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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (14): 3034-3037, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.3034.3037

Optimization of Combined Pile-anchor Supporting Schemes for Deep Foundation Pit

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Abstract: According to the Hefei subway deep foundation pit engineering, this study expounds the pile-anchor supporting scheme of prestressed anchor cable layout optimization. Combined with the actual situation of engineering, numerical simulation was carryed out by using FLAC3D software. The four different layout of prestressed anchor cable is used for simulation analysis, Detailed to carry out the horizontal displacement of the pile and anchor axial force analysis, discuss the anchor cable layout optimization. Calculation results provide a reference for support scheme of similar large deep foundation pit.

Key words: Deep foundation pit, supporting schemes, prestressed anchor cable

INTRODUCTION

The pile-anchor supporting system is soil retaining structure (retaining piles) combined with a pull system of deep foundation pit retaining structure (Xiong *et al*., 2009). The pull system exists, pile bearing most load transfer in the stable region anchor through the anchor system, load by the anchor is scattered to the surrounding rock stability of the soil, so as to give full play to the role of self bearing capacity of formation (He *et al*., 2004). The prestressed anchor (cable) can be closely combined with the retaining pile retaining system, (Yang *et al*., 2006) eliminate the relaxation, improve soil stress-strain relationship, reduce the displacement of retaining structure, achieves the purpose to control deformation, therefore, (Zhang and Fan, 2006) when the surrounding environment of deep foundation pit need to strictly control the deformation of pile anchor, most supporting structure use prestressed anchor (cable). But at the moment, the mechanism of the anchorage is unclear and theoretical calculation of the prestressed anchor design is unrealistic, engineering application is more dependent on experience and engineering analogy (Zhang *et al*., 2006).

ENGINEERING SURVEY AND GEOLOGICAL CONDITIONS

Engineering survey: The scope of station includes 1 and 5 line section of deep foundation pit excavation, the maximum depth is about 15.3 m, the pit has length 66 m and width 48 m and uses the pile anchor retaining structure. Anchor area and the engineering cable arrangement are as shown in Fig. 1 and 2.

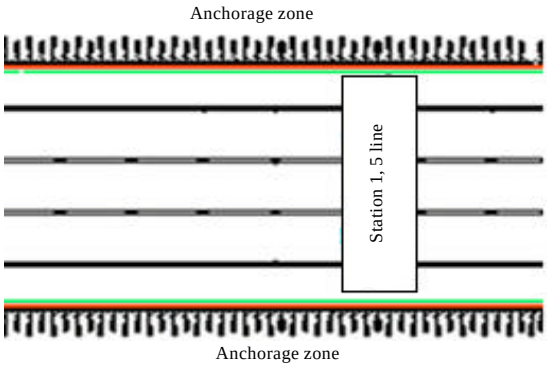

Fig. 1: 1, 5 line cable layout

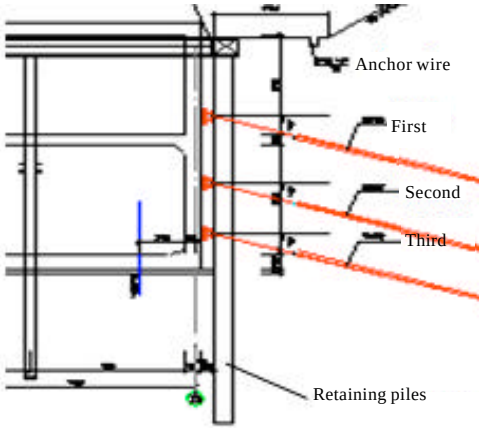

Fig. 2: 1, 5 line cable section layout

Hefei area stratum is undergrown, except the eastern metamorphic rocks outcropped, Hefei Basin has thick continental clastic sediments, Jurassic, Cretaceous to

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Table 1: Soil mechanics param

Materials	Thickness (m)	Modulus of elasticity (MPa)	Poisson ratio	Internal friction angle/(0)	Cohesive strength (kPa)	Appearance density/(g cm^{-3})
Artificial fill	5	3.0	0.22	4	20	2.15
Clay 1	10	12.6	0.37	12	21	1.80
Clay 2	20	14.0	0.40	16	25	2.00

Table 2. Param of anchor cable

Anchor			Cement mortar		
Area (mm^2)	Modulus of elasticity (Pa)	Tensile strength (Pa)	Cohesive strength (MPa)	Rigidity (Pa)	Girth (m)
7.1e-4	2e11	1.32e9	1.0	6e9	0.471

tertiary "red layer" which thickness is up to several kilom. Rock is mudstone and sandstone. Mostly on the upper are covered by pleistocene series, holocene clay layer, local (Shushan) has the volcano rock outcropping.

Station foundation pit involves the formation param as shown in Table 1.

Artificial fill (Q4 mL): The broken bricks, concrete blocks, pieces of broken tiles, garbage composition, color impurity, loose, dry and slightly wet, distributed in the site within the surface, thickness 0.5~2 m. Genus of class 2 soil.

Clay (Q3al): Brown, brown yellow, hard plastic, in compression, containing iron oxide, a small amount of iron manganese nodules, containing a small amount of plant roots, high dry strength. Genus of class II soil.

Clay (Q3al): yellow, brown yellow, hard plastic, the medium compressibility, containing iron oxide, a small amount of iron manganese nodules, surface smooth, high dry strength. Genus of class II soil.

CALCULATION OF PILE ANCHOR SUPPORTING SYSTEM

Param: Soil using Mohr Kulun elastic-plastic model, soil param are shown in Table 1.

The supporting structure of the bored pile, as elastomer, the pile length 25 m, the embedded depth 10 m, pile spacing of 1.5 m, diameter 1.0 m, elastic modulus 28 GPa, Poisson's ratio of 0.2.

Cable is elastomer, is arranged at the top of the pile following 4, 10 and 12 m, param as shown in Table 2.

Model foundation of numerical simulation: The three-dimensional numerical model is used in this study to analyze the problem and it makes full use of the symmetry of structure and load. According to engineering experience, the influence of the excavation depth is 2~4 times of the excavation depth, the width of impact is 3~4 times of the depth of excavation.

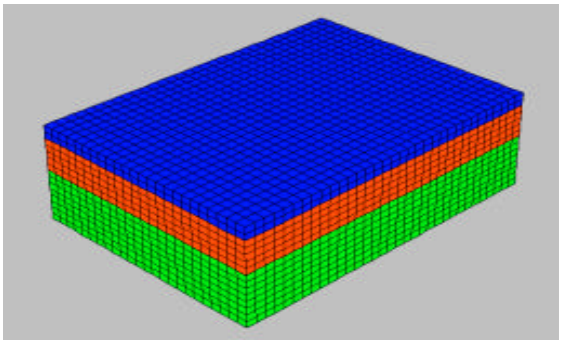

Fig. 3: 3D model and mesh

In this study, calculation of foundation pit is 66 m long, 48 m wide and the depth is 15.3 m. In order to simplify the model of the calculation and analysis of foundation pit, using its symmetry, take its 1/4 calculation. Therefore, the three-dimensional numerical calculation model is 99 m long, 72 m wide and the depth is 30 m. Hexahedral unit 8 was used to simulate soil, pile and anchor cable each unit should be used in simulation. 3D model and the grid is shown in Fig. 3, after the excavation of foundation pit grid diagram is shown in Fig. 4 and the pile and anchor cable layout model is shown in Fig. 5. Unit of soil and pile, anchor cable unit in the node displacement is continuous. Do the following with displacement boundary conditions: the bottom of foundation pit is completely fixed, constraints imposed, respectively around the surface along the normal direction.

Comparison of calculated value analysis and monitoring

Excavation steps: Excavation and support consists of seven steps:

Step 1: The excavation depth of the first layer is 5 m
Step 2: The first row of cable tension (depth 4.00 m)
Step 3: Second layer excavation, excavation to 10 m
Step 4: Stretching second rows of anchor cable (depth 9.00 m)

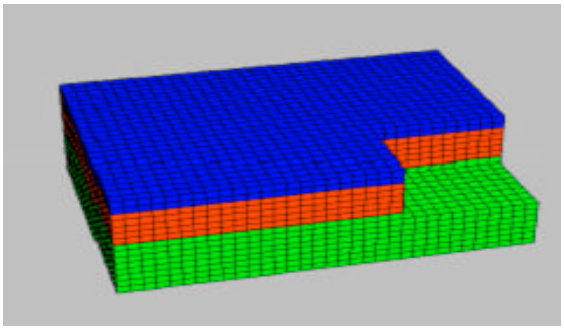

Fig. 4: After the excavation of foundation pit excavation grid

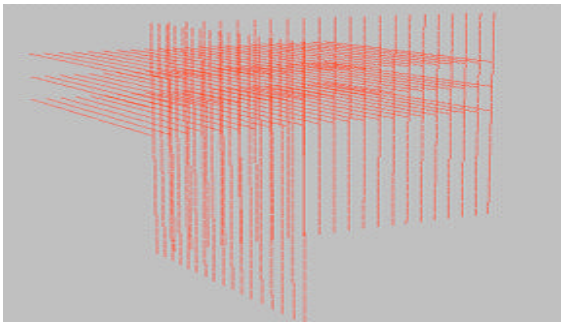

Fig. 5: Pile and anchor cable layout

Step 5: Excavation of the third layer, excavation to 14 m
Step 6: Third rows of cable tension (depth 13.00 m)
Step 7: Excavation of the fourth layer to the substrate 15.3 m, excavation, construction completion

Analysis of numerical calculation and field monitoring data: The midpoint of the horizontal displacement of the pile of the long side of foundation pit was compared with field monitoring data analysis and its simulation results and it was shown in Fig. 6. Seen from the figure, simulation results and the actual level of pile displacement values are generally consistent with the maximum displacement value and the maximum displacement of the pile is at the depth of 10m, the half of pile is smaller than the actual value, the lower half of basically meet the design requirements. Overall meet the design requirements.

CABLE LAYOUT OPTIMIZATION

Line arrangement scheme: According to the different spatial layout of prestressed anchor cable, the application

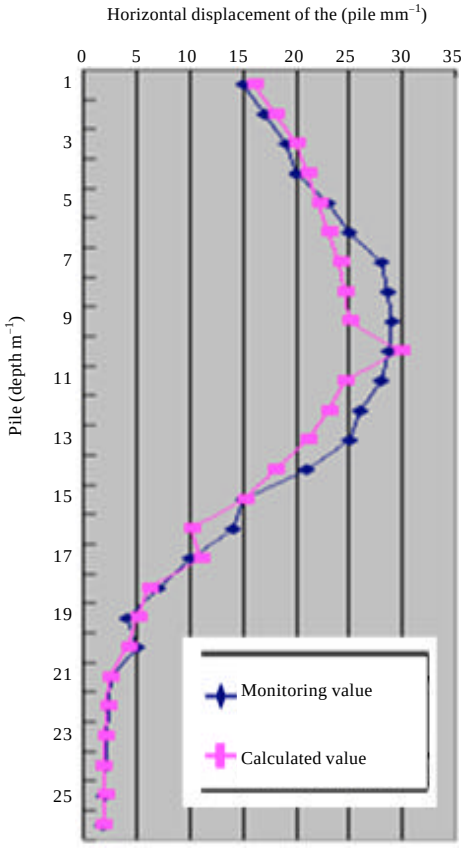

Fig. 6: Simulation calculation and monitoring of pile horizontal displacement curve

of FLAC3D in the following four conditions to carry out the calculation and analysis. The scheme based on pile displacement and axial force of cable development program to optimize the comparison and selection:

- **Scheme 1:** Two anchor cable with one pile and one anchor, two anchor cable were located in the crown top surface of the beam and the depth is -4 and -10 m
- **Scheme 2:** Two anchor cable with two pile and one anchor, two anchor cable were located in the crown top surface of the beam and the depth is -4 and -10 m
- **Scheme 3:** Three anchor cable with two pile and one anchor, three anchor cable were located in the crown top surface of the beam and the depth is -4, -9 and -13 m
- **Scheme 4:** Three anchor cable with one pile and one cable, three anchor cable were located in the crown top surface of the beam and the depth is -4, -9 and -13 m

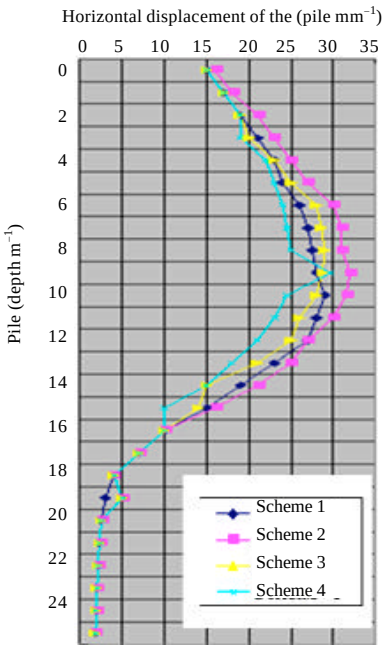

Fig. 7: Horizontal displacement ofthe pile of different schemes

Simulation analysis schemes: In four different layout analysis of the simulation, soil, pile and anchor cable model calculation param are consistent with the initial simulation and selects the foundation long edge midpoint of horizontal displacement of pile and anchor force to carry out calculation and analysis:

- **Scheme 1: Two anchor cable with one pile and one anchor:** The calculation results are shown in Fig. 7: pile maximum displacement is 27.70 millim, a top -10 m position in the pile; the displacement of pile top is 15.07 millim. The maximum axial force of two anchor cable: the first and second, respectively for 96.3 and 224.7Mpa.
- **Scheme 2: Two two pile anchor cable:** Pile maximum displacement is 32.01 millim, a top -9 m position in the pile; the displacement of pile top is 15.94 millim. The maximum axial force of two anchor cable: the first and second, respectively for 120.1 and 257.9 Mpa
- **Scheme 3: Three two pile anchor cable:** Pile maximum displacement is 27.68 millim, a top -8 m position in the pile; the displacement of pile top is 16.12 millim. The maximum axial force of anchor cable: The first, second and third, respectively for 107.5, 240.8 and 223.1 Mpa
- **Scheme 4: Three anchor cable with one pile and one cable:** Pile maximum displacement is 24.64 millim, a top -9 m position in the pile; the displacement of pile top is 15.44 millim. The maximum axial force of anchor cable: the first, second and third, respectively for 86.3, 204.7 and 178.3 Mpa

As a result, scheme 1 and 3 satisfies the horizontal displacement of the pile 30 millim limits, but is very close to the limit and the scheme of three cable 4 pile anchor scheme, for the horizontal displacement of the pile is the most strict control.

CONCLUSION

Simulation and field monitoring data analysis shows that using the combined pile anchor supporting system can effectively control the horizontal displacement of the pile in super deep foundation pit engineering, guarantee the safe and rapid construction of foundation pit engineering. Different prestressed anchor cable layout simulation and analysis shows that the pile anchor system of a pile anchor scheme effectively reduce the horizontal displacement of pile anchor retaining structure of pile and make full use of the properties of materials.

ACKNOWLEDGMENT

The study is subsidized by the Natural Science Foundation of Anhui Province, China (1308085QE85).

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