Research on the Influencing Mechanism of Support Parameters for Pipe-Sheds in Shallow-Buried Tunnels

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Abstract. Urbanization's swift progress has heightened the need for underground space development, necessitating advanced support systems like extra-long pipe-shed technology to ensure safety and stability in challenging geological conditions during tunnel construction. This paper investigates the influencing factors of support parameters for extra-long pipe-shed technology, commonly used in tunnel and underground space construction. Based on current engineering cases involving extra-long pipe-sheds in tunnel construction, a numerical simulation method was employed to study the influence mechanism of parameters such as pipe-shed diameter, circumferential spacing, and support coverage on the effectiveness of the support system. The research also optimized the parameter design for pipe-shed construction, improving quality control and safety during construction. The findings provide theoretical guidance for tunnel support under complex geological conditions and serve as a reference for future similar projects.

Keywords: Pipe-shed, Support parameter, Numerical simulation, Tunnel construction

1 Introduction

With the rapid advancement of urbanization, the demand for underground space development projects has increased significantly. The expansion of urban transportation, underground commercial spaces, and infrastructure construction has driven the rapid growth of tunnel and large underground space engineering. In these projects, tunnel construction often encounters complex geological conditions, making safety and quality control during construction more challenging [1,2]. To ensure construction safety, effective support systems are frequently required [3,4,5]. Extra-long pipe-shed support technology has been widely applied in such projects due to its ability to provide effective pre-support in complex geological conditions, preventing rock mass instability and enhancing construction safety and stability.

The core principle of extra-long pipe-shed support technology lies in forming a ring-shaped support by pre-arranging steel pipes, which stabilizes the surrounding rock and reduces deformation during excavation [6,7]. Specifically, the steel pipes are arranged along the excavation contour of the tunnel or underground space, and the surrounding structure bears the pressure of the surrounding rock, reducing the deformation and

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displacement that may occur during excavation. This technology is particularly important in weak geological conditions, such as soft soil layers, sand layers, karst development zones, or areas with abundant groundwater, where traditional support methods often fail to cope with these complex geological environments. Due to its strong resistance to deformation, the extra-long pipe-shed support effectively supports the surrounding rock before excavation, preventing collapse and large-scale deformation [8,9].

An improper design of these parameters could precipitate inadequate support, potentially leading to rock mass instability or even catastrophic construction incidents. This study fills a critical gap in existing research by providing a comprehensive analysis of the influence of pipe-shed support parameters on tunnel stability, thereby contributing significantly to the advancement of tunneling technology by offering a data-driven approach to optimize construction parameters for enhanced safety and cost-efficiency.

2 Principle of Pipe-Shed Support

(1) Formation of the Support Structure

Pipe-shed support is formed by inserting steel pipes along the excavation contour of the tunnel to create a tubular support ring. Before excavation, the steel pipes are drilled into the surrounding rock using specialized equipment, typically in a parallel or slightly inclined manner. The pipes are spaced at a certain distance from each other, with the length, diameter, and inclination angle of the pipes determined based on the project requirements and geological conditions. This steel pipe support system functions as an integrated structure that distributes surrounding rock pressure, stabilizes the excavation face, and reduces displacement during tunnel excavation.

(2) Pre-Support Function

The primary function of pipe-shed support is to provide pre-support for the surrounding rock before tunnel or underground space excavation begins. Since the surrounding rock remains undisturbed prior to excavation, the pipe-shed can be used to support the rock in advance, minimizing potential damage after excavation. By offering support through the steel pipes, the system effectively mitigates instability and deformation in the surrounding rock during the construction process. This is particularly beneficial in weak soil layers or fractured rock zones, where pipe-shed support helps prevent surface subsidence and collapses.

(3) Load Distribution Mechanism

The steel pipes in the pipe-shed support system interact with the surrounding rock through friction and interlocking, uniformly distributing external loads such as the rock's self-weight and groundwater pressure across the entire pipe-shed structure. This mechanism reduces localized stress concentration at the tunnel excavation face, lowering the risk of rock collapse or deformation. The pipes themselves bear part of the pressure from the surrounding rock and transfer these forces to the unexcavated areas behind, helping to maintain the stability of the rock mass at the excavation front.

(4) Improved Tunnel Stability

By forming a stable protective layer of steel pipes, pipe-shed support limits the movement of the surrounding rock during excavation, especially at the tunnel crown and vault areas. This significantly reduces rock deformation and subsidence. As a result, pipe-shed support technology greatly enhances the stability of tunnel construction, reducing the risks associated with rock mass failure.

3 Study on the Influence of Support Parameters

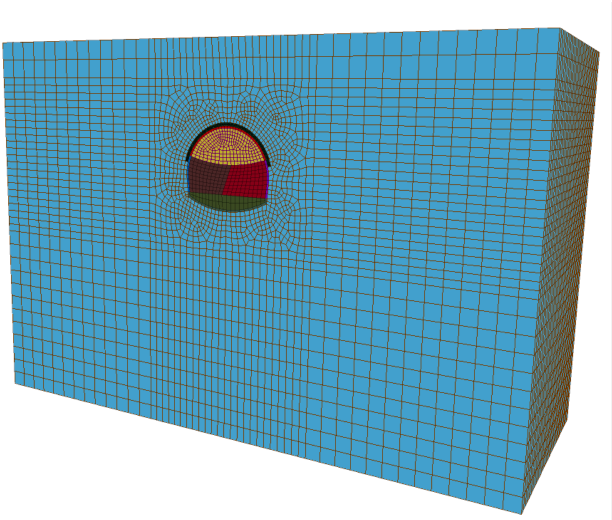

Fig. 1. Numerical simulation models

Table 1. Numerical simulation parameters

Types	Unit weight (kg/m^3)	Elastic modulus (GPa)	Poisson ratio	Cohesion (MPa)	Friction angle (°)
Pipe	77	200	0.25	-	-
Grout	25	17	0.25	1.6	43
Initial support	27	33	0.21	-	-

This study employs finite element analysis (FEA) software to conduct numerical simulations of the extra-long pipe-shed support system, meticulously modeling its performance during the construction phase, the numerical simulation parameters are listed in Table 1. By examining various parameter combinations' impact on load-bearing capacity, deformation behavior, and the stability of the surrounding rock, as depicted in Figure 1, the research delves into the nuances of geological variations, including friction coefficients, shear strengths, and elastic moduli across different strata. This comprehensive approach ensures the precision of the simulation outcomes. Through iterative simulation analyses, the study optimizes the support structure's design parameters, pinpointing the most effective values for critical parameters such as steel pipe diameter, support coverage, and pipe spacing, thereby advancing the understanding and application of pipe-shed support systems in tunneling technology.

3.1 Steel Pipe Diameter

As shown in the Figure 2, the ground settlement was simulated for three different steel pipe diameters: 108 mm, 159 mm, and 219 mm. The results indicate that as the steel pipe diameter increases, its cross-sectional area also increases, enabling it to bear higher external loads. In the pipe-shed support system, the steel pipes work in tandem with the surrounding rock through friction and interlocking, collectively resisting multiple loads, including the pressure from the surrounding rock, the weight of the overlying strata, and groundwater pressure. Larger-diameter steel pipes, due to their higher bending resistance, are more effective at withstanding lateral pressures from the surrounding rock and vertical loads.

Moreover, the larger diameter of the steel pipes creates a greater support interface area within the surrounding rock, further enhancing overall rock stability. Larger-diameter steel pipes provide stronger constraint effects, effectively reducing the loosening and displacement of the surrounding rock caused by excavation and thereby controlling its deformation. The support action between the steel pipes and the surrounding rock is primarily achieved through friction and interlocking forces. Larger-diameter pipes increase the contact area with the surrounding rock, thereby increasing the frictional force and improving the support effectiveness of the steel pipes.

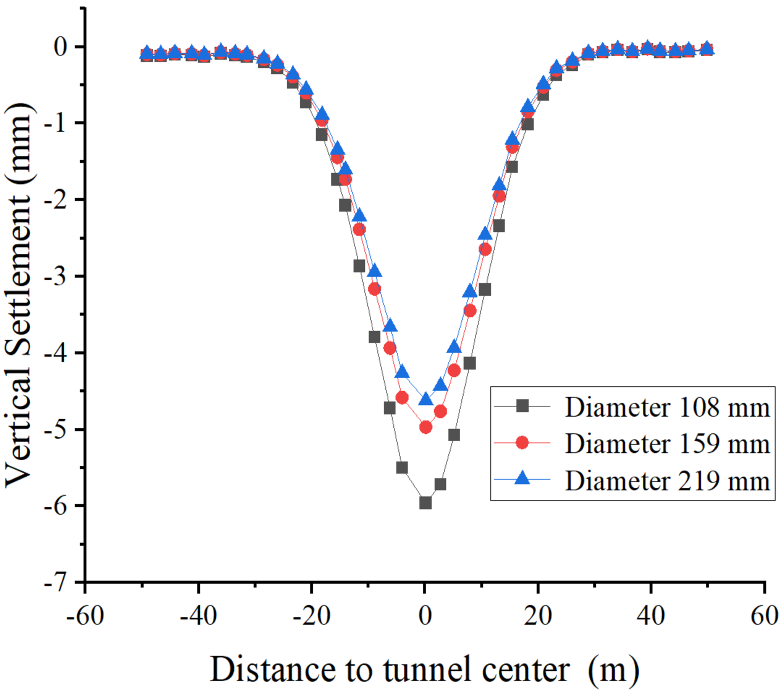

Fig. 2. The influence of pipe diameter.

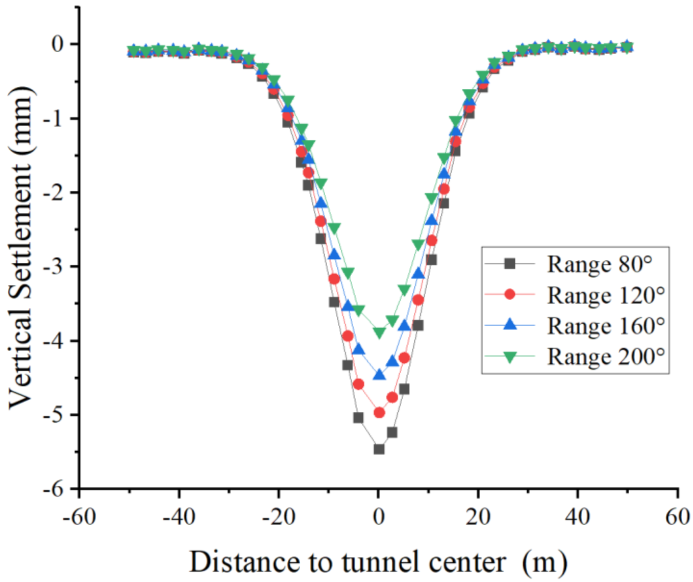

Fig. 3. The influence of support range.

3.2 Support Coverage

As illustrated in the Figure 3, ground settlement was simulated for four different circumferential support coverage scenarios: 80°, 120°, 160°, and 200°. The results indicate that as the support coverage increases, the amount of ground settlement gradually decreases. A larger circumferential support coverage provides a more extensive support interface, allowing the steel pipes to cover a greater area of surrounding rock, which effectively enhances the restraining effect on the rock mass. This increased constraint helps suppress the displacement of the surrounding rock, reducing loosening and deformation during construction and consequently lowering ground settlement.

Furthermore, a broader support coverage enhances the contact area between the steel pipes and the surrounding rock, thereby increasing both the frictional force and interlocking capacity, which further improves the load-bearing capacity of the overall support system.

3.3 Circumferential Spacing

As shown in the Figure 4, ground settlement was simulated for four different circumferential spacing scenarios: 0.3 m, 0.4 m, 0.5 m, and 0.6 m. The results indicate that as the circumferential spacing between the steel pipes decreases, the amount of ground settlement gradually decreases. The circumferential spacing determines the density of the support steel pipes, i.e., the number of pipes arranged per unit length. A smaller spacing results in a higher density of the support system, allowing the surrounding rock pressure to be distributed more uniformly across the pipes, thereby reducing localized stress concentration and enhancing the support effectiveness.

Additionally, with smaller circumferential spacing, the interaction between the steel pipes becomes closer, forming a more compact support framework. This increases the stiffness and stability of the support system, preventing any single pipe from bearing excessive stress or undergoing deformation. Smaller circumferential spacing enhances the interlocking effect of the steel pipes with the surrounding rock, helping to avoid slippage and instability of the rock mass, thus ensuring that the surrounding rock remains stable during excavation.

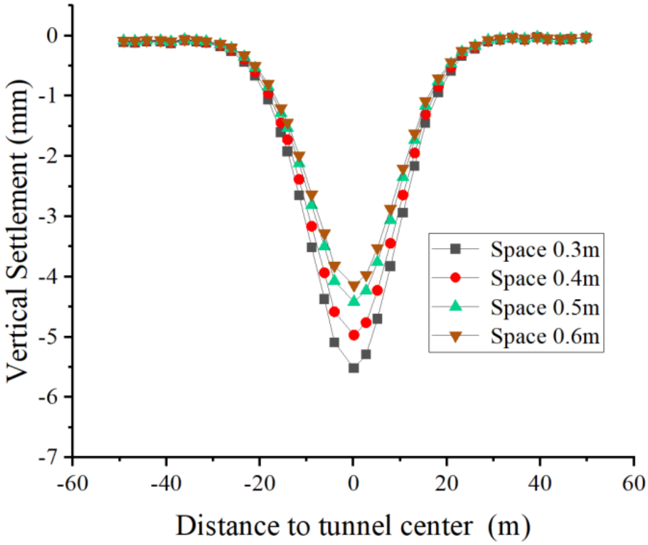

Fig. 4. The influence of pipe space.

4 Conclusions

This research underscores the efficacy of extra-long pipe-shed support technology in bolstering the stability and safety of tunnel and underground space construction in the face of complex geological challenges. Leveraging finite element analysis through numerical simulations, the impact of critical support parameters on the structural integrity and deformation behavior of the surrounding rock were scrutinized.

The results indicate that augmenting the steel pipe diameter substantially boosts the system's load-bearing capacity and fortifies the stability of the rock mass. An expanded support coverage area markedly mitigates ground subsidence, offering a broader support surface and amplifying the containment effect on the adjacent rock. Additionally, reducing the circumferential spacing between pipes augments the support system's density, leading to a more even distribution of stress and enhancing the interplay with the surrounding rock. In essence, the strategic refinement of these parameters is pivotal for optimizing the performance of pipe-shed support systems, thereby augmenting construction quality, safety, and cost-efficiency. This study offers invaluable guidance for future engineering endeavors in tunnel and underground space construction, especially in geologically demanding settings.

While this study offers significant insights into optimizing extra-long pipe-shed support technology through numerical simulations, it may not fully account for the complexities of real-world applications. Future research could further validate and expand these findings by incorporating a wider range of geological conditions, conducting field trials, and examining the long-term performance of the support systems.

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