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Numerical Analysis of Space Effect on the Pile-Anchor Bracing Deep Foundation Pit

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***Abstract*— Combined with practical engineering, using finite difference method of numerical analysis software, pile-anchor combined support model was established. Through the excavation different stages studies of crown beam top horizontal displacement, vertical displacement and horizontal displacement of pile body and bending moment. We obtained that with the increase of excavation depth, crown beam top horizontal displacement and vertical displacement were gradually increased. the farther the distance to internal angle the change bigger displacement were. Space effect were obvious. The maximum pile displacement occurred at 0.8 times the depth of foundation pit. Along the foundation pit depth space effect was also obvious. In the process of excavation construction, there were positive and negative bending moment. The maximum absolute value of negative bending were generally greater than the maximum bending moment.**

***Index Terms*— The pile-anchor combined support,Numerical analysis, The space effect; Horizontal displacement,Pile bending moment**

I. INTRODUCTION

With the rapid development of economy, Urban land was increasingly scarce, The building density was more and more big, The foundation pit was deeper , A single foundation pit supporting method could not meet the requirement of the existing design,Therefore, many scholars had carried out various researches on the combinatorial support of deep foundation pit. The factor design of double-row pile support structure and the stress and deformation characteristics of compound double row piles were studied[1] .Combined with practical engineering . the deformation monitoring, calculation method and design method of composite soil nail wall support structure were studied[2] .The stress and deformation of the cement mixing pile and the bolt combination support structure were carried out the finite element analysis [3] .The existing deep foundation pit was designed
according to the plane strain problem, but the deeper the foundation pit, the more the space effect cannot be ignored. The influence of the angular space effect on the deformation of the underground continuous wall was studied by using the three-dimensional numerical analysis.[6]The spatial effect of the support form of double row pile foundation pit was studied by using numerical simulation method [11].In north China, there was less research on the spatial effect of pile anchor. In this paper, based on actual engineering, the law of the spatial effect of the pile anchor combination supporting structure was analyzed by applying the finite difference method.It was of some guiding significance for future research of pile anchor structure.

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II. PROJECT OVERVIEW

This project was located in SHIJIAZHUANG, The foundation pit design was 80m long, 44m wide and 10m deep, and the support form was the pile anchor combination support,Pile diameter was 1000mm, pile spacing was 2.0m, embedded depth was 4.0 m, total length was 14.0 m.The breadth of crown beam was 1000mm.The height of crown beam was 700mm.The roof was the natural floor.The strength grade of pile and crown beams was C25.The bolt diameter was 150mm, and the horizontal spacing was 2.0m, with a total of 3.The design of the foundation pit were shown in figure 1 and figure 2.

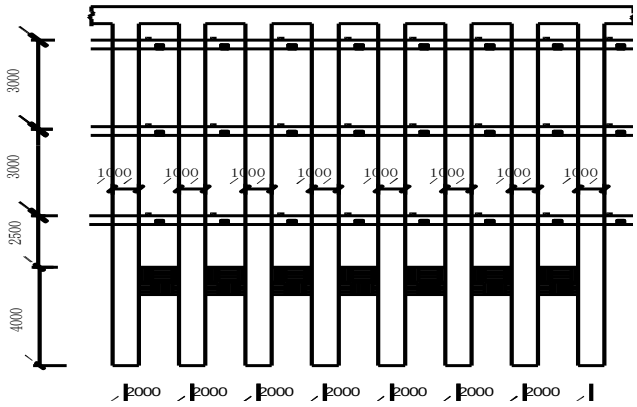

Fig.1 Elevation of pile-anchor combined supportin

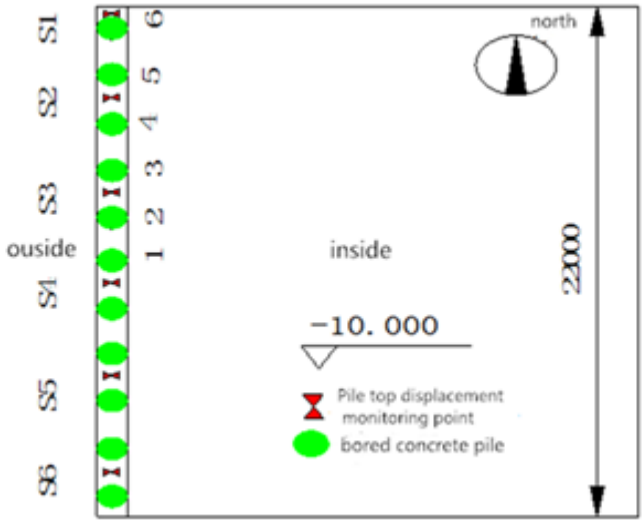

Fig.2planar graph of pile-anchor combined supporting

Table 1 anchor parameter table

Anchor way,	Horizontal spacing(m)	Vertical distance(m)	Angle of incidence(°)	Length(m)	Anchorage length(m)	Prestressed(kN)	The anchor stiffness(MN/m)	The material resistance(kN)
1	2	1.5	15	18	9	100	15	341.6
2	2	3	15	18	10	100	30	341.6
3	2	3	15	18	10	100	30	341.6

III. ESTABLISHMENT OF NUMERICAL ANALYSIS MODEL

Finite difference method was a numerical method to solve the mixed problem of initial value boundary value.It was the basic idea of the problem domain for grid subdivision, then on the grid point, in accordance with the appropriate numerical differential formulas to solve the problem of derivative with difference quotient, thus the problem of the original discrete difference scheme, and then calculate the numerical solution.The finite difference method was convenient and fast in computer.Therefore,

Table 2 excavation process table

No	The type	The depth(m)	The anchor way,
1	excavation	2	---
2	anchor	1.5	first
3	excavation	5	---
4	anchor	4.5	second
5	excavation	8	---
6	anchor	7.5	third
7	excavation	10	---

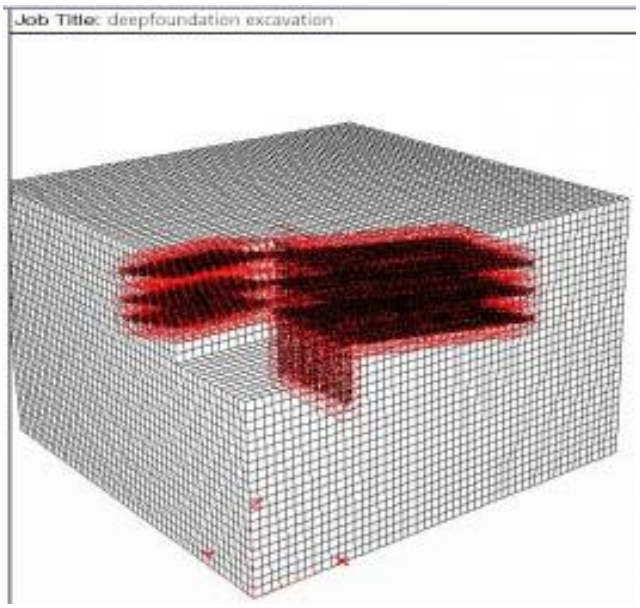

Figure 3 pile-anchor modeling process diagram

numerical analysis software was established by using finite difference method.In order to make the model more convenient, the following basic assumptions were adopted:

The materials of concrete and bolt are isotropic.

The soil was assumed to be an ideal elastic-plastic material, and the soil was simulated by the Mol-coulomb elastic-plastic model

The supporting structure was assumed to be linear elastomer

The influence of construction on soil disturbance was not considered

According to the characteristics of symmetric model, a 1/4 model was established.Boundary conditions adopt displacement boundary conditions.At the bottom of the fixed model, the soil displacement was in all directions.The anchor parameters were shown in table 1. The description of excavation process of foundation pit support were shown in table 2. The numerical analysis

model was shown in figure 3.

IV. THE ANALYSIS OF NUMERICAL MODEL OF PILE ANCHOR SUPPORT

displacement analysis of crown girder

During excavation of the foundation pit, the horizontal displacement and vertical displacement of the crown beam were monitored. The numerical simulation results were compared with the measured results,The numerical simulation curves of S1, S2, S3 horizontal displacement and vertical displacement were calculated.as shown in the figure 4 &5.

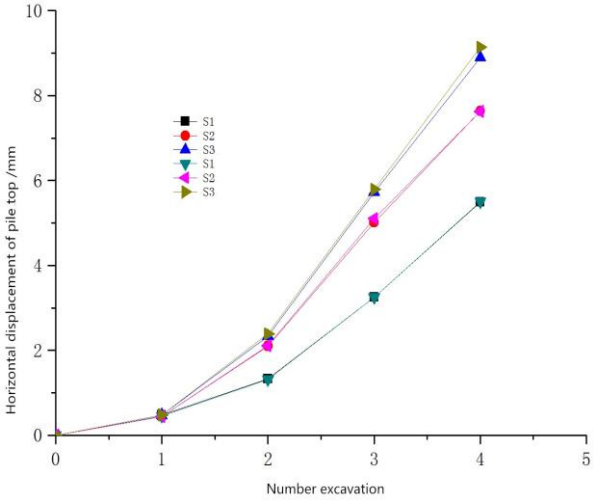

Figure 4. S1, S2, S3 horizontal displacement simulation and monitoring values

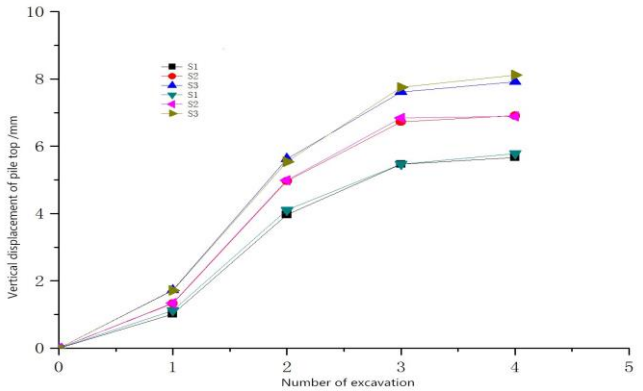

Figure 5. S1, S2, S3 vertical displacement simulation and monitoring values

Comparative analysis of pile top vertical displacement It could be seen from figure 4 and figure 5.

With the increase of excavation depth, the horizontal displacement and vertical displacement of crown beam were gradually increased, both measured and simulated. The results of numerical simulation were close to the actual foundation pit monitoring results, but the increase of different observation points were different. And all was S3 > S2 > S1.It was indicated that the displacement of the foundation pit slope was not equal to the deformation of the excavation process, and the variation amplitude was directly related to the depth of excavation and the location of the observation point.And there was a small change in the Angle of the pit, the farther from the negative Angle, the larger the change, and the obvious spatial effect.

With the increase of excavation depth of foundation pit, the change of horizontal displacement was increasing.The change of vertical displacement was irregular, and the absolute value of horizontal displacement was greater than the absolute value of vertical displacement.The influence of excavation of foundation pit on horizontal displacement was greater than that of vertical displacement.

Analysis of pile - anchor support structurehorizontal displacement results

The horizontal displacement of 1-6 pile in numerical model were recorded.The maximum displacement of each pile were calculated, and the displacement curve of pile
were plotted as shown in FIG. 6

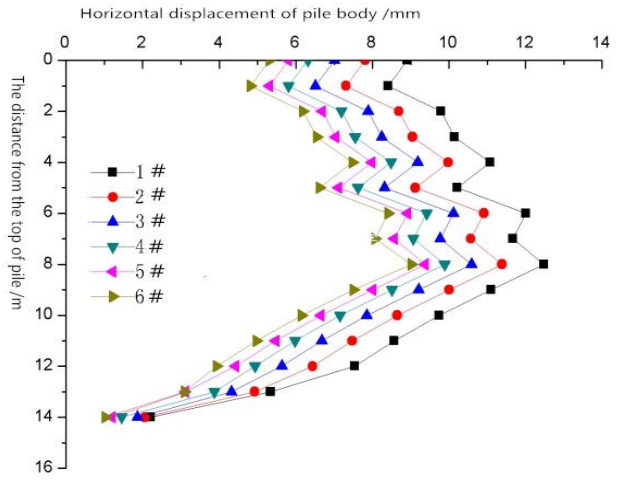

Figure 6 simulation curve of pile horizontal displacement

Table 3 bending moment calculation results

Bending moment	NO.1	NO.2	NO.3	NO.4	NO.5	NO.6
Positive bending moment	56.23	58.09	67.38	73.65	80.43	89.23
Negative bending moment	-185.02	-191.15	-205.12	-213.97	-224.45	-235.67

The curve of the pile was a right convex curve, and the maximum displacement occured at the depth of 0.8.It was indicated that the horizontal deformation of pile body also presents obvious spatial effect along the depth direction.The maximum horizontal displacement of pile was reduced with the 1-6 pile.

The maximum displacement value of pile decreased by 45.8% from no. 1 to no.6.Namely, the closer to the negative Angle, the smaller the deformation, the farther from the negative Angle, the larger the deformation,The spatial effect was consistent with the displacement of crown beam.

analysis of pile anchor support structurepile bending moment

After the excavation, the bending moment of different piles were plotted along the pile in FIG. 7.Take 1# pile for example.The pile body and negative bending moment of the four excavation were sampled, and the data were sorted and the bending moment deformation diagram was shown in figure 8.The final bending moment of different piles were shown in table 3.

Through the above figures 7, figure 8 and table 3, we could see:

In the process of excavation, there were positive and negative moments, and the absolute value of negative bending moment was generally greater than that of positive bending moment.The positive bending moment value of the pile was increased by 3.3 percent from no.1 to no.2.value of the pile was increased by 16.0 percent from

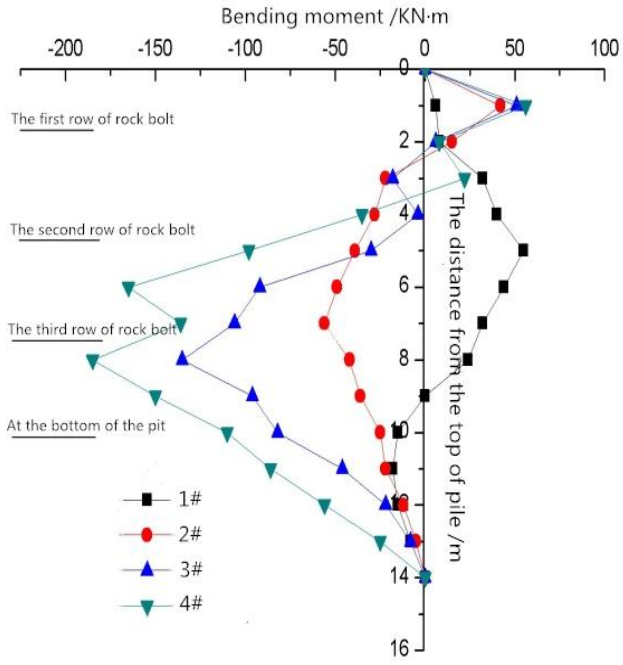

Figure 7 pile anchor bracing numerical simulation bending moment diagram

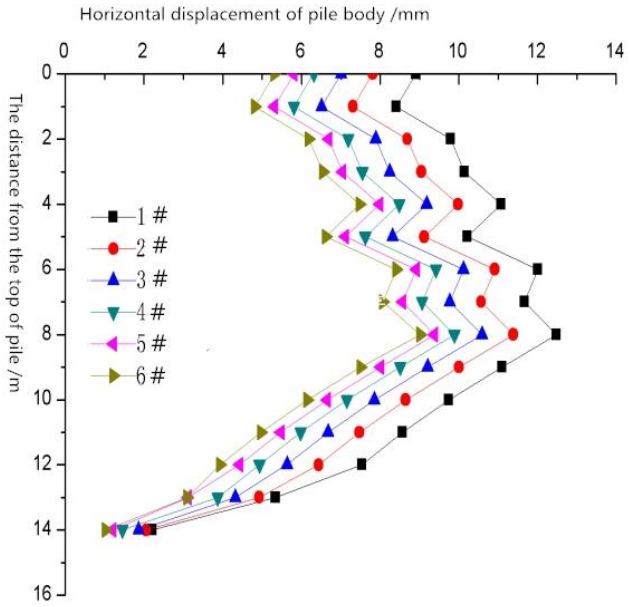

Figure 8 1 # pile bending moment variation during excavation

no.2 to no.3.value of the pile was increased by 9.3 percent from no.3 to no.4.value of the pile was increased by 9.2 percent from no.4 to no.5.value of the pile was increased by 10.9 percent from no.5 to no.6. The nagative bending moment value of the pile was increased by 3.5 percent from no.1 to no.2..value of the pile was increased by 7.1 percent from no.2 to no.3.value of the pile was increased by 4.3 percent from no.3 to no.4.value of the pile was increased by 4.9 percent from no.4 to no.5.value of the pile was increased by 5.0 percent from no.5 to no.6. The absolute value of the pile was gradually increasing from 1 to 6.It was shown that the farther from the edge of the pit, the smaller the absolute value of the pile

With the increase of excavation depth of foundation pit, the absolute value of pile moment increased first and then decreased.The maximum bending moment of the pile was about 0.15 times the foundation pit depth.The maximum bending moment of pile was 0.8 times foundation pit depth.This was similar to the horizontal displacement distribution of the pile.

The bending moment of pile was mutated at the position of the bolt and the bottom of the pit.It was indicated that the joining of the bolt was helpful to resist the adverse effect of excavation on the foundation pit, but the influence was smaller, and its main function was still pile.

V. Conclusions

With the increase of excavation depth, crown beam top horizontal displacement and vertical displacement were gradually increase, but different observation point were not the same as the increase of amplitude, along with the excavation process of displacement of foundation pit slope deformation was not the amount of change, change had direct relationship with the excavation depth and position of observation point, and from nearby pit internal Angle change were small, the farther the distance Yin Angle change were bigger, presents obvious space effect.

With the increase of excavation depth of foundation pit, the change of horizontal displacement were increasing, while the change of vertical displacement were irregular, and the absolute value of horizontal displacement were greater than the absolute value of vertical displacement.Explanation: the effect of excavation on horizontal displacement were greater than that of vertical displacement.

Displacement of pile body curves were right convex arc, the biggest in 0.8 times the depth of foundation pit, the level of the pile body deformation space effect on the direction of the edge of the foundation pit, along the depth direction also presents obvious space effect.

In the process of excavation construction, there were positive and negative bending moment, and the maximum absolute value of negative bending were generally greater than the maximum bending moment, with the increase of excavation depth, pile body showed a trend of decrease after the first increase of absolute value of bending moment, pile body were maximum bending moment about appeared in 0.15 times of the excavation depth, pile on the maximum bending moment was at 0.8 times the depth of foundation pit.

The bending moment of the pile were abrupt in the position of the bolt and the bottom of the pit, These shown.that the joining of the bolt was beneficial to the resistance of excavation to the foundation pit.

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