Monitoring Analysis on Pile-Anchor Retaining System of Foundation Pit to Spatial Effect

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ABSTRACT

Anchorage tension, horizontal displacement and soil pressure of retaining pile were monitored in different parts of foundation pit with pile-anchor retaining system. According to analysis of measured results in-situ, it shows that anchorage tension goes through three stages during its changing process, namely anchorage loss, anchorage increase and anchorage stability. Anchorage tension usually suffers a huge loss in stress after tension, and spatial effect has significant influence on anchorage tension in different parts of foundation pit. Anchorage tension in normal consolidated sand and gravel soil will no longer change with time. Soil pressure of retaining pile experiences a rapid increase initially after excavation, and then tends to stable value. The value of measured total soil pressure accounts for about 75% of which is calculated by theory of Rankine. Results show that set of anchor plays a positive role in reducing lateral displacement of retaining pile. It explains much of spatial effect on irregular foundation pit with convex corner. Test results and rule generated in this paper help to further perfect design theory and method of foundation pit, and have reference value for similar design and construction of foundation pit with pile-anchor retaining system.

KEYWORDS: pile-anchor retaining system; large-scale foundation pit; monitoring analysis; spatial effect

INTRODUCTION

Foundation pit and its retaining structure system belong to complex three-dimensional stress problems. Spatial effect caused by plane shape and excavation depth of foundation pit has significant influence on stress state and deformation of foundation pit and its retaining structure. For irregular shape, horizontal restraints of two direction in soil are weaker around convex corners. The stress state and deformation of this part are different from other parts. Spatial effect affects stability and safety of adjacent buildings[1~8].

According to pertinent papers, the method of numerical simulation is applied in research[9]. In this paper, the work aims at sorting and analyzing anchorage tension, displacement of pile and soil, soil pressure and settlement of surrounding roads. Based on the project in coastal region, it reveals influence rule of stress and deformation of retaining structure and surrounding soil of foundation pit.

ENGINEERING GENERAL SITUATION

GEOLOGICAL CONDITIONS

The thirteen-story resort has three integral basements. Excavation depth is about 7.2~12.9m. South edge of basements is 20m away from urban road. And distances between other three sides and boundary line is 8m, 9m and 12m respectively. They are also adjacent to present buildings. Original geomorphic unit belongs to coastal first terrace. Elevation of foundation pit in south is 4m higher than north. During this survey, groundwater depth varies from 2.27m to 7.58m. Table 1 shows physical and mechanical parameters of soil.

Table 1: Physical and mechanical parameters of soil

No.	Name	Average thickness / m	Water content ω /%	Unit weight γ /kN·m^{-3}	Modulus of compressibility $E_{s0.1\text{-}0.2}$ / MPa	Internal friction angle φ / (°)	Cohesion c /kPa
①	fine sand	6.86	8.9	20.0	6.0	20	14.0
②	gravel soil	4.40	10.8	20.5	13.0	30	8.0
③	silt	4.75	22.2	20.0	5.0	18	17.0
④	muddy-silty clay	10.18	37.8	17.4	2.5	5.0	18.0
⑤	medium sand	2.55	15.1	20.5	13.0	26.0	10.0
⑥	silty clay	8.86	20.7	19.1	8.7	15.0	44.6

RETAINING SCHEME

Overall scheme of retaining structure are slope on the top and pile-anchor below the former. Different parts of foundation pit are segmented to design owing to the difference of elevation owing to the difference of elevation. Figure 1 shows the plan view of foundation pit and retaining structure. For example, Figure 2 shows section 1-1 of retaining structure. Bored piles are applied in this project, with determination values of pile length, pile diameter and spacing of piles equal to 23.1m, 1000mm and 1400mm respectively. End of pile is located at medium sand layer instead of muddy-silty clay layer. Beam is set at the top of retaining piles, with the concrete strength of C30. Reinforced concrete beam's section size is 1200mm×800mm. Retaining pile embedded crown beam depth is greater than 100 mm. Triaxial soil-cement mixing pile of single row with diameter of 850mm is applied in curtain for cutting off drains. There are three prestressed anchors with drilling diameter equal to 150mm. Each pile has been securely anchored by the method of casing pile wall. And diameter of expanding parts is more than 400mm. Horizontal and vertical spacing of anchors are 1.4m and 4.0m. The length of anchor is about 20.0~22.5m. Anchor is made of stranded wire with diameter of 15.2mm. Each wire has four bunches with f_{ptk} and f_{py} equal to 1860N/mm^2 and 1320N/mm^2 respectively. The method of Secondary pressure grouting process is applied in this project. Length of anchoring section is about 9~12m. Anchoring

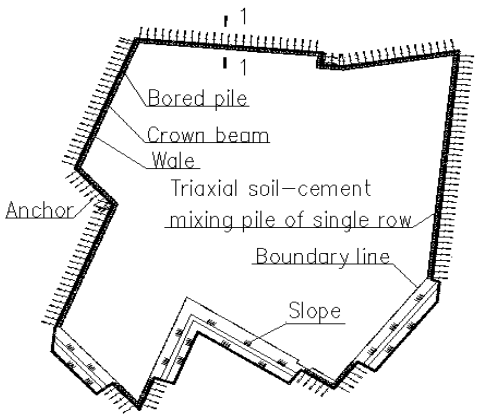


Figure 1: Plan view of foundation pit and retaining structure

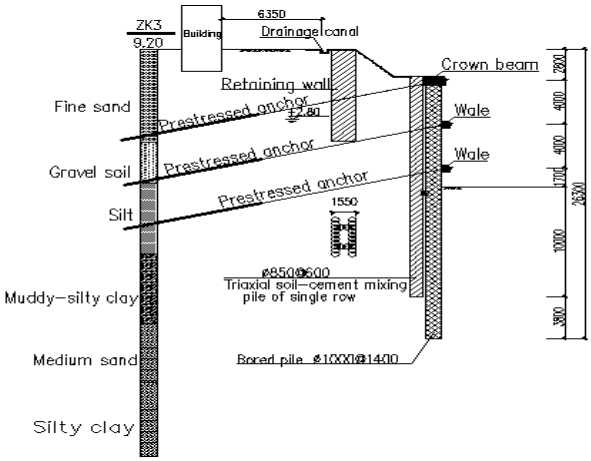
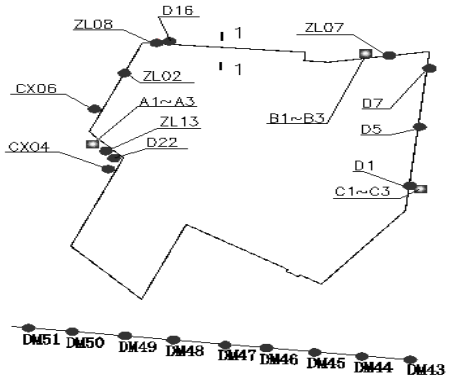


Figure 2: Section 1-1 of retaining structure

force design value is 304~422kN. Inclination of anchor varies from 20° to 25°.

Monitoring results and analysis

Observation started in excavation of foundation pit, with monitoring of anchorage tension, displacement of pile and soil, soil pressure and settlement of surrounding roads. Figure 3 shows parts of the section and monitoring points.



ZL—Anchorage tension; C1~C3—Soil pressure; D—Displacement of retaining pile top
CX—Horizontal displacement of deep retaining pile DM—Settlement of surrounding roads

Figure 3: Plan view of monitoring points

Analysis of anchorage tension

Forty Stress meters are set to monitor change of anchorage tension in the foundation pit. Figure 4 shows the curves of anchorage tension of first anchors, namely ZL02, ZL07, ZL08 and ZL13, with prestress value equal to 315 kN, 290 kN, 280 kN and 385 kN respectively. The displacement of anchor under tension value and pressure remain stable. After fortnight, anchorage tension has been monitored everyday.

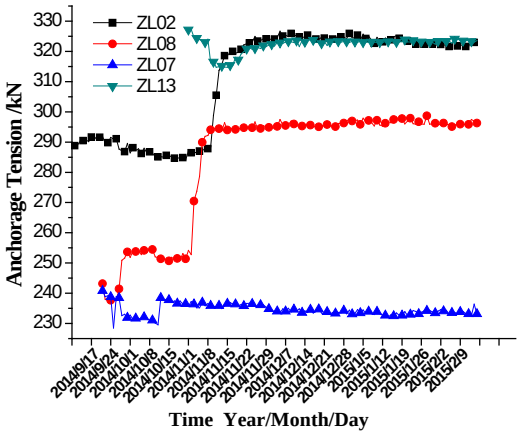


Figure 4: Anchorage tension

For Figure 4, change of anchorage tension can be divided into three stages. At first, the stage of anchorage loss appears. Then anchorage tension increases a lot. Finally, the tension tends to stable. Initial anchorage loss is serious. According to the first monitoring results, anchorage loss of four monitoring points equals to 8.3%, 16.9%, 12.5% and 14.8% respectively. The reason may be explained as follows. Anchorage section is located at layers of fine sand and gravel soil. Hole collapse happened around two layers, owing to the method expanding hole. Flowing void is caused by the lock of adjacent anchor, so anchorage loss is serious at first. Along with excavation, soil pressure has been released, deformation of soil

has also increased simultaneously. Anchorage stress has changed from active state into passive state, and the majority of anchorage tension have increased obviously. After a period of accomplishment of excavation and retaining, the interaction between retaining structure and soil is stable, anchorage tension also tends to stable value.

For plan view of monitoring points, ZL02 is set at the northwestern middle edge of foundation pit. And ZL13 is adjacent to convex corner. Additionally, ZL07 and ZL08 are set at concave corner with angle of 70° and 110° respectively. For comparison of ZL02, ZL13, ZL08, ZL07's monitoring results, anchorage tension of ZL02 and ZL13 equal to the maximum value. Meanwhile, ZL08, ZL07 equal to medium and minimum value in Figure 4. It explains much of spatial effect on foundation pit after excavation.

Analysis of soil pressure

In Figure 3, each pile of A, B, C is selected as test pile to monitor soil pressure of active area. Soil pressure cell bound on reinforced cage of retaining pile by the method of hanging cloth is fix in borehole. The test surface of soil pressure cell is toward side of soil. Figure 5 shows the varieties of soil pressure of point C with different depth. It reveals influence rules of soil pressure along with construction. Three soil pressure cells are set at depth of -5 m, -7 m and -10 m. Figure 6 shows comparison of active soil pressure by in-situ test and theory of Rankine.

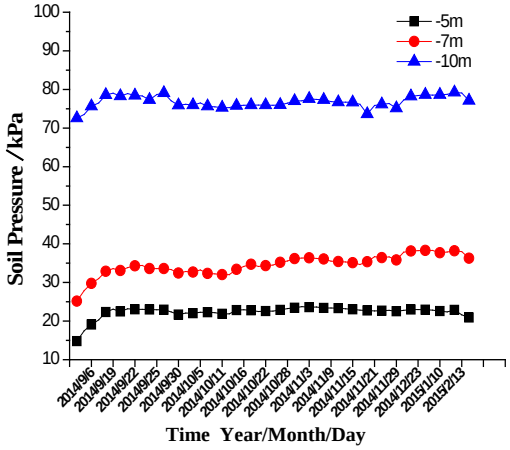


Figure 5: Soil pressure of different depth of point C

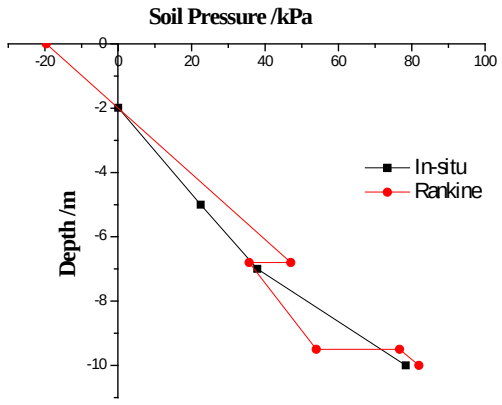


Figure 6: Comparison of active soil pressure by in-situ test and theory of Rankine

As Figure 5 shows, soil stress has been released owing to the horizontal restraint loss of soil. And soil pressure increases as well. This result and the stress rules of anchorage tension in Figure 4 are the same. [10] pointed out, anchorage tension has basically no change in foundation pit in sand and gravel soil layer after a year of accomplishment of excavation. It explains that active soil pressure has basically no change, too. In Figure 6, measured value is significantly less than active soil pressure by the theory of Rankine after excavation. According to measured value, the estimation of total soil pressure is 269 kN/m. Meanwhile,

total soil pressure is 358 kN/m by the theory of Rankine. Measured value accounts for 75% of theoretical calculation value.

Horizontal displacement of retaining pile top

It is necessary to monitor horizontal displacement of retaining pile top. It is the key to ensure safety of foundation pit. In this project, twenty-eight monitoring points are set in-situ. Figure 7 shows data of point D1, D5 and D7 located at east of foundation pit. And Figure 8 shows data of point D16 and D22 located at west of foundation pit. Displacement increase of the rest points forms stepped growth during excavation except D16. It explains that set of anchor can reduce horizontal displacement of pile top obviously. Until lock of the last anchor and accomplishment of excavation, horizontal displacement tends to stable finally. For stable value, displacement of point D5 at eastern middle side of foundation pit is maximum with the value of 29mm. But it's not more than warning value of 30mm. Meanwhile, horizontal displacement of D7 at concave corner is minimum. Displacement of D22 at convex corner located in west of foundation pit is greater than that of D16 at concave corner. The former is six times than the latter. It explains much of spatial effect on irregular foundation pit.

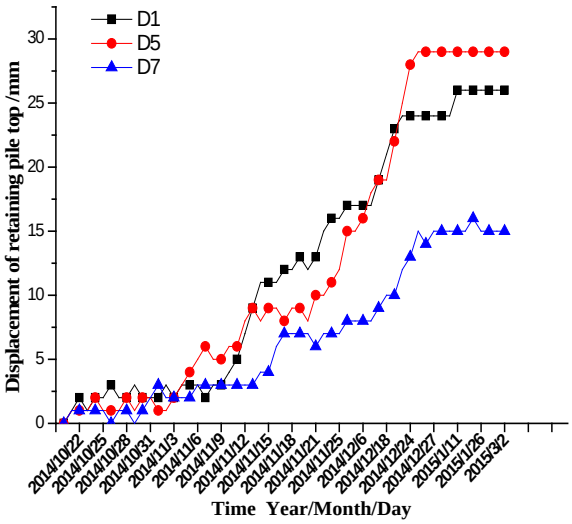


Figure 7: Horizontal displacement of retaining pile top at east of foundation pit

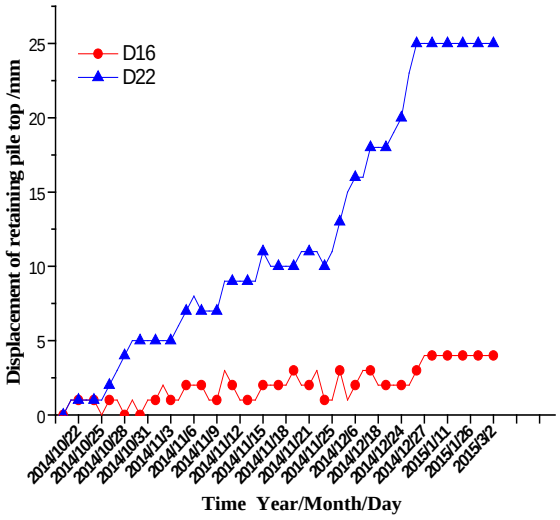


Figure 8: Horizontal displacement of retaining pile top at convex and concave corner in west of foundation pit

Horizontal displacement of deep retaining pile

To monitor horizontal displacement of retaining pile and soil in time, twenty-four test piles are selected to ensure the stability of pit wall and surrounding environment. Seven monitoring points are set on each test pile. And inclinometer is used to monitor horizontal

displacement of different depth of retaining pile or soil. Figure 9 shows displacement of CX04 at convex corner in west of foundation pit.

The monitoring point is set at depth of 10.7 m during excavation. According to the ratio of 1:1. 5, top slope is designed. The retaining pile with length of 26.5m embedded foundation pit below design plane with depth of 17.8m. Anchor is set under the crown beam with depth of 2.6m and 6.6m respectively. Superface of crown beam is located at the depth of -2m in Figure 9.

As Figure 9 shows, at the beginning of anchorage prestress (before October 15th), displacement of upper pile is towards soil owing to anchorage prestress. Displacement of retaining pile top is maximum. Soil pressure behind pile is at passive state. Then it has change from passive state into active state along with construction. Point of the maximal displacement descended to the bottom of excavation. Set of anchor has played a positive role in reducing lateral displacement of retaining pile. The maximum horizontal displacements of monitoring points are less than 3 mm. Test results and discipline explain much of rule of horizontal displacement of deep retaining pile influenced by excavation and anchorage tension.

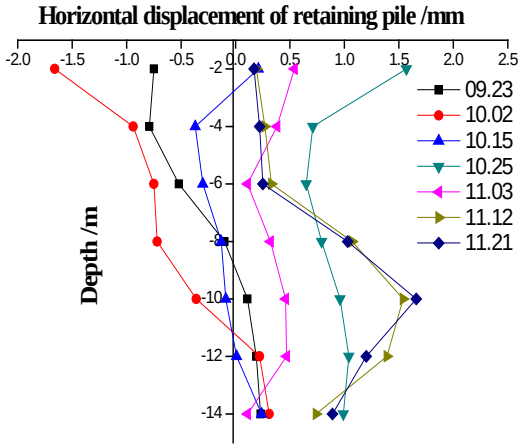


Figure 9 :Curves of horizontal displacement of retaining pile

Settlement of surrounding roads

To avoid adverse effect of urban road by excavation, nine settlement monitoring points of DM43~DM51 are set along northern side of road. Table 2 shows the maximum settlement of all points, with average settlement equal to 3.39mm. Phenomenon of damage has not been found along the road. Pile-anchor retaining system has obtained good effect in foundation pit.

Table 2: Settlement of roads

Point	DM43	DM44	DM45	DM46	DM47	DM48	DM49	DM50	DM51
Settlement /mm	3.23	1.96	3.16	1.64	4.89	5.34	4.20	2.13	3.94

CONCLUSION

As scale and depth of excavation increase, especially for irregular foundation pit with complicated geological conditions and surrounding environment, many new complex problems are difficult to solve by existing theories. It's also difficult to select numerical models and parameters to reveal the real engineering properties, which means the application of information construction plays an important role nowadays. There are two things that count. Firstly, it's critical to monitor stress and deformation of retaining structure and change of surrounding environment to ensure safety and stability of foundation pit. Secondly, the paper helps to further perfect design theory and method of foundation pit. It also provides reasonable values of parameters for numerical models. Test results and rule generated in this paper have reference value for similar design and construction of foundation pit with pile-anchor retaining system.

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