Optimization Design and Construction Control of Deep Excavation Support Structures in Geotechnical Engineering

Qiming Ren

Anhui Transport Consulting & Design Institute Co., Ltd., Hefei, Anhui, 230088, China

Keywords: Geotechnical Engineering; Deep Excavation Support Structures; Optimization Design; Construction Control

Abstract: Against the backdrop of accelerating urbanization, the demand for underground space development is increasing, leading to the widespread use of deep excavation engineering in construction projects such as high-rise buildings and subway tunnels. The support structure for deep excavations is a crucial aspect for ensuring construction safety and the stability of the surrounding environment. The rationality of its structural design and the precision of construction control directly affect the economy and safety of geotechnical engineering. Traditional support design, influenced by issues such as complex geological conditions and simplified load calculations, has begun to exhibit problems like resource waste and schedule delays. How to optimize the design of deep excavation support structures and achieve refined construction control is a major issue urgently needing resolution in geotechnical engineering. This paper analyzes the importance of construction control for deep excavation support structures in geotechnical engineering, proposes reasonable and effective optimization design schemes and construction control strategies, providing a reference for the development of engineering construction.

1. Introduction

Against the backdrop of increasingly tight urban space, the development and utilization of underground space is an effective measure to expand urban capacity and improve urban functions. Deep excavations are a core element of underground space development, and their structural stability is a key facility for ensuring the safety of geotechnical engineering and the stability of the surrounding environment. However, deep excavation engineering involves complex geological conditions and high construction risks, leading to numerous risk challenges in the design and construction process of support structures. Traditional support structure design methods cannot meet the needs of modern geotechnical engineering. Therefore, in-depth exploration of optimization design and construction control strategies for deep excavation support structures in geotechnical engineering has significant practical importance.

2. Importance of Construction Control for Deep Excavation Support in Geotechnical Engineering

2.1 Ensuring Construction Safety

Geotechnical engineering faces complex geological environments during the deep excavation phase. Strengthening construction control for deep excavation support can ensure overall construction safety, avoiding dangerous accidents such as excavation collapse and ground settlement. Simultaneously, effective construction control measures can smoothly realize the design scheme of the deep excavation support structure. Multiple steps, from the hole formation of support piles to the installation of reinforcement cages, will enhance the stability and bearing capacity of the support structure, avoiding issues like insufficient strength and excessive deformation of the support structure, thereby providing safety protection for the deep excavation and the surrounding

  DOI: 10.25236/icacel.2025.203

environment. Furthermore, scientific and reasonable construction control measures can help construction units grasp data such as settlement and displacement, nipping potential safety hazards in the bud upon discovery.

2.2 Ensuring Project Schedule

Deep excavation support in geotechnical engineering is a major phase in the initial construction of underground engineering, and its construction progress directly affects the commencement of the main works. By strengthening construction control of deep excavation support, the smooth connection and efficient advancement of various processes can be ensured, avoiding schedule delays caused by process chaos or excessive waiting times. Additionally, effective construction control strategies can fully assess changes in geological conditions and influencing factors of the surrounding environment, enabling the project to progress steadily according to plan and ultimately achieve the goal of delivery and use.

3. Optimization Design of Deep Excavation Support Structures in Geotechnical Engineering

3.1 Optimizing Support Structure Type Selection

During the optimization design process of deep excavation support structures in geotechnical engineering, optimizing the type selection of the support structure should be based on engineering geological conditions, surrounding environmental constraints, and economic requirements, employing multi-dimensional comprehensive analysis methods. Construction units must conduct detailed geological surveys and environmental investigations to clarify key parameters such as soil layer distribution, groundwater conditions, and underground pipeline distribution, providing basic data support for support structure type selection. An evaluation index system for support structure type selection should also be established, coupled with the use of the Analytic Hierarchy Process (AHP) to quantitatively rank alternative support schemes. For example, in deep excavation projects in narrow urban areas, prefabricated support structures with small footprint and low construction noise can be prioritized. In areas with uniform strata and moderate excavation depth, more economical soil nailing walls or composite soil nailing wall schemes can be adopted, providing a basis for subsequent refined design [1]. Subsequently, in the multi-dimensional comprehensive quantitative evaluation and optimization stage, the selected feasible schemes should undergo refined design and analysis. Numerical simulation technology should be used to predict the excavation deformation, internal forces of the support structure, and impact on adjacent buildings for each scheme. A quantitative evaluation system should be established from dimensions such as safety, economy, and schedule. The final step can use the AHP method to comprehensively score each scheme according to the specific needs of the project, selecting the support structure type that strictly meets safety and environmental prerequisites, thus completing the entire process of optimization selection.

3.2 Dynamic Adjustment of Structural Parameters

The key to enhancing the scientific and economic nature of the optimization design of deep excavation support structures in geotechnical engineering is the dynamic adjustment of structural parameters. During the excavation phase, construction units should use automated monitoring equipment to collect key parameters such as support structure deformation and soil lateral pressure in real-time, while recording construction conditions and environmental factors. On this basis, finite element software should be used to build a 3D numerical model, parameterizing the support structure, bracing system, and soil constitutive relationship. Sensitivity analysis should identify core parameters affecting support safety and establish quantitative relational equations, providing a theoretical basis for dynamic adjustment. The entire process relies on an information platform for data integration and back-analysis, using monitoring data to inversely deduce the actual mechanical parameters of the soil, correcting the numerical model, conducting predictions and multi-scheme comparisons, thereby achieving refined adjustment of support parameters.

3.3 Collaborative Optimization of Construction Technology and Processes

The optimization design of deep excavation support structures in geotechnical engineering should focus on the collaborative optimization of construction technology and processes. Dynamic construction simulation models should be created based on geological conditions and support structure types. BIM technology should be utilized to integrate process parameters for support piles, anchor cables, soil nailing walls, etc., deeply analyzing the spatiotemporal coupling relationships between different processes and identifying potential conflict risks and critical paths. For instance, during the construction of diaphragm walls, the alternate panel method can be chosen for segmented construction. Numerical simulation methods can optimize the sequence of panel division to avoid stress concentration caused by temperature differences in concrete pouring of adjacent panels, reducing non-productive waiting time. Meanwhile, construction units can divide the support structure construction into different standardized units. Intelligent monitoring systems can be introduced to provide feedback on data such as support structure deformation and soil displacement. Based on the final monitoring results, the pre-stress of anchor cables can be optimized, forming a good adaptation relationship between process execution and geological conditions.

4. Construction Control Strategies for Deep Excavation Support Structures in Geotechnical Engineering

4.1 Developing Refined Construction Scheme Design

Developing a refined construction scheme design for the construction control of deep excavation support structures is a core aspect) for ensuring project safety, quality, and efficiency. Specific strategies should be dynamically adjusted around geological conditions, structural characteristics, and the construction environment.

Firstly, construction units should reference geological survey data to build a 3D geological model of the excavation. Finite element numerical simulation should be used to analyze soil deformation, support forces, and groundwater seepage patterns under different working conditions. For complex strata such as soft soil and sand layers, support parameters can be adjusted in real-time based on the actual geological conditions revealed during excavation, ensuring the adaptability of the support system to the geological conditions [2].

Secondly, the excavation should be divided into layered and segmented construction units, clarifying the excavation depth and segment length for each layer. During the formulation of standardized operating procedures for support structure construction, intelligent monitoring equipment can be introduced to provide real-time feedback on construction quality data, achieving quality control of key processes.

Finally, construction units must translate the design scheme into quantifiable, executable construction control parameters. When parameter deviations occur, a feedback mechanism should be initiated immediately to dynamically adjust and optimize subsequent construction parameters. For every major risk, specific, operable emergency plans should be formulated. Emergency plans should be designed in coordination with the construction scheme and monitoring plan to ensure that losses are minimized when dangers occur.

4.2 Standardized Control of the Whole-Process Construction Technology

Deep excavation support construction in geotechnical engineering requires the establishment of a standardized control system covering the entire cycle of design, construction, and monitoring to ensure the safety of the support structure and the stability of the surrounding environment. Before construction, a special construction scheme should be prepared, organized for expert demonstration, and technical disclosure completed. Focus on verifying the match between the geological survey report and the support design, clarifying technical parameters and acceptance criteria for each process. The earthwork excavation stage must follow the principles of layered and segmented excavation, and symmetrical balance. The excavation depth of each layer must be within the range required by the support design; over-excavation or undercutting is strictly prohibited. Meanwhile, the temporal and spatial effect theory can be applied to control the excavation pace during earthwork excavation. Support structure construction should be carried out immediately after each excavation step, effectively shortening the exposure time of the excavation. During support pile construction, the alternate pile construction method should be chosen. Construction of adjacent piles can proceed only after the concrete strength of the neighboring pile reaches 70%. Pile position deviation should be controlled within 50mm. In the dewatering construction phase, the installation of well pipes and the backfilling process of filter material must be strictly standardized. The water level drawdown should be dynamically monitored to ensure the dewatering effect meets excavation requirements. Throughout the construction process, an automated monitoring system covering the excavation itself and the surrounding environment should be established. Key indicators such as support structure displacement, settlement, strut axial force, and groundwater level should be continuously monitored. Multi-level warning thresholds should be set. Upon data abnormality, emergency plans should be activated immediately to achieve informationalized construction and dynamic optimization. The post-construction management model must ensure that all construction process records, inspection reports, monitoring data, etc., are converted into standardized as-built documentation, providing reliable data support for subsequent similar projects.

4.3 Implementing Multi-Dimensional Monitoring and Early Warning

Construction control of deep excavation support structures in geotechnical engineering should implement multi-dimensional monitoring and early warning by building a multi-parameter collaborative monitoring network. Use a combination of total stations, 3D laser scanners, and GNSS reference stations to track and monitor the horizontal displacement and vertical settlement of support pile tops in real-time, focusing on stress concentration areas such as corners and sections with changing cross-sections. Fiber Bragg Grating (FBG) sensors should be deployed on the capping beams to identify potential slip surfaces [3]. For mechanical response monitoring, vibrating wire strain gauges should be embedded in the support piles to monitor changes in bending moment along the pile shaft. For environmental effect monitoring, pore water pressure gauges and piezometers can be chosen to monitor water pressure changes on the wall side. Inclinometers should be used to capture deep-seated horizontal soil displacement. Install static levels and crack meters on surrounding buildings, simultaneously monitoring vibration velocity and frequency to assess the impact of construction on existing structures. Construction units can also opt for a combination of manual and automated monitoring. Automated monitoring systems can be used to collect key indicators and transmit them wirelessly. Manual precision measurements should regularly calibrate the automated system, improving the accuracy of supplementary point measurements. Multi-dimensional monitoring and early warning for deep excavation support construction should be matched with a three-level warning mechanism, setting different colored warning levels. A red warning indicates the construction faces extreme risk and must stop immediately; a yellow warning indicates that the risk is approaching the threshold, requiring the construction unit to activate emergency plans. An orange warning requires the construction unit to continuously increase monitoring frequency and adjust parameters based on the construction situation.

4.4 Implementing Whole-Process Responsibility Closed-Loop Management

To ensure the construction safety and quality of deep excavation support structures, geotechnical engineering needs to build a responsibility closed-loop management system covering the entire cycle of design, construction, monitoring, and acceptance. First, establish a multi-party responsibility subject linkage mechanism, solidifying the rights and responsibilities of all parties through the signing of responsibility statements. The entire construction process should be broken down into multiple key control nodes, including support pile hole acceptance, reinforcement cage hoisting, capping beam pouring, etc. Construction units should use BIM technology to build an IoT monitoring system, deploying intelligent sensors on the support structure to collect parameters such as displacement, settlement, and stress in real-time. On this basis, a digital platform for construction management should be developed to achieve whole-process traceability from problem discovery to resolution. Furthermore, construction units must establish efficient information circulation mechanisms. Daily meetings and weekly coordination meetings should serve as fixed nodes for summarizing and analyzing construction data and monitoring data. Site personnel should report discovered problems immediately according to procedures, forming a complete information closed loop of problem discovery, reporting, analysis and decision-making, and on-site execution.

4.5 Implementing Hierarchical Management and Control of Risk Sources

Construction control of deep excavation support structures in geotechnical engineering should implement a hierarchical management and control strategy for risk sources, building a risk grading system based on dynamic identification. Combining geological survey reports, surrounding environmental data, and construction method characteristics, potential risk sources such as support structure instability, soil collapse, groundwater leakage, and settlement of surrounding structures should be systematically identified. On this basis, choose the LEC evaluation method or risk matrix method for quantitative assessment, dividing risks into four levels: major, significant, general, and low risk, and formulate a dynamically updated risk list. Differentiated control measures should be implemented for different risk levels [4]. For major risks, special schemes need to be established, using automated monitoring systems to provide real-time feedback on displacement and settlement data. Significant risks can be prevented by strengthening process acceptance, increasing the frequency of ultrasonic flaw detection, and reserving standby dewatering wells. For general risks, pre-shift technical briefings should be conducted well. Low risks can be managed routinely using standardized operating procedures and regular inspections. Additionally, construction units should utilize automated monitoring technology to monitor key indicators such as excavation deformation, strut axial force, and groundwater level in real-time. Monitoring data should be compared with design warning values. Upon detecting abnormalities, adjustment measures should be taken according to the pre-plan to achieve dynamic closed-loop risk management. The transmission of risk information requires the establishment of smooth communication mechanisms, holding regular risk analysis meetings. Especially for major risks, emergency drills must be organized regularly to ensure all personnel are familiar with escape routes and emergency response procedures.

5. Conclusion

In summary, the optimization design and construction control of deep excavation support structures play an important role in promoting the development of geotechnical engineering construction. Reasonable and effective support structure design can ensure the safety and stability of engineering construction, achieving simultaneous improvement of economic and social benefits. Therefore, construction units should attach importance to the refined design of construction schemes, carry out multi-dimensional monitoring and early warning, implement whole-process responsibility closed-loop management, and implement hierarchical management and control of risk sources, thereby providing guarantees for urban construction and infrastructure development.

References

[1] Yang Zilin. Impact and Reflection of Geotechnical Engineering Investigation on Deep Excavation Support Construction [J]. Engineering Technology Research, 2024, 6(15):45-47.

[2] Lin Bin. Research on Key Technologies of Design and Construction of Deep Excavation Support Adjacent to Subways [J]. Guangzhou Architecture, 2025, 53(4):10-14.

[3] Yang Erzhou, Liu Jiaying. Application Research of Deep Excavation Construction Technology in Civil Engineering [J]. China Kitchen & Bathroom, 2025, 24(1):114-116.

[4] Wu Min. Analysis of Deep Excavation Construction Technology in Civil Engineering Construction [J]. Computer Procurement, 2024(27):86-88.