Application of Artificial Intelligence in the Construction of Extra-Long Large Pipe Sheds in Shallow-Buried Tunnels

Huijun Zhang [1], Junyang Chen [2*]

[1]Mengji Railway Co., Ltd., Hohhot, China
[2]China Railway No.4 Engineering Group Co., Ltd., Hefei, China

*516976970@qq.com

Abstract. In the construction process of shallow-buried tunnels, the technology of extra-long large pipe sheds is widely used due to its ability to effectively stabilize the excavation face. However, the implementation of this technology faces numerous challenges due to complex geological conditions, intricate construction procedures, and environmental constraints. The rapid development of artificial intelligence (AI) has provided new ideas and solutions for optimizing the construction of extra-long large pipe sheds. This paper reviews the main application scenarios of AI in the construction of extra-long large pipe sheds in shallow-buried tunnels, exploring its potential applications in construction parameter optimization, construction risk prediction, and quality control. Based on practical engineering cases, the paper analyzes the actual effects of AI technology in improving construction efficiency, reducing risks, and saving costs.

Keywords: Artificial Intelligence; Shallow-Buried Tunnel; Extra-Long Large Pipe Shed; Construction Optimization; Risk Prediction

1 Introduction

With the acceleration of urbanization, the demand for tunnel engineering, especially shallow-buried tunnels, is increasing. Shallow-buried tunnels are typically located in densely populated urban areas, with numerous buildings and transportation facilities above them. During construction, there are high requirements for surface settlement, building safety, and control of construction disturbances [1-2]. As an effective support technology, extra-long large pipe sheds can ensure smooth construction under complex geological conditions. However, the construction process of extra-long large pipe sheds is complicated, with diverse procedures, and its effectiveness is influenced by various factors, including geological conditions, construction equipment, and the technical level of operators, leading to considerable uncertainty [3-5].

Traditional methods for constructing extra-long large pipe sheds often rely on the experience of construction personnel and on-site monitoring data. This approach can struggle to achieve precise control in complex construction environments and rapidly

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_17

changing geological conditions. In recent years, with the rapid development of artificial intelligence (AI) technology, the application research of AI in the engineering field has gradually increased, particularly in data analysis, pattern recognition, and predictive modeling, where AI has demonstrated unique advantages [6-8]. By incorporating AI technology, automated data analysis, optimization of construction parameters, and real-time prediction of construction risks can be achieved during the construction of extra-long large pipe sheds, providing strong support for improving construction quality and reducing costs [9-10].

This study aims to explore the application of AI technology in the construction of extra-long large pipe sheds in shallow-buried tunnels. By combining practical engineering cases, it analyzes the application effects of AI in construction optimization, risk prediction, and quality control, and discusses future development directions.

2 Engineering Background

The F Tunnel is located in Inner Mongolia Autonomous Region. It is a single-bore double-line tunnel situated in a moderately low mountainous area with significant topographical variations. The terrain is relatively gentle, characterized by rolling hills and developed intermountain gullies, interspersed with depressions. Most sections are covered with low vegetation, with ground elevations ranging from 1234.27 to 1268.61 meters, resulting in a maximum elevation difference of 34.34 meters and well-developed vegetation. The tunnel is 1098 meters long, with all sections classified as Class V surrounding rock, and the maximum burial depth of the tunnel is approximately 29 meters.

Due to the shallow burial of the entire tunnel (with the shallowest depth being 5 meters and the maximum depth being 29 meters) and the poor surrounding rock conditions, it is necessary to ensure excavation stability. Therefore, large pipe sheds are used for advanced support in the arch section of the tunnel within a 140° range, as shown in Figure 1.

Fig. 1. Diagram of Advanced Long Pipe Shed

3 Intelligent Optimization Technology for Pipe Shed Parameters

The design and construction parameters of pipe sheds, such as diameter, length, arrangement, insertion angle, and spacing, directly impact the safety and economy of tunnel excavation. Traditional design methods for pipe shed parameters often rely on experience and analogical analysis, making it difficult to achieve optimal results under complex and variable geological conditions. Therefore, it is particularly important to introduce intelligent optimization technology to improve design accuracy, reduce construction risks, and lower costs.

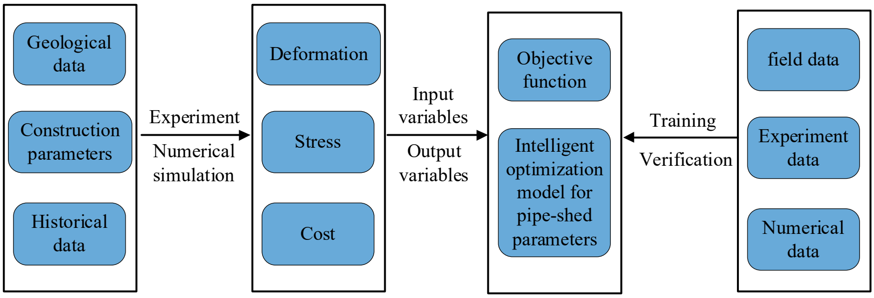
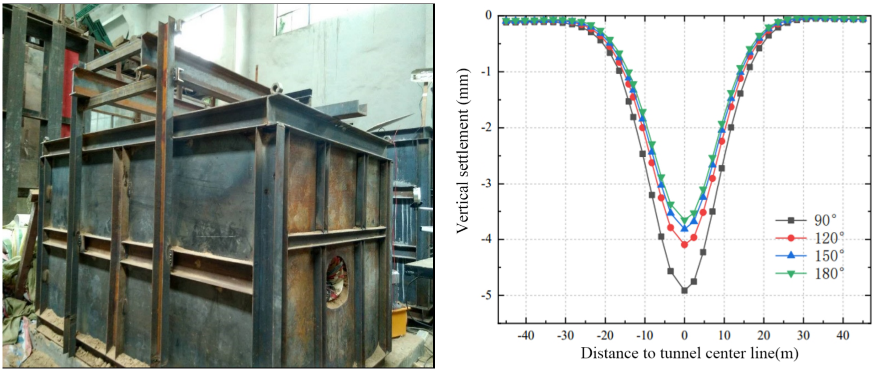


Fig. 2. Diagram of intelligent optimization technology for pipe-shed parameters



(a) (b)

Fig. 3. The model test results of shallow-buried tunnel with different pipe shed parameters.

The framework for intelligent optimization technology of pipe shed parameters is illustrated in Figure 2. First, a large amount of geological data (such as stratum distribution, lithology, groundwater levels, etc.), construction parameters (such as excavation cross-section, tunnel span, depth, etc.), and historical engineering data are collected. Next, numerical models are established based on the data, and laboratory experiments are conducted to obtain deformation, stress states, and pipe shed reinforcement costs under different geological and construction conditions as well as varying pipe shed parameters, as shown in Fig. 3. Then, the pipe shed parameters (diameter, length, arrangement, insertion angle, spacing) are set as the objective function, while the deformation, stress state, pipe shed reinforcement costs, geological data, and construction parameters of the shallow-buried tunnel serve as input variables to construct an intelligent optimization model for pipe shed parameters, as shown in Fig. 4. Finally, the intelligent optimization model for pipe shed parameters is trained based on field data, laboratory test data, and numerical simulation data.

4 Intelligent Warning Technology for Construction Risks in Shallow-Buried Tunnels

Shallow-buried tunnels often traverse complex geological conditions, such as weak soil layers, karst areas, and regions with abundant groundwater, making collapses one of the most common and dangerous accidents. Once a collapse occurs, the consequences can be severe, potentially leading to irreversible losses. By predicting and providing early warnings, preventive measures can be taken to reduce the likelihood of collapses, significantly enhancing the safety of the shallow-buried tunnel construction process.

In this project, a mechanical model for analyzing the stability of the surrounding rock is first established, taking into account the physical and mechanical properties of the rock-soil body, the softening effect of groundwater on the surrounding rock, construction disturbances, and other factors to calculate the safety factor of the surrounding rock, as shown in Fig. 4. Subsequently, numerical simulations are conducted using the finite element method or discrete element method to predict the deformation and stress distribution of the surrounding rock under different construction conditions, assessing the risk of collapse, as shown in Fig. 5. Then, by integrating multi-source data, machine learning models (such as random forests, support vector machines, neural networks, etc.) are utilized to predict collapse risks. These models can identify potential risk areas by learning from existing data patterns. Finally, the system issues warnings about potential collapse risks based on real-time monitoring data and model predictions, providing risk level assessments to assist construction personnel in taking timely preventive measures.

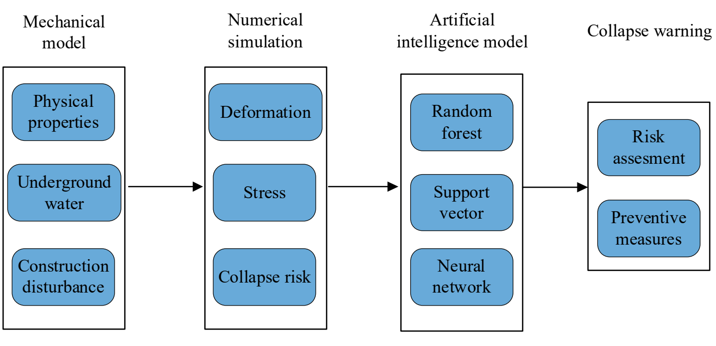


Fig. 4. Intelligent warning technical framework for construction risk of pipe-shed shallow-buried tunnel.

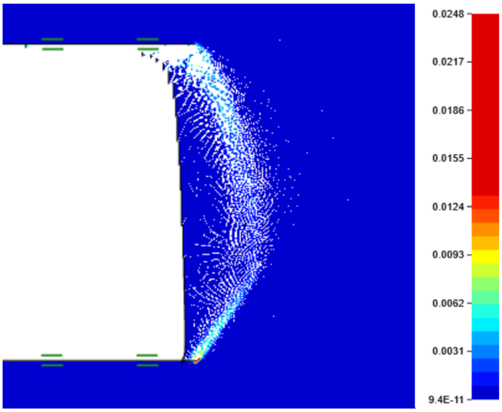


Fig. 5. The collapse risk simulation of pipe-shed shallow-buried tunnel.

5 Intelligent Control Technology for Construction Quality of Pipe Sheds in Shallow-Buried Tunnels

Due to the concealed nature of pipe shed construction in shallow-buried tunnels, quality cannot be observed with the naked eye. This makes it difficult to detect potential construction defects during subsequent tunnel excavation processes. Issues such as pipe shed displacement, deformation, or uneven grouting may only manifest during later use. Furthermore, the construction accuracy of large pipe sheds directly affects the overall structural safety and performance of the tunnel, making intelligent control technology for pipe shed quality essential.

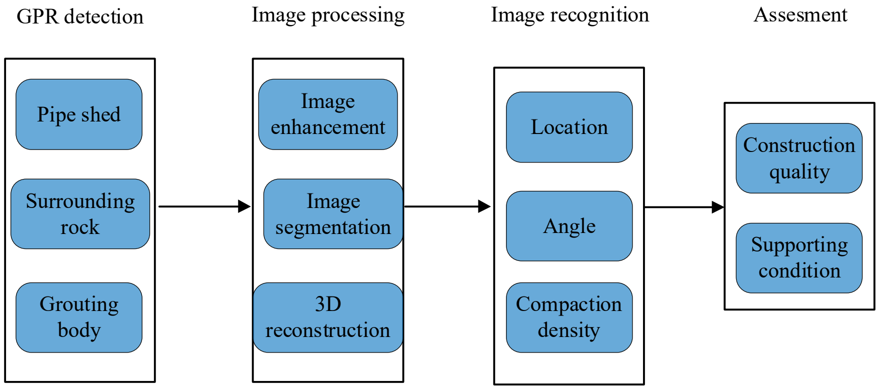


Fig. 6. Intelligent control technical framework for construction quality of shallow-buried tunnel pipe shed.

As shown in Fig. 6, geological radar detection technology is employed to scan the pipe sheds within the surrounding rock of the excavated tunnel, constructing a threedimensional image that reflects the true condition of the pipe sheds. Advanced data processing algorithms are utilized to denoise and process the raw data collected by the geological radar, generating high-quality images of the pipe shed structure. Intelligent image recognition technology is then applied to analyze the radar images, automatically identifying information such as the position, shape, cracks, and voids of the pipe sheds. Subsequently, the obtained detection information is compared with construction design data to assess the construction quality of the pipe sheds, including key quality indicators such as position, shape, and density. Visualization tools are used to display the results of the geological radar detection, providing a clear presentation of the geological environment surrounding the pipe sheds and the construction quality, thereby assisting engineering technicians in quickly understanding the construction status and potential risks.

6 Conclusion

This study explores the application of artificial intelligence technology in the construction of extra-long large pipe sheds in shallow-buried tunnels, emphasizing its importance in areas such as construction parameter optimization, risk prediction, and quality control. Analysis of the Fengzhen Tunnel project reveals that traditional design methods for pipe sheds struggle to adapt to complex geological conditions, whereas AI technology can collect and analyze large amounts of geological and construction data to establish intelligent optimization models, enabling precise design of pipe shed parameters and subsequently enhancing the safety and economy of tunnel excavation.

Furthermore, the common risk of collapses during shallow-buried tunnel construction can be effectively predicted by establishing a mechanical model for analyzing the stability of the surrounding rock and integrating machine learning methods. This approach helps identify potential risk areas and issue early warnings, thereby reducing the likelihood of accidents. In terms of construction quality control, the application of intelligent geological radar detection technology allows for a comprehensive assessment of the quality of pipe shed construction. Through intelligent image recognition technology, the condition of the pipe sheds can be automatically identified, ensuring the controllability of quality during the construction process.

Overall, the introduction of artificial intelligence technology not only enhances construction efficiency and safety but also significantly reduces risks and costs, providing new insights for future tunnel construction and promoting the intelligent transformation of the industry.

References

1. Lyu H M, Shen S L, Zhou A, et al. Calculation of pressure on the shallow-buried twin-tunnel in layered strata[J]. Tunnelling and Underground Space Technology, 2020, 103: 103465.
2. Lei M, Peng L, Shi C. Model test to investigate the failure mechanisms and lining stress characteristics of shallow buried tunnels under unsymmetrical loading[J]. Tunnelling and Underground Space Technology, 2015, 46: 64-75.

3. Sun L, Zhao Q, Liu L, et al. Key Technologies for One-Time Installation of Super-Long Pipe Sheds in Tunnel Support Construction: A Case Study on Songhuai Youyuan Station (Line 9) in Zhengzhou Metro[J]. Buildings, 2024, 14(7): 2079.
4. Bao L, Wei F. Tunnel construction in shallow soft rock using the pipe shed support[J]. Scientific Reports, 2024, 14(1): 3401.
5. Jiang C T, Mao W, Zhang Y, et al. Influence of external insert angle on structural deformation of long pipe shed with shallow hole[J]. Scientific Reports, 2023, 13(1): 14141.
6. Ayawah P E A, Sebbeh-Newton S, Azure J W A, et al. A review and case study of Artificial intelligence and Machine learning methods used for ground condition prediction ahead of tunnel boring Machines[J]. Tunnelling and Underground Space Technology, 2022, 125: 104497.
7. Baghbani A, Baghbani H, Shalchiyan M M, et al. Utilizing artificial intelligence and finite element method to simulate the effects of new tunnels on existing tunnel deformation[J]. Journal of Computational and Cognitive Engineering, 2024, 3(2): 166-175.
8. Mahmoodzadeh A, Mohammadi M, Daraei A, et al. Decision-making in tunneling using artificial intelligence tools[J]. Tunnelling and Underground Space Technology, 2020, 103: 103514.
9. Liu L, Song Z, Li X. Artificial intelligence in tunnel construction: A comprehensive review of hotspots and frontier topics[J]. Geohazard Mechanics, 2023.
10. Afzal F, Yunfei S, Nazir M, et al. A review of artificial intelligence based risk assessment methods for capturing complexity-risk interdependencies: Cost overrun in construction projects[J]. International Journal of Managing Projects in Business, 2021, 14(2): 300-328.