

Innovation and Practice of Settlement Control Technology in Geotechnical and Underground Engineering Construction

Zhangyu Wen

Xihua University, Chengdu, Sichuan 610039

Abstract: In the construction of underground projects, the issue of surface subsidence is becoming increasingly prominent, posing a serious threat to both engineering safety and the surrounding environment. This paper focuses on the research of surface subsidence control technology in underground projects, conducting a systematic analysis from two perspectives: influencing factors and control measures. It explains the mechanisms by which factors such as soil conditions, groundwater levels, depth, cross-sectional dimensions, and construction techniques influence subsidence. The paper emphasizes key technologies for controlling subsidence, including the optimization of tunnel excavation techniques, advanced support, grouting reinforcement, and monitoring and early warning systems, and proposes practical technical points and implementation strategies. By integrating engineering practice with theoretical analysis, this paper aims to provide scientific guidance for the management of surface subsidence in underground projects.

Keywords: Underground engineering; Surface subsidence; Settlement control; Grouting reinforcement; Monitoring and early warning

Introduction

As urban modernization advances, the development and utilization of underground spaces are becoming increasingly frequent. Large-scale underground projects, such as subways, tunnels, and underground utility corridors, play a crucial role in alleviating traffic congestion, enhancing the urban environment, and improving infrastructure. However, these projects inevitably disturb the ground layers, leading to stress field adjustments and potential engineering disasters like surface subsidence. Therefore, studying the impact patterns and control measures of surface subsidence from underground projects is essential for ensuring project quality, protecting the surrounding environment, and promoting the safe development of underground space.

1. Factors affecting surface settlement of underground engineering

1.1 Stratigraphic soil conditions

The physical and mechanical properties of soil, such as its compressibility, strength, and permeability, directly influence the degree of deformation under external loads. For instance, weak soil layers, including silty mud, silty clay, and soft clay, are highly compressible and have low strength. When disturbed or loaded, these layers can easily deform significantly, leading to noticeable surface subsidence. In contrast, hard soil layers, such as medium dense sand, hard clay, and weathered rock, deform less and settle less. Additionally, the uniformity and continuity of the soil layers also affect the distribution of subsidence.

1.2 Groundwater level change

Changes in the groundwater level significantly affect the effective stress state of soil, leading to compression deformation of the soil skeleton. When the groundwater level drops, the effective stress in the overlying soil increases, causing a sudden rise in the contact stress between soil particles, which ultimately results in additional consolidation settlement of the soil. This is particularly true in formations such as water-rich sand layers and confined aquifers, where the groundwater level drop caused by pumping can lead to significant regional ground subsidence. Conversely, when the groundwater level rises, the effective stress in the soil decreases, and the soil skeleton undergoes a certain degree of elastic deformation, resulting in a relatively minor rebound deformation.

1.3 Tunnel burial depth and section size

The disturbance from shallow tunnel excavation primarily affects the surface soil layer. Due to its proximity to the ground, it can easily cause significant ground subsidence. As the tunnel depth increases, the disturbance shifts to deeper soil layers, reducing its impact on the surface soil and decreasing ground subsidence. However, when the tunnel is buried deep, the soil stress significantly increases. The stress release from excavation further expands the plastic zone, potentially causing some ground deformation.

1.4 Construction technology selection

Different tunnel construction methods significantly affect the disturbance of the surrounding soil, leading to varying degrees of surface subsidence. Among common tunnel construction methods, the open-cut method causes the most severe disturbance to the surrounding rock due to prolonged exposure of the excavation face, which can easily lead to large-scale ground displacement and surface subsidence. In contrast, methods like the shield method and the mining method, by setting up enclosed working faces and promptly implementing support measures, effectively limit soil deformation and control surface subsidence. For instance, the shield method uses measures such as soil chamber pressurization and synchronous grouting to minimize soil loss in front of the excavation face, resulting in better subsidence control. The mining method, with its short advance excavation and timely cyclic sealing, causes less disturbance to the surrounding rock but is relatively slower in construction progress.

1.5 Timeliness of support system

After the tunnel excavation, the timeliness, completeness, and reliability of the support system are crucial for controlling rock deformation and reducing surface subsidence. The initial support is a critical period for the development of rock deformation. Timely and appropriate initial support measures can effectively limit rock relaxation deformation and prevent the expansion of plastic zones. Secondary lining is essential for long-term deformation control and overall stability, significantly enhancing the stiffness of the tunnel structure and preventing further deformation. In terms of initial support methods, using pipe sheds, small pipes, and other advanced supports can pre-strengthen the rock, control the deformation at the face, and thus reduce surface subsidence.

2. Innovation and practice of settlement control technology

2.1 Optimization of tunnel excavation technology

To address the issue of surface subsidence caused by traditional full-face excavation, optimizing tunnel excavation techniques is crucial for controlling subsidence. Partial excavation involves dividing large-section tunnels into smaller sections and excavating them sequentially, such as using the bench method or the ring excavation method. For example, in ring excavation, the upper section is excavated first, followed by the initial support installation, and then the lower section is excavated. This approach effectively reduces the unloading area, thereby controlling rock deformation. Additionally, by reasonably scheduling the excavation sequence, prioritizing the excavation of the middle or arch top, and then excavating the side walls after the initial support forms a closed loop, the settlement of the arch top can be further reduced. During partial excavation, advanced support measures like pipe sheds or advance small pipes can be used to reinforce the surrounding rock and enhance its self-stabilization ability. For instance, advance small pipes are typically made of seamless steel pipes with a diameter of $\phi 42\text{mm}$, spaced 200-300mm circumferentially, and laid 10-15m ahead. This effectively strengthens the surrounding rock and limits deformation. Moreover, the intermediate partition construction method involves setting up longitudinal partitions to divide the large section into left and right sections for excavation, and then removing the intermediate partitions to form a single section. The partitions can be made of reinforced concrete, with a thickness of 300-500mm, effectively limiting the deformation of the surrounding rock on both sides, thus controlling surface subsidence^[1].

2.2 Key points of advanced support technology

Advance support is a crucial auxiliary method in tunnel construction, effectively reducing surface subsidence. For pipe canopy support, seamless steel pipes with diameters of $\phi 108\sim 159\text{mm}$ and wall thicknesses of 6-10mm are typically used, with a circumferential spacing of 300-500mm. These pipes are installed by drilling holes in the full-section drill rig in front of the face and then inserting them to form a closed pipe canopy support system. To enhance the effectiveness of the pipe canopy, cement slurry can be injected into the pipes to increase their stiffness, and grouting between the outer wall of the pipes and the hole walls can also be performed to improve the overall integrity of the surrounding rock. Pipe canopy support can effectively limit soil deformation in front of the face, particularly in controlling subsidence during the construction of tunnels through water-rich sand layers. For advance small pipe support, small steel pipes with diameters of $\phi 42\sim 89\text{mm}$ and wall thicknesses of 3-4mm are generally used, with a circumferential spacing of 200-400mm. Small pipes are reinforced using single-pipe double-liquid grouting, with the grout being a cement-water glass double-liquid slurry, which has a short solidification time and excellent durability. Small pipe support can form a reinforced zone in front of the tunnel face, thereby enhancing the strength and self-stability of the surrounding rock. Advance support also requires careful consideration of the scope and degree of reinforcement. Generally, the length of advance support should be at least 0.5 to 1 times the diameter of the tunnel, and the reinforcement range of small pipes should cover 1 to 2 times the tunnel diameter above the collapse line^[2].

2.3 Analysis of grouting reinforcement measures

Grouting reinforcement is a crucial method for controlling the settlement of underground projects, applicable to various scenarios such

as soil reinforcement at tunnel face and protection of surface structures. For tunnel face grouting, advanced grouting can be applied in front of excavation, forming a reinforced zone that enhances soil strength and limits deformation^[3]. Typically, grouting pipes with diameters of $\phi 42\sim 60\text{mm}$ are arranged in a ring pattern, spaced $0.3\sim 0.5\text{m}$ apart. When encountering layers like quicksand or gravel, pipe ring grouting can be used, with the grouting pipe spacing increased to form a grouting reinforcement ring, which blocks water and sand flow, ultimately enhancing the stability of the tunnel face. Additionally, it is essential to strictly control the grouting pressure and volume, typically not exceeding 0.5MPa to prevent excessive pressure from causing ground uplift and deformation. For surface structures, measures such as through-drilling or behind-the-wall grouting can be employed to protect and reinforce them. For example, in through-drilling grouting, grouting pipes are installed along both sides of the building foundation to form a grouting curtain, reducing uneven settlement of the building. The hole spacing is generally $1\sim 2\text{m}$, and the grouting pressure is $0.3\sim 0.5\text{MPa}$. It is also important to inspect the grouting effect, using methods such as core sampling and standard penetration tests to evaluate the reinforcement effectiveness and optimize the grouting parameters as needed.

3. Conclusion

In summary, the surface subsidence of underground projects involves multiple factors, including engineering geology, hydrogeology, and construction disturbances. This is an objective reality. Therefore, controlling subsidence cannot rely solely on a single measure but requires a comprehensive approach that includes geological surveys, design optimization, construction control, and monitoring and early warning systems, all tailored to the specific conditions of the project. As underground projects expand into deeper and more complex environments, higher demands for subsidence control naturally arise. Only by combining theoretical innovation with practical application can we continuously enhance the prevention and control capabilities of surface subsidence in underground projects, thereby ensuring the safe development and utilization of underground space.

References

- [1] Zhang Zhuqing. Research on the Monitoring Technology and Settlement Control Measures for Underground and Above-ground Coordinated Operations of Subway Shield Tunnels in Key Areas [J]. *Construction Engineering*, 2025, 47(04):618-624.
- [2] Hu Qinglei. Research on Geotechnical Engineering Investigation and Construction Treatment Technology for Building Engineering [J]. *Urban Construction Theory Research (Electronic Edition)*, 2025, (08):106-108.
- [3] Wang Haixu, Li Yao. Research on Deep Foundation Pit Support Technology in High-rise Building Engineering Construction [J]. *Engineering Machinery and Maintenance*, 2025, (01):86-88.