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Three-dimensional numerical analysis of deformation of various combined support forms

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Abstract. The complex environment around the foundation pit affects the selection of foundation pit support, and the excavation works become more complicated. Taking the foundation pit engineering of Central Hospital of Shengli Oil Field in Dongying as an example, the finite element analysis of pile anchor, double row pile, double row pile and inclined bracing combined support form is carried out by using MADIS GTS/NX three-dimensional finite element analysis software. The variation trend and stiffness variation of foundation pit displacement under different supporting forms are analyzed. The combined support form is a complicated support form. The result of finite element calculation shows that because of the different stiffness of the supporting structure, the stress concentration phenomenon and the structural displacement abrupt exist near the boundary of different support forms, but under the same support form, the displacement of soil mass increases with the distance of the distance to the corner of the foundation pit. As the length of foundation pit increases, the displacement of foundation pit has obvious spatial effect.

1. Introduction

With the development of urban construction, more and more buildings are rising, and the surrounding environment of the foundation pit of the newly built buildings near the existing buildings will become more and more complex. A single form of support often cannot meet the security of foundation pit support. Many scholars have done the corresponding research on the combined support form of foundation pit. Sun Jun[1] academician of Tongji University made theoretical prediction of foundation pit deformation in combination with space-time utility for excavation of foundation pit in Shanghai soft soil foundation. Considering the space-time utility of foundation pit,Liu Jianhang[2] made a numerical simulation analysis of the shape law of a subway foundation pit project by using finite element method, and put forward the hypothesis that the soft soil itself adjusts the ground movement. Taking the foundation pit of Central Hospital of Shengli Oil Field in Dongying as an example, this paper uses MADIS GTS/NX 3D finite element analysis software. In the whole process of excavation simulation, the internal force and deformation of the foundation pit under different support forms are analyzed, and the factors affecting the deformation of the composite support structure are analyzed and summarized on the basis of the simulation results.

As shown in figure 1, the shape of the foundation pit is roughly rectangular, with a length of about 107 meters from east to west, a width of about 70 meters from north to south, and a perimeter of about 360 meters. The proposed project ±0 is 5.80 meters, the site topography is generally flat, the elevation is about 5.0 meters, and the excavation depth of foundation pit is about 6-8.5 meters.

There is a building image building on the south side of the foundation pit (the foundation of the frame structure powder spray pile, the foundation buried about 0.8 meters), and the border line of the main building of the bottom line of the foundation pit excavation is about 4.2-10.7 meters.

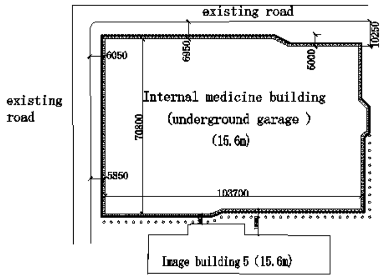

Figure 1. The periphery of the foundation pit

The geomorphic unit of the proposed building is the alluvial plain of the Yellow River Delta. Within the scope of the project, the strata are Quaternary strata, mainly composed of prime fill, silty soil, silty clay and some silts.

The main physical and mechanical parameters of the formation are shown in table 1.

2. Support condition of foundation pit

Because of the complex surrounding environment of foundation pit, the supporting form of foundation pit adopts the combination support form of pile anchor, double row pile and pile brace (see figure 2). The excavation depth of foundation pit is 7 m.

2.1. Cantilever support structure

The cantilever supporting structure is adopted in the South and east part of the foundation pit. The double row pile is composed of two row pile diameter 800mm and long 16m filling pile, the center distance of the inner row pile is 1500mm, the net distance of the outer row pile is 3000mm, the distance between the piles of the pile is 3000mm, and the pile is connected with the continuous beam (see figure 3).

2.2. Pile-braced support structure

Because there is an image building on the south side of the foundation pit and it is close to the foundation pit, in order to ensure the safety of the foundation pit, the diagonal braces are added on the foundation of the double row piles. The diagonal brace is 30 degrees of support and the cross section is 600mm * 800mm rectangle. The spacing is 8000mm (see figure 4).

2.3. Pile-anchor supporting structure

The west side and the north side of the foundation pit are adjacent to the road. The pile anchor supporting structure is adopted, the pile depth of the supporting pile is 16m, the pile diameter is 800 mm. Two anchor rods and one anchor are arranged along the side of the foundation pit, the horizontal spacing of the anchor rod is 1.5m, the vertical spacing is 2.5 meters. The anchor rod adopts a self - drilling anchor rod, the pre - added stress is 100KN, the anchoring section has a valid diameter of 150mm, the angle of incidence of the anchor rod is 15 degrees, and the anchor rod is transversely provided with two 25B channel steel as the waist beam (see figure 5).

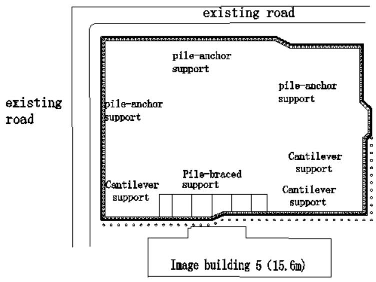

Figure 2. General plan of foundation pit support

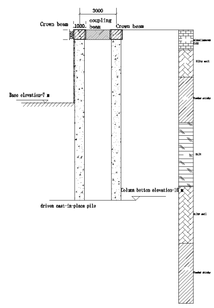

Figure 3. Schematic Diagram of Cantilever Support Section

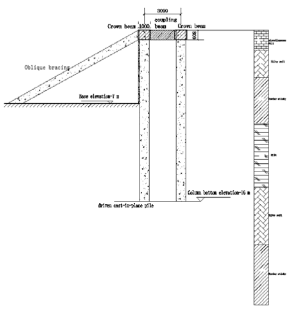

Figure 4. pile brace support section diagram

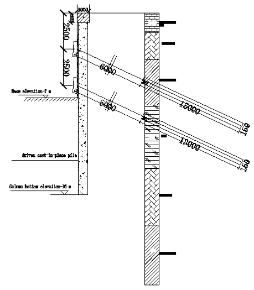

Figure 5. schematic diagram of pile anchor bracing structure

3. Three dimensional model establishment

3.1 The Establishment of Computational Model

According to the specification, the in-plane calculation model takes 3-5 times the excavation depth of the foundation pit, and the soil is based on the Moll-Coulomb elastoplastic constitutive model.Beam element is used in concrete structure with inner support, column, etc.The prestressed anchor cable is established for the anchor modeling assistant, and the embedded truss element is used.In order to simplify the establishment of the model, the equal-stiffness of the pile body is simplified to the underground continuous wall, the external pile adopts solid element, and the inner row pile adopts 2D element(see figure 6).

The main physical and mechanical parameters of the strata are shown in table 1.

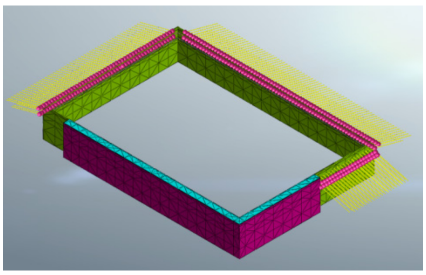

Figure 6. Enclosure structure diagram

Table 1. Simulation parameter value

Layer number	Soil name	Depth (m)	Severe (kN/m3)	Compression modulus E_s (Mpa)	Poisson ratio υ	Cohesive force(kPa)	Internal friction angle(°)
1	Plain fill	1.10	18.0	15.00	0.30#	6.00	15.00
2	Silty soil	3.40	19.2	30.00	0.25#	7.00	25.20

3	Clay soil	2.50	19.0	19.69	0.35#	16.00	17.70
4	Silt	11.20	19.0	35.00	0.20#	3.00	26.50
5	Steel	--	78	6×10^7	0.20#	--	--
6	Concrete	--	24	6×10^6	0.23#	--	--
Layer number	Support unit	Size (mm)	Severe (kN/m3)	Compression modulus E_s (Mpa)	Poisson ratio υ	simulated cell	
7	coupling beam	220	24	3×10^6	0.23#	Solid unit 3D	
8	anchor wire	Φ150	78	3×10^7	0.20#	Truss element 1D	
9	Outer row pile	220	24	3×10^6	0.23#	Solid unit 3D	
10	Inner row pile	313	24	3×10^6	0.23#	Plate element 2D	
11	Oblique bracing	800*600	24	3×10^6	0.23#	Beam element 1D	

(Notice："#" Indicates that the value takes empirical value.)

3.2 Model boundary constraint

The numerical simulation load is self-weight load, building load and surrounding load of foundation pit. (in order to simplify the establishment of model, the surrounding building of foundation pit is simplified as uniform load).The boundary conditions of the 3D model are as follows: the bottom of the model is Z-oriented, the front and rear of the model are Y-direction, and the left and right of the model is X-directional.

3.3 Setting of simulated construction condition

In the simulation process, the construction sequence of foundation pit excavation will have a great impact on the results of foundation pit simulation. The simulation flow of deformation effect analysis of foundation pit maintenance structure is shown in table 2:

Table 2. Simulation conditions

Field	Working condition	Construction description
	1	The calculation of the stress field in the initial site
Internal Medicine Building	2	Double row pile construction
	3	Obliquely braced upper soil excavation
	4	Soil excavation at the first stage of foundation pitExcavation of the first layer of soil, construction of the first row of Anchorage cables and girders
	5	Excavation of the second layer of soil, construction of the second row of Anchorage cables and girders
	6	Foundation pit excavation to the bottom, foundation pit floor construction, inclined bracing construction
	7	Construction of second row anchorage cable and waist beam
	8	Soil excavation under inclined brace

4. Finite element simulation results and analysis

4.1. Lateral displacement of piles in various supporting forms

The excavation of the foundation pit causes the load on both sides of the surrounding pile to be unbalanced, so that the horizontal direction displacement and deformation of the enclosure structure are caused, the original stress state method of the surrounding soil body of the surrounding pile is changed, and the formation movement is caused , and lateral deformation of the surrounding pile is caused.

As shown by the simulation data in figure 7, the displacement changes at the position of the pile-braced support structure show the shape of "bulging". The lateral displacement of the pile is large and small in the middle, and the maximum displacement is about 6.8 mm (the control value is 35 mm ） and the maximum displacement is about -6 m.The lateral displacement of cantilever support structure decreases gradually with the increase of pile depth, and the maximum lateral displacement is at the end of the pile, showing a forward tilting deformation curve, and the maximum displacement is about 10.6mm.In the position of pile anchor supporting structure, the overall displacement is more overall. The maximum displacement is the upper part of the pile, which is about 5mm, and the maximum displacement is about -3m.

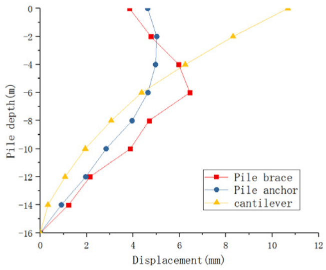

Figure 7. Lateral displacement diagram of retaining pile

4.2. Analysis of displacement of piles in different positions with different working conditions

Under different working conditions, the deformation of pile body is changed, as shown in figure 8, figure 9, figure 10, respectively, the curves of pile supporting, pile anchor and cantilever support structure change with the lateral displacement of working condition, as the working condition goes on, The displacement curve of pile increases gradually. However, the variation of pile body is not the same under different working conditions, and the change of pile body is the largest between the third and fifth working conditions.

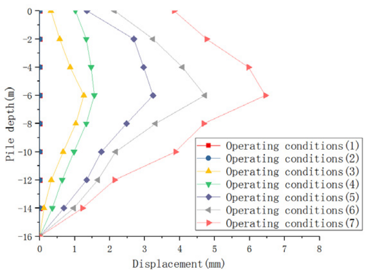

Figure 8. Lateral displacement diagram of pile-braced support under working conditions

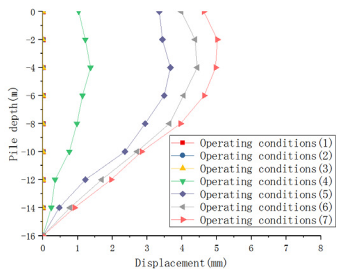

Figure 9. pile anchor support lateral displacement diagram under working conditions

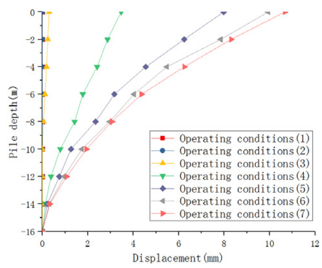

Figure 10. Lateral displacement diagram of cantilever support under working conditions

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5. Conclusion and summary

（1）Through the simulation calculation, the lateral displacement of the maintenance pile under different supporting conditions is obtained, and the displacement curve is drawn.

（2）From the displacement diagram of retaining pile wall, it can be concluded that the deformation and displacement of foundation pit conform to the basic law under the same supporting form. In the cantilever support, the horizontal maximum displacement is located at the top of the pile, showing a forward curve.In pile anchor support, the maximum horizontal displacement of supporting pile wall is in the middle and upper part of foundation pit. Because of the constraint of pile anchor support, the horizontal displacement at the top of foundation pit is smaller than that of cantilever support. In pile-braced support, because of the constraint of inclined brace on the top of the pile, the displacement of the top of the pile is the smallest than that of the other two kinds of support, showing the shape of bulging. The horizontal displacement of three kinds of supporting structures increases gradually with the time of working conditions, and has obvious space time effect.

（3）In the face of complex surrounding environment, a variety of composite support structures are chosen in the face of complex surrounding environment. Through three-dimensional numerical simulation, the displacement changes of the retaining structure are better reacted, and the results show that the support form used in the base pit has achieved good support effect.

Acknowledgments

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References

[1] Sun Jun. Environmental geotechnical problems in excavation of urban foundation pit [J]. Underground space, 1999,19 (4): 257-265.

[2] Liu Jianhang. Theory and practice of Space-time effect in soft soil Foundation Pit Engineering [C] / academic and Technical Symposium on Cross-Strait Tunnel and Underground Engineering. 1999.

[3] Wang Zhaolei, Yang Zhiyin, Zhang Jun, et al. Three dimensional numerical analysis of pile-bolted composite support structure [J]. Journal of Geotechnical Engineering, 2012,34s 1: 230-232.

[4] Shao Quan, Xu Xuelan, Xu Song, et al. Three dimensional numerical analysis of deformation influencing factors of pile anchor braced composite support structure in deep foundation pit [J]. Journal of Geotechnical Engineering, 2014,36s 2: 87-91.

[5] Feng Shenduo, Jiang Xiaoguang, Yang Zhiyin, et al. Discussion on the Engineering Application and deformation Coordination of the combined support Technology of pile (Wall, Wall, bracing and Anchor) [J]. Shenzhen Civil & Architectural, 2013,341: 49-52.

[6] Liu Guobin, Wang Weidong. Manual for Foundation Pit Engineering [M]. China Construction Industry Press, 2009.

[7] Zhang Yu-cheng, Yang Guanghua, Hu Hai-ying, et al. Combined Application of multiple support types in the Design of large Deep Foundation Pit [J]. Journal of Geotechnical Engineering, 2014,36s 2: 198-204.