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STABILITY ANALYSIS OF SLOPE SUPPORTED BY PRESTRESSED ANCHOR PILE SLAB BASED ON FLAC3D

Abstract: *Stability problems in high fill slope projects in mountainous and hilly areas have become a key challenge affecting project safety. The article is devoted to discussing the existing research results on the determination of potential slip surface, stability analysis, optimization of support structure parameters, and numerical simulation analysis of high-fill slopes in mountainous and hilly areas. In the article, a FLAC3D three-dimensional numerical model of a typical high-fill slope was established, which revealed the spatial distribution characteristics of potential landslide fracture surfaces of multilevel slopes, and the results showed that multilevel slopes often had more than one potential landslide fracture surface, which needed to be "graded management" in the actual project; A two-parameter orthogonal test was designed and implemented to comparatively analyze the interaction mechanism between the pile-slab-prestressed anchor cable composite support structure and soil, and reveals the sensitivity of the anchoring depth of the pile and prestressing stress of the anchor cable in the prestressed anchor cable-pile-retaining plate support structure to the slope safety coefficient, and the calculation results show that increasing the embedment depth of the pile and increasing the prestressing stress of the anchor cable can improve the slope safety coefficient; The article also reveals that there are critical values of pile embedment depth and anchor cable prestress, beyond which the contribution of increasing the embedment depth or anchor cable prestress to improving the slope safety coefficient will decrease, and further determines the optimal values of pile embedment depth and anchor cable prestress for this typical slope project. The results and ideas in the paper provide technical references for the design and construction of similar projects, as well as methods and ideas for scientific colleagues to further carry out numerical simulations of related projects.*

Key words: High slope, slope stability, numerical simulation analysis, pile-slab-prestressing anchor cable, retaining structure, parameter sensitivity.

Formulation of the problem. With the rapid development of economy and the accelerated evolution of urbanization, the problem of land resource utilization in China, which is "an inch of land is worth a pound of gold", is becoming more and more prominent. In order to meet the demand for infrastructure construction in mountainous and hilly areas and new urban areas, high-fill slope engineering has gradually become an important topic in the field of geotechnical engineering. High-fill slopes usually refer to earthworks with a fill height of more than 20 meters, steep slopes and complex geological conditions, and are widely found in highways, railroads, airports, water conservancy hubs and urban development projects. However, due to the inhomogeneity of the fill material, the nonlinear characteristics of the soil ontological relationship, and the complex coupling effect of external loads (e.g., rainfall, earthquakes, and construction disturbances), the stability problem of high-fill slopes has always been a difficult point in engineering design and construction. If the slope is destabilized, it will cause geological disasters such as landslides and landslides, resulting in serious economic losses and casualties. Therefore, how to assess the stability of high-fill slopes by scientific means and design economically reasonable support programs has become a key problem in the field of geotechnical engineering.

Traditional high-fill slope stability analysis is mostly based on limit equilibrium theory or simplified numerical models, such as Bishop's method and Janbu's method. Although these methods are easy to calculate, it is difficult to accurately reflect the real stress-strain relationship of the soil, the progressive damage process and the interaction mechanism between the retaining structure and the soil. With the progress of computer technology and numerical simulation methods, the finite difference method software represented by FLAC3D (Fast Lagrangian Analysis of Continua in 3 Dimensions) has gradually become a mainstream tool for geotechnical engineering numerical analysis. Based on the explicit Lagrangian algorithm, FLAC3D can effectively simulate large deformation, nonlinear materials and complex boundary conditions, which is especially suitable for the dynamic analysis of slope instability, foundation settlement, underground excavation and other problems. By constructing a three-dimensional geological model and combining elastic-plastic ontological relationship and strength discount method, FLAC3D can realize quantitative assessment of slope stability coefficient, location of potential slip surface and deformation characteristics, and provide theoretical basis for the design and optimization of support structure.

Analysis of recent achievements. In recent years, scientists had carried out a lot of research around the stability of high-fill slopes and support technology. In the aspect of slope stability analysis, Yao Y, et al. (2024) [1, c. 4] developed a slope energy visualization program based on thermodynamic principle from the perspective of energy change using FLAC3D, and carried out a validation analysis through two actual slope cases, which showed that the deformation and destruction of slopes were essentially driven by energy, and there was a correspondence between the energy stabilization stage and slope equilibrium stage, the energy dissipation stage and slope deformation stage, and the energy mutation stage and slope destruction stage, and the coefficient of safety and sliding surface of the slope could be determined by using the energy mutation relationship, and the calculation error was only 0.02. Wang Chongjing et al. (2023) [2, c. 69] simulated and analyzed the stability change law of soil slopes under rainfall conditions by FLAC3D, the increase of daily rainfall will cause the stability of shallow soil body to rise briefly and then decline, when the daily rainfall of 150 mm, the stability coefficient tends to be close to 1, the slope was in the limit state. Liu L, et al. (2024) [3, c. 2] analyzed the local dynamic factor of safety (FOS) of slopes based on the energy criterion, considering the groundwater level, impact load and load location, etc. The study showed that the groundwater level is the main influencing factor of slope stability compared to the load location and impact load and should be prioritized. Bračko, T., et al. [4, c. 4] (2022) used Geo-Studio's SEEP/W module to analyze surface infiltration modeling of slopes and found that when soil permeability was low, the factor of safety decreased during the rainfall period and subsequent days. Nanehkaran Y. A, et al. (2023) [5, c. 3] compared the estimation results of multilayer perceptron (MLP), decision tree (DT), support vector machine (SVM), and random forest (RF) learning algorithms with the objective of slope safety factor estimation based on the computational intelligence and machine learning methods and validated the results by using the Janbu limit equilibrium analysis method (LEM) and GeoStudio for validation. The results showed that MLP>SVM>RF>DT in the order of accuracy of the estimation results, which provided an idea for the intelligent prediction of slope stability. Bardhan A, et al. (2022) [6, c. 8] addressed several artificial intelligence (AI) techniques for machine learning (ML) algorithms, including adaptive neuro-fuzzy inference systems, artificial neural networks, extreme learning machines, functional networks, genetic programming, Gaussian process regression, least squares support vector machines, multivariate adaptive regression spline, minimal maximum probability machine regression, correlation Vector Machines and Support Vector Machines are comprehensively summarized, and challenges and future visions of AI techniques for solving slope stability problems were discussed. Raghuvanshi, T. K. (2019) [7, c. 103] comprehensively discussed the common “planar mode” damage mechanism in layered and metamorphosed sedimentary rocks, stating that planar damage occured when structural discontinuities (e.g., preferred orientations of laminated surfaces, faulted surfaces, or jointed groups) dip towards the valley or excavation direction at an angle that was less than the angle of the gradient and more than the friction angle of the discontinuity. The stability of such slopes depended on geometry, rock type, potential damage surface characteristics, groundwater conditions, dynamic loading and overloading conditions. Liu, X., et al. (2020) [8, c. 3] A direct Monte Carlo simulation (MCS) method for circular and/or non-circular potential sliding surface slopes was developed based on the theory of slope system reliability analysis by limit equilibrium method (LEM). The method could correctly estimate the failure probability of a slope system, which significantly improved the computational efficiency of LEM-based slope system reliability analysis.

In the research of slope support system, Fan R Q, et al. (2025) [9, c. 7] used Flac3D and orthogonal tests to comparatively analyze the influence of five influencing factors, such as pile diameter, pile spacing, anchor pre-stressing, anchoring angle, and number of rows of anchors, on the deformation of the deep foundation pit, and obtained the optimal pile-anchor design parameters, which not only ensured the safety and stability of the foundation pit, but also reduced the construction cost. Luan, L., et al. (2020) [10, c. 3] proposed an analytical model for calculating the horizontal dynamic impedance of group piles connected by an arbitrary pile foundation with a rigid pile cap, and the derived solution could robustly take into account the effect of inter-pile interactions on the impedance of the group piles. The expression took into account the coupling of the source and receiver pile displacements, and the proposed solution could be directly used to determine the frequency-dependent impedance of a group pile consisting of an arbitrary number of piles, but this numerical modeling was difficult to build, so it was not very popular. Zeng H., et al. (2024) [11, c. 1240] developed an analytical model for seismic stability of slopes based on the limit equilibrium theory with frame anchor reinforced slopes. They considered the anchor prestressing force as a homogeneous force acting on the slope surface, and explored its reinforcing effect on the slope and its influence on the slope stability. They also established a functional relationship between the coordinates of the center position of the potential sliding surface and the safety factor, which could dynamically search the center position region of the potential sliding surface, so as to obtained the minimum safety factor and its corresponding center position coordinates. However, this method was only applicable to homogeneous soil slope projects with circular sliding surfaces. Li Y, et al. (2023) [12, c. 4] investigated the dynamic behavior of the slope system and the progressive damage process of piles using the finite element method (FEM) with three different reinforcement schemes, unsupported, pile-supported and pile-anchored supported. The results showed that the shear and flexural capacities of piles were substantially improved in pile-anchored structures, but under simulated seismic loading, cracking occured in the pile near the sliding surface in a very short period of time when the peak ground acceleration arrived. Therefore, for support structures with seismic requirements, it is necessary to reinforce the piles near the sliding surface. Zheng G, et al. (2024) [13, c. 764] numerically modeled the mechanism of anchor failure and pit collapse using the finite difference method. They found that in the anchor– beam– pile support system, when the anchor fails, it leaded to the destruction of the cover beams and cross beams, which triggered the destruction of the piles, and accelerated the process of pit collapse. Therefore, the damage conditions of anchors should be considered in the design of cover (brace) beams to improve the overall safety performance of the support system. Ma, T., et al. (2022) [14, c. 5] Based on the elastic fulcrum method and the principle of deformation coordination of pile-anchor structure at the top of the pile and the anchor end, the computational model of the support structure under the synergistic action of the top beam and the simplified computational method of the internal force, displacement and the overall stability of the side slope were constructed. And combined with engineering cases, the simulation calculations of pile-anchored structures with and without roof beams are compared and analyzed using PLAXIS 3D and Geo Studio. It is showned that the top beam effectively enhances the pile bearing capacity while restricting the development of pile top displacement, and the synergistic effect of the top beam leaded to a more substantial improvement in the safety factor of the slope. Bulko, R., et al. (2024) [15, c. 1269] numerically modeled the self-drilling anchored reinforced concrete micropile supported slopes using Plaxis 2D. The safety coefficients of the slopes before and after reinforcement were also evaluated by the ϕ-c discount method, and the results showed that the reinforcement of micropiles significantly improved the stability of the slopes.

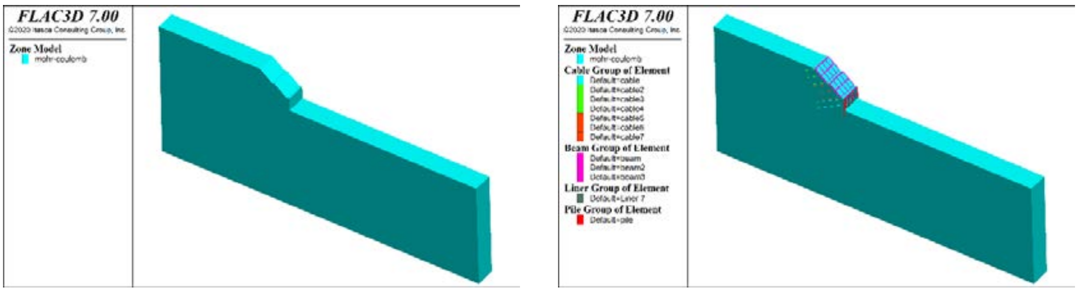
The goal of this study were to reveal the deformation and damage mechanism of high-fill slopes, to explore the interaction mechanism between the pile-slab-prestressed anchor cable composite support structure and soil, to evaluate the sensitivity to the slope safety factor at different support parameters, and to propose the optimal design of the parameters. This study not only provided technical references for the design and construction of similar projects, but also enriched the application method system of FLAC3D in the numerical simulation of high-fill slopes.

Research results. Numerical analysis is a complex method of analysis, but the development of computers has made the implementation of this method for solving problems simple and feasible. In practical engineering problems, it is often the case that a more complex engineering problem is simplified into a physical model, which is then transformed into a mathematical problem to be solved. For engineering problems modeled with continuum medium mechanics, differential equations of motion, geometric equations, and eigenstructural equations generally arise during the solution process. For specific simple engineering problems, which can be solved mathematically based on initial and boundary conditions, the However, for the more difficult engineering problems, due to the complexity of the constitutive relationship (stress-strain relationship), the mathematical solution method makes the problem solution complicated or even infeasible, which can be solved by numerical analysis can achieve good results. In this paper, a systematic numerical analysis of the slope stability of a high-fill slope project using a combination of prestressed anchor pile slab wall and frame prestressed anchor retaining structure was carried out by FLAC3D. The numerical model of the slope before and after support was shown in Fig. 1. The soil parameters of bedrock and fill layers determined from the engineering investigation report were shown in Table 1.

1. Safety analysis of the slope without retaining structure

Safety, economy and aesthetics are the goals of slope management projects. Since there are many potential sliding surfaces on a slope, when the first sliding area is reinforced, it does not mean that the slope will be stabilized, and there is a possibility of destabilizing damage along other potential sliding surfaces. Therefore, the location and shape of the slope slip surface should first be determined, which is especially critical for complex slopes. There are many ways to determine the sliding surface, this paper realized the search of multiple sliding surfaces by setting the boundary conditions to preset the safety height, i.e., the range of h_e heights above the bottom of the model was set as the safety zone (limited to the corresponding normal displacement), as shown in Fig. 2(a). The factor of safety were calculated under different h_e conditions using the strength reduction method, and the potential slip surface and slope safety coefficients were obtained as listed in Table 2, and the corresponding slip surface cloud diagrams are shown in Fig. 2(b)~(d).

As can be seen from Fig. 2, when no retaining structure was installed, the three h_e corresponding conditions all have slip surfaces, and the slip surfaces were through from the bottom of the cor-



(a) Model without retaining structure (b) Model with retaining structure

Fig. 1. FLAC3D numerical model of the slope before and after support

Table 1. Soil parameters of the slope

	Young's modulus E/MPa	Poisson's ratio ν	Cohesion C/kPa	Angle of friction φ/°	Density ρ/(kg/m³)
Filler	10	0.32	40	33	1800
Bedrock	76	0.25	95	45	2200

responding slopes to the top of the slopes, and the slopes were in an unsafe condition. From Table 2, with the sliding surface shear exit moving up, the slope safety coefficient gradually increased, but from the overall point of view the safety coefficient were significantly lower than the specification requirements (especially the first two conditions), the slope tended to be unsafe, and need to be reinforced to ensure the safety of the slope.

Table 2. Options for different safety heights and factor of safety

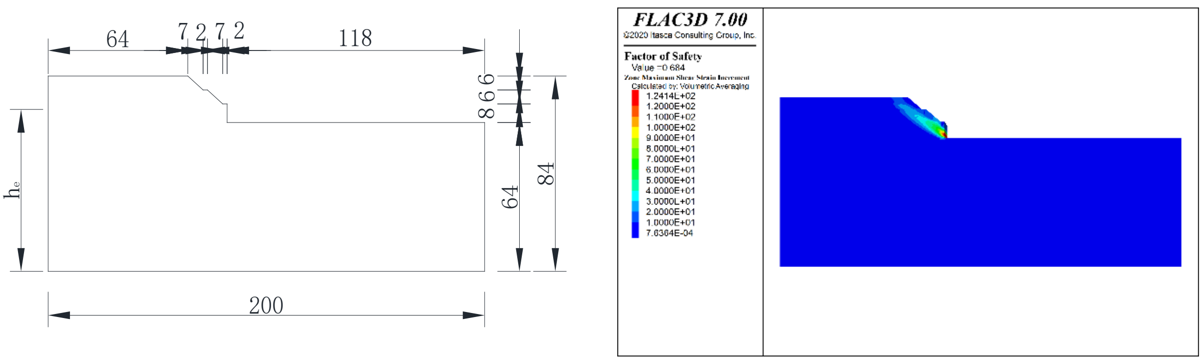
Safety height h_e/m	64	72	78
FOS	0.684	0.746	0.975

2. Analysis of slope safety with retaining structure

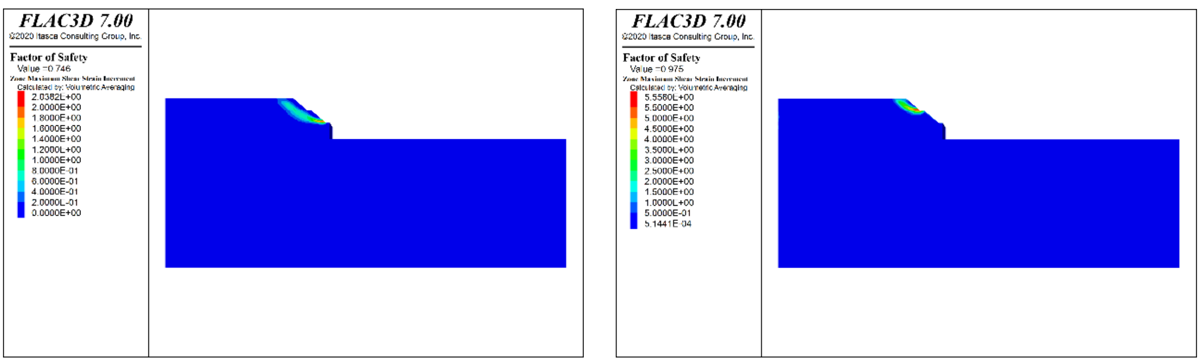
Based on the principle of "strengthening the foot of the slope", a prestressed anchor pile slab retaining wall was used at the vertical slope to prevent overall destabilization; Then, the upper two-stage slopes were reinforced with a frame prestressed anchor cable retaining structure, and the slope dimensions were shown in Figure 2(a). The relevant requirements of the retaining structure were as follows (see Table 3 for value parameters):

The vertical slope: reinforced concrete piles (cross-section size 2m×1m, concrete strength grade C30, pile spacing 4m, one beam at the top and one at the waist of the piles, reinforcement of the beams and piles according to the design documents), baffle plate (thickness 200mm, concrete strength grade C30, double-layered bi-directionally reinforced), prestressing anchor cables (one bundle at each intersection of the beams and the piles, 4 per technique, diameter 17.8 mm. Angle of inclination 30°, length 20 meters, grouting scope is 1/3 area inside the anchor cable).

The upper slopes: frame beams (i.e. longitudinal and transverse lattice girders with a cross-section size of 0.3m x 0.3m, concrete strength class C30, longitudinal reinforcement and hoop reinforcement configured according to the design documents), prestressing anchor cables (one bundle at each intersection of the beams with the piles, 4 cables per art, diameter 17.8mm, inclination angle 30°, grouting scope is the inner 1/3 of the area of the anchor cables. The length in the first level slope above the foot of the slope is 14 meters, and the prestressing locking value is 100kN; the length in the second level slope is 10 meters, and the prestressing locking value is 80kN).



(c) $h_e = 72$ (d) $h_e = 78$



(a) Schematic diagram of the range of safety heights (unit: m) (b)$h_e = 64$

Fig. 2. Contour of Maximun Shear Strain Increment of safety heights

In order to study the influence of the embedment depth of the pile and the value of the prestressing stress of the anchor cable in the prestressed anchor cable pile slab support structure on the stability of the slope, orthogonal tests for the analysis of slope safety under different working conditions were designed and implemented, and the test scheme and test results are shown in Table 4.

In the orthogonal tests for slope safety analysis using FLAC3D, the Moore-Cullen principal model was used for both bedrock and fill layers. In the numerical simulation of each condition, the simulation was carried out by changing only the corresponding parameters of the upright slope at the foot of the slope (pile embedment depth d and anchor cable prestress T) in order to exclude the influence of other factors and to improve the correlation between the results and the variables.

(1) Effect of pile embedding depth (d) on slope stability

In order to study the effect of the embedment depth of the pile in the prestressed anchor pile slab wall on the slope stability, four working conditions with the anchor prestress T=0 were selected for one-factor simulation. The corresponding results of the calculation of the safety coefficients are shown in Table 4. The cloud diagram of the incremental shear strain of the slope at T=0 is shown in Fig. 3.

Analyzing the maximum shear strain increment cloud shown in Fig. 4, it can be found that when the anchor prestress is kept constant, with the increase of pile embedment depth, the shear strain concentration area of the potential slip surface of the slope is gradually shifted to the deeper part of the slope and the range is reduced, which indicates that the restraining effect of the pile on the soil is significantly enhanced. The increase in embedment depth not only improves the pile's overturning resistance, but also effectively shares the slope sliding force by expanding the contact length between the pile body and the stabilized rock and soil body, thus reducing the overall shear damage risk.

(2) Effect of anchor cable prestressing (T) on slope stability

The application of prestressing is extremely widely promoted in geotechnical anchoring technology, and the application of prestressing can improve the mechanical properties of the geotechnical soil, and can effectively inhibit the relaxation deformation and potential slip of the geotechnical soil. Thus, FLAC3D was utilized to apply prestressing to the anchors for each condition separately according to the scheme in Table 4 (Fig. 4), and the safety factor was calculated. The slope safety coefficients for each working condition were obtained by simulation (filled into Table 4).

Finally, based on the simulation calculation results of orthogonal tests listed in Table 4, the relationship curves between pile embedment depth and anchor prestress and slope safety coefficient were compiled and plotted as shown in Fig. 5.

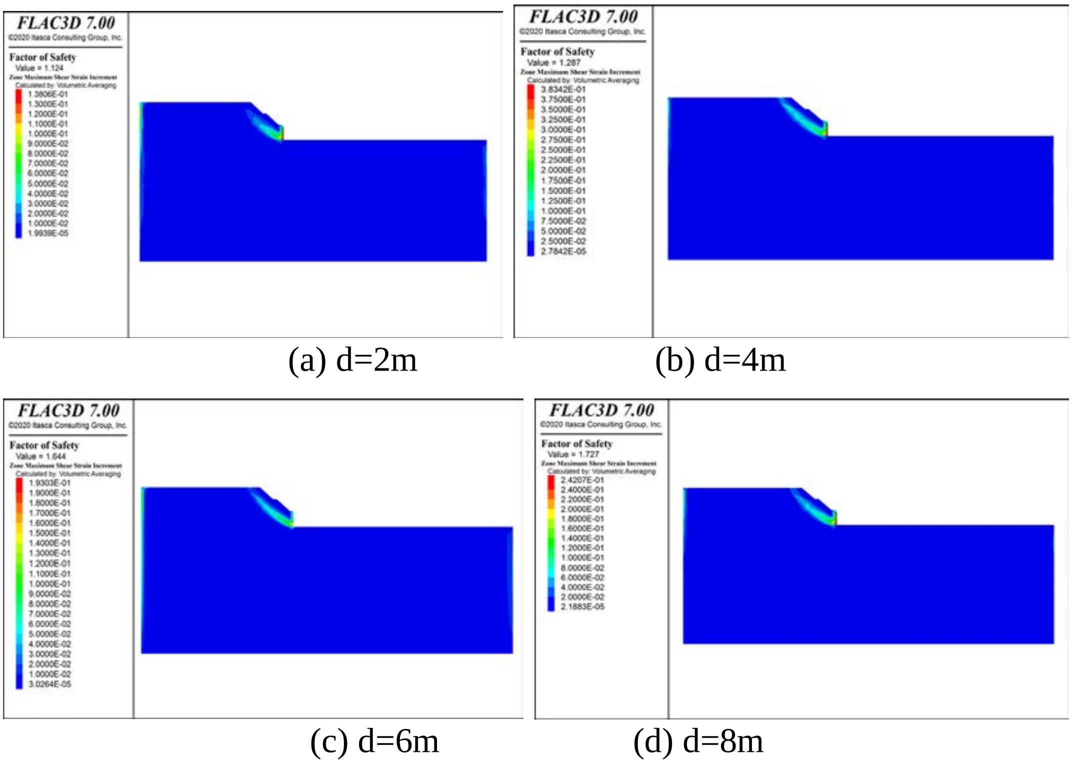
Analyzing Fig. 5(a), it can be seen that when no prestressing is applied to the anchors, the slope safety factor increases accordingly with the increase of pile embedment depth, and the increase of FOS is smaller when the pile embedment depth is small (d < 4 m); When d increases from 4 to 6 meters, the FOS increases the most and the curve tends to increase steeply; when d increases from 6 to 8 meters, the FOS increase

Table 3. Parameters of slope support structures

Parameters / Structures	Young's modulus E/MPa	Poisson's ratio ν	Density ρ/(kg/m³)
Piles	3×10^4	**0.2**	**2600**
Baffles	3×10^4	**0.2**	**2400**
Beams	3×10^4	**0.2**	2500

Table 4. Orthogonal test scheme and result statistics of slope safety analysis under different conditions

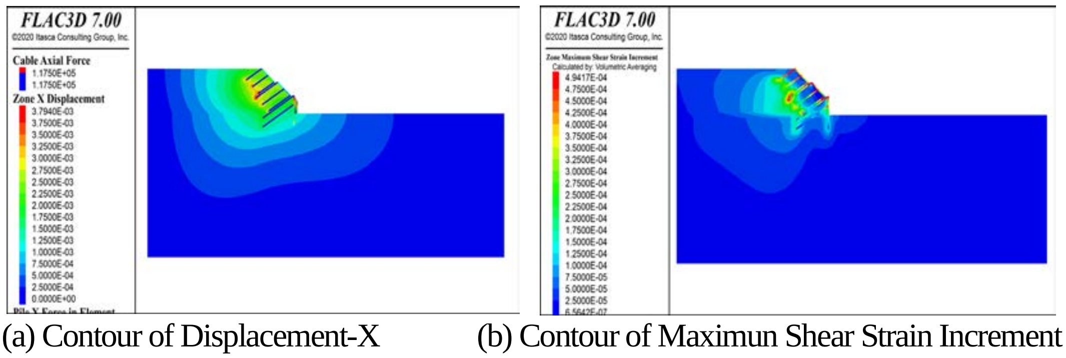
FOS / The Embedment Depth /m	The Anchor Prestress T/kN		
	0	**250**	**500**
2	1.124	1.583	1.682
4	1.287	1.721	1.805
6	1.644	1.756	1.845
8	1.727	1.806	1.912



(a) d=2m (b) d=4m

(c) d=6m (d) d=8m

Fig. 3. Contour of Maximun Shear Strain Increment of T=0kN

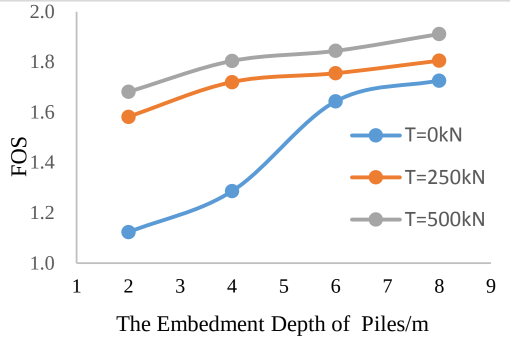


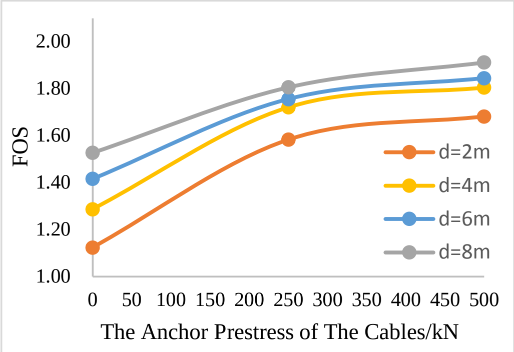
(a) Contour of Displacement-X (b) Contour of Maximun Shear Strain Increment

Fig.4 Contour of the slope when prestress was applying to the cables (d=6m)

decreases again and the curve tends to flatten. The above phenomenon shows that there is a correlation between FOS and d, and there is a critical value (d=6m in this case), which needs to be prioritized when carrying out the scheme design in order to achieve a more reasonable engineering synthesis. When the prestressing force was applied to the anchors, the FOS increased significantly and increased accordingly with the increase of T. Especially in the case of small d, the contribution of T to the FOS was more prominent, and the curve as a whole showed a tendency of surge followed by a slow increase, which implies that there is a critical value of T, and that the increase in the FOS will tend to be moderated by the continual increase of T after exceeding the critical value.

From Fig. 5(b), it can be seen that when the pile embedment depth is kept constant, the FOS increases accordingly with the increase of T. This is mainly due to the fact that the application of anchor prestressing force effectively suppresses the shear deformation of the soil body and enhances the integrality of the support structure. For the same value





(a) FOS-d curve (b) FOS-T curve

Fig. 5. FOS trends of the slope

of T, as d increases, FOS increases accordingly. It was worth noting that all four curves showed a uniform development trend: a steep increase followed by a slow increase, which indicated that there was a critical threshold for T. When the prestressing force exceeded the ultimate frictional resistance between the soil and the anchoring solid, the anchors may undergo debonding failure, leading to a significant weakening of the effect of the factor of safety enhancement. In addition, excessive prestressing will also trigger local stress concentration in the pile body and even cause structural damage to the pile. In specific engineering practice, it is necessary to consider the soil parameters, density of anchor arrangement and bending capacity of the pile body, and determine the optimal application range of prestressing through numerical simulation and on-site monitoring to achieve a balance between safety and economy.

Conclusions. In this paper, taking a tertiary slope project as an example, a three-dimensional numerical model was established based on FLAD3D, and multiple sliding surfaces of the slope were searched by using the method of assuming the safety height, and the orthogonal test program used to investigate the correlation between the parameters of the supporting structure and the slope safety factor was systematically designed and implemented:

(1) Multi-level high slopes often have more than one sliding surface, in engineering practice need to comprehensively use a variety of analysis methods and management tools. The spatial distribution characteristics and interaction mechanisms of sliding surfaces at all levels should be systematically analyzed, with particular attention to the influence of sensitive factors such as weak interlayers and changes in the water table on the shear strength of sliding surfaces.

(2) As the depth of pile embedment increases, the slope safety factor increases accordingly, with the increase being first larger and then smaller. It suggested that there was a critical value of pile embedment depth beyond which the rate of increase in the factor of safety plateaus, and might even be controlled by excessive bending moments in the pile resulting in the pile's own strength. Meanwhile, excessive embedment depths may be uneconomical due to construction difficulties and cost spikes. The engineering design should be combined with geological exploration data and pile-soil interaction analysis to optimize the embedment depth and ensure that the support system achieves the optimal solution between safety redundancy and resource investment.

(3) Prestressing the anchors could significantly improve the overall factor of safety of the slope, which was more obvious when the embedment depth of the pile was small. As the value of anchor prestress increased the slope safety factor increased accordingly, the increase was first large and then small. This means that there is a critical value for the prestressing of the anchors, and when this value is exceeded the contribution of the increase in prestressing to the improvement of the slope safety coefficient will be reduced. Excessive prestressing may also lead to the concentration of stress in the pile body near the anchorage point, which may cause damage to the pile structure in serious cases, thus threatening the safety of the whole support system.

Therefore, in the specific project, we should take into account the overall stability of the slope and the characteristics of the multi-sliding surface, the management should follow the principle of "hierarchical management, the main and secondary", the establishment of multi-level protection structure, and combined with the slope drainage system to optimize the underground seepage field. For the deep sliding surface, pile + prestressed anchor anchoring technology can be implemented, while ecological protection measures such as lattice girders + vegetation slope protection can be adopted for shallow sliding areas. In the construction process, automatic slope monitoring system can be established to realize dynamic design through the real-time feedback of displacement, stress and other data to ensure the synergistic effect of different levels of support structures, and finally achieve the optimal balance of overall stability and engineering economy.

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АНАЛІЗ СТІЙКОСТІ СХИЛУ, ОПЕРТОГО НА ПОПЕРЕДНЬО НАПРУЖЕНУ АНКЕРНО-ПАЛЬОВУ ПЛИТУ НА ОСНОВІ FLAC3D

Анотація. *Через складні геологічні умови, гідрологічне середовище та вплив частої людської діяльності проблема стійкості проєктів з високим рівнем насипу в гірських та горбистих районах стала ключовим викликом, який обмежує безпеку та сталий розвиток регіональних проєктів. Тому посилення дослідження стійкості гірських насипних схилів є нагальною потребою для забезпечення інженерної безпеки та сприяння якісному розвитку гірської економіки. Ця стаття бере аналіз стійкості схилів та оптимізацію проектних параметрів опорної конструкції при проектуванні гірських та горбистих територій як відправну точку, а чутливість двох параметрів попереднього напруження анкерного кабелю та глибини занурення палі на стійкість схилу при проектуванні попередньо напруженої опорної конструкції анкерного кабелю-палі, що утримує плиту, як об'єкт аналізу, та систематично розглядає результати досліджень щодо визначення потенційної поверхні ковзання схилів з високим рівнем насипу, аналізу стійкості, оптимізації параметрів опорної конструкції, а також чисельне моделювання та аналіз. аналіз та чисельне моделювання. В якості об'єкту дослідження обрано типовий схил з високим насипом, на основі даних геологічних вишукувань та натурних випробувань створено тривимірну чисельну модель FLAC3D на основі онтологічного зв'язку Мура-Кулона, розраховано коефіцієнти стійкості схилу в природному робочому стані з використанням методу дисконтування міцності, проаналізовано характеристики просторового розподілу потенційних поверхонь ковзання, проведено порівняння механізму взаємодії композитної опорної конструкції палі-плити-притискаючі анкерні кабелі з ґрунтом, спроектовано та виконано ортогональні випробування. Проведено ортогональні випробування для систематичного аналізу та кількісної оцінки чутливості глибини занурення палі та зусилля попереднього напруження анкерного кабелю до коефіцієнта запасу стійкості схилу, а також надано пропозиції щодо оптимізації параметрів. Ця стаття містить технічні рекомендації для проектування та будівництва подібних проектів, а також методи та ідеї для подальшого чисельного моделювання споріднених проектів науковими колегами.*

Ключові слова: Високий укіс, стійкість укосу, чисельний імітаційний аналіз, пале-плита-анкерний трос, що вдавлюється, несуча конструкція, чутливість параметрів.

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