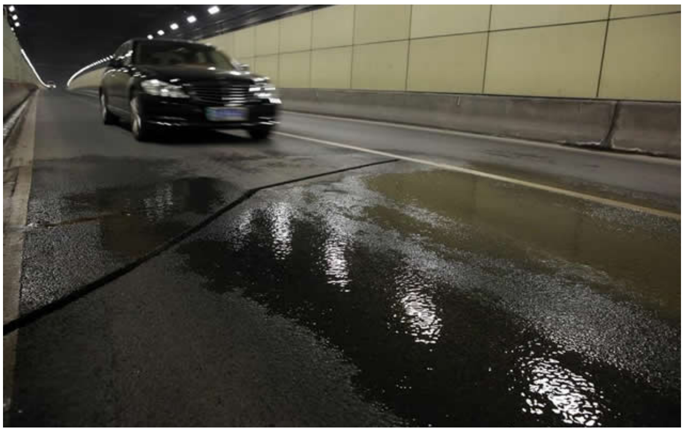

Figure 3. Water leakage in Jinfeng Tunnel. This defect not only causes erosion to the lining material, leading to a decrease in structural strength but also poses a threat to the overall stability of the Jinfeng Tunnel in the long run

5. Technical strategies for reinforcement and treatment of defects

5.1. Technical strategy for circular grouting reinforcement

5.1.1. Technical solution

In response to the initial support deformation defect in the Jinfeng Tunnel, the project team, along with the construction unit, conducted a repair meeting analysis and decided to adopt a technical solution combining the addition of temporary arch supports with circular grouting reinforcement. Specifically, the length of the initial support arch was set to 6 m. After completing the arch construction, repair work on the secondary lining was carried out using 4φ25 steel bars, and the concrete grade was increased from C25 used in previous construction to C30. Circular grouting reinforcement is a construction technique that involves injecting grout around the perimeter of the initial support structure to form a continuous and dense grout ring, thereby enhancing the overall bearing capacity and stability of the support structure.

5.1.2. Reinforcement construction treatment

The specific implementation strategy includes preliminary preparation, drilling, grouting, and inspection.

(1) Step 1: Preliminary preparation. In this phase, investigations and assessments of the defect problems are carried out to confirm the specific construction plan. The construction unit arranges technical personnel to conduct a detailed investigation and technical evaluation of the initial support deformation in the tunnel, covering the detection of deformation location, deformation range, and deformation degree. Simultaneously, a detailed analysis of the quality conditions of the Jinfeng Tunnel and the stress situation of the support is performed. Based on the investigation results, the grouting reinforcement scheme is confirmed, including the arrangement of grouting holes, grout materials, performance parameters, grouting volume, grouting pressure, and a series of other technical parameters. Finally, the construction unit confirms the construction plan, arranging grouting holes around the initial support structure circularly, with a main monitoring interval of 1.5 m, forming a circle of grouting hole networks.

Longitudinally, a row of grouting holes is arranged every 2 m, and the hole depth is designed to be 3.5 m. In terms of grouting methods, vertical drilling is adopted for shallow deformation areas, and inclined drilling (15° ~ 30°) is adopted for deeper areas to ensure a wider coverage of the grout. For cement grout, ordinary portland cement is used, configured into a cement slurry with a water-cement ratio of 0.5. Water-reducing agents and stabilizers are added to the cement slurry, and the initial grouting pressure is set at 0.3 MPa ~ 0.5 MPa, gradually increasing to 0.5 MPa ~ 1.0 MPa based on the specific diffusion of the slurry. For high-permeability areas, the grouting pressure is increased to 1.5 MPa.

(2) Step 2: Grouting drilling based on the design plan. During the operation phase, construction workers are required to strictly control the hole depth and angle. After completing the drilling, high-pressure air is used to clean the holes to ensure that there are no residuals inside [4].

(3) Step 3: Grouting. During the construction operation, high-pressure grouting equipment is used to inject the slurry into the drilled holes according to the preset grouting pressure. It is required to ensure that the slurry fully penetrates and fills the gaps and cracks in the support structure. Professional personnel are arranged to conduct real-time monitoring, strictly recording the grouting pressure, flow rate, and slurry consumption. The grouting strategy is flexibly adjusted based on the grouting effect. After completing the grouting, the grouting effect is inspected using geological radar to confirm that the support structure has been adequately reinforced [5].

5.2. Technical strategy for repairing lining cracks

5.2.1. Technical solution

In response to the cracking problems in the secondary lining of the left and right tunnels of the Jinfeng Tunnel, the project department and the construction unit have studied and decided to adopt steel strips combined with shotcrete reinforcement for cracks with a width of less than 5 mm in the plain concrete lining. During the construction, steel strips are arranged longitudinally along the outer edge of the lining contour, and C25 concrete is used as the spraying material. For cracks with a width greater than 5 mm and areas with dense networks of cracks in the secondary lining, a three-limb grating combined with shotcrete reinforcement is adopted. Grooves are cut into the original secondary lining surface, followed by the installation of three-limb gratings in a longitudinal direction and the application of 13 cm thick C25 concrete.

5.2.2. Repair and reinforcement construction

(1) Repair of cracks less than 5 mm: Repair of cracks less than 5 mm in the left and right tunnels of the Jinfeng Tunnel [6].

(i) Step 1: Preparation. Comprehensively clean the construction area to ensure that the surface is free of loose materials, impurities, and harmful substances, providing a good bonding interface for the repair work.

(ii) Step 2: Arrange steel strips. Construction workers are arranged to place W280 steel strips along the longitudinal contour of the lining, with a longitudinal spacing accurately controlled at 0.8 m. Before construction, measurements are taken to confirm the positions of the steel strips and mark them to ensure accurate placement.

(iii) Step 3: Shotcrete construction. C25 concrete is used for spraying and reinforcement. During construction, strict control of the concrete spraying thickness is required to ensure that it meets the structural strength and durability requirements. Workers are instructed to pay close attention to the uniformity and surface flatness of the concrete during the spraying operation, minimizing unevenness and irregularities on the structural surface. After completing the construction, necessary curing measures are strictly implemented to ensure complete solidification of the concrete and maximize its performance [7].

(2) Repair of cracks greater than 5 mm: Repair construction is organized for cracks greater than 5 mm in the secondary lining of the left and right tunnels of the Jinfeng Tunnel.

(i) Step 1: Surface treatment. Construction workers are arranged to chisel grooves on the surface of the secondary lining, with the width and depth of the grooves flexibly adjusted based on the specific conditions of the cracks, to ensure the smooth embedding of the three-limb grid [8].

(ii) Step 2: Installation of the three-limb grid. The three-limb grid is arranged longitudinally along the cracks, with strict control of the longitudinal spacing at 1.0 m. During installation, it is necessary to ensure that the grid fits tightly with the chiseled groove and is fixed securely. After installation, steel mesh is hung, ensuring that the steel bars are tightly bonded to the grid.

(iii) Step 3: Concrete spraying. C25 concrete is used for basin concrete spraying, with strict control of the thickness at 13 cm. During the spraying operation, construction workers are required to pay strict attention to the uniformity of concrete distribution, and no pores or weakened areas should appear. After spraying, technical personnel are arranged to carry out concrete curing strictly following standards.

(3) Technical strategy for groove cutting and pipe burying: Technical plan to address the leakage problem caused by cracks in the secondary lining of the Jinfeng Tunnel. For areas where the water leakage is only at the water outlet point, construction workers are arranged to clean up the concrete around the water outlet, then chisel a groove (length × width × depth = 50 mm × 50 mm × 40 mm) at the water outlet point, and finally use instant leakage stopper to block the water outlet. For areas with severe water leakage, pipe-burying technology is adopted to divert groundwater to the side of the ditch.

(4) Reinforcement construction for treatment during the repair phase of water leakage areas.

(i) Step 1: Preparation. Construction workers are arranged to carefully clean the concrete surface around the water outlet, and then chisel a square groove of 50 mm × 50 mm × 40 mm as a space to accommodate the sealing material, ensuring that the material can fully block the leakage point. After grooving, the sealing material is selected and quickly filled into the groove. Because the material hardens very quickly, the filling operation needs to be completed rapidly. After filling, the leakage-stopping material is compacted to ensure it has a good sealing effect [9].

(5) For areas with severe leakage, pipe-burying technology is adopted to solve the leakage problem in the form of drainage.

(i) Step 1: Preparation. Before construction, a comprehensive analysis of the source of leakage is conducted to determine the path and pressure conditions of the water flow, facilitating reasonable design of the drainage pipe network layout.

(ii) Step 2: Confirm technical parameters. Based on the investigation results, the number and location of pipes to be buried at each leakage point are determined.

(iii) Step 3: Bury the drainage pipes. The leaking water in the cracks is drained to the side of the tunnel ditch. This process requires ensuring the tightness of pipe connections and the smoothness of drainage. Concurrently, a collection and drainage system is built on the side of the ditch to properly dispose of the discharged water and prevent it from reverse infiltration or penetration into other structures, causing impact.

(iv) Step 4: Inspection. After the completion of pipe installation, a systematic water flow test is conducted to confirm the effectiveness and reliability of the drainage system. Additionally, the operating unit needs to regularly inspect and maintain the drainage system to ensure its long-term normal operation [10].

6. Conclusion

In summary, this article takes the newly built tunnel, the Jinfeng Tunnel in Chongqing as an example to analyze the diseases that occurred after the tunnel was completed, including initial support deformation, secondary lining cracking, and water leakage problems. Subsequently, the construction unit's treatment and reinforcement plans and construction processes for various issues of the Jinfeng Tunnel are discussed in detail. Tunnel operation and construction units in China can learn from the practical construction methods of the Jinfeng Tunnel discussed in this article to effectively control the further deterioration of newly built tunnel issues. This can create the first line of defense for the long-term safe and stable operation of newly built tunnels, protecting the lives and property safety of tunnel users while improving the comfort of tunnel traffic.

Disclosure statement

The author declares no conflict of interest.

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