

Review

Research on In-situ Expansion Construction Technology for Existing Super-Large Section Tunnels

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Abstract: Taking the first in-situ expansion project of an existing single-tube three-lane highway tunnel in China (the DaChangshan No.1 Tunnel on the Zhongkai Expressway) as the research object, this paper summarizes and introduces the key technologies involved in the in-situ expansion construction of existing super-large section tunnels, including the lining cutting scheme for large-span tunnels, the temporary support system for in-situ expanded tunnels, and the zonal excavation scheme for tunnel in-situ expansion. The research results can provide a reference for the in-situ expansion construction of existing super-large section tunnels under similar conditions.

Keywords: tunnel engineering; tunnel in-situ expansion; tunnel lining demolition; tunnel temporary support

1. Introduction

In the early stage of transportation construction in China, restricted by domestic transportation demands and the level of construction technology, the initially constructed expressway facilities were generally designed as two-way four-lane or two-way six-lane systems. At that time, traffic volumes were relatively low, and the primary objective of highway construction was to establish a basic national transportation network to support regional connectivity and economic development. However, with the rapid growth of China's economy, the acceleration of urbanization, and the continuous increase in vehicle ownership, traffic demand has risen dramatically over the past decades. As a result, many of these early-built expressways are no longer able to accommodate the ever-growing traffic flow and transportation needs of modern society. Traffic congestion, reduced travel efficiency, and increased safety risks have gradually become common issues on several important transportation corridors.

Therefore, the widening and upgrading of existing highways has become an urgent task for transportation authorities. Through reconstruction and expansion projects, it is possible to significantly improve road capacity, enhance traffic safety, and optimize the overall performance of the highway network. Consequently, a new round of expressway reconstruction and expansion projects is expected to be implemented progressively across different regions in China to adapt to future transportation demands and support sustainable economic growth [1].

Taking the current regional expressway development plan in Guangdong Province as an example, a number of reconstruction and expansion projects have been included in the regional transportation strategy. These projects aim to improve connectivity within the Guangdong-Hong Kong-Macao Greater Bay Area and enhance the efficiency of major transportation corridors. Representative projects include the reconstruction and expansion of the Fogang-Taihe section and the Guangzhou-Shenzhen section of the G4

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Beijing-Hong Kong-Macao Expressway, the Heyuan Reshui-Huizhou Pingnan section of the G25 Changchun-Shenzhen Expressway, the He'ao-Shenzhen Airport section of the G15 Shenyang-Haikou Expressway, as well as sections of the G78 Shantou-Kunming Expressway, the Changping-Humen Expressway, and the Dongguan-Shenzhen Expressway [2]. These projects are expected to play an important role in improving regional transportation efficiency, supporting economic integration, and promoting balanced regional development.

Tunnel reconstruction and expansion projects are often the key nodes of expressway reconstruction and expansion programs. Different from newly-built tunnels, in-situ tunnel expansion requires the demolition of existing tunnel structures, which causes secondary disturbance to the surrounding rock mass of the tunnel. This construction method is characterized by higher risks and is prone to induce surrounding rock instability and other accidents. At present, domestic and international research on tunnel reconstruction and expansion is basically limited to small-section tunnels [3]. Typical overseas projects include the White Haven Tunnel in the United States, the Okura Tunnel in Japan, and the Nazzano Tunnel in Italy, all of which are small-section tunnel expansion projects converting two-lane tunnels into three-lane tunnels or single-track railway tunnels into double-track ones [4-6]. Similarly, in-situ tunnel expansion projects in China are mostly confined to single-tube two-lane tunnel expansion, with representative cases including the Damu Mountain Tunnel, the Yuzhou Tunnel, and the Gushan Tunnel [7-9]. To date, there are no available reference cases for the in-situ expansion of super-large section highway tunnels such as existing three-lane highway tunnels. Against this backdrop, this paper takes the in-situ expansion project of the DaChangshan No.1 Tunnel on the Zhongkai Expressway as the research background, systematically summarizes the construction technology for the in-situ expansion of existing three-lane highway tunnels, and provides a reference for similar in-situ expansion projects of super-large section tunnels.

2. Project Overview

The DaChangshan No.1 Tunnel is a key node of the Phase I Project of the Zhongkai Expressway. With a length of 662 m for the left tunnel tube and 624 m for the right tunnel tube, it has a maximum excavation span of 18 m and a maximum excavation cross-sectional area of 170 m², thus being classified as a super-large section tunnel (cross-sectional area > 100 m²) [10]. Originally designed as a three-lane tunnel, the DaChangshan No.1 Tunnel has been upgraded from a three-lane to a four-lane configuration to fully meet the traffic volume demand of the Shenzhen-Zhongshan Link. Constrained by the road alignment connection at the front and rear sections of the area where the tunnel is located, the tunnel adopts the unilateral in-situ expansion method to maintain the original road alignment. After expansion, the maximum excavation span of the tunnel is adjusted to 21.35 m, and the maximum excavation cross-sectional area is increased to 250 m².

The tunnel passes through strata dominated by silty clay and granite, with a maximum buried depth of 137 m. The surrounding rock mass of the tunnel is categorized by grades, as shown in Figure 1. Class V surrounding rock accounts for 14.2% of the total tunnel length, Class IV surrounding rock accounts for 17.1%, and Class III surrounding rock accounts for 68.7%. The surrounding rock at the tunnel entrance is mainly composed of colluvial and eluvial gravel soil as well as strongly weathered granite porphyry, as illustrated in Figure 2. The stratum lithology at the tunnel exit consists of residual and slope deposits of silty clay and fully to strongly weathered granite porphyry. In its natural state, the soil mass is in a plastic-hard plastic or cloddy state, which softens upon contact with water, exhibiting poor mechanical properties and stability, leading to unfavorable tunneling conditions. After excavation, it is prone to risks such as collapse and roof fall.

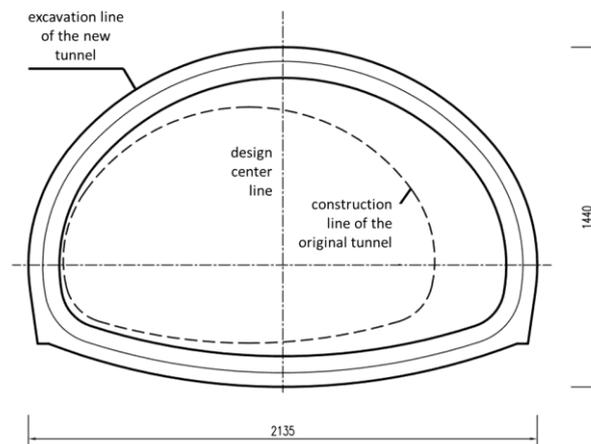


Figure 1. Cross-sectional design drawing of DaChangshan No.1 Tunnel.



Figure 2. On-site view of DaChangshan No.1 Tunnel.

3. Research on Lining Demolition Scheme for Existing Super-large Section Tunnels

For traditional in-situ expansion projects of single-tube two-lane tunnels, the construction is carried out based on two core considerations. First, given the relatively small span and strong self-stabilization capacity of two-lane tunnels, the secondary lining and primary support are demolished sequentially as appropriate, followed by cross-section expansion excavation and re-construction of new primary support and secondary lining. Second, the intermediate diaphragm wall is installed by fully utilizing the lateral confinement of the rock mass to be expanded, which plays a role in span reduction and ensures the safety of expansion excavation. However, three-lane tunnels themselves are large-span flat structures. Demolishing the existing lining on this basis and continuing to follow the expansion excavation method of single-tube two-lane tunnels will most likely lead to structural instability and surrounding rock collapse [11]. Therefore, the safe demolition of the lining of existing large-section tunnels is the key to the smooth implementation of tunnel in-situ expansion projects.

To ensure construction safety, circumferential and longitudinal cutting must be performed prior to the demolition of the existing secondary lining structure, as shown in Figure 3. The existing secondary lining structure is demolished in blocks through circumferential and longitudinal cutting seams, reducing the risk associated with a single demolition operation. Cutting work shall be conducted before the demolition of the secondary lining concrete of the existing tunnel, with circumferential cutting implemented first, followed by longitudinal cutting. After circumferential cutting, longitudinal seam cutting is carried out in combination with the design of expansion excavation zones and temporary support, as illustrated in Figure 4.



Figure 3. Schematic diagram of circumferential cutting effect of existing lining.



Figure 4. On-site construction diagram of existing lining cutting.

To address the problems associated with lining cutting construction, a mobile lining cutting trolley has been specially developed, as shown in Figure 5. Modified from conventional mobile trolleys used in tunnels, this trolley serves as an operating platform for lining cutting equipment. It features a mobile arc-shaped track truss and arc-shaped tracks installed on the top of the trolley. The truss is equipped with tracks along the tunnel axis, solving the problem of repeated trolley movement during cutting and improving cutting efficiency. Cutting equipment and saw blades are mounted on the arc-shaped tracks, and the end of the cutting equipment adopts a hydraulic vertical rotation structure. This avoids the need for a hydraulic telescopic system and resolves issues related to saw blade removal and cutting truss displacement. Furthermore, cutting equipment and saw blades can be installed at both ends of the arc-shaped track, accelerating the cutting progress.

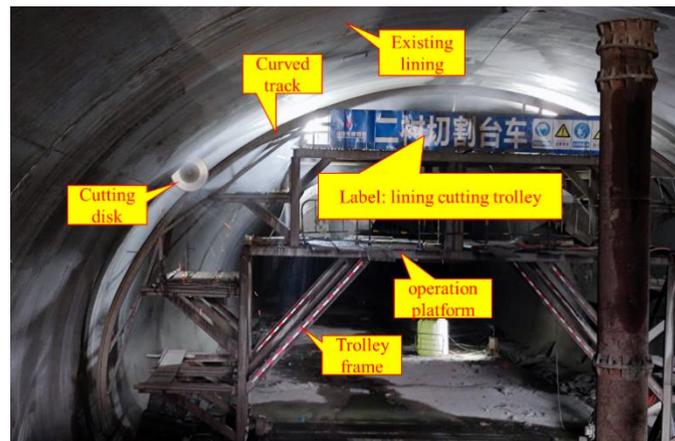


Figure 5. On-site diagram of the lining cutting trolley.

In addition, regarding the temporary support design for the lining cutting system, the project first adopted the stratum-structure method to calculate the axial force, bending moment, and corresponding safety factor during the demolition process of the original tunnel secondary lining. The calculation results indicate that the conventional I-steel support measures can no longer guarantee the safety of the original tunnel lining during demolition. Therefore, before the block demolition of the existing lining of the DaChangshan No.1 Tunnel, in addition to the conventional temporary I-steel supports, vertical $\Phi 609 \times 16$ steel pipe supports were additionally installed to reduce the bending moment of the existing secondary lining structure (Table 1).

Table 1. Force Statistics of Secondary Lining Demolition for the Original Tunnel.

Scheme	Axial Force (kN)	Bending Moment (kN·m)	Safety Factor
Before demolition	-1681	268	4.91
Conventional I-steel support	-1687	645	0.82
$\Phi 609 \times 16$ steel pipe support	-578	275	3.39

Due to the large one-time installation height of the $\Phi 609 \times 16$ steel pipes, segmental installation is required. Mobile temporary support frames fabricated from I18 I-steel can be used to assist the installation, and the upper and lower connections with high-strength expansion bolts are manually assisted. Each unit of the steel arch frame and temporary support is formed by welding I-steel and connecting plates, with adjacent units connected by bolts. The $\Phi 609 \times 16$ steel pipe supports are arranged at intervals of 5 m, with two pipes laid per lining segment. Meanwhile, double-piece composite I20b I-steel beams are installed between the two steel pipes.

In summary, in the in-situ expansion project of the DaChangshan No.1 Tunnel, the adoption of construction measures such as the circumferential and longitudinal lining cutting scheme and the additional installation of vertical steel pipe supports has ensured the safety of the lining demolition of the existing large-section tunnel.

4. Research on In-situ Expansion Construction Scheme

According to the on-site geological conditions, the DaChangshan No.1 Tunnel adopts targeted expansion excavation zoning and construction sequence schemes for different

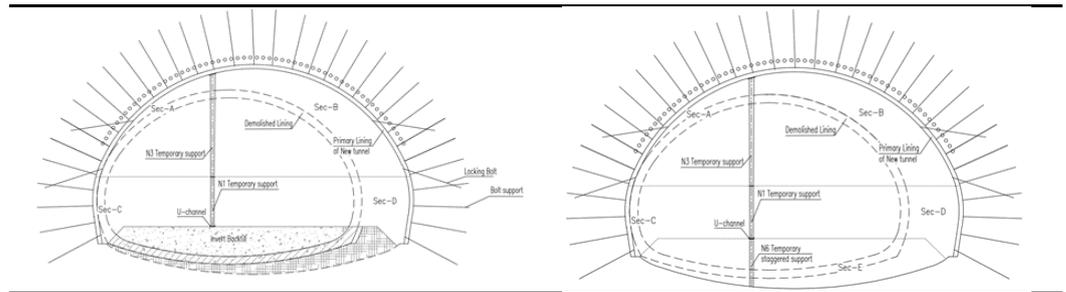
surrounding rock classes. For Class V surrounding rock, the *deformation-controlled double-side heading excavation method* is applied; for Class IV surrounding rock in the tunnel body, the *center diaphragm (CD) method* is adopted for expansion excavation; for Class III surrounding rock in the tunnel body, the *two-bench excavation method* is utilized. The overall construction process of each method is as follows:

Advanced support → Temporary support → Zonal demolition of existing secondary lining → Zonal demolition of existing primary support → Zonal expansion excavation following the contour of the new tunnel → Construction of primary support and temporary support after expansion excavation → Move to the next zone after advancing a certain distance.

Taking the expansion excavation construction of the Class V surrounding rock section as an example, the step-by-step construction process is shown in the Table 2.

Table 2. Construction Sequence of Expansion Excavation for Class V Surrounding Rock.

<p style="text-align: center;">Step 1</p> <ol style="list-style-type: none"> (1) Cut the lining of the existing tunnel and implement advanced support following the contour of the new tunnel; (2) Install steel pipe supports for the original tunnel lining and temporary vertical supports for the lower cross-section of the expanded tunnel; (3) Backfill to the tunnel haunch position with sandbags. 	<p style="text-align: center;">Step 2</p> <ol style="list-style-type: none"> (1) Demolish the original tunnel lining structure of the upper bench (Sec-A) of the left pilot tunnel, and perform chiseling and expansion excavation in accordance with the contour of the new tunnel; (2) Construct the primary support and temporary support for the upper bench of the left pilot tunnel.
<p style="text-align: center;">Step 3</p> <ol style="list-style-type: none"> (1) Demolish the original tunnel lining structure of the lower bench (Sec-C) of the left pilot tunnel, and perform chiseling and expansion excavation following the contour of the new tunnel; (2) Construct the primary support for the lower bench of the left pilot tunnel. 	<p style="text-align: center;">Step 4</p> <ol style="list-style-type: none"> (1) Demolish the original tunnel lining structure of the lower bench (Sec-D) of the right pilot tunnel, and perform chiseling and expansion excavation following the contour of the new tunnel; (2) Construct the primary support for the lower bench of the right pilot tunnel.



Steps 3-5

Demolish the original tunnel lining structure of the pilot tunnels in the sequence of Sec-A→Sec-B→Sec-C→Sec-D, conduct expansion excavation according to the contour of the new tunnel, and construct the primary support and temporary support for the corresponding pilot tunnels.

Step 6

Demolish the temporary invert, set up temporary staggered supports at the bottom with channel steel lapping, and carry out the excavation of invert Sec-5.

5. Analysis of On-site Monitoring Data

5.1. Settlement Deformation

To further investigate the construction mechanical characteristics of the in-situ expanded tunnel and ensure safe construction of the project, a full-process monitoring was conducted on the representative section LK10+560 during the expansion excavation of Class V surrounding rock at the exit of the left tunnel tube, spanning from May 2021 to December 2021. The layout of monitoring points is shown in Figure 6.

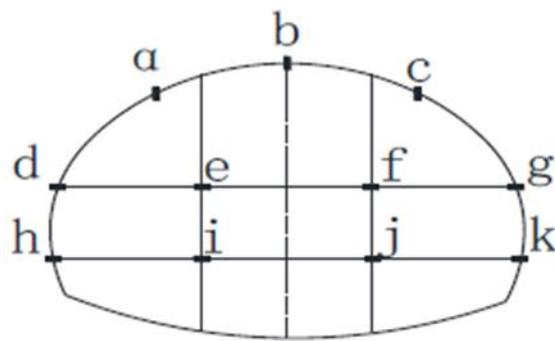


Figure 6. Schematic diagram of monitoring point layout.

The monitoring points for tunnel crown settlement were embedded in the primary support of the expanded excavation, and the monitoring data are presented in Figure 7. It can be seen from the crown settlement data that the rate of crown settlement exhibited a trend of being fast at first and then slow. An obvious displacement increment occurred when the temporary supports were removed, but the subsequent settlement tended to stabilize, with the final crown settlement reaching 10.1 mm.

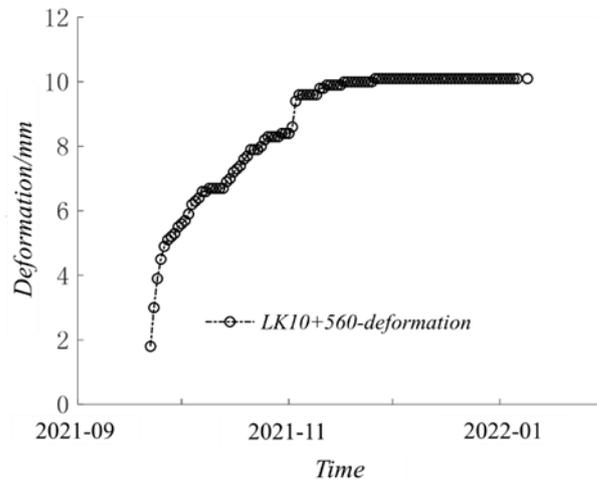


Figure 7. Crown settlement monitoring data of section LK10+560.

5.2. Horizontal Convergence

Regarding horizontal convergence, it can be observed that the convergence deformation at the tunnel haunch was greater than that at the tunnel bottom; the convergence deformation at the haunch (d-g) was 8 mm (Figure 8).

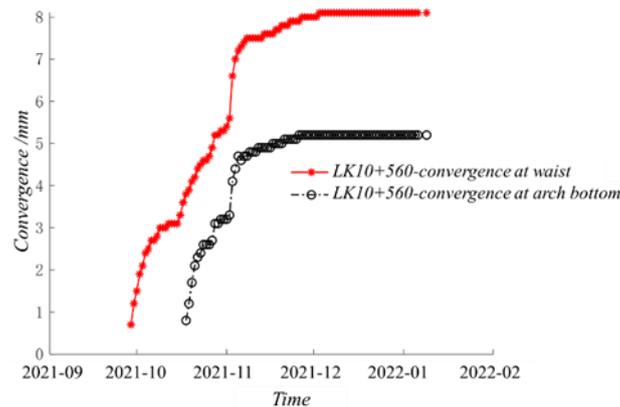


Figure 8. Haunch convergence monitoring data of section LK10+560.

5.3. Deep Displacement of Surrounding Rock

The layout positions of deep displacement monitoring points for surrounding rock are shown in the Figure 9. Among them, the deep displacement meter D2 was installed on September 26, 2021, D3 on October 14, 2021, and D1 on October 19, 2021. The monitoring results of the measuring points are shown in Figure 10.

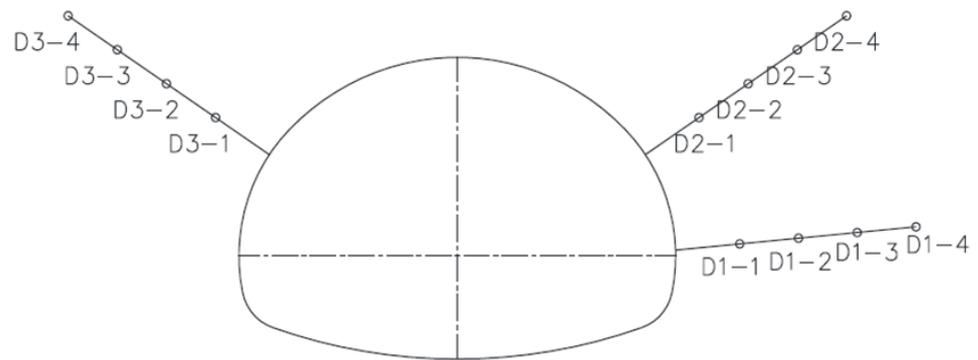
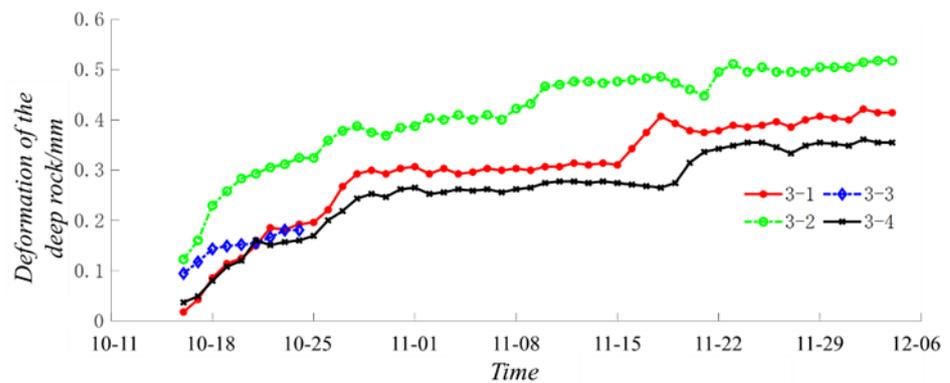
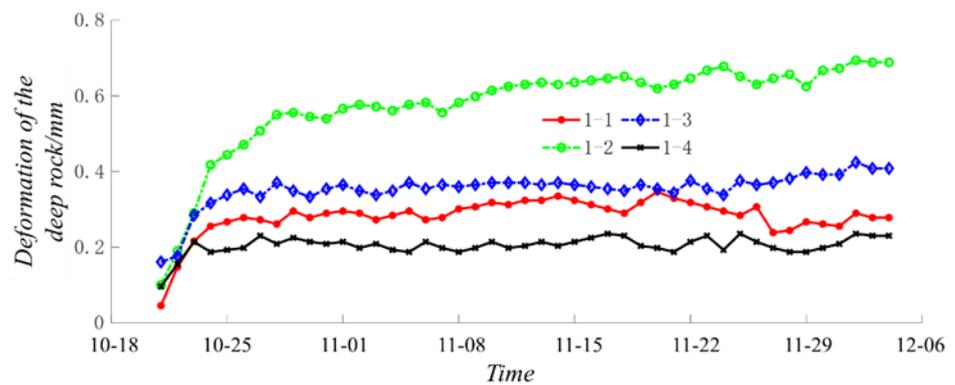


Figure 9. Schematic diagram of deep displacement monitoring point layout in surrounding rock



(a) Variation of deep displacement at tunnel shoulder.



(b) Variation of deep displacement at tunnel haunch.

Figure 10. Deep displacement monitoring data.

It can be concluded from the figures that

- 1) Overall, the surrounding rock displacement occurred in the shallow surrounding rock of the tunnel, with the deep displacement less than 1 mm, indicating an obvious arching effect.
- 2) The farther the surrounding rock was from the tunnel excavation face, the smaller the displacement was. At the position 8 m away from the excavation face, the surrounding rock displacement at the tunnel shoulder was only 0.3 mm.

- 3) The maximum displacement of the surrounding rock at the tunnel haunch occurred at the position 4 m away from the tunnel excavation face, which might be related to the stress concentration at this location.

6. Conclusions

Based on China's first in-situ expansion project of an existing three-lane tunnel-the DaChangshan No.1 Tunnel, this paper elaborates on the key technologies involved in the in-situ expansion of existing large-section tunnels, including the lining cutting and demolition scheme, temporary support system, as well as the optimization of zonal expansion excavation and construction sequence. The aforementioned technologies have effectively guaranteed the smooth completion and on-schedule opening to traffic of the DaChangshan No.1 Tunnel in-situ expansion project.

Field practice experience demonstrates that the in-situ expansion construction technologies discussed in this paper are scientific, reasonable and highly feasible. These technologies can provide a valuable reference for the design and construction of similar in-situ expansion projects of super-large section highway tunnels, and thus possess excellent popularization value.

References

1. C. He, and B. Wang, "Research progress and development trends of highway tunnels in China," *Journal of Modern Transportation*, vol. 21, no. 4, pp. 209-223, 2013. doi: 10.1007/s40534-013-0029-4
2. L. Yuming, "Digital Identity," In *Sovereignty Blockchain 2.0: New Forces Changing the World of Future*, 2022, pp. 87-125. doi: 10.1007/978-981-19-3862-7_3
3. H. Yang, J. Gao, Y. Ding, X. Chen, Z. Lin, H. Wu, and Z. Yang, "Mechanical response of broken surrounding rock by in-situ expansion of highway tunnel," *Bulletin of Engineering Geology and the Environment*, vol. 84, no. 5, p. 214, 2025. doi: 10.1007/s10064-025-04232-z
4. X. Zheng, X. Kang, K. Xu, T. Chen, X. Huo, and C. Chen, "Study on Evolution of Surrounding Rock Stability and Structural Mechanical Behavior During In-Situ Expansion of Existing Tunnels in Weak Rock Mass," In *2025 8th International Conference on Traffic Transportation and Civil Architecture (ICTCA 2025)*. SAE Technical Paper., December, 2025. doi: 10.4271/2025-99-0207
5. X. Cheng, B. Wang, X. Guo, and L. Zhang, "A novel in-situ tunnel expansion method based on removable prestressed active support technology for rapid construction," *Tunnelling and Underground Space Technology*, vol. 168, p. 107155, 2026. doi: 10.1016/j.tust.2025.107155
6. R. SpA, "Widening the Nazzano motorway tunnel from two to three lanes+ an emergency lane without interrupting traffic," .
7. S. Zhao, W. Sun, X. Liu, X. Zhou, X. Deng, Z. Zhong, and H. Yang, "Mechanical responses and reinforcement assessment of non-typical in-situ enlargement for closely spaced tunnel groups in weak surrounding rock," *Transportation Geotechnics*, 2026. doi: 10.1016/j.trgeo.2026.101931
8. H. Dayong, Z. Xingwu, L. Lei, C. Hao, L. Dong, Y. Zihai, and Y. Jiajia, "Study on the construction method for in-situ expansion of existing large cross-section tunnels," *Discover Applied Sciences*, vol. 7, no. 6, p. 556, 2025. doi: 10.21203/rs.3.rs-5446124/v1
9. F. Hou, Y. Luo, Q. Jiang, J. Chen, T. Li, and F. Dong, "Analysis on construction deformation and supporting structure of two-step and threesection excavation method for super larger span highway tunnel," *Stavební obzor-Civil Engineering Journal*, vol. 29, no. 1, 2020. doi: 10.14311/cej.2020.01.0010
10. N. A. Munfah, and C. J. Hung, "First Comprehensive Tunnel Design Manual in the United States," *North American Tunneling 2010 Proceedings*, vol. 387, 2010.
11. F. Dong, Y. Luo, J. Chen, C. Wang, Y. Liu, and W. Xun, "Mechanical Behavior of Secondary Lining in Super Large-Span Tunnels Considering Temperature Effects," *Symmetry*, vol. 16, no. 3, p. 339, 2024. doi: 10.3390/sym16030339

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