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Common Support Structure Solutions For High-fill Slopes

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Abstract

High-fill slopes are susceptible to landslides, collapses and other disasters due to the large filling height and poor soil stability, and need to be supported scientifically to ensure safety. The purpose of this paper is to analyze the applicable scenarios and technical principles, and provide selection basis for engineering practice. Elucidating the reinforcement mechanism and synergistic application value of different technologies to optimize the shear strength and overall stability of slopes and reduce disaster risk, while taking into account ecological restoration and economic benefits and reducing long-term maintenance costs. It can provide theoretical support and practical reference for the design of safe, economic and sustainable slope management programs in complex terrain development.

Keywords: High-fill project, Slope stability, Support structure, Active protection technology, Environmental protection

Анотація

Високонасипні схили схильні до зсувів, обвалів та інших катастроф через велику висоту насипу і погану стійкість ґрунту, і потребують наукової підтримки для забезпечення безпеки. Метою цієї статті є аналіз застосовних сценаріїв і технічних принципів, а також надання основи для вибору для інженерної практики. З'ясування механізму зміцнення та синергетичної цінності застосування різних технологій для оптимізації міцності на зсув і загальної стійкості схилів та зменшення ризику стихійних лих, беручи до уваги екологічне відновлення та економічні вигоди, а також зменшення довгострокових витрат на утримання. Він може надати теоретичну підтримку і практичні рекомендації для розробки безпечних, економічних і сталих програм управління схилами в умовах складної забудови місцевості.

Ключові слова: Проект з високим рівнем заповнення, Стабільність схилу, Опорна конструкція, Технологія активного захисту, Захист навколишнього середовища

Introduction

Because of the large filling height and significant self-weight of soil, high-fill slope is prone to slip, collapse and other geological disasters under the influence of natural camping force and man-made activities, which threaten the safety of surrounding buildings, transportation routes and people. Scientific and reasonable support design can effectively disperse the load, enhance the shear strength and inhibit the deformation of soil through the structure of retaining wall, anti-slip piles, and anchors, etc., so as to avoid the occurrence of disasters and safeguard the safety of people's lives and properties. The support structure can reduce soil erosion, reduce the surface erosion of the slope and maintain the ecological balance of the region through measures such as vegetation restoration and optimization of the drainage system, especially in ecologically sensitive areas to minimize the damage to the natural environment.

Results of the study

In order to obtain the optimal combination of pile-anchor design parameters, Fan R Q, et al. (2025) [1]

used Flac3D software to comparatively analyze the effects of the main parameters of the supporting structure on the deformation of deep foundation pits. In order to explore the reinforcing effect of frame anchor support system on slopes, Zeng H, et al. (2024) [2] based on the limit equilibrium theory, the anchor prestressing force is regarded as a homogeneous force acting on the slope surface, and the functional relationship between the coordinates of the center location of potential sliding surface and the safety factor is established, which can dynamically search the center location area of potential sliding surface. However, this method is only applicable to homogeneous soil slope projects with circular sliding surfaces. In order to study the response of the supporting structure under seismic loading, Li Y, et al. (2023) [3]used the finite element method to investigate the dynamic behavior of slopes under three different reinforcement schemes, namely, unsupported, pile-supported, and pile-anchor-supported, which revealed that anchors improve the shear and bending capacities of piles. In order to analyze the damage mechanism of anchor, beam, and pile-supported slopes, Zheng G, et al. (2024) [4] used the finite difference method to numerically simulate the mechanism of anchor failure and pit collapse, and found that when the anchor fails, it will lead to the destruction of the cover beams and beams, which will lead to the destruction of the piles, accelerating the process of pit collapse. Ma, T., et al. (2022) [5] constructed a simplified calculation method for the support structure under the synergistic action of roof beams based on the elastic fulcrum method and the principle of deformation coordination of pile-anchor structure at the top of the pile and at the anchor end, and found that the roof beams can enhance the bearing capacity of the piles and reduce the displacement of the top of the piles. In order to analyze the effectiveness of micropiles in supporting slopes, Bulko, R., et al. (2024) [6] performed numerical simulations of self-drilling anchored reinforced concrete micropiles supporting slopes using Plaxis 2D, which revealed that the micropiles can significantly improve the stability of slopes.

Commonly used support structure solutions for high-fill slopes.

Anti-slip pile support. Through reinforced concrete piles embedded in the stable stratum below the potential slip surface, the anti-slip moment is formed by utilizing the shear strength of the pile and the friction force of the surrounding rock and soil bodies to balance the downward sliding force of the slope. The piles can be arranged in single or multiple rows, and common forms include circular piles, rectangular piles, and combined pile walls. It is suitable for deep sliding (depth of sliding surface >5m), large thrust slopes, especially for filling slopes or natural slopes with weak interlayers. However, the construction period of this program is long, the cost is high, and it is difficult to form piles in complex strata (e.g. karst area).

Soil nail wall support. Soil nails (reinforced or steel pipes) are implanted in the interior of the slope at a certain spacing, forming a reinforcement by grouting and synergizing with the sprayed concrete layer on the slope surface to form a composite gravity retaining wall. Soil nails constrain soil deformation through friction and bonding to improve overall stability. It is suitable for excavated slopes with a height of ≤15m, especially for loose strata such as sandy soil and pulverized soil. The length of soil nails is generally 0.5~1.0 times of the slope height, with horizontal spacing of 1~2m and inclination angle of 5°~20°. However, it is not applicable to high water pressure, fluid-plastic soil and strong expansive rock and soil.

Anchor cable support. There are two types of anchors: non-prestressed anchors and prestressed anchors. Anchor cables are bonded to the geotechnical by drilling and grouting, while anchor cables are actively reinforced by prestressing. The anchored section provides the pull-out force and the free section transmits the tensile force to the external load-bearing structure (e.g., lattice girders, baffles), forming an “active reinforcement” system. Non-prestressed anchor cable is suitable for shallow reinforcement (anchorage depth 3~8m), mostly combined with lattice beams for weathered rocky slopes. Prestressing anchors are suitable for high slopes or critical projects that need to control deformation, with anchoring depths of up to 15~50m and design tonnages of 100~3000kN. Prestressing anchors require high construction accuracy and regular monitoring of long-term prestressing losses.

Reinforced earth retaining wall. Geosynthetics (e.g. geogrids, geotextiles) are laid in layers in the fill, limiting lateral deformation through the friction between the reinforcement and the fill to form a self-stabilizing reinforced soil structure. Walls can be made of modular concrete panels or flexible materials such as eco-bags. It is suitable for fill slopes (height ≤ 20m), especially at sites with low foundation bearing capacity or where rapid construction is required. However, it has strict requirements for filler quality (particle size, gradation), and long-term durability is affected by ultraviolet light and chemical and biological erosion.

Lattice anchor support. It consists of reinforced concrete lattice girders (frames) with anchor cables (ropes). The lattice girder divides the slope surface into grid cells and transfers the load to the deep stabilizing layer through the anchor cable, forming a "girder-anchor-soil" synergistic force system, which has the functions of both surface layer protection and deep layer reinforcement. It is suitable for rocky slopes (e.g. highway cut slopes) with severe weathering of the surface layer, which need to be ecologically restored. It is complicated to construct and is not suitable for slopes with loose soil or high deformation.

Retaining wall support. This scheme resists the earth pressure through the self-weight of the wall or structural stiffness and is categorized into gravity, cantilever, and buttress types. Gravity retaining walls rely on self-weight to balance earth pressures; cantilevered types are stabilized by moment balancing between the heel and toe plates. Gravity type retaining wall is suitable for filling slope with height ≤8m, the material can be slurry masonry or concrete, and the foundation bearing capacity is required ≥150kPa. cantilever type/fenestration type retaining wall is suitable for slope with height of 8~12m, and it needs to be equipped with steel reinforcement to resist the bending moment. The method occupies a large space, has poor seismic performance, and high walls are prone to toppling.

Ecological slope protection technology. The method combines the root system of vegetation soil-fixing effect with engineering measures (such as three-dimensional mesh mats, planting bags), through plant transpiration to reduce the pore water pressure, while using flexible structures to adapt to the deformation of the slope, to achieve the dual objectives of protection and ecological recovery. It is suitable for low-risk, slope <45 ° soil slope or rocky slope surface greening. Often used in combination with soil nails, lattice structures and other rigid structures to form a "rigid-flexible" system. It has limited protection and requires long-term maintenance for vegetation survival.

Composite support system. In the actual project, using a combination of multiple support technology support system is also often seen. For example, "anti-slip pile + anchor cable" is used for deep reinforcement of ultra-high slopes; "soil nail wall + ecological slope protection" can balance the stability and landscape needs; "reinforced soil retaining wall + drainage system" can solve the problem of seepage on high-fill slopes. The "reinforced soil retaining wall + drainage system" can solve the problem of seepage on high-fill slopes. When selecting applications in specific projects, it is often necessary to comprehensively consider the requirements of slope height, geological conditions, construction period, construction cost and environmental protection, etc., and the optimization analysis of design parameters can be carried out through numerical simulation methods if necessary.

Conclusion

This paper briefly summarizes eight commonly used support techniques for high-fill slopes, describes their working principles, scope of application and limitations, and provides a reference for selecting suitable support techniques, further expanding composite protection techniques and optimizing support parameters in engineering practice.

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