Experimental study on the influence of umbrella anchor on the reinforcement effect of micro pile

Qinwen Liu[1,a], Shuxue Song[1,b], Yilin He[2,c], Yong Xiong[2,d*], Jialin He[2,e]

[1]Head Section, Middle Branch of China South-to-North Water Diversion, Co. Ltd, Henan Nanyang, China
[2]Changjiang River Scientific Research Institute, Wuhan, China

[a]354487202@qq.com, [b]23152252@qq.com
[c]1370976379@qq.com, [d*]313960770@qq.com
[e]2710234549@qq.com

Abstract. The construction of micro pile is more convenient than that of anti-slide pile, but the anti-slide ability is low and the deformation control ability is insufficient. The combined support of prestressed umbrella anchor and micro pile for channel slope is the solution. The indoor model test was carried out to analyze the influence of umbrella anchor on the reinforcement effect and deformation control ability of micro-piles under the condition of pile-anchor combined reinforcement. The research shows that : 1. The combined reinforcement of the slope with umbrella anchor and micro pile can greatly increase the maximum bearing capacity of the slope under the condition of single reinforcement of micro pile, and significantly reduce the horizontal displacement of the slope ; compared with the micro-pile reinforcement, the convergence trend of the horizontal displacement of the slope under the combined reinforcement condition is more obvious, the deformation timeliness is reduced, and the total displacement is relatively small; the engineering example shows that the combined reinforcement of micro-pile and umbrella anchor has immediate reinforcement effect and strong deformation control ability, which can be used for slope emergency rescue and permanent repair project. The research results provide theoretical basis and experimental basis for the popularization and application of umbrella anchor in pile-anchor combined reinforcement.

Keywords: pile-anchor combined support; umbrella anchor; indoor reduced scale experiment.

1 Introduction

After excavation and unloading of deep excavation channel project slopes, their stability is affected by groundwater, external loads and environmental changes, and deformation and long-term development problems will inevitably occur during operation, becoming a safety hazard of channel slopes, which are usually reinforced by anchoring

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and shoring, and micropiles and umbrella anchors are common support and reinforcement techniques.

Micropiles were initially used to carry vertical loads of buildings. In the 1990s, Wayne[1-2] proposed to place micropiles at specific angles to mobilize the bending resistance of micropiles to reinforce slopes, and also considered the vertical bearing capacity of micropiles when they were placed at an inclination, and subsequent studies also proved the slope reinforcement capacity of micropiles; Sung June Lee[3] buried micropiles in sandy soil and conducted a study on cyclic The mechanical behavior of micropiles under axial load was studied by Sung June Lee[3], who distinguished the micropile lateral friction resistance from that of conventional CIP piles; Zhou Depei[4] conducted slope support by combined structure of micropiles under different geological conditions and studied its anti-slip mechanism; Xian Fei[5] established a model of micropiles in terms of numerical calculation and elaborated its anti-slip mechanism; Huang Yongyong[6,8-10] summarized the construction method of micropiles, but the load-bearing capacity of micropile reinforcement is limited, and the group pile construction disturbs the soil of the slope, so it is difficult to ensure the stability during construction, and the joint support method containing micropiles is generally used for slope reinforcement.

In terms of joint reinforcement of slope support, Zhang Xiaofei[12-14] et al. applied the effect of joint pile-anchor support to rocky slope or soil slope and proved the reliability of joint support method by integrating numerical model and experimental data; Bao Yongping[15-16] et al. studied the construction method, mechanical mechanism and the coordination mechanism of deformation between the two for mini-pile composite soil nail wall support, and made a study on the existing construction method The recommendations were made on the existing construction method, mechanical mechanism and the coordination mechanism of deformation between the two, and the existing construction method, design scheme calculation mode, etc.; Ding Guangwen[17-18] et al. applied the mini-pile group pile composite structure for support and gave a mini-pile construction scheme, which achieved good reinforcement effect; Li Baoping[19-20] et al. carried out monitoring calculation and numerical simulation on the deformation characteristics of the pile-anchor structure, and concluded that the space-time effect should be considered in the design.

The research related to umbrella anchors has made great progress in recent years. The team of Changjiang Academy of Sciences proposed the tensioned self-locking umbrella anchor [7,11], the basic principle of which is to strike the umbrella anchor with retracted ends into the fracture surface and tension it so that the ends are opened and embedded in the soil to provide anti-slip force for the slope. The subsequent development of the umbrella anchor has given the anchoring mechanism, arrangement method and installation parameters of the umbrella anchor through field tests, indoor model tests, combined with numerical analysis.

In summary, the use of micropiles for slope support is relatively mature at present, but for projects with high requirements of duration and quality, micropile support obviously cannot meet the requirements, while the use of micropiles and umbrella anchors for joint support can significantly shorten the duration and bring into play the reinforcement effect instantly while the construction is completed, and the umbrella anchors can also be used to reinforce the deep soil body of the slope and increase the slip resistance of the slope. However, there is less research about the joint support of miniature pile-umbrella anchor (hereinafter referred to as pile-anchor structure), therefore, there is a need to conduct experimental research on the application of umbrella anchor in the joint support of pile-anchor.

To this end, indoor model tests of combined pile-anchor reinforcement with micro-piles are conducted to test the load-displacement data of micropiles and umbrella anchors under different reinforcement conditions, analyze the relationship between landslide stability and applied load, compare and analyze the effect of combined pile-anchor reinforcement on slope stability and deformation control, and test the combined reinforcement effect of micropiles and umbrella anchors with field examples of combined pile-anchor reinforcement. It also provides experimental support for the application of combined micro-pile and umbrella anchor reinforcement.

2 Indoor test protocol

The slope loading model tests were carried out in a square model box with 80 cm side length for two types of reinforcement conditions, namely, mini-pile and combined pile-anchor reinforcement. The test simulates a mini-pile with a prototype diameter of 300mm at a scale of 1:2 and an umbrella anchor plate with the original size of 100mm×200mm at a scale of 1:2. The same graded loading scheme is used to apply the load and compare the change of sliding body displacement of the slope model and its relationship with the load under the two conditions.

2.1 Model Settings

To ensure that the sliding surface of the model can be controlled, a fixed sliding surface is set inside the slope model. The slope and the sliding surface are shown in Figure 1, and the overall shape of the slope is shown in Figure 2, in which the slope inclination is 56°, the internal fixed sliding surface inclination is set to 31°, and a platform of 20cm in length and 10cm in height is reserved at the foot of the slope.

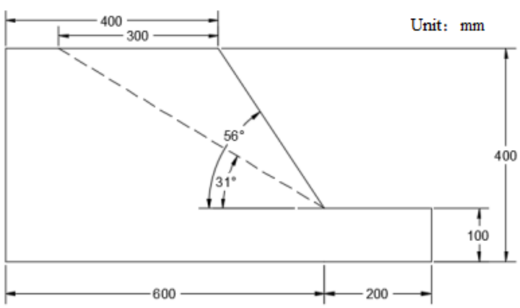


Fig. 1. slope section

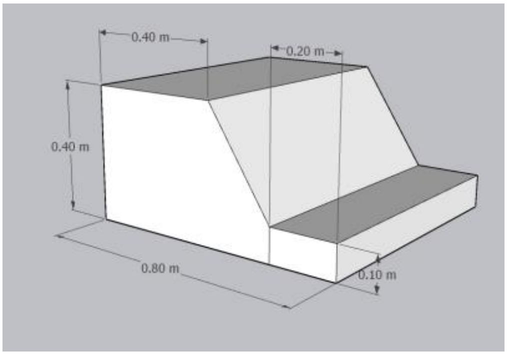
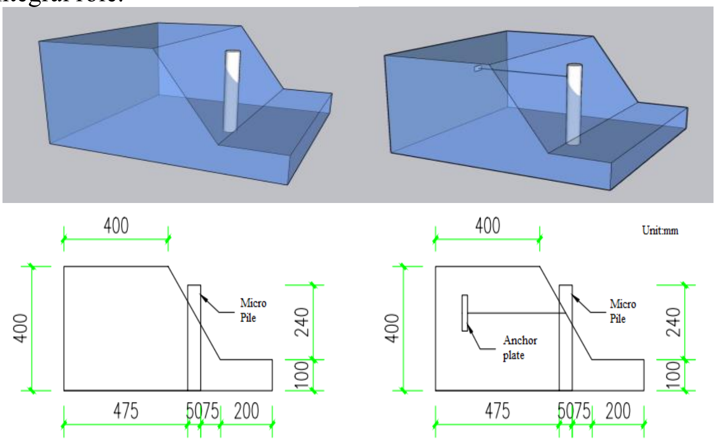


Fig. 2. slope schematic diagram

2.2 Experimental design

The material of the mini-pile body in the mini-pile test group is precast concrete, which is buried at half of the width of the slope, and the location is shown in Figure 3(a). Buried at half the width of the slope; the umbrella anchor is replaced by the anchor plate equivalent, so as to achieve the effect of enlarged head at the end of the umbrella anchor. The anchor plate is a rectangular plate of 10 cm in length and 5 cm in width with a steel strand attached to the center, and the anchor plate is placed horizontally with its centerline intersecting vertically with the centerline of the pile. The anchor plate is placed horizontally with its centerline intersecting vertically with the centerline of the pile body. The steel strand is straightened and tightly connected to the exposed part of the pile body during the burial process, so that the anchor plate and the pile body form an integral role.



(a)Mini-pile cross-section (b)Pile-anchor combination structure section

Fig. 3. Installation profile

3 Analysis of indoor test data

The soil samples used in the indoor tests were tested and the physical property indexes were as follows: the specific gravity of soil particles was 2.75, the optimum moisture content was 23.6%, the maximum dry density was 1.63 g/cm3, the dry density of soil samples was 1.55 g/cm3, and the undrained strength was 38.6 kPa. the taken soil samples were dried and rolled, and then the reshaped soil samples were prepared according to the optimum moisture content.

3.1 Model filling

The model is filled with a layered filling method, each layer of soil is 5cm high, and the compaction degree is controlled to 95%. The required soil material for each layer was calculated according to the wet density of soil and the volume of soil layer, and the soil material was evenly poured into the model box for compaction, and the height of soil layer was measured in time during the compaction process. After the compaction of the soil layer is completed, the soil surface is scraped to increase the interlayer adhesion, and then the next layer is compacted.

In the process of model filling, the pile body or anchor plate is buried at the predetermined position, and the burial process is kept vertical, and the anchor plate strand is kept horizontal, and a slight tension can be applied to make the strand and the pile body closely connected.

After 8 consecutive layers of soil are filled to form a cubic soil layer, the cubic body is sloped for the first time according to the design plan to form a potential sliding surface. After the completion of the first slope cutting, Vaseline is applied on the surface of the slope, after which a layer of plastic film is laid to fit the surface of the slope, and holes should be made in the plastic film at the location of the steel strand and pile body to make the anchor plate or pile body pass through the potential sliding surface into the stable soil layer. The plastic film can slightly exceed the surface of the slope to prevent the film from shrinking inward during the subsequent filling and compaction. After laying, a second compaction is carried out until the original cubic soil layer is formed again.

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

3.2 Test process

After the model filling was completed, hydraulic jacks, percent tables and other instruments were installed according to the design requirements. The main data recorded in this test are jack load, slope top settlement, slope horizontal displacement and test time, and the installation of model loading and testing equipment is shown in Figure 4.

Fig. 4. Model installation diagram

The loading mode is graded loading, 1kN under each level of loading, and a reading is taken at an interval of 3min, and the steady state of deformation is when the displacement increment between two readings does not exceed 0.01mm or the reading continues to be stable, and the next level of loading can only be applied after the deformation is stable, and the test is terminated when the soil slope model shows obvious rupture or the displacement continues to grow.

In the test, a percentage meter with magnetic support is placed on the top of the slope to measure the settlement, and the horizontal displacement of the mini-pile is measured by adjusting the attitude of the percentage meter on the slope surface.

3.3 Analysis of experimental data

The test data are listed in Table 1, and the horizontal displacement and settlement of the two sets of tests under all levels of load are obtained, and the load-settlement curve, load-horizontal displacement curve, and horizontal displacement-settlement curve are drawn from the test results as shown in Fig. 5, Fig. 6, and Fig. 7.

Table 1. Test data record table

Load/kN	\	1	2	3	4	5	6	7	8	9	10	11	12
Combined pile-anchor	Horizontal displacement/mm	0.004	0.006	0.008	0.028	0.059	0.088	0.112	0.184	0.29	0.682	1.263	2.637
	Settling/mm	0.018	0.063	0.143	0.245	0.337	0.427	0.509	0.677	0.828	2.358	2.588	5.073
Micro Pile	Horizontal displacement/mm	0.014	0.018	0.036	0.061	0.102	0.149	0.192	0.309	0.506	4.832	\	\
	Settling/mm	0.047	0.134	0.21	0.322	0.439	0.549	0.635	0.807	0.979	3.107	\	\

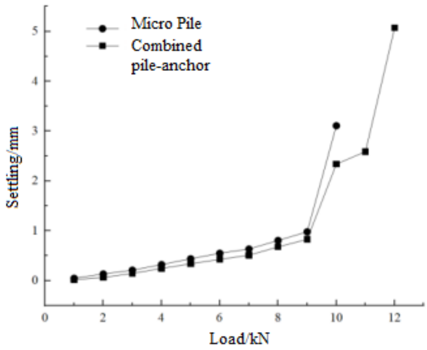


Fig. 5. load-settlement curve

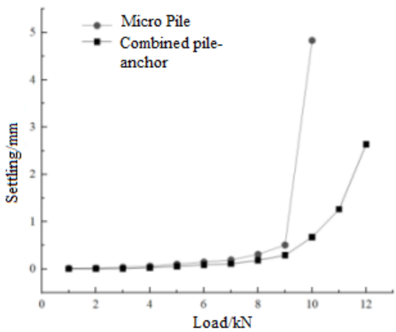


Fig. 6. load-horizontal displacement curve

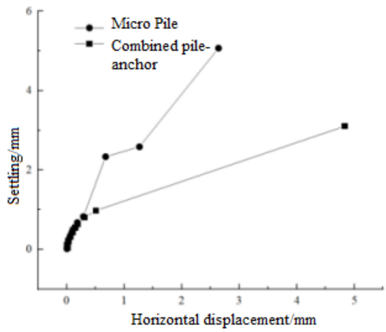


Fig. 7. horizontal displacement - settlement curve

From the test results, it can be seen that the ultimate load of the slope using mini-pile reinforcement model is about 9kN, after exceeding the ultimate load, the settlement of the slope top and the horizontal displacement of the slope surface show a rapid rise, at this time, the mini-pile has been disconnected from the soil around the pile, and the sliding body has appeared; the ultimate load of the slope of the joint pile-anchor support structure is above 12kN, at this time, the joint pile-anchor support structure is also insufficient to resist the upper load, the mini-pile and the soil around the pile The sliding body slides along the slip crack surface and the slope is damaged. Thus, the ultimate load of the combined pile-anchor support structure is 30% higher than that of the micropile support structure.

From the data in Table 1, it can be seen that the horizontal displacement and vertical settlement of the former are smaller for the combined pile-anchor support and the mini-pile support under the same load, and the horizontal displacement of the combined pile-anchor support structure is within 57.8% of the horizontal displacement of the mini-pile before the load is loaded at 5kN, and the horizontal displacement of the combined pile-anchor support is within 60% of the horizontal displacement of the mini-pile when it is loaded from 5kN to 9kN. When the load is 10kN, the displacement of the mini-pile support has a sudden change generated compared with the upper load applied, at this time, the mini-pile support structure is considered to have become unstable; at the early stage of loading, before the load is 4kN, the settlement of the joint pile-anchor support structure is 16% to 30% of the settlement of the mini-pile structure, and during the loading period from 4kN to 10kN, the settlement of the joint pile-anchor support structure is about 60% of the mini-pile structure Slightly floating, it can be seen that the horizontal anti-slip effect of the combined pile-anchor support structure is more enhanced than that of the micropile support structure, and the vertical settlement is also reduced compared with that of the micropile support structure, from which the advantages of the combined pile-anchor support structure can be seen.

In order to illustrate the convergence trend of deformatioVn in the above test, a power function can be used to fit the data and describe the deformation rate by power exponent.

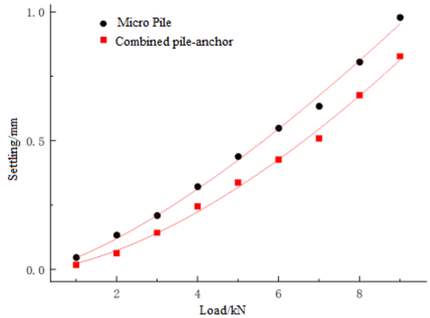


Fig. 8. Load-settlement fitting curve

Table 2. Load-settlement fitting data record table

Equation	$y = a*x^b$	
Parameters	Micro Pile	Combined pile-anchor
a	0.046	0.024
b	1.372	1.58
R^2	0.996	0.995

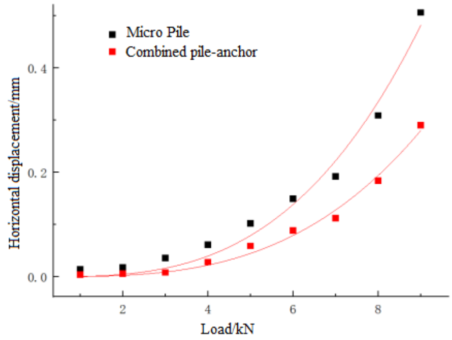


Fig. 9. load-horizontal displacement curve

Table 3. Horizontal displacement-settlement fitting data record table

Equation	y = a*x^b	
Parameters	Micro Pile	Combined pile-anchor
a	5.63097E-4	2.97381E-4
b	3.07	3.11
R^2	0.981	0.989

It is obvious from the data in Table 2 and Table 3 above and the images in Figure 8 and Figure 9 that the change of slope displacement is more obvious in the mini-pile reinforcement mode under the same load, and the deformation rate is faster in the mini-pile support mode when the slope soil is detached from the support structure.

The horizontal displacement of the combined pile-anchor support structure under equal load is divided by the horizontal displacement of the mini-pile support structure and expressed as δh; similarly, the vertical settlement of the two support structures is divided by each other and expressed as δv.

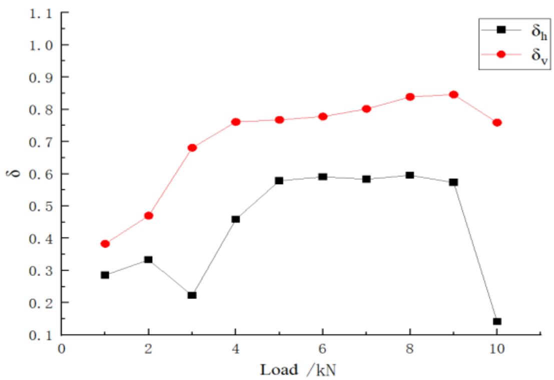


Fig. 10. horizontal displacement ratio diagram

On the basis of the data in Figure 10, the percentage reduction of slope displacement by combined pile-anchor support compared with single support by mini-pile can be calculated, and the data therein are plotted as a dotted line graph as shown in Figure 10.

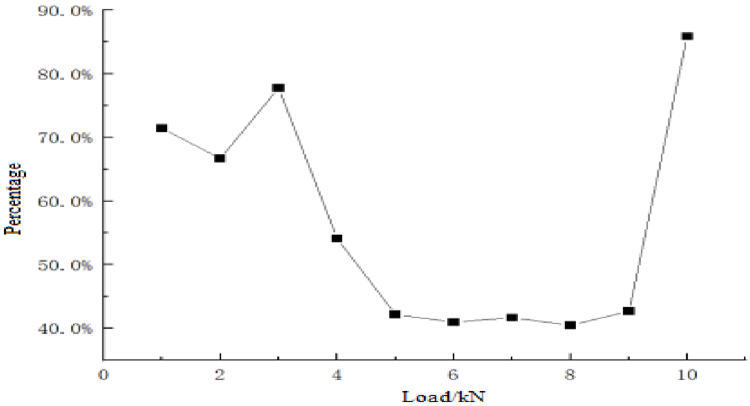


Fig. 11. percentage increase in reinforcement capacity

In summary, it can be seen that under the same upper load, the horizontal displacement of the slope appearing in the joint pile-anchor support structure is smaller, and the horizontal displacement of the slope is reduced by 80%, and the ultimate load when damage occurs, the joint pile-anchor support structure is also larger; from the horizontal displacement-load curve, it can be seen that the curve of the joint pile-anchor support structure is more gentle, and it can be seen that under the same settlement, the horizontal displacement of the joint support The horizontal displacement of the slope in the structure develops more slowly, and, as can be seen from Figure 11, the control of the displacement is significantly improved with the participation of the umbrella anchor in the support, and it can be considered that the joint pile-anchor support effectively improves the anti-slip capacity of the slope.

4 Analysis of the effect of combined reinforcement of micropiles and umbrella anchors

4.1 Project Overview

The site test canal section slide body is located in the stratum soil microfracture is more developed, the slope surface has appeared cracks, the support measures to provide high strength requirements, and the project is an emergency rescue project, the requirements for the construction period is tight, need to quickly complete the construction, and immediately produce reinforcement effect. Therefore, the reinforcement method of joint support of mini-pile and umbrella anchor was adopted. Among them, the potential sliding surface of the swelling soil slope tested on site is shown in Figure 12.

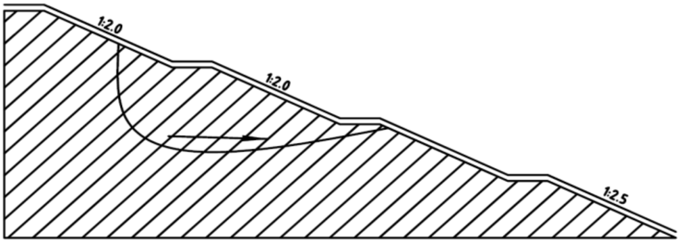


Fig. 12. potential sliding surface of expansive soil slope in demonstration section

The length of the sliding body of the slope is 120m, and the arrangement of umbrella anchors and mini-piles is as follows: 6 rows of umbrella anchors are arranged on the slope of the third grade of the left bank of the channel section, with a spacing of 2.4m in the vertical direction of water flow and 3.4m in the direction of water flow, and an angle of 30° with the horizontal direction; a row of mini-piles is set at the foot of the slope of the third grade of the left bank, with a total of 36 piles and a spacing of 3.4m along the axial direction of the channel, as shown in Figure 13, and the reinforcement is completed as shown in Figure 14.

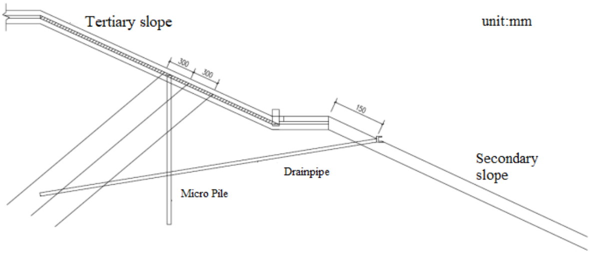


Fig. 13. sectional drawing of partially umbrella anchor and micropile

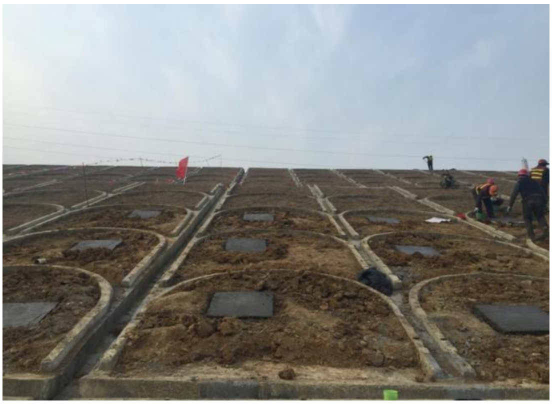


Fig. 14. Site after pile-anchor joint reinforcement

4.2 Reinforcement effect analysis

After the joint pile-anchor reinforcement of the slide body, inclination measurement tubes were set on the first-grade, third-grade and fourth-grade roads to monitor the horizontal displacement of the slope, specifically: one inclination measurement tube was buried at the first-grade road on the left bank, with a depth of 24m, and the displacement-time function image is shown in Figure 15; two inclination measurement tubes were buried at the third-grade road on the left bank, with a depth of 24m and 14m respectively, and the displacement-time function image is shown in Figure 16; three inclination measurement tubes were laid on the fourth-grade drainage slope, with a depth of 24m, and the displacement-time function image is shown in Figure 17.The accumulated displacement in the direction of the maximum displacement process line A of the left bank four-stage horse path measurement ramp is shown in Figure 17, where the three curves represent the accumulated displacement of the three measurement points respectively.The legends in Fig. 15 and Fig. 16 indicate the position of the tilt pipe for distinction only, and have no practical meaning.

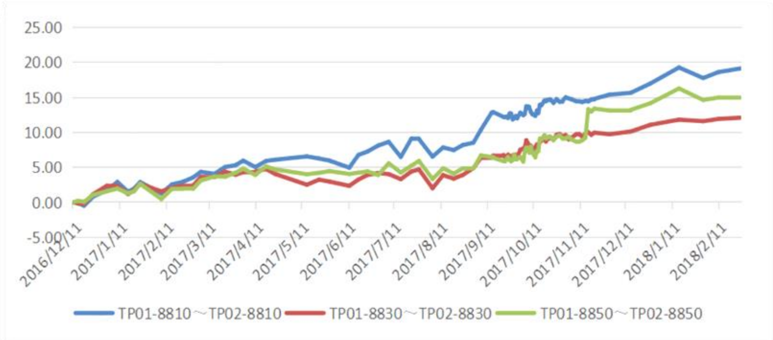


Fig. 15. horizontal displacement of first-class horseway

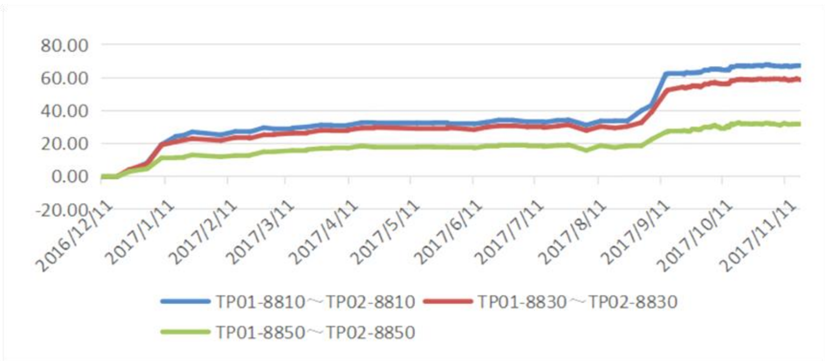


Fig. 16. horizontal displacement of tertiary carriageway

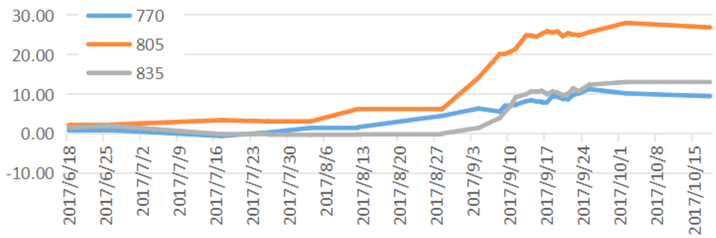


Fig. 17. horizontal displacement of the fourth-class horseway

From the figure, it can be seen that the horizontal deformation of the deep soil of the Grade 3 and Grade 4 roads is less and the growth rate is very small in one and a half years after the completion of the support; while the displacement-time curve of the Grade 1 road shows a fluctuating state due to the proximity to the channel and the influence of groundwater, which is presumed to be closely related to the rainfall.

Combining with the placement of the combined pile-anchor support structure and the displacement direction of the channel slope when it is not supported, it can be judged that the umbrella anchor in the combined pile-anchor support structure mainly provides the bearing capacity and integrity, and the mini-pile provides the lateral deformation stiffness. Among them, the end enlarged head of the umbrella anchor can enhance the slip resistance strength of the slope by squeezing the deep soil body.

5 Conclusion

(1) Combined pile-anchor support can significantly improve the stability of slope, and the ultimate slope bearing capacity is increased by nearly 30% compared with that of mini-pile reinforcement;

(2) The combined pile-anchor reinforcement can significantly improve the development trend of slope displacement, showing a more obvious convergence state, and the displacement volume is reduced by 80% compared with the single reinforcement of mini-pile;

(3) The combined mini-pile-umbrella anchor support structure has the advantages of large anchorage force, fast and convenient construction and instant reinforcement, which can be widely used in emergency scenarios such as rescue and disaster relief and rapid reinforcement.

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