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

In the engineering construction process, taking into account the slope hazard characteristics and selecting support technology is a core task from the perspective of geotechnical engineering design. From the origin of support technology perspective, the shotcrete and anchor support originates from the evolution of anchor rod support and was combined with a shotcrete. It must be designed using the data from geotechnical engineering surveys and is yet to undergo further enhancement via mechanical analysis. In this sense, its construction efficiency, cost control ability and spatial adaptability are much higher than that of traditional support methods such as steel sheet piles and row piles, especially for deep excavation projects with complex geological conditions in a small space [1]. As geomechanics theory continues to advance, construction equipment upgrade remains continuing efficient and material technology is constantly developing, its application range of shotcrete and anchor support is expanding. But in a complex stratum, such as soft soil and water-rich ground, whether the design is adapted to the actual geological conditions or the construction connection and design requirements can be connected correctly still need further engineering practice optimization and solution.

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

The essence of the design principle of shotcrete and anchor support technology is to effectively construct a stable foundation support system through the composite effect of anchor rods, shotcrete layers, and reinforced soil mass. It mechanism related to the influence of geotechnical engineering on sugarcane diffusion can be divided into three aspects and must be fully discussed together with the mechanical characteristics of this discipline:

2.1 Anchoring Effect of Anchor Rods

Through the design, one end of the anchor rod is drilled deep in the stable soil or rock layer at the slope foot based on geotechnical engineering survey stratigraphic distribution parameters and the other end is connected to shotcrete. From mechanical calculations, the tensile parameters of the anchor rod are confirmed. The anchor rod transmits the tensile stress of the surface soil mass to the

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deep stable stratum, thus restricting the lateral displacement of the soil and increasing anti-slide stability [2]. At the same time, in the design and construction of grouting process, considering the permeability of the stratum, enable grout to completely fill the gap between anchor rod and borehole wall, bond with surrounding soil, so as to form high-strength anchorage section, enhance the anchoring effect. This prevents the loosening of strata causing anchorage failure and also guarantees that the required strength for tension in steel support bearing capacity is achieved.

2.2 Protective and Supporting Role of the Shotcrete Layer

According to the lateral earth pressure calculated from geotechnical design, designers guide construction unit to uniformly spray concrete slurry with high-pressure spraying technology on the slope surface and allow it to quickly bond with soil layer, forming a continuous protective layer. For the design of this layer, it must fulfil two functions: First, to separate the infiltration and immersion through rainwater and groundwater into the slope soil, which softens and decreases shear strength. Thus, the layer thickness and density must be chosen according to site-specific hydrogeological conditions. And the second purpose reduce lateral earth pressure so as to control slope soil dispersion based on consolidated and increase safety in local excavation and to transfer some of them onto anchor rods, sharing load with it. Therefore the layer needs to have an equal strength and stiffness as the calculated earth pressure value [3].

2.3 Synergistic Interaction between the Support System and the Soil Mass

In the design phase of geotechnical engineering, designers must fully consider the mutual support between the support system and slope soil, instead of separating the design flow of the support structure. In one aspect, the support structure can modify the state of stress transmission inside the soil in order to improve its shear strength and deformation resistance. The soil, in turn, applies a reaction force to the support structure forming an interdependent "support-soil" force system. In order to guarantee the synergistic effect, this synergy needs to be checked and verified by using numerical simulation or mechanical analysis in the presence of other supportive systems, but from a long time point of view (more specifically, through long term involvement).

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

3.1 Integration of Preliminary Geological Survey and Design Data

All design of shotcrete and anchor support must be supported by geological survey, first. The drilling, in-situ testing and laboratory tests should be used by the survey team to clarify important parameters such as the distribution, density and cohesion of each soil layer. These data directly governs the core parameters of design such as anchor rod length and layer thickness, accurately locate a possible sliding surface, then lay the foundation for force calculation and stability analysis. Objectives: The survey team must identify the depth of burial, groundwater level and type and pore water coefficient of permeability layers. It is used by designers to analyse the effect of groundwater on slope stability to avoid soil softening from being submerged. Designers need to combine drainage or dewatering plans into the design phase and must also ensure that ground settlement around the excavated site does not risk the stability of the support system or surrounding buildings while dewatering [4]. Moreover, designers must carry out on-site investigations of the surrounding environment by successfully obtaining the allowable deformation value of slope based on environmental protection requirements, which can serve as a core index to determine the design for controlling the support structure degenerate control.

3.2 Determination of Support Parameters

How Designers Strike a Balance Between Safety and Cost Accordingly, designers need to strike this balance with respect to the depth excavated, geological conditions encountered, and environmental conditions. After this, when we design anchor rods, we must ensure that the length of these rods will reach the sliding surface. The crawling section length is determined according to the

frictional resistance of the stratum so that it can provide a sufficient anchoring force, and the free section length needs to meet the soil displacement constraint. By decreasing the distance between anchor rods in the soft soil interlayers under poor stability conditions. In cases of corrosion and water saturated strata, the anchor rods selected must be corrosion-resistant [5]. Shotcrete layer strength grade not lower than basic standard. The strength grade can be enhanced in the deep areas with heavy lateral earth pressure. The thickness of the layer should be such that the stability on soil design is maintained, and if often necessary to increase up to 35% when the surface is uneven or soil loose. The specification and distance of the reinforced concrete mesh are determined according to the internal force calculation of the layer. To avoid disintegration in the stages of a support system, connection bars must ensure lasting adherence between the reinforcement mesh and the anchor rods. In design of drainage system, the site catchment and groundwater condition should be considered: for intercepting drain away from slope edge, its cross-sectional size and slope must reach smooth drainage; drainage ditches are arranged along the gradient of slope to make them more dense in areas where significant groundwater seepage is present; while setting drainage blind ditch should be set on lower part of the slope or bottom of excavation so as to fill material shall in line with soil permeability.

3.3 Force Calculation and Stability Analysis of the Support Structure

Designers go on and check the feasibility of the scheme through calculations after designing support parameters. Limit equilibrium method is used to compute the force acting on the anchor rods applying a design criterion for both the tensile strength of the anchor rods and frictional resistance in anchorage section. They should take into account other concurrent loads like construction, additional rainwater loads and seismic in order to prevent anchor failure when applying the maximum conditions. When designers calculate the data of the shotcrete layer, they mainly utilize Rankine's or Coulomb's earth pressure theorem to calculate the lateral earth pressure, then through analyzing these forces with both stability and deformation to ensure the shear and flexural strength and tight connection between ground soil layers. For the overall stability analysis of the slope designers utilize the limit equilibrium method to calculate a safety factor and verify that it is above code. The analysis captures detrimental elements like seismic motion, groundwater flow pressure, and construction loads. In earthquake-prone areas, it is a necessity to specifically analyze the seismic condition.

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

In the stage of construction preparation, it is mainly to convert the design parameters into operational plans, and to ensure the quality of materials in a timely manner for the construction unit. When transforming the design parameters, personnel should first be organized to clean up the excavation site, remove debris and obstacles, and flatten on the surface of the ground. In the design depth of excavation and the actual construction load, upright spacing and ledger step distance during the erection of scaffolding for acceptable force checks and service requirements, thus avoiding collapse in future [6].

The type of equipment is selected according to the design requirements: anchor rod drilling rigs are required to be selected in accordance with the designed borehole diameter and depth, hard rock is suitable for impact type, soft soil is suitable for rotary type, which must meet the drill lifted fast and good; shotcrete machines first need to adjust air pressure and spraying volume according to the scheme before construction, it should also do test spray on a few samples first if they can get concrete density can reach design strength. Additionally, technical disclosure is crucial. The design key points need to be explained by drawing and combined with the previous engineering cases and precautions, so that construction personnel really understand the design intent.

Material control should cover the whole process from the arrival of anchor rod steel bars and

steel strands to checking their certificate of conformity and inspection report, confirming specifications and materials with design unit (sampling to send for third party testing of mechanical properties); cement used for shotcrete must be ordinary Portland cement meeting design strength grade with checking producing date; sand gravel mud content particle gradation shall also be controlled as well as, potable water absolute mixing in line; the reinforcement mesh processed according to the design requirements like spacing or weld points have been checked too; grouting materials mixed by ratio using weighing scales controlling amount measuring slump so material complying with design requirents which comes from source.

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

The following is the construction specification: The unit must excavate and support according to design requirements, ensuring that processing should be smooth, high efficiency and controllable quality. Excavate step by step layer by layer, the height of each digging is less than or equal to the support height; reduce excavation speed in soft soil strata, and implement layered breaking if conditions permit in hard rock strata; after excavation, leave a horizontal layer for manual trimming, wipe loose soil on the slope surface with a broom or dustpan shovel to adapt the slope angle supports its design value when performing retrieval works, be concerned with areas that are not excavated at all but only have quartz sand located manually trim them down to level [7].

Once the excavation is complete, we still have to check in on that stratum. The technical personnel in the field applies ground-penetrating radar for scanning and comparing actual stratum at site with the survey design, mainly to identify detected soft soil interlayers, karst caves or underground pipelines. If discrepancies are found, stop work immediately and notify the design and survey units, jointly determine adjustment plans; change orders should be manifested as written change orders. No work can commence until each party has signed-off, thereby allowing the excavation to be incorporated into geological reality.

Anchor rod construction should strictly follow design requirements: surveyors set out line using total stations to mark the position and then check coordinates; construction personnel should use the selected drilling rig to drill holes, record encountered stratum conditions, adjust parameters when hard rock or boulders are encountered during drilling, and blow debris and accumulated water after drilling with high-pressure air; directly and straightly put anchor rod body in place, confirm that grouting pipe is less blocked; mixing the grout according to design ratio by grouting personnel (bottom up), controlling pressure and amount of fulid injected into well-hole until cloudy fluid overflows from hole mouth. Pull-out tests are performed to measure anchoring force on samples, utilising the cement base set. Only when the test is passed can the next process be initiated.

Must keep the reinforcement mesh and shotcrete intact. The reinforcement mesh sheet is put down near the slope, with overlap length specified in the design and firmly fastened to anchor rods by connection bars. Quality panels inspected for flatness and connection quality; shotcrete is mixed based on the design mix ratio and sprayed layer by layer from bottom to top while managing thickness, distance, and angle. Final set, before surface leveling, after that curing (water; geotextile covered). Once the curing process is done, the layer thickness and strength are again examined and areas not up to standard must be re-sprayed. At the same time, first of all, it is planned to build drains along with a support system: intercepting drains and drainage ditches are performed in accordance with the design location and dimensions.

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

The construction unit should set up a complete support monitoring system to perform dynamically managed and traceable quality. In the design of monitoring plan, place the key locations on slope monitoring points according to design requirements: displace points at slope top, stress points at anchor rod heads or strain points in concrete layer with density set as per specification and covering location where potential danger exists. Monitoring will be monitored during the implementation by the construction unit depending on clear frequency: once 1-day measuring data in construction, when it rains or change something should increase to 2-3 times; If not working, analyze, monitor after every 3-5 days way of slope stability. Analysis of monitoring

data collected by personnel is performed with high-accuracy PU equipment like GNSS displacement instruments to measure horizontal and vertical translocations of the slope, instrumented anchor rod tension as well as layer stress, which are written into reports on the same day.

Monitoring data must be compared with design allowable values by the construction unit. If the displacement reaches one of the upper limit or suddenly tension increases, must timely stop working; organize technician to find out the reason and report to a design unit in time. Design unit according to the abnormal data, to determine the reinforcement plan, the construction unit implements measures such as adding anchor rods, densification of reinforcement mesh or thickening the layer. You closely monitor it after reinforcement until data reaches an equilibrium state to ensure support system safety.

The construction unit, meanwhile, has to keep proper records from the site: test reports of building materials, logs of construction progress on-site as well as data collected during monitoring and change orders should be filed along the project phase. Prominent nodes anchors, anchor rod pull-out tests and concrete strength tests should be performed, recording time and results. At the same time, a quality responsibility traceability system is established so that there is no ambiguity about who is in charge of each process and the information of construction and inspection personnel must be recorded to facilitate identification of responsible persons at every level when quality problems arise thus realizing designconstructionmonitoring closed-loop management [8].

5. Conclusion

The design of the shotcrete and anchor support for the deep excavation slopes must always focus on geotechnical engineering designed. The construction unit guarantees the stability of the support system by accurately translating design requirements, implementing control over material and process quality, and conducting dynamic monitoring and optimization. Every link must be well connected with not only the practical geology and engineering needs, while solving problems that arise during construction. The accumulated geotechnical engineering experience and technical testing of shotcrete-anchor support can provide reliable references for subsequent similar project practices in order to promote the better applicationof shotcrete anchor support technology in geotechnicalengineering.

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