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: With the rapid urbanization process, the development of underground space is needed to be accelerated, and deep excavation engineering has been commonly applied in construction scenarios such as high-rise buildings and subway tunnels. The structural design rationality and construction control precision of geotechnical engineering have a direct impact on the economy and safety. Traditional design of support is based on factors such as geological conditions complex, load calculation and simplified issues have begun to appear wasteful use of resources and schedule delays. The optimization design methods of deep excavation support structures and the fine control of construction are significant issues which IT engineering urgently need to be solved. Deep excavation support structures play a key role in geotechnical engineering, this paper studies its importance of construction control, proposes reasonable and effective optimization design schemes and construction control strategy, providing reference for the development of engineering construction.

1.Introduction

With the space of Urban areas becoming tighter and tighter, it is an important measure to expand urban capacity and optimization the functions of urban in that processes when making use of underground space. The stability of deep excavations, an essential infrastructure facility in underground space development, is crucial for the safety of geotechnical engineering and surrounding environment. Nevertheless, the deep excavation engineering has extremely complicated geological conditions and high construction risks, which form numerous risk challenges for the design and construction process of the support structure. Traditional approaches to the support structure design are inadequate for modern geotechnical engineering. Thus, the in-depth study of optimization design and construction control strategy for deep excavation support structures in geotechnical engineering is very important from a practical perspective.

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

2.1 Ensuring Construction Safety

The deep excavation stage presents intricate geological conditions to geotechnical engineering. Strengthening the construction control of deep foundation pit support can be effectively carried out to ensure the overall safety of construction during the process, so as to avoid dangerous accidents such as excavation collapse and ground settlement. At the same time, through effective control measures in the construction of underground space, smoothly implement the scheme design of deep excavation support structure. The piecing together of several separate steps—from hole formation for support piles to the placement of reinforcement cages—will reinforce the foundation that supports this structure, helping prevent failure modes such as destructive strength deficiencies and excessive deformation during deep excavation. At the same time, scientifically and reasonably controlling construction measures can enable construction units to control various data such as settlement and displacement in a timely manner, eliminating potential safety hazards at the first time

DOI: 10.25236/icacel.2025.124

they are discovered.

2.2 Ensuring Project Schedule

In geotechnical engineering, deep excavation support is a key stage in the early construction of underground works; its construction period significantly influences the commencement time of subordinate projects. The deep excavation support should be supported by construction control to ensure that various processes are connected smoothly and progress effectively, and that problems such as process disorder or excessive waiting time do not lead to schedule delays. In addition, when the geological conditions and factors affecting both sides of surrounding environment have been fully explored under effective construction control strategy, the project can smoothly reach plan and finally achieve delivery and use target.

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

3.1 Optimizing Support Structure Type Selection

In the optimization design stage of deep excavation support structures in geotechnical engineering, the type selection optimization of support structure must rely on engineering geological condition, environmental constraints in surroundings and economic requirements to conduct multi-dimensional comprehensive analysis. Plant Construction Unit shall perform detailed geological survey and environmental investigation, clarify important parameters such as the distribution of soil layer, groundwater condition and underground channel distribution, provide basic data support for type selection in support structure. Furthermore, an evaluation index system for types of support structures should be developed and alternative support schemes had better use the Analytic Hierarchy Process (AHP) to quantitatively rank. In example, in deep excavation projects in narrow urban areas, you may want to prioritize prefabricated support structures that have small footprint and low noise during construction. For the site with uniform soil layer and disposal depth of 3 m, it can evaluate economic scheme as soil nailing wall or composite soil nailing wall, and lay a foundation for further detailed design [1]. Then, multi dimensional comprehensive quantitative evaluation and optimization of the selected feasible schemes range should be conducted through refined design and analysis. Prediction of excavation deformation, internal forces of the support structure, and impact on surrounding buildings should be carried out using numerical simulation technology for each scheme. Establish a quantitative evaluation system from safety, economy, schedule and other dimensions. Using the AHP method in the last stage can comprehensively score each scheme according to project-specific needs and select the support structure type that strictly meets safety and environment prerequisites, which completes optimization selection.

3.2 Dynamic Adjustment of Structural Parameters

Dynamic adjustment of structural parameter is the essence to improve scientific and economic nature during geotechnical engineering deep excavation support structure's optimization design. Real-time data collection should be conducted by construction units using automated monitoring equipment for key parameters (eg support structure deformation, soil lateral pressure, etc.) during the excavation stage. Construction conditions and environmental factors are also recorded simultaneously. Based on this, a three-dimensional numerical model should be constructed using finite element software, and the support structure, bracing system and soil constitutive relationship should all be parameterized. It is necessary to do sensitivity analysis for key parameters that significantly impact support safety and formulate quantitative relational equations between parameters to provide a theoretical basis for dynamic adjustment of mining. The whole process based on an information platform, for data fusion and reverse analysis, carried out the inversion calculation from monitoring data of actual mechanical parameters of soil, corrected numerical model and prediction multi-scheme comparison, to realize fine adjustment for support parameters.

3.3 Collaborative Optimization of Construction Technology and Processes

In geotechnical engineering, the optimization design should emphasize collaborative optimization of construction technology and process through the deep excavation support structure as the center. Dynamic construction simulation models should be developed for geological conditions and support structure types. Conduct in-depth research on the spatiotemporal coupling relationships between different construction processes, as well as between these processes and various elements involved in the construction of support piles, anchor cables, and anchor walls; perform network-based conflict risk assessments and identify critical paths; and subsequently apply Building Information Modeling (BIM) technology to integrate process parameters in foundation engineering. Example, in the case of constructing diaphragm walls for segmented construction, one can go with alternate panel method. The actual pouring of adjacent panel construction in a series would cause temperature difference and high tension, therefore non-productive waiting time occurs. When it comes to construction units, there is an option of constructing the support structure in different standardized parts. Setup intelligent monitoring systems to feed back support structure deformation, soil displacement and other data. The final monitoring results can be used to optimize the pre-stress of anchor cables, and its adaptation relationship with process execution and geological conditions can be established.

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

4.1 Developing Refined Construction Scheme Design

It is a key element of project safety, quality, and efficiency developing the construction scheme construction control design of deep excavation retaining structure. The specific technical strategies should be realized dynamically according to the geological condition, structural characteristics and construction environment.

The construction units are the first to refer to geological survey data and construct a 3D geological model for excavation. In this step, the finite element numerical simulation should be applied to study soil deformation, support force and groundwater seepage pattern under various working conditions. The parameters of support can be modified in real time according to the actual geological conditions exposed during excavation for complex strata such as soft soil and sand layers, so that the support system has adaptability to the geological conditions [2].

Second, the excavation shall be segmented into layered construction units, reporting the common depth of excavation and length of segment for each layer. Intelligent monitoring equipment may be adopted during the preparation of standardized operating procedures for support structure construction to conduct real-time feedback on raw data regarding quality and achieve quality control in key processes .

Finally, the construction units must break down the design scheme into quantitative controllable parameters for actual execution of construction. Once some parameters deviate, a feedback mechanism can be used to immediately adjust the subsequent construction parameters dynamically and optimize them. For each significant risk, detailed and practical emergency plans need to be developed. It is important that emergency plans are scripted and executed with the construction scheme and monitoring plan so that when dangers occur, losses can be mitigated.

4.2 Standardized Control of the Whole-Process Construction Technology

In the field of geotechnical engineering, methods for supporting deep excavations are established through a standardized control system covering the whole cycle from design to construction and monitoring, which enables ensuring both stability of the support structure and surrounding environment. Preparation of special construction scheme, organization to expert demonstrate and technical disclosure shall be completed before construction. A good based on the geological survey report to do the verification and support design, clarify each process technical parameters and acceptance criteria. Earthwork excavation should be consistent with layered and segmented excavation, symmetrical balance. The excavation depth of each layer shall meet the requirements for both the design and technical sections when supporting, no over-digging or undercutting is allowed. Meanwhile, the theory of temporal and spatial effect can be used to control the pace of excavation in earthwork excavation. The construction of support structure should be immediately executed after the excavation step, which means that it will take shorter time to expose to surrounding environment. Instead pile construction mode should be selected during support pile process. Next, Construction of nearby piles can only follow after 70% of concrete strength achieved for the adjacent pile. Control the pile position displacement within 50mm. During the dewatering construction stage, we should strictly standardize well pipe installation and backfilling of filter material. Dynamic water level drawdown monitoring is done to ensure the dewatering effect meets excavation requirements. An automated monitoring system comprising the excavation itself and the surrounding environment should be utilized during all phases of construction. To this end, continuous monitoring is needed for the key indicators (e.g., support structure displacement; settlement; strut axial force; groundwater level). Warnings thresholds should be multi level The initial response can be achieved through an informationalized construction, and the plan will be dynamically optimized as data interference or outliers have been detected in advance. The management model after construction should ensure that all construction process records, inspection reports, monitoring data etc.are turned into standardized as-built materials to provide reliable data for the next similar project.

4.3 Implementing Multi-Dimensional Monitoring and Early Warning

For geotechnical engineering, the construction control of deep excavation support structure should establish a multi-parameter collaborative monitoring network to realize multi-dimensional monitoring and early warning. Simultaneous tracking and monitoring of the horizontal displacement and vertical settlement quality of support pile tops in real-time, using a combination of total stations, 3D laser scanners, and GNSS reference stations for stress concentration areas such as corners and sections with changing cross-sections. FBG sensors must be installed on the capping beams to detect potential slip surfaces [3]. Mechanical Response Monitoring: During this step, it is recommended to embed vibrating wire strain gauges in the associated support piles (primary and secondary) for monitoring bending moment changes along the pile shaft. Pore water pressure gauges and piezometers can be selected for monitoring the monitoring of seepage water pressure changes on the wall side, if there are needs to analyze environmental effects. Deep-seated horizontal soil displacement is captured using inclinometer. So, if the construction within that subdivision is going to happen towards an existing structure, you can install static levels and crack meters on buildings around that job site while maintaining vibration velocity and frequency monitoring. A hybrid approach using a mix of manual and automated monitoring can also be used by construction units. Automatic protocols for continuous monitoring can be designed to collect important signs and transmit them through wireless communication. The automated system can be calibrated by manual precision measurements regularly, allowing for more accurate supplementary point measurements. Multi-dimensional monitoring and early warning for deep excavation support construction should be with a three-level warning mechanism, provides different colored warning levels. A red warning shows that the construction is at extreme risk and cannot continue, while a yellow warning indicates that the risk has approached the limit, requiring the construction unit to launch emergency plans. The orange warning requires the construction unit to continuously increase monitoring frequency and adjust parameters according to the construction situation.

4.4 Implementing Whole-Process Responsibility Closed-Loop Management

In order to maintain the construction safety and quality of deep excavation support structures, geotechnical engineering must establish a responsibility closed-loop management system traversing through all cycle of design, construction, monitoring and acceptance phases. Formulate and establish the multi-party responsibility subject linkage mechanism, and clarify that all parties implement their respective rights and responsibilities by signing responsibility statements. The whole construction process should be divided to several control key nodes like support pile hole acceptance, reinforcement cage hoisting, capping beam pouring and so on;Construction unit uses BIM technology to establish the IoT monitoring system and puts intelligent sensors on the support structure to collect parameters including displacement, settlement,,stress in real time. Therefore, a digital construction management platform should to achieve whole-process traceability from problem discovery to solution. Moreover, construction units should establish effective information circulation mechanism. Construction data and monitoring data will be summarized and analyzed in daily meetings, with fixed nodes for weekly coordination meeting. Site personnel to immediately report found problems, according to procedures, complete the process of problem discovery, reporting, analysis and decision-making and on-site implementation of information closed loop.

4.5 Implementing Hierarchical Management and Control of Risk Sources

Deep excavation support structures in geotechnical engineering are equipped with a hierarchical management and control strategy for risk sources, which require construction control based on dynamic identification of the risk grading system. By the time of geological survey report, surrounding environmental information and construction method should comprehensively identify potential risk source such as support structure instability, soil collapse, groundwater leakage and adjacent building settlement. Based on this, select LEC evaluation method or risk matrix method when carrying out quantitative assessment, classify risks into four levels (major, significant, general and low risk), and prepare risk list which should be updated dynamically. For different risk levels differentiated control measures are to be applied [4]. For significant risks, special schemes should be put into place with automated monitoring systems that can periodically provide dataset updates of dislocation and released — in real time. Enhancing process acceptance, increasing frequency of ultrasonic flaw detection and stand reserving standby dewatering wells can avoid significant risks. General risks are conducted well through pre-shift technical briefings. Routine need of low risk can be aware easily as its use adherence to standardized operating procedures and inspection in a scheduled way. In addition, construction units should implement automated monitoring technology to constantly monitor key indicators, such as excavation deformation, strut axial force and groundwater level. We should compare the monitoring data with design warning values. After discovery of anomaly, adjustment needs to be carried out based on pre-defined plan for dynamic closed-loop risk management. It is necessary to set up smooth channels to transmit risk information and hold regular risk analysis meetings. It is critical that the household conduct emergency drills on a regular basis, particularly for high-forgetfulness risks, and that each person has sufficient awareness of escape routes and actions in the event of an emergency.

5. Conclusion

To sum up, the optimization design and construction control of deep excavation support structures are crucial in facilitating geotechnical engineering construction development. The construction design of support structures is reasonable and effective, which can guarantee engineering construction safety and stability, at the same time to realize the economic benefits and social benefits simultaneously improve specific purpose. For that, construction units must value the systematic design of construction plans, do multidimensional monitor and early-warning in advance, the overall responsibility closed-loop management of the whole process, hierarchical management and control risk source for urban project and infrastructure development to provide guarantee.

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.