Analysis of the Influence of Umbrella Anchors on the Effectiveness of Micropile Reinforcement in Channel Slopes

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Abstract. The construction of micropiles is convenient, but the slip resistance is limited and the deformation control ability is insufficient, and the use of umbrella anchors and slip-resistant piles joint reinforcement is the solution. In order to study the enhancement effect of umbrella anchors on the reinforcing effect and deformation control ability of micropiles, an indoor model test of umbrella anchors-micropile joint reinforcement of landslides was carried out, and the top settlement and horizontal displacement of umbrella anchors-micropiles during graded load holding were tested by adopting the graded loading method, and a finite element analysis model was established to analyze the enhancement effect of umbrella anchors on the reinforcing effect of micropiles. The results show that: compared with the single reinforcement of mini-pile, the joint reinforcement of umbrella anchor and mini-pile can significantly enhance the stability of slope resistance by more than 20%; the horizontal displacement of the pile top shows a slow increase with the increase of load, and then grows rapidly, and the joint reinforcement of umbrella anchor-micropile can reduce the horizontal displacement of the pile top by 50% under the same loading condition; after the umbrella anchor combined with the mini-pile reinforcement, the maximal moment of the body of the mini-pile decreases and the maximal moment of the body of the mini-pile is directed to the steel strand at the point of maximum bending moment. The maximum bending moment is shifted to the strand action point and the value of maximum bending moment is reduced. The zero point of shear force of the miniature pile body is shifted downward away from the strand action point, and the maximum shear force value is reduced. The research results provide basic support for the popularization and application of umbrella anchor in channel slope reinforcement.

Keywords: Micro pile; Umbrella anchor-micro pile joint; Anti-sliding stability; Landslide deformation.

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1 Introduction

China is a vast country with a large mountainous area, and landslides and other geologic disasters occur frequently[1,2], and every year, landslide disasters cause serious losses to people's production and life. The formation of landslides can be generally categorized into internal and external causes[3-8], the internal causes are related to the structure of the landslide geotechnical body, geological structure, stress level, and other factors, while the external causes mainly include rainfall, earthquakes, or human activity factors. Among them, anthropogenic factors, such as blasting, mountain excavation, and engineering loads, are often one of the main factors causing slope sliding. Therefore, the slope support problem caused by excavation has become the focus in research[9-11].

As a common slope support method, micro-pile structure, with the advantages of flexible pile arrangement, less disturbance to the surrounding rock and soil layers, fast construction speed, and material saving, has been gradually applied in geotechnical engineering fields such as slope support, foundation reinforcement, and highway rescue and repair[12,13]. However, unlike ordinary skid-resistant pile foundations, micro-piles have small diameters, and the cross-sectional area is usually much lower than the pile length, which makes their length and slenderness comparisons large, and their bending stiffness is small[14,15], which results in the disadvantage of insufficient skid-resistant bearing capacity, and restricts the application of micropiles.

Umbrella anchor is a slope prestressing anchoring technology independently developed by the Yangtze River Academy of Sciences, and the engineering practice shows that the technology has a large ultimate anchoring force of single anchor, and the prestressing can significantly improve the deformation control capacity of the slope. Studies have shown[16,17]that the combination of grouted anchors and anti-slip piles can greatly improve the anchoring effect and significantly reduce the deformation of the top of the pile. The anchorage force of umbrella anchor structure differs greatly from that of grouted anchors, and the enhancement effect after joint reinforcement with mini-piles differs greatly from that of conventional pile-anchor joint reinforcement, and there are very few relevant referable research results.

In order to grasp the enhancement ratio of umbrella anchors to the anti-slip capacity and deformation control of micropile slope reinforcement, it is proposed to carry out the indoor model test of micropiles and joint reinforcement of umbrella anchors and micropiles[18-23], to test the deformation process of graded loading under the above mentioned comparative conditions, as well as to add umbrella anchors to existing micropile slopes, to form a means of support with umbrella anchors-miniropiles in a joint role, and to analyze the anti-slip effect of the micropiles and umbrella anchors-micropile joint support in a comparative manner.

2 Design of the experiment

Relying on the slope of an airport relocation project to carry out related research. The model test is taken from the engineering site, simulating the slope rate of the site. In order to simulate the slope instability, the slope body is set up the fissure surface that inside the slope. According to the regional geological data and the stratum exposed by this investigation borehole, the umbrella anchor and micro-pile reinforcement layer is a residual soil layer, and the physical properties of the anchored soil samples measured by the indoor test are shown in Table 1.

Table 1. Soil parameters

parameters	Unit	
Specific gravity		2.75
Optimum moisture content	%	23.6
Maximum dry density	g/cm^3	1.63
Dry density	g/cm^3	1.55
Cohesion	kPa	94.06
Angle of internal friction	°	9.67

2.1 Model settings

The test was carried out in a model box with an inner diameter of 80cm x 80cm x 80cm. Before the test, the model needs to be filled according to the design landslide form. As shown in Figure 1 for the model test design slope section, in order to make the slope model in the overlying load can produce significant sliding deformation, the design slope gradient of 56°, the potential sliding surface horizontal inclination of 31°, set up in front of the slope length of 20cm, high 10cm platform, the specific characteristics of the slope model as shown in Figure 1.

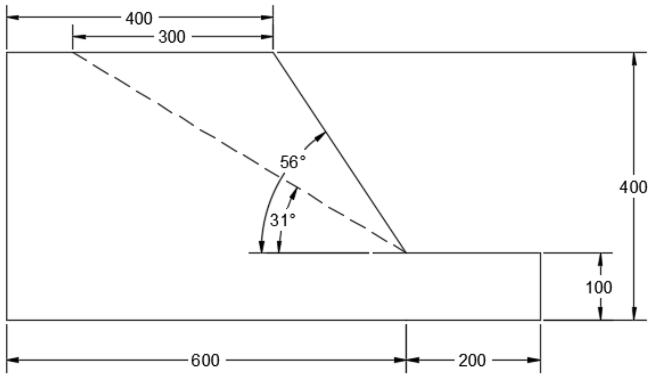


Fig. 1. Slope section

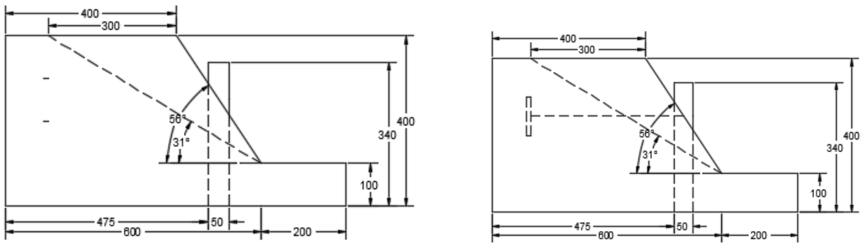
2.2 Pilot program

Two sets of test conditions were designed for this test, see Table 2.

Table 2. Test conditions

Working condition	With or without piles	With or without anchors
MP model	Yes	No
UAP model	Yes	Yes

The piles used in the test were precast concrete piles with a diameter of 5 cm and a height of 34 cm. the umbrella anchor model used was a 10 cm×10 cm rigid anchor plate with a thickness of 2 cm. the concrete piles and the anchor plate were connected by stranded wire. Two sets of working conditions are designed as shown in Figure. 2. Among them, working condition 1 is a single-pile anchorage capacity test test, and the concrete pile is buried in the longitudinal direction at half of the width of the slope, and the transverse position is shown in the figure. The pile passes through the designed sliding surface directly to the bottom of the slope model, simulating the resistant pile foundation driven into the bedrock in the project. Case 2 is a single-pile-umbrella anchor anchorage capacity test, the concrete pile and the anchor plate are buried in half of the width of the slope in the longitudinal direction, and the horizontal position is shown in the figure. The anchor plate was placed vertically and buried 25 cm behind the designed sliding surface, which was used to simulate the state when the umbrella anchor structure was fully opened horizontally for landslide support. The concrete pile and the anchor plate are connected by steel strands to form a functional whole.



(a)Condition1 (b)Condition2

Fig. 2. Each case section

2.3 Model filling

The model was first filled according to the design plan. The soil samples taken were dried and compacted and then prepared for remodeling according to the optimum moisture content.

The model filling adopts the layered filling method, and the model filling is carried out according to the following steps:

(1) The filling height of each layer is 5cm, and the compaction degree is controlled as 95%. Calculate the required soil material for each layer according to the wet density of the soil and the volume of the soil layer, pour the soil material evenly into the model box for compaction, and measure the height of the soil layer in time during the compaction process. After the soil layer is compacted, the surface of the soil is scraped to increase the bonding between the layers, and then the next layer is compacted.

(2) In the process of model filling, concrete piles or anchor plates are buried at predetermined locations according to the design program. In the process of burying the anchor plate, it is necessary to straighten the strand, and the strand can be slightly loaded so that the strand is taut, and then the filling and compaction is carried out.

(3) After consecutively completing 8 layers of soil filling to form a cubic soil layer, according to the design program for the first time to cut slopes on the cube to form a potential sliding surface. After the completion of the first slope cutting, the surface of the slope is coated with petroleum jelly, and then a layer of plastic film is laid to fit the surface of the slope, and the plastic film should be perforated at the location of the strands and piles, and the plastic film can slightly exceed the surface of the slope in order to prevent the film from shrinking inward in the process of subsequent filling and compaction. After the completion of the laying of the second compaction filling, until the original cubic soil layer is re-formed.

(4) The cubic soil layer was sloped a second time according to the design plan to form the design slope. After the second slope cutting is completed, the entire model is filled.

2.4 Test loading

The test was carried out by placing hydraulic jacks above the sliding surface of the platform at the top of the slope for loading, and the loading control mode was graded loading. Before loading, a vertical meter was set at the top of the miniature pile to measure the settlement of the pile; a horizontal meter was set in front of the pile to measure the horizontal displacement of the pile. During the loading process, the load increment of each level is designed to be 1kN, and the readings are taken at 3min intervals. When the settlement is less than 0.1mm in half an hour or the percentile meter readings no longer change, the next level of load is applied. When there is obvious damage to the slope or the percentage meter reading continues to increase significantly, it can be considered that the slope sliding damage, end of the test.

3 Test results and analysis

From the test results, the settlement-time curve and horizontal displacement-time curve of the mini-pile are plotted, as shown in Figure. 3. From the figure, it can be seen that in the micro-pile supported sliding slope model test, when the test is carried out to the 111th min, at this time corresponding to the overburden load is 9kN, the settlement-time curve and horizontal displacement-time curve will appear obvious inflection point, with the growth of time and overburden load, the landslide settlement and horizontal displacement will be very much increased, and the landslide damage occurs.

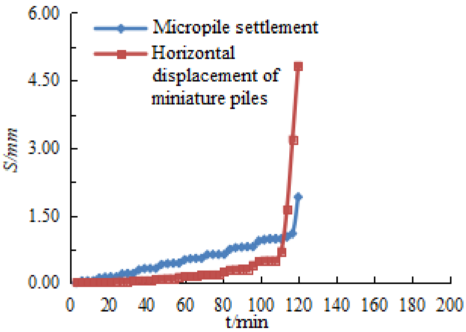


Fig. 3. Micropile displacement-time curve

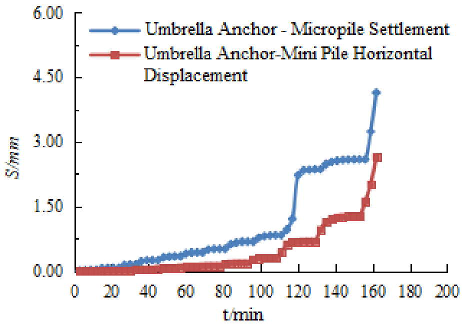


Fig. 4. Displacement time-history curve of combined support

The settlement-time curve and horizontal displacement-time curve of the sliding slope supported by micropile-umbrella anchor are shown in Figure. 4. It can be analyzed that when the test was conducted to 153min, the overlying load was 11kN and the landslide was damaged. Comparing with Figure. 3, it can be seen that compared with the mini-pile support, the mini-pile-umbrella-anchor model linkage structure effectively improves the anti-slip stability of the soil layer of the slope, and its resistance to the overtopping load is increased by more than 20%.

Comparative analysis of the same load level, the top of the pile horizontal displacement can be seen, micropile single reinforcement before the destruction of the displacement of 0.71mm, while the use of umbrella anchors and micropile joint reinforcement, under the same load, the top of the pile displacement reduced value of 0.27mm, the top of the pile displacement is reduced by more than 50%, it can be seen that the umbrella anchors can significantly improve the micropile deformation control ability of the slope.

As shown in Figure. 5, the displacement (settlement and horizontal displacement)-load curve of landslide supported by micropile and umbrella anchor-micropile combination is shown. It can be seen that both curves went through two distinctly different stages: at the beginning of loading, when the overlying load was small, the displacement of the two structures increased slowly with the growth of the overlying load, and the displacement of the umbrella anchor-micropile joint support developed slightly more slowly, but not significantly. When the overburden load exceeds a certain value, the curve appears inflection point, and the continued increase of load will cause a rapid increase in displacement and landslide damage. Among them, the umbrella anchor-micropile shows better resistance to the overtopping load and the damage is delayed.

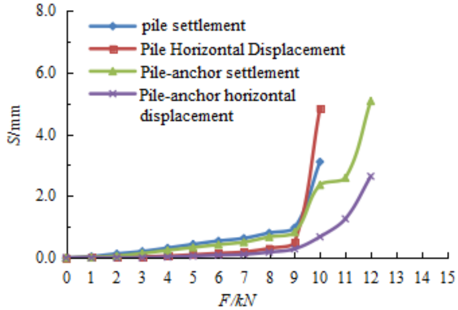


Fig. 5. Displacement-load curve

4 Finite element simulation (FEM)

Based on the experimental design, Plaxis2D software was used to establish the finite element analysis software for micropile and umbrella anchor-micropile joint support.

4.1 Parameter selection

Establish a 2D finite element analysis model, simplify the umbrella anchor and micropile structure to be treated as a plate structure, and calculate the relevant parameters according to the test micropile pile diameter and pile length, in which the micropile is designed with reference to the general concrete structure and the umbrella anchor is designed with reference to the general steel plate structure; the modulus of elasticity of the strand is taken as the value of E=145GPa, and the diameter of the strand is 1cm; and the model is established through the contact surface unit in order to simulate the structure of the slip-cracking surface. The relevant parameters are shown in Table 3.

Table 3. Finite element parameter

Parameter	Unit	Soil	Slippery surface	Micropile	Umbrella anchor
γ	kN/m^3	20		80	80
E	kN/m^2	8000	2000	30×10^6	200×10^6
c	kN/m^2	94.06	10	-	-
ϕ	°	9.67	-	-	-
EA	kN/m	-	-	510×10^3	2×10^6
EI	$kN\cdot m^2$	-	-	9.204	1667

In Plaxis2D finite element software, the axial stiffness EA and flexural stiffness of the plate unit are calculated according to the cube with width 1. In the parameter selection, the relevant parameters are converted according to the results of the indoor test to obtain the calculated parameters in the table.

4.2 Modeling and meshing

For the calculation, the soil unit is established with reference to the fill model and the slip fracture surface is set up. After that, the micropile and umbrella anchor structure were designed according to the model test scheme, and the distributed load was set up at the top of the landslide. Finally, the quadrangle mesh was divided according to Plaxis2D software, and the mesh was encrypted near the slip face, loads, micropiles and strand structure. A total of 3091 cells and 25773 nodes were generated in the finite element calculation model.

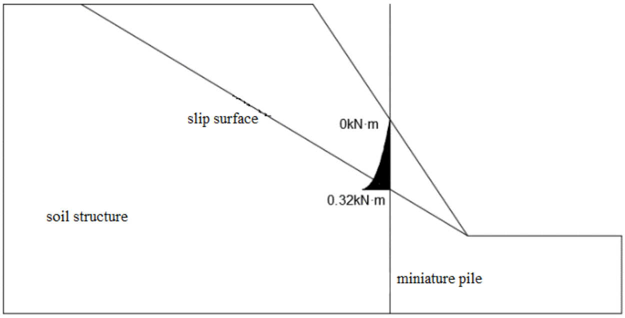
4.3 Calculation flow and boundary conditions

Referring to the test conditions, the left and lower boundaries of the model and the right boundary of the right platform are set as fixed boundaries, and the rest of the boundaries are free boundaries.

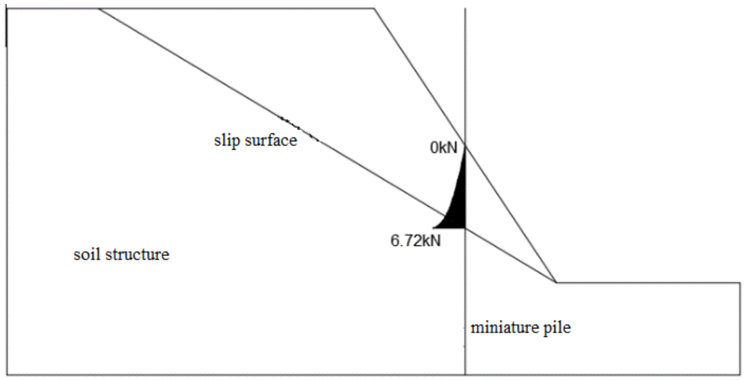
The calculation process is as follows: 1) the initial ground stress field is balanced and the historical consolidation displacement is zeroed; 2) the replacement of units such as anchor plate, strand, and micropile is carried out, and the soil-anchor contact surface is set up to simulate the burial process of each unit in the actual project; 3) uniform load is applied at the top of the soil layer, and the results of the distribution of the structural internal force are obtained through repeated trial calculations.

4.4 Finite element calculation results and analysis

The internal force of the structure of the micropile and umbrella anchor-micropile joint action is qualitatively analyzed by finite element calculation. As shown in Figure. 6, the internal force diagram of the pile body by finite element analysis of the sliding slope supported by the micropile is shown.



(a)bending moment

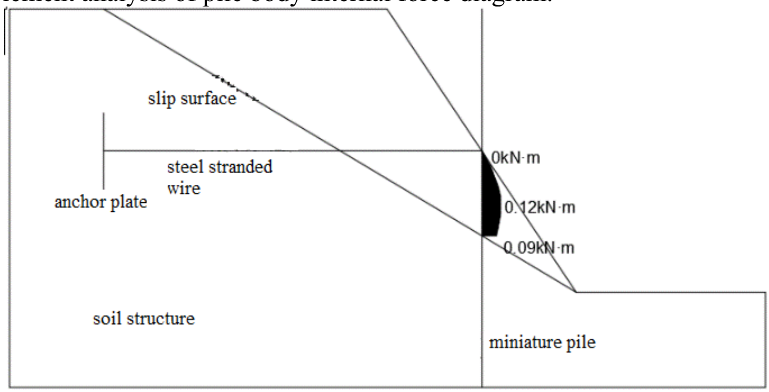


(b)shearing force

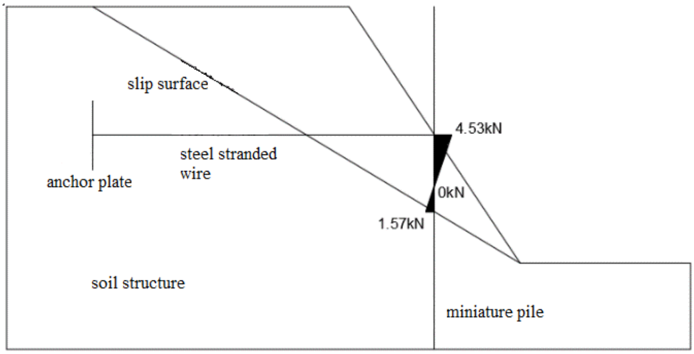
Fig. 6. Internal force diagram of micro-pile structure

It can be analyzed that, under the action of overburden load, the bending moment and shear force distribution of the miniature pile body are similar: they start from the surface of the landslide and develop downward, and reach the maximum value when they develop to the designed slip surface. Throughout the landslide loading process, the part of the miniature pile above the slip surface is subjected to large bending deformation by the action of landslide soil, the upper part of the pile body is subjected to obvious bending, resulting in obvious outward tilting, and the part of the pile body intersected by the slip surface and the pile body is subjected to shear concentration, so that the pile body is prone to shear fracture damage.

As shown in Figure 7 for the umbrella anchor - micro-pile joint support sliding slope finite element analysis of pile body internal force diagram.



(a)bending moment



(b)shearing force

Fig. 7. Internal force diagram of combined support micro-pile

Comparing Figure. 6 and Figure. 7, it can be seen that under the action of umbrella anchor structure, the internal force distribution of the miniature pile is optimized, and the addition of umbrella anchor is similar to applying a centralized load to the pile body at the action point (the action point of the design is the location of the landslide surface), which results in the redistribution of the internal force of the miniature pile: the miniature pile continues to be bent outward obviously, but the position of the maximum bending moment is shifted to the action point of the umbrella anchor, and it shows the middle protruding state under the action of the overloading load. At the same time, the zero point of shear force is shifted downward away from the umbrella anchor point. At the same time, the zero point of shear force is shifted downward away from the point of umbrella anchor. Under the same overtopping load, the concentration of shear stress in the pile body decreases, and the location of shear breakage of the pile body is not located at the junction of the sliding surface and the pile body, so that the mini-pile is capable of resisting larger overtopping load.

Further comparative analysis shows that the maximum shear force is 6.72kN and the maximum bending moment is 0.32kN^m, while the maximum shear force is 4.53kN in the case of joint support, which is reduced by about 33% compared with that of the single minipile, and the maximum bending moment is 0.12kN^m, which is reduced by about 63% compared with that of the single minipile. The inclusion of umbrella anchor structure limitedly reduces the stress concentration of the micropile, which enables the micropile to withstand a larger overtopping load.

5 Conclusions

Through the indoor micropile and micropile-umbrella anchor joint support landslide model test and finite element calculation analysis, the following conclusions are obtained:

(1) The slope stability can be effectively improved by using umbrella anchor and micropile joint reinforcement, and the slip resistance of the reinforced slope is improved by more than 20% compared with the single way of micropile reinforcement.

(2) With the single reinforcement of micropiles and the joint reinforcement of umbrella anchors and micropiles, the horizontal displacement of pile tops increases slowly and then rapidly with the increase of load; after the joint support of umbrella anchors and micropiles, the horizontal displacement of pile tops decreases by more than 50% under the same load condition, which can significantly improve the deformation control ability.

(3) After joint reinforcement of umbrella anchor and micropile, the bending concentration position of micropile is shifted to the direction of action point, presenting the middle protruding pattern, the maximum bending moment value of micropile is reduced by more than 60% after the joint reinforcement of umbrella anchor and micropile; the zero point of shear stress is shifted to the direction of sliding surface, and the maximum shear force value is reduced by about 33%.

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