Research on Shotcrete and Anchor Support Technology for Deep Excavation Slopes in Geotechnical Engineering Design

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Abstract: In recent years, with the rapid development of high-rise buildings and underground engineering, the application of deep excavation engineering in the field of geotechnical engineering has become increasingly widespread. The stability of slopes is directly related to the overall safety of the project and has become a core concern of the industry. Shotcrete and anchor support technology has gradually become one of the mainstream choices for deep excavation slope support due to its fast construction speed, controllable cost, and minimal disturbance to the surrounding environment. This study, based on the practical needs of geotechnical engineering design, deeply analyzes the mechanism of shotcrete and anchor support technology, systematically reviews key points in the design stage, and integrates the entire construction process with quality control measures, aiming to provide a practical reference for optimizing the application of shotcrete and anchor support in deep excavation slopes in actual projects.

1. Introduction

From the perspective of geotechnical engineering design, selecting suitable support technology and ensuring slope stability are core tasks throughout the entire engineering construction process. Shotcrete and anchor support technology has evolved from anchor rod support and shotcrete support. Its design relies on data obtained from geotechnical engineering surveys and needs to be advanced combined with mechanical analysis. Compared to traditional support methods such as steel sheet piles and row piles, it offers higher construction efficiency, easier cost control, and greater spatial adaptability, making it particularly suitable for deep excavation projects with complex geological conditions and limited construction space [1]. With the improvement of geomechanics theory, the updating of construction equipment, and the advancement of material technology, the application range of shotcrete and anchor support is continuously expanding. However, in complex strata such as soft soil and water-rich ground, issues such as whether the design is adapted to the actual geological conditions and whether the construction links and design requirements can be accurately connected still need to be further optimized and solved with more engineering practice.

2. Mechanism of Shotcrete and Anchor Support Technology for Deep Excavation Slopes

The design core of shotcrete and anchor support technology is to build a stable support system through the synergistic interaction of anchor rods, shotcrete layers, and the reinforced soil mass. Its mechanism of action needs to be comprehensively analyzed in conjunction with the mechanical characteristics of geotechnical engineering and can be divided into three aspects:

2.1 Anchoring Effect of Anchor Rods

Based on the stratigraphic distribution data obtained from geotechnical engineering surveys,

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designers embed one end of the anchor rod into the deep stable soil or rock layer of the slope and connect the other end to the shotcrete layer. The tensile parameters of the anchor rod are determined through mechanical calculations. The anchor rod transfers the tensile stress of the surface soil mass to the deep stable stratum, thereby limiting the lateral displacement of the soil and enhancing the anti-sliding stability of the slope [2]. Simultaneously, the grouting process is designed considering the permeability of the stratum, allowing the grout to fully fill the gap between the anchor rod and the borehole wall and bond with the surrounding soil to form a high-strength anchorage section, further strengthening the anchoring effect. This avoids anchor failure due to loose strata and ensures the tensile bearing capacity of the support structure meets the design requirements.

2.2 Protective and Supporting Role of the Shotcrete Layer

Based on the calculated lateral earth pressure from the geotechnical design, designers guide the construction unit to use high-pressure spraying technology to evenly cover the slope surface with concrete slurry, allowing it to quickly combine with the soil to form a continuous protective layer. From a design perspective, this layer needs to achieve dual functions: first, to isolate the infiltration and immersion of rainwater and groundwater into the slope soil, preventing the softening of the soil and the consequent reduction in shear strength. Therefore, the thickness and density of the layer need to be determined based on the site's hydrogeological conditions. Second, to restrain the dispersed slope soil into a whole, the lateral earth pressure to reduce the risk of local collapse, and simultaneously transfer the load to the anchor rods, sharing the support pressure with them. Hence, the strength and stiffness of the layer need to precisely match the calculated earth pressure value [3].

2.3 Synergistic Interaction between the Support System and the Soil Mass

During the geotechnical engineering design phase, designers must fully consider the interaction between the support system and the slope soil, avoiding isolated design of the support structure. On one hand, the support structure can adjust the stress distribution state of the soil, enhancing its shear strength and deformation resistance. On the other hand, the soil exerts a reaction force on the support structure, forming an interdependent force system of "support-soil." To ensure the synergistic effect, designers need to verify this synergy through numerical simulation or mechanical analysis, ensuring the support system continues to function stably over the long term.

3. Key Design Points of Shotcrete and Anchor Support Technology for Deep Excavation Slopes

3.1 Integration of Preliminary Geological Survey and Design Data

Before conducting the shotcrete and anchor support design, designers must base their work on the geological survey as the core foundation. The survey team should use drilling, in-situ testing, and laboratory tests to clarify key parameters such as the distribution, density, and cohesion of each soil layer. These data directly determine core design elements like anchor rod length and layer thickness, and accurately locate potential sliding surfaces, providing a basis for subsequent force calculation and stability analysis. The survey team needs to determine the buried depth, type of groundwater level, and the permeability coefficient of the strata. Designers use this to assess the impact of groundwater on slope stability, preventing soil softening due to immersion. During the design phase, designers must simultaneously plan drainage or dewatering measures, considering both the stability of the support system and the safety of surrounding buildings, to prevent ground settlement caused by dewatering[4]. Furthermore, designers need to conduct on-site investigations of the environment around the excavation, determine the allowable deformation value of the slope based on environmental protection requirements, and use it as a core indicator for the deformation control design of the support structure.

3.2 Determination of Support Parameters

Designers need to balance safety and economy based on excavation depth, geological conditions, and environmental constraints. In anchor rod design, it is necessary to ensure the anchor rod length covers the potential sliding surface. The length of the anchorage section is calculated based on the frictional resistance of the stratum to ensure sufficient anchoring force, and the length of the free section must meet the constraint of soil displacement. In areas with poor stability such as soft soil interlayers, the anchor rod spacing can be appropriately reduced. In water-rich or corrosive strata, corrosion-resistant anchor rods must be selected [5]. The strength grade of the shotcrete layer should not be lower than the basic standard. In deep areas with high lateral earth pressure, the strength grade can be increased. The layer thickness needs to match the soil stability and should be appropriately increased when the surface is uneven or the soil is loose. The specification and spacing of the reinforcement mesh are set based on the internal force calculation of the layer. Connection bars must ensure a firm connection between the reinforcement mesh and the anchor rods to avoid disintegration of the support system. In the design of the drainage system, designers need to consider the site catchment and groundwater conditions: intercepting drains should be away from the slope edge, and their cross-sectional size and slope must ensure smooth drainage; drainage ditches are arranged along the slope gradient and should be denser in areas with significant groundwater seepage; drainage blind ditches are set at the lower part of the slope or the bottom of the excavation, and the filler material must match the permeability of the soil to prevent pore clogging.

3.3 Force Calculation and Stability Analysis of the Support Structure

After determining the support parameters, designers need to verify the feasibility of the scheme through calculations. The force on the anchor rods is calculated using the limit equilibrium method to verify the tensile strength of the anchor rods and the frictional resistance of the anchorage section. Simultaneously, construction loads, additional rainwater loads, and seismic loads should be considered to avoid anchor failure under extreme conditions. In the calculation of the shotcrete layer, designers calculate the lateral earth pressure using Rankine's or Coulomb's earth pressure theory to determine the internal forces of the layer, verify the strength and stiffness of the layer, and ensure the layer is tightly combined with the soil to prevent peeling. In the overall stability analysis of the slope, designers use the limit equilibrium method to calculate the safety factor, ensuring it meets code requirements. The analysis must include adverse factors such as seismic action, groundwater seepage force, and construction loads. Seismic condition analysis must be specifically conducted in earthquake-prone areas.

4. Construction Process and Quality Control Measures for Deep Excavation Slope Shotcrete and Anchor Support Based on Geotechnical Engineering Design

4.1 Construction Preparation Stage: Design Transformation and Material Control

During the construction preparation stage, the core task for the construction unit is to translate the design parameters into operational plans and ensure material quality. In terms of design parameter transformation, personnel should first be organized to clear the excavation site, remove debris and obstacles, and level the ground surface. When erecting construction scaffolding, the structure should be designed considering the excavation depth and actual construction loads, determining the upright spacing and ledger step distance, and conducting force checks to ensure the scaffolding's load-bearing capacity and avoid collapse later [6].

Equipment selection must follow design requirements: anchor rod drilling rigs should be selected based on the designed borehole diameter and depth; impact type is suitable for hard rock, rotary type for soft soil, ensuring fast and good drilling; shotcrete machines should have their air pressure and spraying volume adjusted in advance, and test sprays should be conducted on samples to confirm whether the concrete density can achieve the design strength. Additionally, technical disclosure is crucial. Technical personnel need to explain the design key points using drawings, combined with previous engineering cases and precautions, so that construction personnel truly understand the design intent.

Material control must cover the entire process: upon arrival of anchor rod steel bars and steel strands, check the certificate of conformity and inspection report, verify specifications and materials with the design unit, then sample and send for third-party testing of mechanical properties; the cement used for shotcrete should be ordinary Portland cement of the design strength grade, check the production date; sand and gravel must control mud content and particle gradation; use potable water for mixing; the reinforcement mesh should be processed according to design specifications, with checking spacing and weld points; grouting materials should be mixed according to the ratio, use weighing scales to control the amount, measure slump to check fluidity, ensuring materials comply with design requirements from the source.

4.2 Excavation and Support Construction Stage: Process Connection and Process Control

The construction unit needs to excavate and support according to the designed requirements, ensuring smooth processes and controllable quality. During excavation, proceed layer by layer, matching the depth of each layer with the support height; slow down the excavation speed in soft soil strata, and use layered breaking in hard rock strata; after excavation, leave a layer for manual trimming, remove loose soil from the slope, ensure the gradient is the same as the design, and pay attention to under-excavated areas, manually trimming them to the design elevation [7].

After excavation is completed, the stratum needs to be inspected. Technical personnel use ground-penetrating radar on-site to scan and compare the actual stratum with the survey design, focusing on identifying detected soft soil interlayers, karst caves, or underground pipelines. If discrepancies are found, work must be stopped immediately, and the design and survey units notified to jointly decide on adjustment plans, documented as written change orders. Work can only continue after all parties sign, ensuring the excavation adapts to the actual geology.

Anchor rod construction must strictly follow design requirements: surveyors use total stations to set out lines according to the design position and then verify the coordinates; construction personnel use the selected drilling rig to drill holes, record encountered stratum conditions, adjust drilling parameters when encountering hard rock or boulders, and use high-pressure air to blow out debris and accumulated water after drilling; when placing the anchor rod body, ensure it is straight and check if the grouting pipe is clear; the grouting personnel mix the grout according to the design ratio, use the bottom-up grouting method, control the pressure and amount, and stop only when grout overflows from the hole mouth. After the grout initial set, sample pull-out tests for anchoring force are conducted. The next process can only proceed after passing the test.

The reinforcement mesh and shotcrete must maintain integrity. The reinforcement mesh is laid close to the slope, with overlap length according to design requirements, and fastened firmly to the anchor rods with connection bars. Quality inspectors check flatness and connection quality; shotcrete is mixed according to the design mix ratio, sprayed layer by layer from bottom to top, controlling thickness, distance, and angle. The surface is leveled before final set, and after setting, water is sprinkled or geotextile is covered for curing. At the end of the curing period, the layer thickness and strength are tested again, and re-spraying is required for substandard areas. Simultaneously, the drainage system is constructed along with the support, with intercepting drains and drainage ditches built according to the design location and size.

4.3 Support Monitoring and Optimization Stage: Dynamic Control and Quality Traceability

The construction unit needs to establish a comprehensive support monitoring system to achieve dynamic management and quality traceability. When formulating the monitoring plan, arrange monitoring points at key locations of the slope according to design requirements, such as displacement points at the slope top, stress points at the anchor rod heads, and strain points on the concrete layer, with density according to specifications, covering dangerous areas. During monitoring implementation by the construction unit, the frequency must be clear: measure once daily during construction, increase to 2-3 times during rain or changes; measure once every 3-5 days when not working, depending on slope stability. Monitoring personnel use high-precision equipment, such as GNSS displacement instruments and stress sensors, to record horizontal and vertical displacement of the slope, anchor rod tension, and layer stress, compiling data into reports on the same day.

The construction unit must compare monitoring data with design allowable values. If displacement approaches the upper limit or tension suddenly increases, work must be stopped immediately, technicians organized to find the cause, and the design unit notified promptly. The design unit determines a reinforcement plan based on the abnormal data, and the construction unit implements it, such as adding anchor rods, densifying the reinforcement mesh, or thickening the layer. Monitoring continues after reinforcement until data stabilizes, ensuring the safety of the support system.

The construction unit must also maintain good documentation throughout the process: material test reports, construction logs, monitoring data, and change orders should be archived according to the project phase. Key nodes, such as anchor rod pull-out tests and concrete strength tests, should record time and results. Simultaneously, establish a quality responsibility traceability system, clarify the responsible person for each process, record information of construction and inspection personnel, so that responsible persons can be identified in case of quality issues, achieving closed-loop management of design, construction, and monitoring [8].

5. Conclusion

The construction and quality control of shotcrete and anchor support for deep excavation slopes must always be centered on geotechnical engineering design. Through accurate translation of design requirements, strict control of material and process quality, and dynamic monitoring and optimization, the construction unit can ensure the stability of the support system. From preliminary preparation to later monitoring, every link must be closely connected to the actual geology and engineering needs, not only solvingproruption problems during construction but also accumulating practical experience, providing reliable reference for subsequent similar projects, and promoting the better application of shotcrete and anchor support technology in the field of geotechnical engineering.

References

[1] Chai, Q. Z. Research on Support Construction Technology for Deep Excavation of High-rise Buildings in Thick Soft Soil[J]. China Construction Metal Structure, 2025, 24(10): 34-36.

[2] Zhou, X. Y. Research on Shotcrete and Anchor Support Technology for Deep Excavation Slopes in Geotechnical Engineering Design[J]. Modern Engineering Technology, 2025, 4(3): 89-92.

[3] Ren, X. Y. Research on Shotcrete and Anchor Support Construction Technology for Deep Excavation in High-rise Building Engineering[J]. Construction Machinery & Maintenance, 2024(5): 22-24.

[4] He, X. D. Shotcrete and Anchor Support and Quality Control for Deep Excavation Slopes in Geotechnical Engineering Design[J]. Bulk Cement, 2024(1): 27-29,32.

[5] Zhao, L., Chang, W. S. Application of Shotcrete and Anchor Support Technology for Deep Excavation Slopes in Geotechnical Engineering[J]. Sichuan Building Materials, 2021, 47(9): 78-79.

[6] Ma, N. Shotcrete and Anchor Support Technology for Deep Excavation Slopes in Geotechnical Engineering Construction and Its Quality Control[J]. Nonferrous Metals Design, 2021, 48(1): 66-70.

[7] Liu, Z. Y., Shu, Z. L. Application Analysis of Shotcrete and Anchor Support for Deep Excavation Slopes in Geotechnical Engineering Construction[J]. China Metal Bulletin, 2020(11): 153-154.

[8] Li, J. Z. Application of Shotcrete and Anchor Support Technology in Municipal Road Engineering[J]. Smart City, 2020,6(7): 185-186.