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Impact of Anti-slip Pile Position on the Reinforcement Effect of Loess Slope and Ecological Protection

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Abstract

In this paper, the stability of loess slopes with different pile placements was analyzed by establishing finite element model with actual measurement data and field indoor experimental data as the research background. It is found that the stability coefficient of the slope reinforced by using Anti-slip piles is increased by 23.4%~27.5%, and the stability coefficient of the slope with different pile placements is non-linear, and the stability coefficient of the slope reaches the maximum and minimum value at the middle and lower part of the slope and the upper part of the slope, respectively. Through finite element simulation of the slope, the specific effects of Anti-slip pile placement on the stability of loess slope are deduced, and reasonable suggestions are made for the installation of Anti-slip piles in combination with the local ecological environmental protection and the maximum realization of economic benefits.

Keywords

Anti-slip Piles; Loess Slopes; Stability; Strength Discounting Method; Numerical Simulation.

1. Introduction

As one of the common means of slope reinforcement, Anti-slip piles are widely used in various practical slope problems. The reasonable selection of pile spacing, pile position, pile material and pile shape can help people solve the landslide problem well, and in recent years, experts and scholars at home and abroad have carried out a series of relevant researches on this issue. Zou Shengtang et al [1] used the elastic-plastic finite element strength reduction method based on ABAQUS finite element software to conduct three-dimensional numerical analysis of soil slopes reinforced by Anti-slip piles, and found that for homogeneous landslides, Anti-slip piles can be set in the middle of the slope downward under the premise that it is difficult to determine the sliding surface of the slope; Peng Yu et al [2] analyzed the influence of pile lateral angle on pile spacing based on the basis of pile spacing calculation, defined the design value of pile lateral angle, and explored the better value. Wei Shaowei et al [3] compared the force performance of Anti-slip pile with rectangular section pile through indoor model test, and concluded that the force performance of Anti-slip pile with circular section is basically the same as that of Anti-slip pile with rectangular section under the same conditions, and the force transfer is uniform in the process of force, and the strength requirement for the embedded end of pile bottom is low, which has good Anti-slip bearing capacity; Ding Qiaojun et al [4] established a numerical model by FLAC3D to analyze the effects of different cross-sectional dimensions, anchorage depth and pile spacing of antiskid piles on slope displacement, safety factor, maximum bending moment and shear force. The results show that increasing the cross-sectional size of Anti-slip piles can reduce the slope deformation, reduce the slope force and improve the stability of the slope; suitable anchorage depth and spacing of Anti-slip piles can make the slope deformation the least, force the most reasonable and stability the best; Zhu Yong et al [5] used finite element numerical simulation to analyze the influence law of pile position,

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pile length and other factors on the stability state of Anti-slip pile reinforced slope, and obtained the optimal pile position and critical pile length and other He Wenye et al [6] used the strength reduction method to calculate the slope safety factor under different length, spacing and section size of Anti-slip piles, and the results showed that the slope stability analysis of the orthogonal test scheme showed that the pile spacing had the greatest influence on the slope safety factor, followed by the section size, and the pile length had the least influence; Wang Congcong et al [7] analyzed the effect of Anti-slip piles on slope reinforcement based on the finite difference software FLAC 3D, explored the influence of pile position, pile length and pile elastic modulus on slope stability coefficient and critical slip surface, and proposed the concept of effective embedment depth.

However, there are still shortcomings in the research on the reasonable pile placement of Anti-slip piles, and the research on the correspondence between the selection of different pile positions and the slope stability coefficient should be carried out in depth. Therefore, this paper takes an actual slope project as the background, takes the placement of different pile positions as the consideration factor, and the correspondence between the selection of pile positions and slope stability coefficient as the research objective, which has certain reference value for the actual slope project.

2. Geological Structures

Longnan City is located in the intersection of the Tibetan Plateau and Loess Plateau, geological structure is complex, strong neotectonic movement, geological environment is fragile. The region's topography is undulating, steep mountains, broken mountains, extreme weather frequently. In addition, the frequent human engineering activities in recent years have had an increasingly strong impact on the geological environment, making geological disasters such as mudslides, landslides, landslides and unstable slopes very developed. It is one of the four major geological disaster areas in China.

Longnan City located in a mid-latitude zone with semi-arid climate, dry and windy in spring and autumn, with an annual average wind speed of 0.94 m/s, dominated by northeasterly winds. The annual average temperature in the study area is 9°C, the average temperature in January is -5°C, and the average temperature in July is 23°C, which are the lowest and highest temperature months of the year, respectively, and the annual sunshine hours in the area are 2100-2700 h.

The rainfall data of Longnan City in the past years are shown in Figure 1. The rainfall mostly occurs in July-September every year, and the concentrated rainfall makes the landslide incidents increase suddenly during this period. From the figure, we can observe that in recent years, the annual average precipitation in Longnan City area shows a gradually increasing trend, and due to the nature of loess geology in Northwest China, the impact of transient rainfall on the loess slopes in this area cannot be ignored.

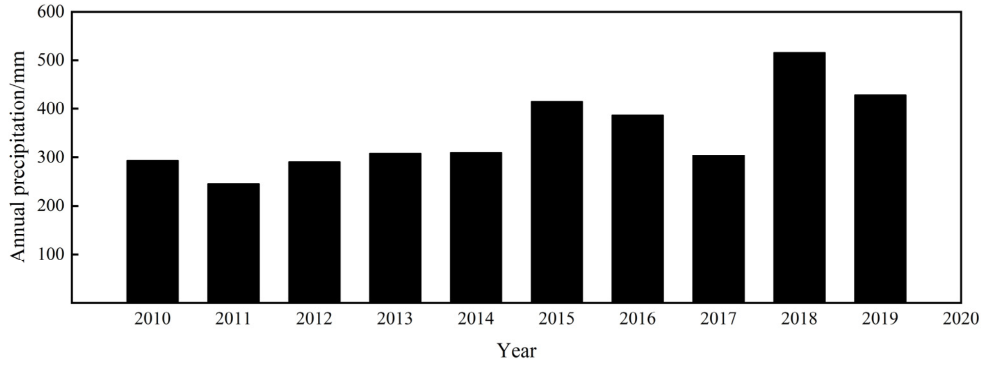

Figure 1. Annual precipitation of Longnan City from 2010 to 2019

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It is because the transient and intense rainfall will cause rapid changes in the water content of loess slopes that the water content equivalent stratification model is very suitable for analyzing the loess slopes in the study area. The study area is a geological hazard-prone area, and Anti-slip piles need to be installed on the slope for reinforcement, and this paper conducts relevant research on the different locations of Anti-slip piles.

3. Numerical Simulation

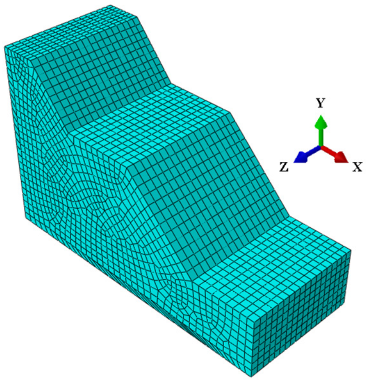

Figure 2. Slope finite element model

The finite element model construction and mesh division of the slope based on the field data investigation and indoor experimental research are shown in Figure 2.

The stability analysis of the slope is carried out by using the finite element analysis model of Figure. 2 combined with the strength reduction method with the top point of the secondary step shoulder of the slope as the tracking point, and the change curve of the slope stability coefficient is shown in Figure 3.

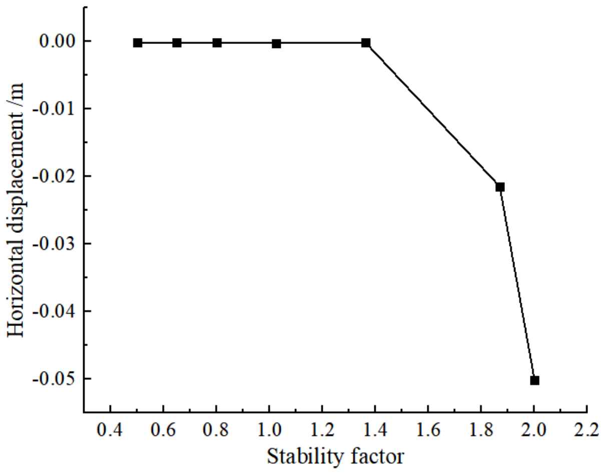

Figure 3. Stability coefficient variation curve

Combining with Figure 3 and using the abrupt change of horizontal displacement at the tracking point as the judgment criterion of slope stability, the stability coefficient of the slope is 1.362.

4. Anti-slip Pile Placement Simulation

Based on the finite element model in Figure. 2, the slope is reinforced by Anti-slip piles, which are placed in the upper, middle and lower parts of the lower part of the slope, as well as in the middle and upper part and lower part of the slope for slope stability analysis.

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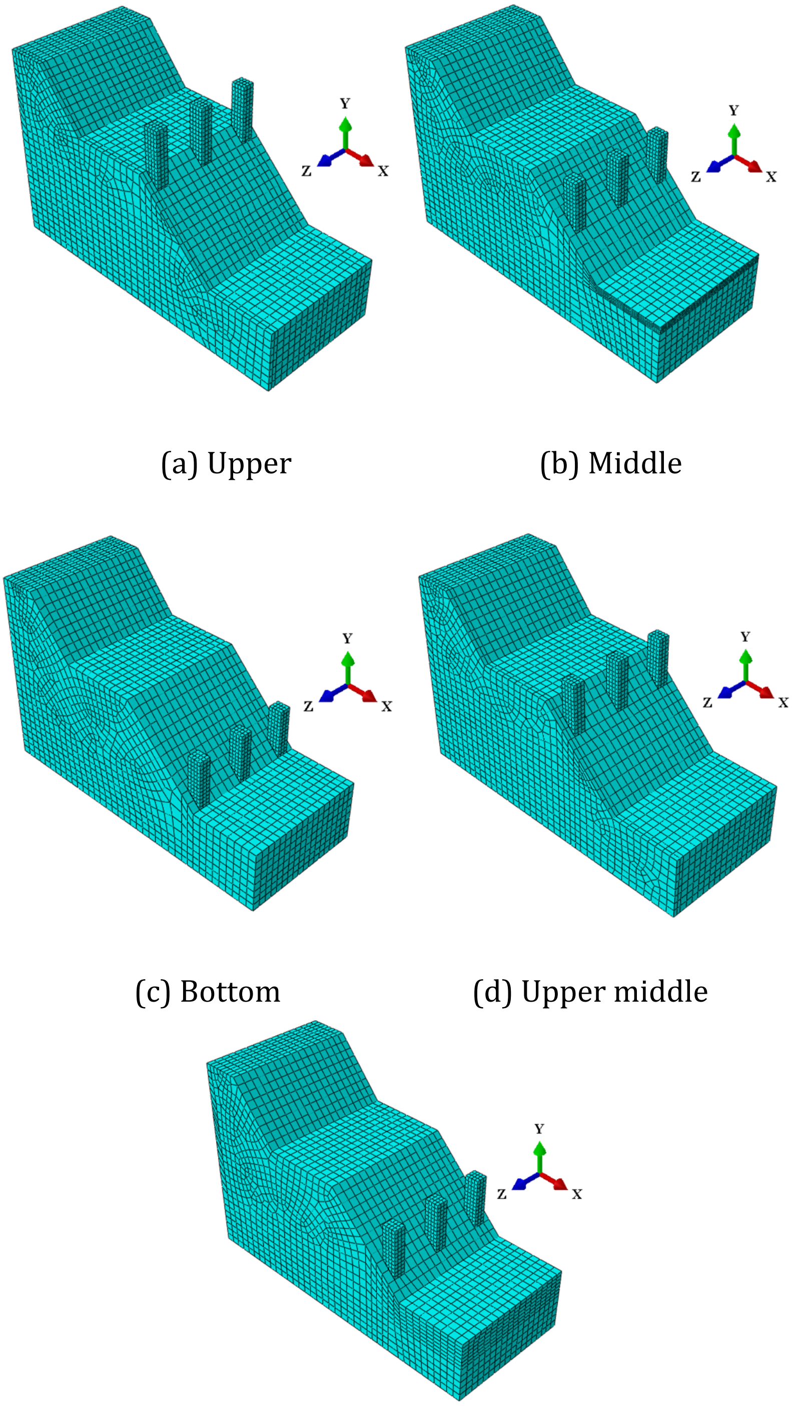

(a) Upper (b) Middle

(c) Bottom (d) Upper middle

(e) Lower middle

Figure 4. Schematic diagram of Anti-slip pile laying

The stability coefficient change curve of the slope under the corresponding pile position is shown in Figure 5 (1 indicates no Anti-slip pile reinforcement; 2 indicates the upper part; 3 indicates the middle and upper part; 4 indicates the middle part; 5 indicates the middle and lower part; 6 indicates the lower part).

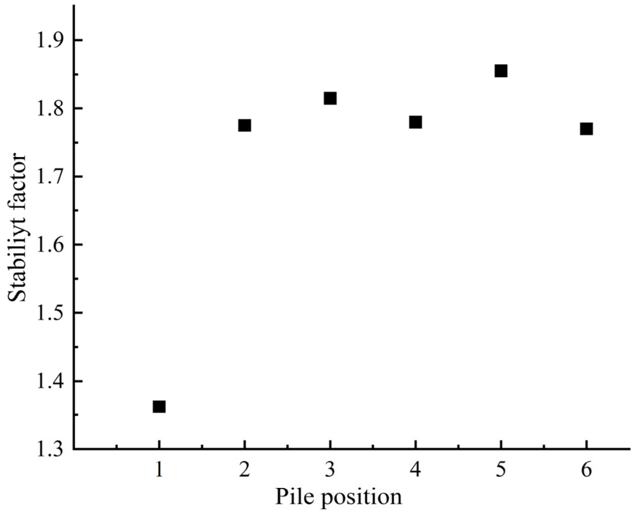

Figure 5. Stability coefficient variation curves of different pile positions

It can be found from Figure 5 that the stability coefficient of the slope increases by 23.4%-27.5% before and after reinforcement; the stability coefficient is the largest when the Anti-slip piles are placed in the middle and lower part of the slope, and the stability coefficient is the smallest when the Anti-slip piles are placed in the upper part of the slope. In the simulation, it was also found that the deformation of the Anti-slip piles was the largest when the Anti-slip piles were placed below the middle of the slope compared to other locations.

5. Conclusion

Through the finite element numerical simulation of the actual slope project, the following conclusions are drawn in this paper.

(1) The stability coefficient of Anti-slip pile is the largest when it is deployed in the middle and lower positions, while the stability coefficient is the smallest when it is deployed in the upper position.

(2) The stability coefficient of the slope is significantly improved before and after reinforcement, which verifies the feasibility of the reinforcement scheme.

(3) The stability coefficient of the slope does not show a linear change but a curvilinear change with the gradual downward movement of the pile placement.

(4) For the sake of ecological protection, the Anti-slip piles are less destructive to the slope vegetation when they are set in the upper part; for the sake of economic benefits, the Anti-slip piles are easier and less costly to construct when they are set in the upper part.

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