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Analysis of Influencing Factors of Supporting Effect for Pile-Anchor in Soft Soil Foundation

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ABSTRACT

In order to analyze the applicability of the pile-anchor retaining structure in soft soil foundation, combined with some examples of foundation pit engineering in Lianyungang area, the deformation characteristics of pile-anchor was analyzed and think anchorage angle has a greater impact on supporting effect, so the numerical model was established to calculate the influence of different anchorage angle to pit's deformation, the results show: there is a different from rock slope anchorage, foundation pit of soft ground has not the optimal anchorage angle, but anchorage angle is bigger, the better. In addition, the foundation pit in soft soil, the pile-anchor structure is prone to rotate, which exacerbated the deformation of the soil. This kind of phenomenon will be intensified, when the anchorage Angle is larger, when the anchorage angle reaches a certain value, the pile bottom even has a reverse displacement.

KEYWORDS: Marine clay; Pile-anchor structure; Anchorage angle; Deformation characteristics; Infiltration phenomenon

INTRODUCTION

In the supporting of soft soil foundation, due to the engineering properties of soft soil, its supporting structure usually use double piles, diaphragm wall, the inner support and other forms[1-5], in general, pile-anchor structure is used less, but due to the pile-anchor structure has good technical economic conditions in some projects, in some excavation, it has also been applied. But in the soft soil foundation in soft soil due to poor engineering properties, application of pile - anchor supporting structure should pay more attention[6-9].

Domestic and foreign scholars have been studied in this area, LI Shu[10], et al. who based on the deformation characteristics of 37 pit foundation in Beijing area, and statistical analysis, the association of deformation and excavation depth, aspect ratio, and supporting structure form. JIANG Hong-sheng[11], et al. who analyzed the association of excavation form and deformation, the main analysis is the deformation feature of soil nail wall, bolting-shotcreting and pile-anchor. Luo Wei Jin[12], et al. who introduce an excavation instance, the force and deformation of pile-anchor structure are analyzed, that the pile-anchor structure will lead to a larger deformation of foundation pit in soft soil area, that should pay more caution. Liu Xing-yun[13] who described the design and calculation of pile-anchor supporting structure in soft soil foundation and precaution of construction.

in pile-anchor supporting structure, we should not use pipe and other soil compaction pile, should adopt bored pile. Zeng Jian-hua, et al[14] who introduced the application of pile-anchor structure in soft soil foundation, the cost of pile-anchor retaining structure could reduce 30% than bored plus inner support and shorten the construction period.

In currently, the application analysis of pile-anchor retaining structure in soft soil foundation is more, the main content focus on calculation method of pile-anchor structure, excavation deformation monitoring, method of construction and so on. But, there is little research about the deformation characteristic and influencing factors of supporting effect. In this paper, an excavation engineering of marine soft soil in Lianyungang was taken for example, Design overview and reason of too big deformation is introduced, and the deformation characteristic of pile-anchor structure was analyzed by numerical simulation, the main analysis content is the impact of cable anchor's angle, anchor length, retaining pile's length on the supporting effect, it could provide a theoretical basis for engineering design.

STUDY OF ENGINEERING CASE

The pile-anchor structure was used in one engineering in Lianyungang city, the representative cross-section was shown in Figure 1. Retaining pile is PHC600 prestressed pipe pile, pile length is 12m, embedded in solid clay layer, with 3 beams and 7 wires strand. Anchor anchored angle is 35 ° ~ 40 °, the anchorage length is 8m, anchoring segment position is in the clay layer with better strength, the average depth of the excavation is about 4.1m. Pit's location is in typical marine soft soil site, the physical and mechanical parameter of foundation soil was shown in Table 1.

Table 1: Physical and mechanical parameters of soil

Name	Thickness (m)	Bulk Density (KN/m^3(	Void Ratio	Carrying Capacity (KPa)	Deformation Modulus (MPa)	Cohesion (KPa)	Friction Angle (°)
Plain Fill	1	18.5	0.95	68	4.34	8	10
Silt	10	17.3	1.34	24	1.41	6	3
Clay	5	18.7	0.84	248	16.57	22	16
Silty Clay	4	19.1	0.82	203	17.30	28	18
Clay Sand	2	18.4	0.96	312	13.45	18	12
Clay	7	19.2	0.77	276	32.30	33	23

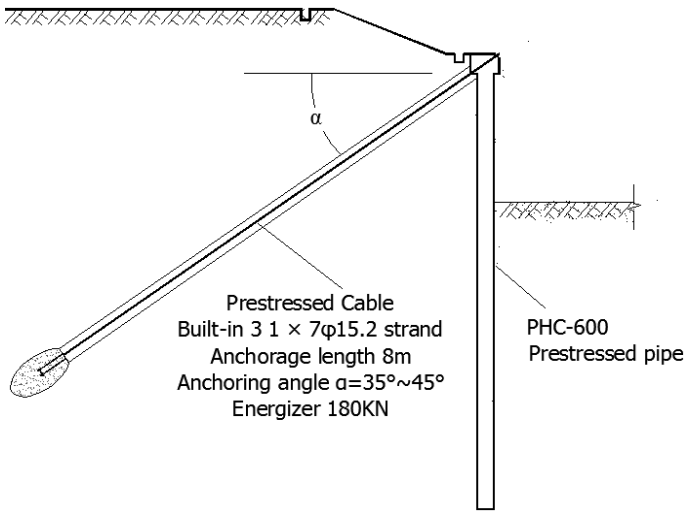

Figure 1: Design schematic of pit cross-section

Figure 2: Scene photo of pit with large deformation

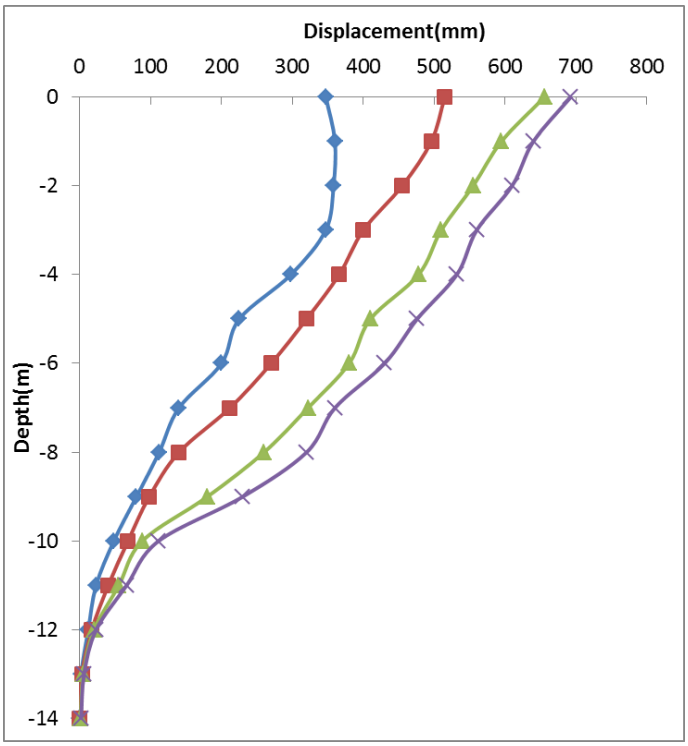

Figure 3: Monitoring data of horizontal displacement

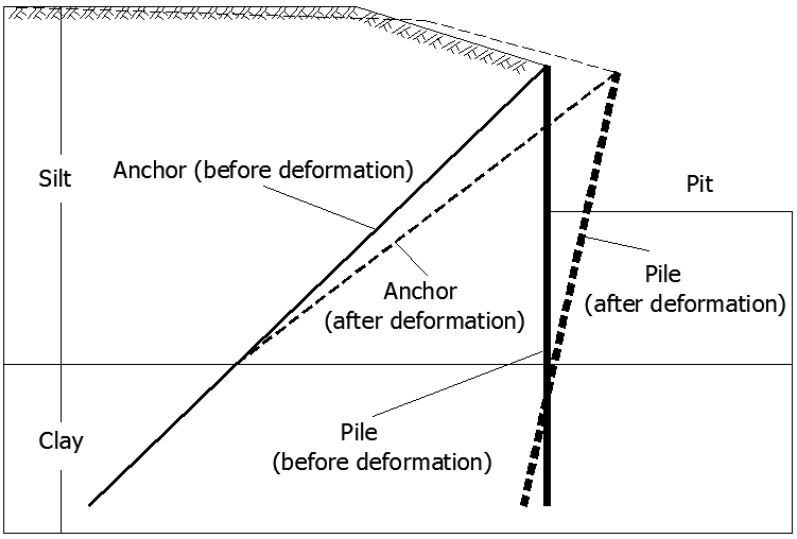

Figure 4: Schematic of rotation by pile anchor structure

By measured data on-site, the excavation deformation generally larger, most of the monitoring points is about 50mm, and the amount of displacement is increasing along with the increasing of anchor angle, ground subsidence and cracks occurred in varying degrees, and even displacement of some monitoring points are up to ten centimeters. Figure 2 is the picture of excessive deformation portion, it can also be seen from the reference, the lampposts are obvious tilting. The monitoring result of deformation was shown in Figure 3, from the analysis of the reason that the fundamental factor is the poor engineering properties of soft soil, the using of pile-anchor supporting structure cannot effectively control the deformation of foundation pit. In addition, the pile-anchor structure in soft soil will whirl when soil deformation is large, shown in Figure 4, especially in the larger anchor angle, the limit function of cable to pile is weakened, making it easier to produce rotation.

NUMERICAL SIMULATION ANALYSIS

Numerical model

By analysis of engineering example in soft soil foundation, the pile-anchor supporting structure due to large deformation of soil will cause the rotation of the supporting structure, resulting in deformation of foundation pit continues to increase, especially for larger anchor angle, this phenomenon is worsened. Therefore, numerical model was established to analyze this phenomenon in this article.

Numerical model was established according to the project shown in Figure 2, the model size is 40 × 40m, soil parameters are in Table 1, the prestressed anchor structural unit comes with cable in FLAC[15], cable anchor on the clay layer, pipe pile use solid elements, pile length is 12m, as shown in Figure 5, soil constitutive use the Mohr-Coulomb model.

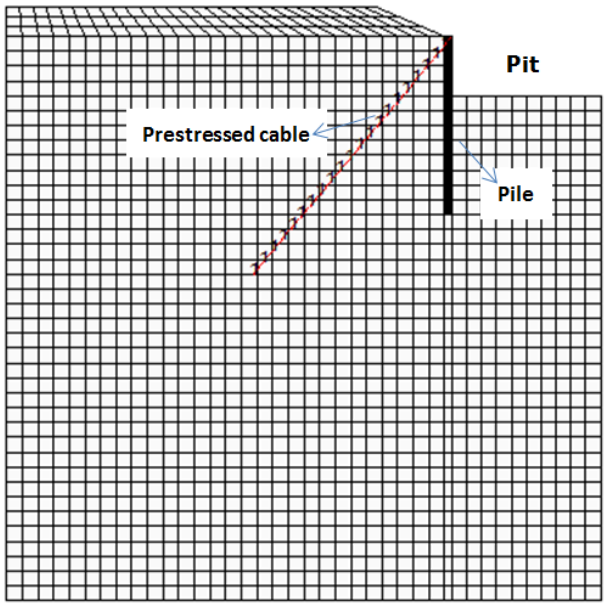

Figure 5: The element grid used in the numerical model

Pile-soil deformation law

To analyze the effect of the angle of prestressed cables, set anchor angle 25°, 30°, 35°, 40°, 45°, 50°, 7 kinds of working conditions, Figure 6 is the horizontal displacement of foundation with anchoring angle 55 °, the maximum displacement occurs near the top of the pile, the value is 437.5mm. The displacement of soil decreases as the depth increases, but to the bottom of the pile still has a large deformation.

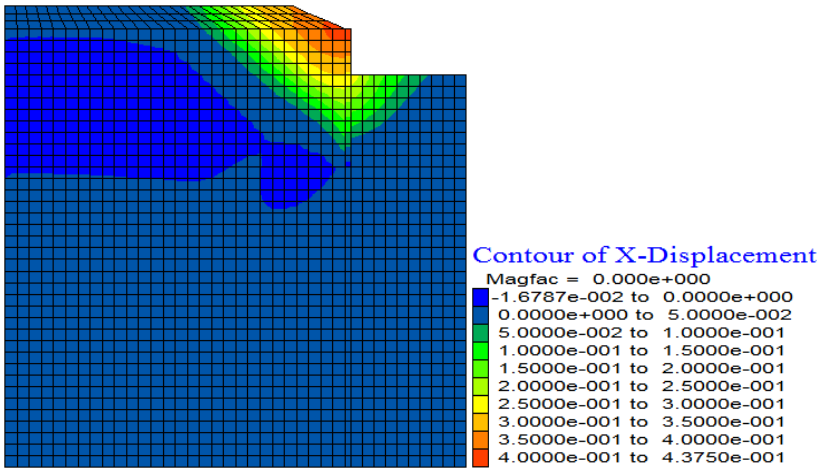

Figure 6: Deformation cloud of pit

Figure 7 is the shear strain increment cloud with anchored angle 55 °, the maximum value is about 6.8 × 10-2, shear strain increment link together almost, and the sliding surface located in the lower bottom of the pit, pit have an overall slippage trend.

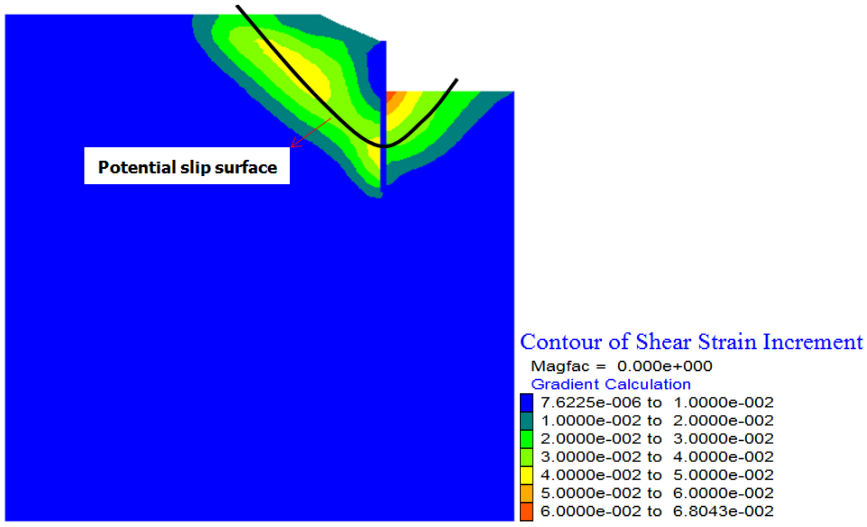

Figure 7: SSI cloud of pit

Other conditions similar to this calculation, it gives only the analysis results, Figure 8 is the comparison chart of maximum horizontal displacement for foundation pit by each condition, It can be seen as the anchor angle increases, the maximum horizontal displacement increases, especially when the anchor angle reaches 45°, the maximum horizontal displacement increases rapidly from a few centimeters to tens of centimeters.

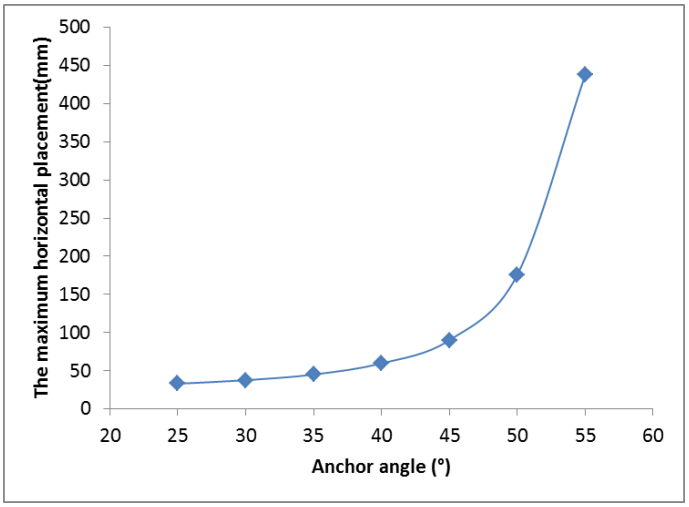

Figure 8: The maximum horizontal displacement of each condition

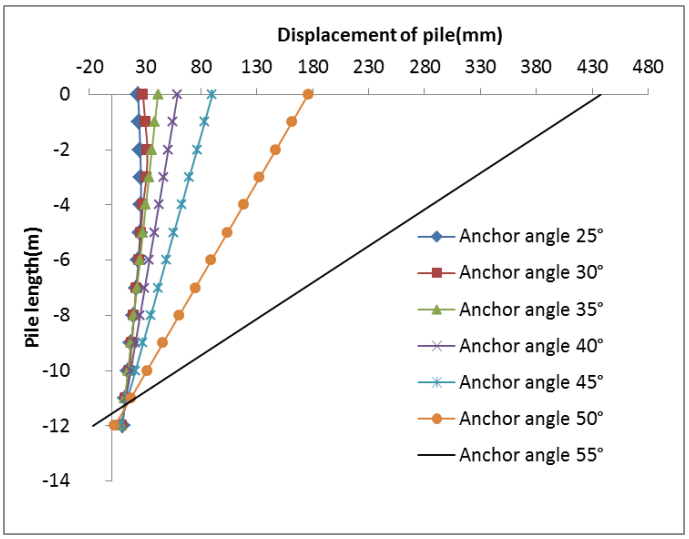

Figure 9: Horizontal displacement contrast of pile

Fig. 9 is the displacement distribution of pile under various condition, when the pile displacement is small, namely anchoring angle is 25° and 30°, the pile displacement is in nonlinear distribution, the maximum displacement is located The following top of the pile about 2m. When the angle reaches 35°, displacement of pile is substantially in linear distribution, the maximum displacement are located on top of the pile, the minimum displacement is located in the bottom of the pile. When the anchor angle reaches 45 °, pile top displacement increases rapidly, and when the anchor angle is 55 °, the bottom of the pile appeared negative displacement.

The comparison of displacement to bottom of pile by each condition is shown in Fig. 10, the pile bottom all exist displacement when anchor angle is from 25° ~ 55°, it shows the level of bearing capacity for pile in the soft soil is lower. Further, with the increase of the anchor angle, pile Bottom's displacement is gradually reduced and even generate negative displacement, its value reached 16.8mm, it shows that pile is gradually rotate with the increasing of foundation pit's displacement, this conclusion is consistent with the analysis above, that anchor angle is greater the support system is more prone to rotate. This phenomenon can also be obtained from the axial force in the anchor, as shown in Figure 11. From the figure 11, as the angle of anchor increases, anchor axial force increase gradually. But when the anchor angle reach 55 ° (At this point displacement up to about 440mm) anchor axial force not only did not continue to increase, but reduced. It shows that anchor occur relaxation compared to the previous working conditions, this is due to the pile-anchor structure it occur rotation.

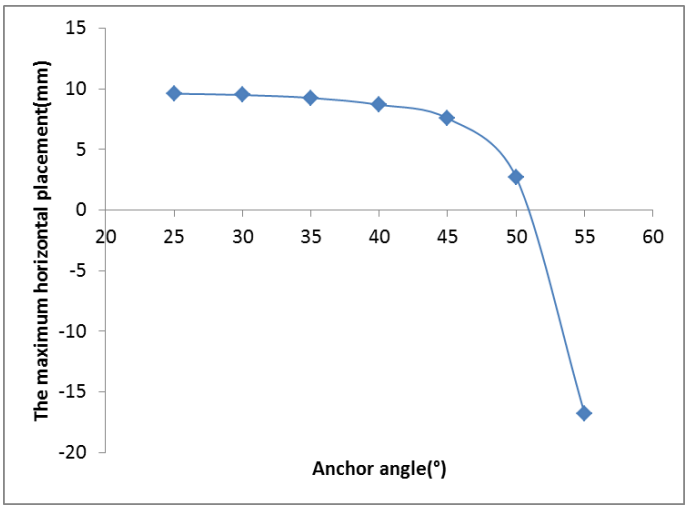

Figure 10 Horizontal displacement contrast of pile bottom

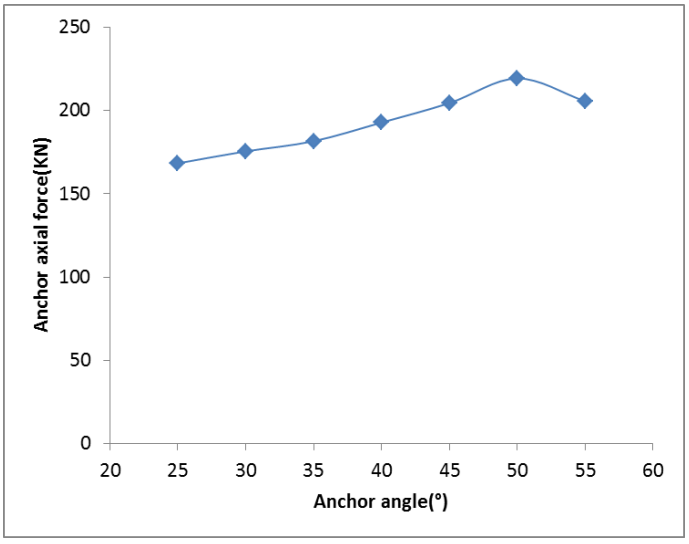

Figure 11: The anchor axial force of each condition

Figure 12 is anchor deformation vector of anchoring angle for 55° and 50°, the maximum deformation is 525.8mm and 219.2mm, from the deformation characteristics of view, it is consistent with the above analysis, anchor occur different degree of rotation.

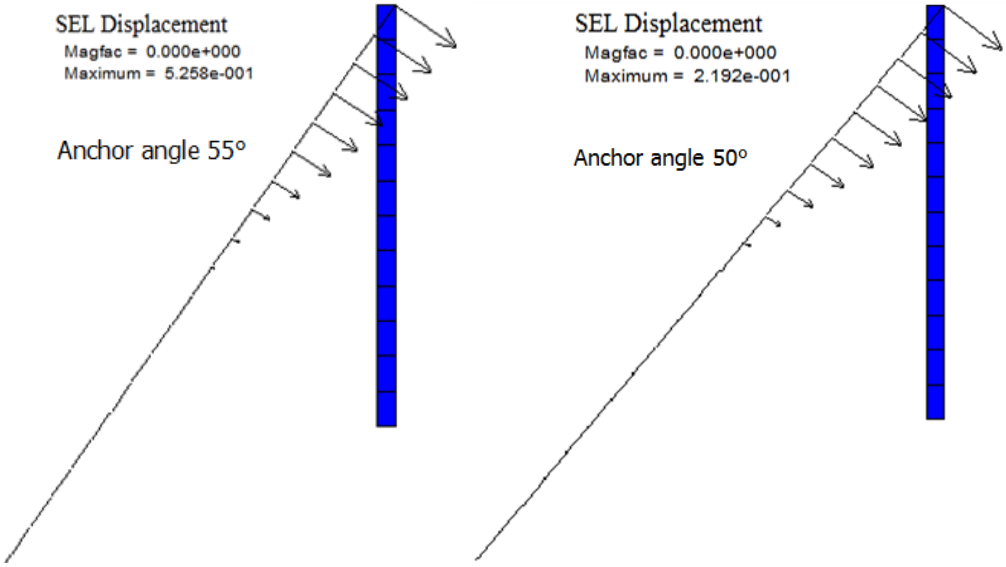

Figure 12: Vector of anchor deformation

Fig. 13 is a relationship between the anchor angle and the anchor's maximum displacement, the deformation of cable suddenly increase, when the anchor angle reach 50°, the maximum displacement of anchor and anchor angle become exponential relationship by fitting the curve.

Fig. 14 is a graph of anchoring anchorage segment's slippage and anchor angle, with the increase of anchor angle, the anchor segment's slippage is also increasing, this is consistent with the law of pit deformation, but when the anchor angle reach 50°, slippage of anchoring section does not increase but a decreasing trend, it proves the pile anchor structure with larger anchor angle is prone to rotate once again.

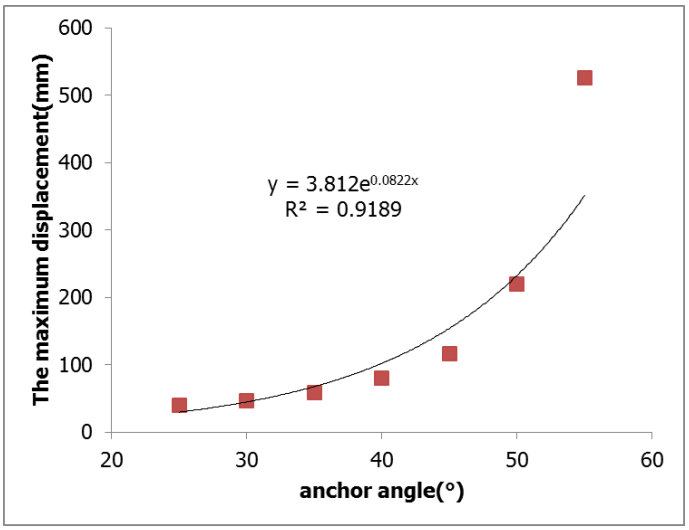

Figure 13: The maximum displacement of anchor

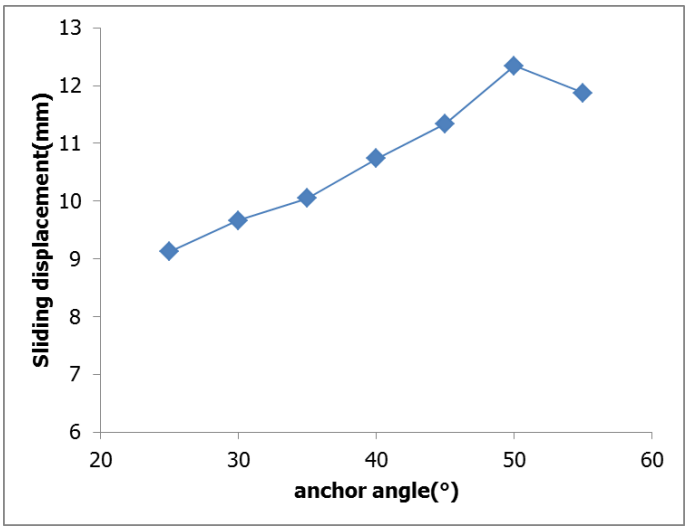

Figure 14: Sliding displacement of anchoring segment

Shear stress distribution of pile-soil interface

Pile-soil's deformation and stress are closely related, therefore, it is necessary to analysis the interaction law of pile and soil, this paper give the shear and normal stress of pile-soil interface. Fig. 15 is the shear stress distribution along the pile of pile-soil interface, the position of interface is on pile's left. From each condition's value of shear stress, with the increase of the anchor angle, shear stress of pile-soil interface also increases, which is consistent with the law of deformation.

From the shear stress distribution along the pile, the top of pile withstand greater shear stress, at about 10kPa, from 1m to 6m of following pile top bear smaller shear stress, at about 3kPa. Top of the pile's shear stress have amplification phenomenon due to the connection of cable and pile top, this constraint improve the normal stress, so it bear large shear stress near the pile top.

At the following pile top 6m, shear stress of pile-soil interface increases rapidly to about 20kPa, Max is located near the following of pile top 9m, the reason for this is twofold: First, as the depth increases, the interface to withstand normal stress has also increased, so the corresponding shear stress will increase, Second, soil at 1m ~ 6m following of pile top under large deformation, will have a slip between pile and soil, a portion of shear stress has been released, therefore, from the top of the pile under 6m to 9m, there is no smooth transition, but a sudden increase.

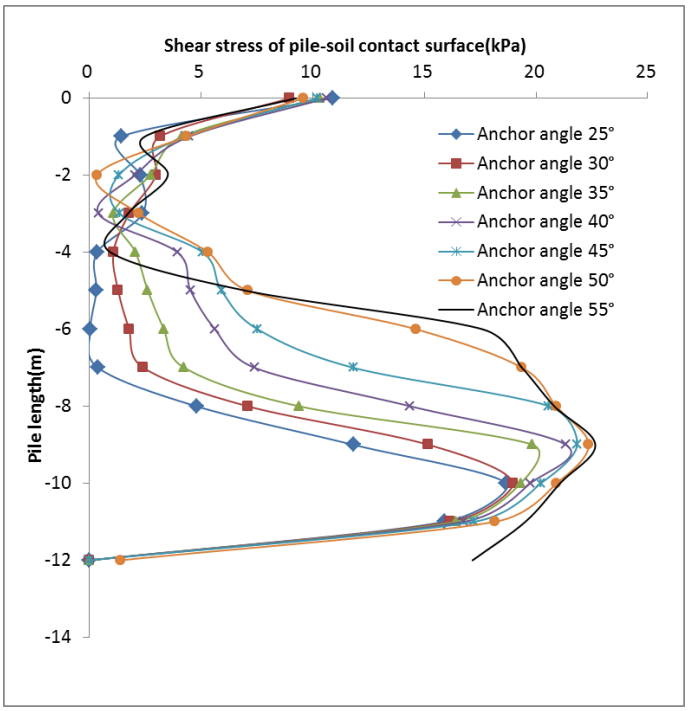

Figure 15: SS distribution of pile-soil interface（left side）

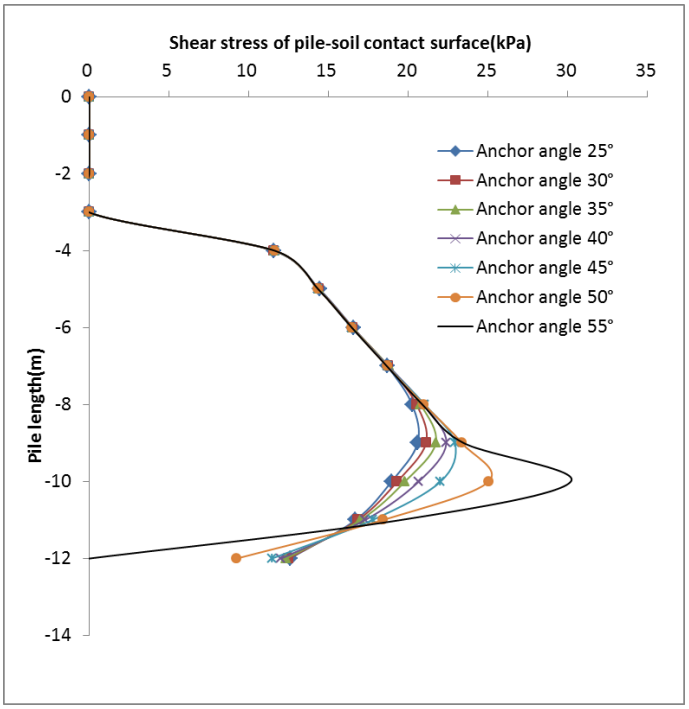

Figure 16: SS distribution of pile-soil interface（right side）

Form 9 m below the pile top to pile bottom, shear stress of pile-soil interface decrease rapidly, in addition to the condition of anchoring angle 50° and 55°, the remaining conditions are rapidly reduced to 0kPa, This is because the soil deformation at pile bottom is almost zero, but there is a

small deformation at the pile bottom, "Infiltration" phenomenon occur between the pile and soil, that pile bottom permeate to the right soil, and the pile bottom separate the left soil, therefore, the shear stress rapidly decreased to 0kPa. But when anchor angle is 50° and 55°, the rotation phenomenon of pile-anchor structure increase gradually, soil deformation is driven by pile bottom, slippage between pile and soil has occurred. So the shear stress of interface is not reduced to 0kPa for this two conditions, shear stress of pile Bottom for anchor angle of 50° is 1.4kPa, and anchor angle of 55° is 17.2kPa, which displacement of pile bottom has reach -16.8mm.

Fig. 16 is shear stress distribution of interface along the right side of pile, the law is similar to the left side, this will not repeat. It is noted that in the face of the excavation, there is no interaction between the pile and soil, stress of interface is 0kPa.

Normal stress distribution of pile-soil interface

Fig. 17 is a normal stress distribution of pile-soil interface on pile's left, and distributio law is similar to shear stress, anchor angle increases, the greater the normal stress. The normal stress of pile top is not zero, which is the cable tension's sake. The normal stress within the range of 9m following pile top shows an increasing trend with increasing depth, when the depth is more than 9m, the normal stress decreases rapidly to 0kPa, this is still caused by the "infiltration" phenomenon. Therefore, the normal stress of pile-soil interface is almost zero, but only the anchor angle is 50° and 55°, and when the angle is 55°, the normal stress is still about 93.2kPa.

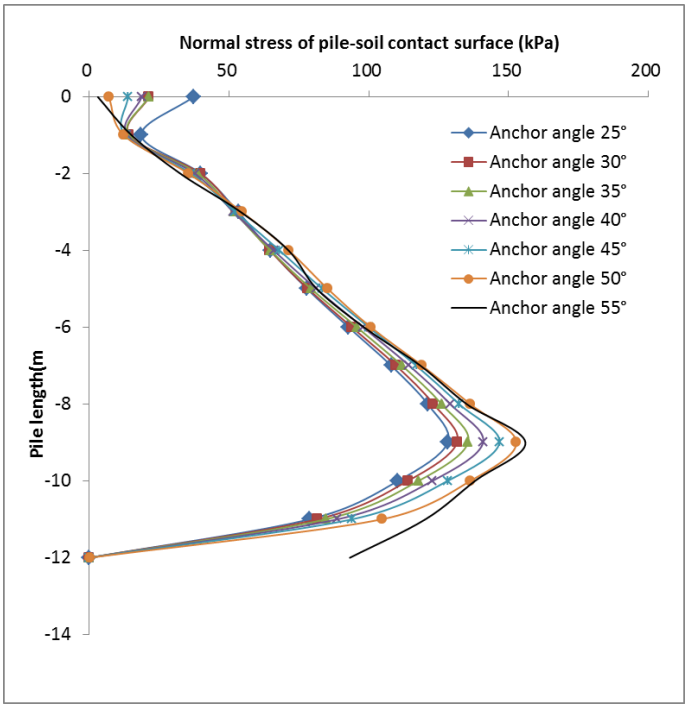

Figure 17: NS distribution of pile-soil contact surface

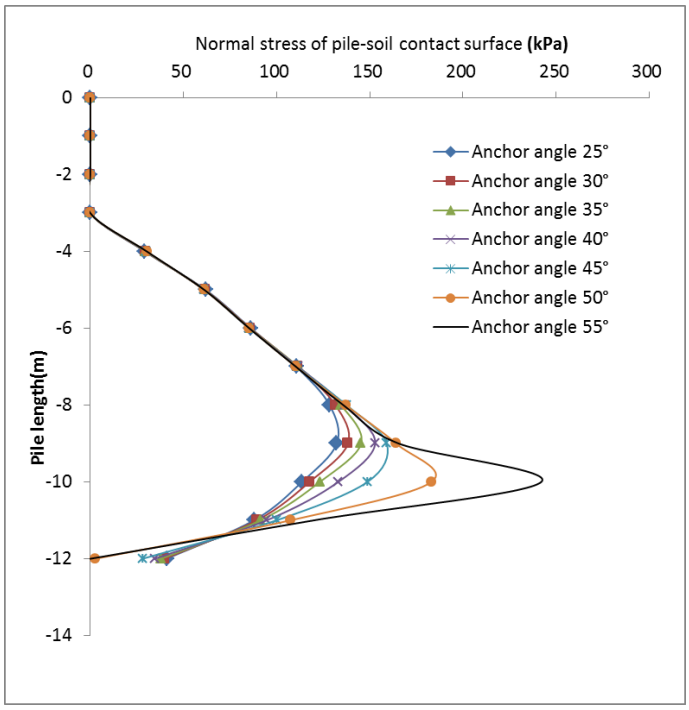

Figure 18: NS distribution of pile-soil contact surface

Fig. 18 is the distribution of normal stress on the right side of pile-soil interface, it is similar to the previous law, it shows that numerical simulation is reliable and consistent.

Effect of supporting effect by anchorage length

In the rock slope, the cable anchor length is generally considered to be the best value 6m, But in the soft soil foundation, the situation is not the same, Therefore, this article calculated the anchorage length 4m, 6m, 8m, 10m, 12m and 14m, six kinds of working conditions, wherein the anchored angle is 40°, the rest of the calculation conditions consistent with the foregoing. Fig. 19 is the relationship between the length of the cable anchor and pit maximum displacement, maximum displacement of the anchor, as can be seen from the figure, with the increase of the length of the anchoring, both the displacement amount is gradually reduced, When anchor length reach 8m, the displacement development becomes gentle, it shows that increasing of anchorage length has little effect on supporting effect, therefore, the optimal anchor length in soft soil is 8m.

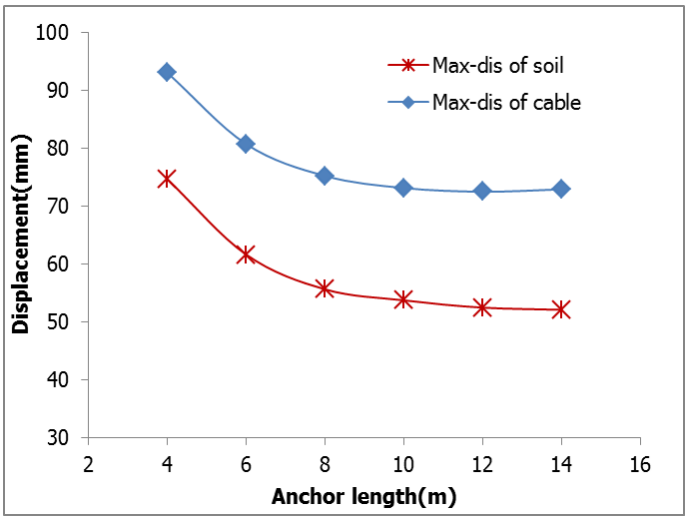

Figure 19: Relationship of anchor length and displacement

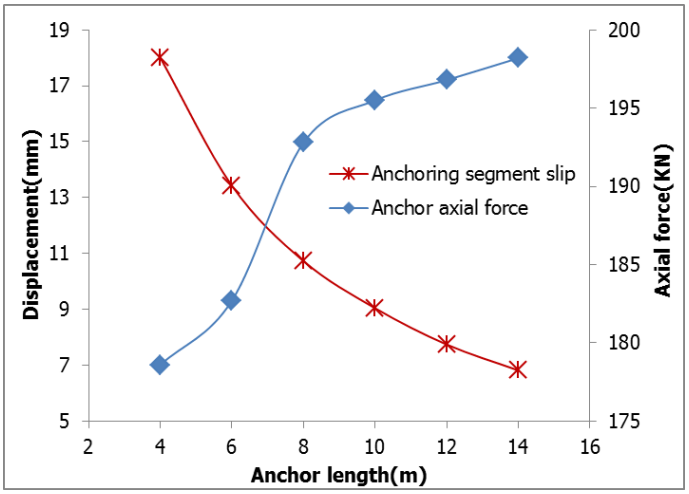

Figure 20: Relationship of anchor length and displacement

Fig. 20 is the relationship between the length of prestressed cable and anchoring segment's slippage, axial force, as can be seen, with the increase of the anchor length, the slip amount of anchoring segment is gradually reduced, It shows again that the problem of cable slippage in soft soil, with increasing of anchoring section, axial force is gradually increased, and it is the opposite trend to slip amount of anchoring segment, this shows that the greater length of anchoring segment can play the role of support better. From the figure can also know obviously that anchorage length 8m is a demarcation point, before, anchor axial force increases rapidly, after reaching 8m anchor axial force increases slowdown, This proves once again the best in soft soil anchor anchorage length is 8m.

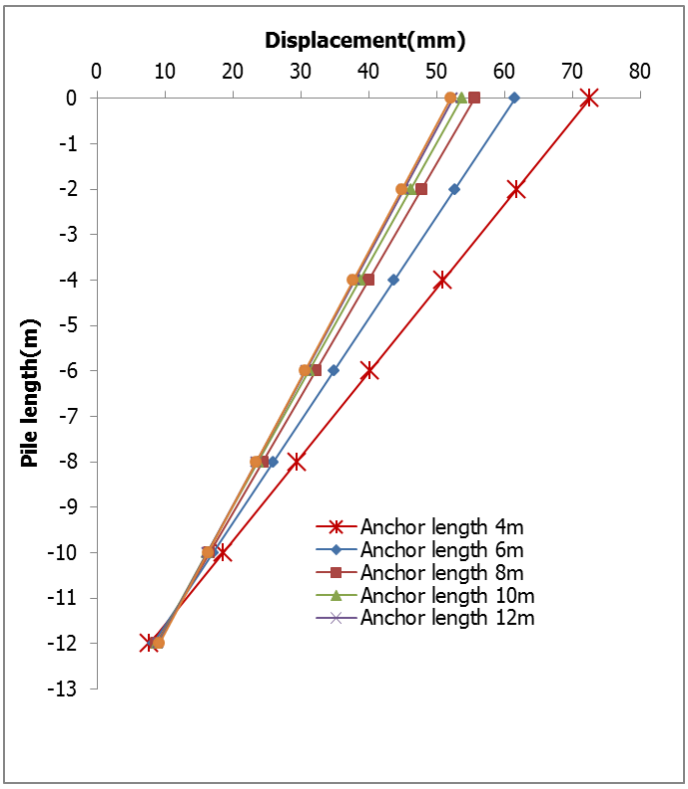

Figure 21: Displacement of pile

Figure 21 is displacement distribution of pile body, the characteristic is consistent with above analysis of the anchor angle, pile displacement is still in linear distribution, and has tendency to rotate, with increasing of the anchor length, pile displacement decreases, when the anchorage length is up to 8m, the decreasing trend slowed down.

CONCLUSIONS

Combined with theoretical analysis of engineering example for pile-anchor supporting structure in soft soil foundation, we get a little understanding:

(1) According to the analysis of actual project, the using of pile-anchor supporting in soft soil foundation is prone to large displacement due to the poor nature of the soil, the numerical analysis also showed that is easy to generate overall instability, and the sliding surface will be located in the bottom of the pit. Therefore, the design should be strengthen in soft soil foundation.

(2) The retaining structure of pile-anchor will be prone to rotate due to numerical analysis, especially in soft soil or cable anchor angle is large, the distribution of anchor axial force and slip characteristics of anchoring section also demonstrates this phenomenon, and this phenomenon can exacerbate the deformation of the pit, in practical application should control the angle and the length of free section, the longer the free section will be more prone to rotate.

(3) Under various conditions, the amount of slip to anchor segments were about 10mm, cable's anchorage is the problem that should be note in soft soil. In actual use, it is easy to fail due to excessive slip of anchoring section. To solve this problem, we can make certain field trial, then determine the specific parameters of anchoring segments, such as the length of the anchor, the anchor diameter and so on.

(4) From the distribution characteristics of contact surface stress for pile-soil, among contact surface of pile-soil, the maximum of shear stress and normal stress are located in the following 9m at the top of the pile. Due to poor engineering properties of soft soil, it is prone to generate "infiltrate" phenomenon between the pile and the soil, therefore, in the bottom of the pile, the distribution of contact surface stress is anomaly, in the design we should pay more attention to the rollover resistance of bracing pile.

(5) The best anchor length of prestressed anchor is 8m in soft soil foundation, it is different to the rock medium which is 6m. With the increase of the length of the cable anchor, anchor segment slippage decreases, anchor axial force is gradually increased, and the prestressed anchor structure will play a greater role.

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