Investigation of the Mechanism of Crack Prevention in Tunnel Linings Using Geotextile Stress Absorption Laye

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Abstract. To address the issue of cracks appearing in the side walls and arches of a tunnel in Xinjiang after the formwork removal of the secondary lining, a comprehensive site investigation was conducted. The causes of the cracks were analyzed based on geological conditions, engineering design, construction, and concrete shrinkage. A method involving the installation of a geotextile stress absorption layer between the primary support and the secondary lining was proposed based on the actual site conditions. This method was tested on site and analyzed through numerical simulation. The results indicated a delayed occurrence and significant reduction in the number of cracks. The type of cracks transitioned predominantly from circumferential to longitudinal, and the crack lengths were reduced to between 0.2 m and 1.7 m. There was a notable improvement in the stress distribution within the lining structure, enhancing the safety of the secondary lining. This study provides insights that can be applied to optimize construction practices, quality management, and cost control in tunnel engineering.

Keywords: Lining Cracks; Stress-Absorbing Layer; Remedial Measures

1 Introduction

Cracking of tunnel linings is a common issue during construction and operation. It not only affects construction quality and final acceptance but also accelerates deterioration due to water ingress through cracks, compromising the tunnel's long-term performance.

Shao Zhushan [1] conducted a systematic study on the causes of lining cracks, crack classifications, detection methods, evaluation standards, and repair measures. Zhang [2] investigated the impact of cracks on structural performance, summarizing the deformation processes and failure modes of tunnel lining cracks. The presence of these cracks poses significant risks to the safe operation and service life of tunnels, making the adoption of preventative measures imperative.

During curing, the drying shrinkage of lining concrete under constraint induces shrinkage stress, leading to crack formation. Employing geotextile as a stress absorption layer can absorb structural stress through plastic deformation, mitigating stress

Y. Zhang et al. (eds.), *Proceedings of the 2024 10th International Conference on Architectural, Civil and Hydraulic Engineering (ICACHE 2024)*, Advances in Engineering Research 259,
https://doi.org/10.2991/978-94-6463-658-1_73

concentration at crack tips and thus preventing cracks[3]. Furthermore, geotextile's high extensibility allows crack-induced stress to disperse outward, reducing stress concentration at the crack tip[4]. According to Nie[5], the resistance to crack tip stress and the service life of the stress absorption layer increase with its thickness.

While geotextile stress absorption layers have shown significant success in both new and rehabilitated asphalt pavement projects, their application in tunnel linings remains under-researched. Through field experiments and numerical simulations, this study found that geotextile stress absorption layers not only effectively prevent lining cracks but are also easy to install and cost-efficient, offering strong applicability and broad potential for use. These findings provide valuable technical support for tunnel construction practices and could contribute to the improvement and optimization of tunnel lining standards, enhancing both safety and durability.

2 Project Site Conditions

2.1 Project Overview

A tunnel project in Xinjiang spans a total length of 37.35 km with a longitudinal slope of 1:5000. Located in the piedmont alluvial-proluvial plain area at the southern foot of the Altai Mountains, specifically in the Beita Mountain region, the terrain generally slopes from high elevations in the north to lower elevations in the south. Ground elevations along the tunnel alignment range from 710 to 910 meters above sea level. The overlying rock mass in this section is 70 to 79 meters thick. The tunnel passes through geological formations primarily composed of extremely soft rock, classified as Class V surrounding rock. The tunnel adopts a composite lining structure designed according to the principles of the New Austrian Tunneling Method (NATM).

2.2 Overview of Cracks

Monitoring was conducted on both active and existing cracks at the tunnel site to statistically assess the extent of crack-related damage. Specifically, after standard construction procedures, cracks appeared in the three-segment secondary lining concrete between station numbers SD58+491.207 and SD58+527.207 in the downstream section of the tunnel. The distribution of cracks in this segment is illustrated in Figure 1.

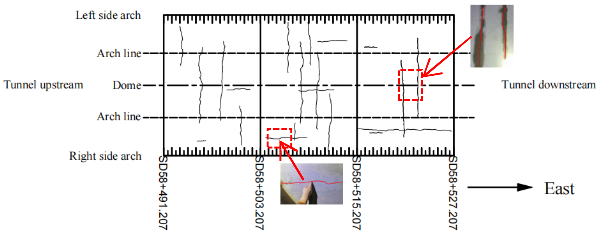


Fig. 1. Distribution map of tunnel lining cracks in the monitoring section

The cracks in this section exhibit the following characteristics: Cracks began to appear within 72 to 120 hours after the tunnel lining was demolded. There are two types of cracks: longitudinal cracks and circumferential cracks, a total of 20 cracks. Eight longitudinal cracks are horizontally distributed along the tunnel's longitudinal axis, with lengths ranging from 1 to 12 meters. Twelve circumferential cracks develop circumferentially along the tunnel lining, mostly perpendicular to the tunnel axis. They originate from the springline or below, extend along the sidewalls and arch haunches up to the arch crown, and continue further, with lengths between 2 and 9.6 meters. The monitored tunnel section passes through extremely soft rock formations. Among the 20 observed cracks, 16 exhibit water seepage—specifically, 10 circumferential cracks and 6 longitudinal cracks.

3 Field Experiment on Preventing Lining Cracks Using a Geotextile Stress Absorption Layer

During the concrete pouring and curing stages of tunnel linings, factors such as drying shrinkage, temperature changes, and applied loads can lead to the formation of cracks. These cracks not only compromise the structural integrity of the tunnel but also threaten its safety and longevity. To effectively prevent such cracking, the introduction of a geotextile stress absorption layer has proven to be a key mitigation strategy. This method involves placing a layer of geotextile between the initial support and the secondary lining concrete during construction. The geotextile acts as a stress absorption layer, effectively absorbing and redistributing stress, alleviating stress concentrations, and slowing the progression of cracks.

3.1 Experiment Preparation

Selection of Geotextile: A 500 g/m² long-filament spunbonded needle-punched nonwoven geotextile was locally procured for the project. This material exhibits high toughness, excellent wear resistance, good air and water permeability, and possesses a certain degree of elasticity.

Test Locations: The first field test was conducted downstream of the tunnel between station numbers SD58+455.207 and SD58+419.207. The second field test took place between station numbers SD58+191.207 and SD58+251.207.

Test Conditions: The raw materials, mix proportions, concrete mixing, transportation, and construction conditions for both field test sections were consistent with those of the monitored sections.

Test Procedure: The geotextile was moistened with water and laid starting from the arch crown, affixed to the initial support surface using shot nails. The overlap width was 50 mm, with shot nail spacing of 0.8–1 m along the side walls and 0.5–0.8 m at the top. Figure 2 illustrates the onsite installation of the geotextile.

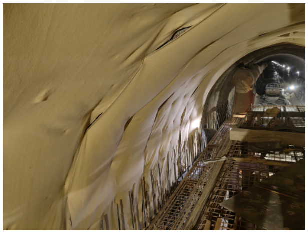


Fig. 2. On-site construction of laying and hanging geotextiles

3.2 Test Results and Analysis

After demolding the lining concrete in the two geotextile field tests, continuous observations were conducted over a period of 10 days. Under identical construction conditions, the cracking conditions of the lining were observed and are presented in Figures 3 and 4.

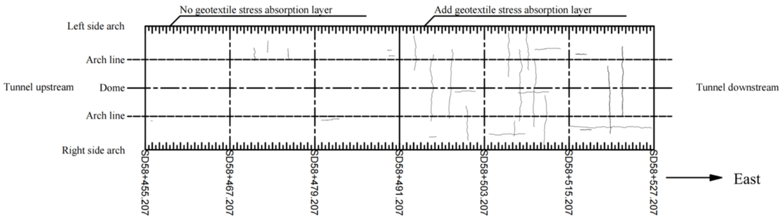


Fig. 3. Distribution diagram of lining cracks in the first test

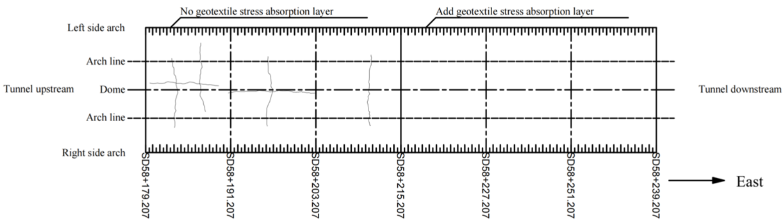
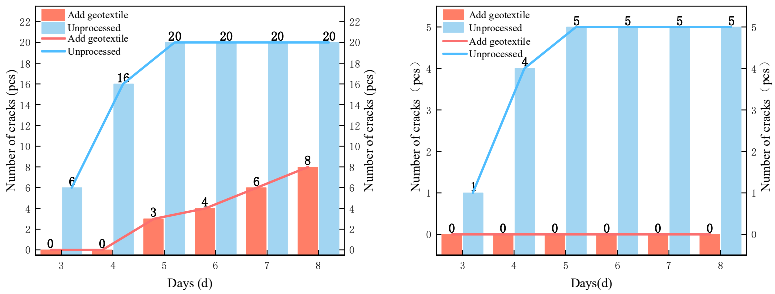


Fig. 4. Distribution diagram of lining cracks in the second test

3.2.1 Timing of Crack Occurrence.

As shown in Figure 5, the timing of crack occurrence was observed during the field tests. In the first field test, cracks appeared on the third day after demolding in the section without the geotextile. In contrast, cracks in the section with the geotextile emerged on the fifth day, indicating a significant delay in crack initiation. In the second field test, cracks were first observed on the third day after demolding in the section without the geotextile, whereas no cracks were detected in the section with the geotextile.

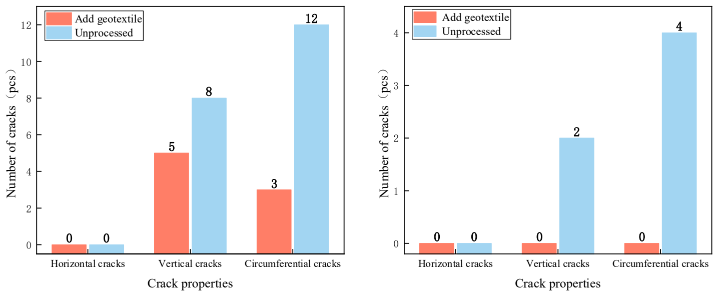


(a)First field test (b)Second field test

Fig. 5. Crack appearance time

3.2.2 Crack Types.

As shown in Figure 6, the types of cracks observed on the lining surfaces during the two field tests in Tunnel are presented. In the first field test, the lining with the geotextile stress absorption layer exhibited 3 circumferential cracks and 5 longitudinal cracks. In the second field test, the section with the geotextile had 2 longitudinal cracks and 4 circumferential cracks. The application of the geotextile stress absorption layer significantly reduced the number of both circumferential and longitudinal cracks. Moreover, the overall crack pattern shifted from predominantly circumferential cracks to predominantly longitudinal cracks.

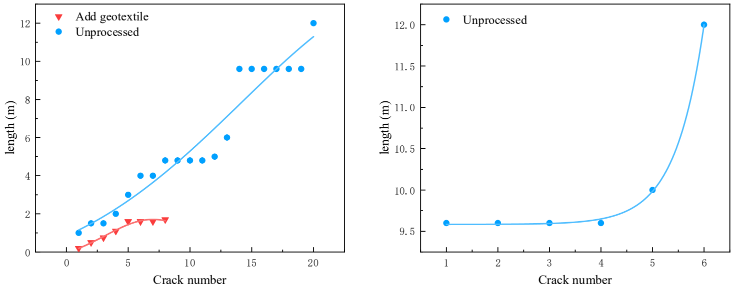


(a)First field test (b)Second field test

Fig. 6. Crack categories

3.2.3 Crack Lengths.

Figure 7 illustrates the lengths of lining cracks observed in the two field test sections. In both experiments, the cracks on the lining surfaces without the geotextile ranged from 1 m to 12 m. In the first field test, the cracks on the lining with the geotextile generally ranged from 0.2 m to 1.7 m; in the second field test, no cracks were observed. These results clearly demonstrate that the application of the geotextile stress absorption layer significantly reduced the lengths of the lining cracks.

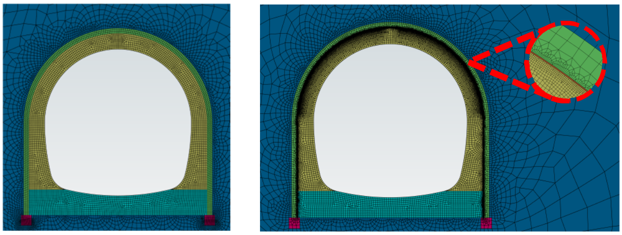


(a)First field test (b)Second field test

Fig. 7. Crack length

4 Numerical Simulation

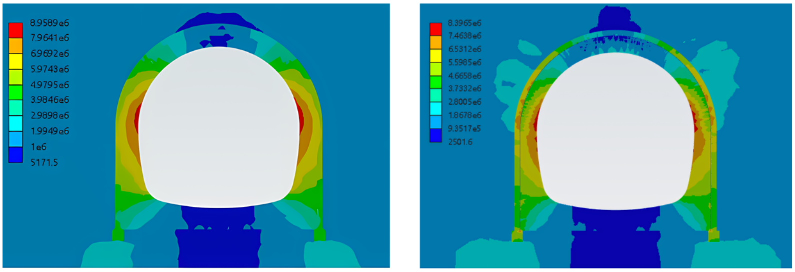
Based on the actual site conditions, we utilized Ansys modeling software to simulate the effect of applying a geotextile stress absorption layer to the tunnel lining. A comparative analysis was conducted against the scenario without the geotextile layer. Figure 8 illustrates a schematic diagram of the tunnel cross-sectional model.



(a)Add geotextile (b)Unprocessed

Fig. 8. Schematic diagram of tunnel cross-section model

Simulations were performed for both conditions. As shown in Figure 9, the load distribution cloud diagram of the tunnel lining indicates that, in the structure without the geotextile stress absorption layer, the load is primarily concentrated at the arch haunch. After applying the geotextile stress absorption layer, the maximum stress at the arch haunch decreased by 6.27%, effectively mitigating the stress concentration within the lining structure.



(a)Add geotextile (b)Unprocessed

Fig. 9. Tunnel lining load cloud map

5 Conclusion

(1)Field monitoring indicates that surface cracks in tunnel linings predominantly manifest as longitudinal and circumferential cracks, mostly occurring within 72 to 120 hours after form removal, especially in zones of extremely soft rock. Analysis of geological conditions, design and construction factors, and concrete shrinkage reveals that the primary cause of cracking is the constraint imposed by the initial support on the secondary lining concrete, which inhibits free shrinkage deformation. This constraint leads to internal stresses exceeding the concrete's tensile strength, resulting in crack formation.

(2)Field experiments were conducted to assess the effectiveness of using a geotextile stress absorption layer to prevent tunnel lining cracks. The results showed that, compared to linings without the stress absorption layer, those with the geotextile layer experienced a significant reduction in the number of cracks, a delay in crack initiation by more than 48 hours, an improvement in crack patterns favoring longitudinal cracks, and a reduction in crack lengths to between 0.2 m and 1.7 m. The crack prevention effect was remarkable.

(3)The application of a geotextile stress absorption layer significantly reduced stress concentrations at typical locations within the tunnel lining compared to linings without the layer. This resulted in a more uniform stress distribution in the secondary lining, preventing damage due to localized excessive stresses.

Although this study has achieved significant results in preventing tunnel lining cracks, the limited scale of the experiment did not fully account for the long-term durability of the geotextile stress absorption layer under various geological conditions. Therefore, future research should explore its performance in different geological environments and under dynamic loads, as well as assess its long-term effectiveness and applicability.

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