Monitoring and Analysis of Deformation Laws of Deep Foundation Pit Considering Spatial Effect

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Abstract— *Starting with the analysis of the foundation pit design, the support structure of foundation pit was designed and checked combined with a large deep foundation pit project in Shijiazhuang; According to the current codes, the monitoring scheme considering spatial effect is established; The fiber grating sensor was introduced in the monitoring of the lateral pressure of foundation pit slope, which could realize the on-line, dynamic and real-time monitoring. The field test results showed that spatial effect was significantly reflected in the deformation, earth pressure and other aspects: the foundation pit slope of central settlement is 40%~65% bigger than corner ,horizontal displacement in the middle is 28%~42% larger than corner; The amplification of the positive angle to the settlement and horizontal displacement reached 48% and 11% respectively; The maximum horizontal displacement of the deep soil is located at the depth of 15%~35% below the excavation face; lateral earth pressure of Slope changed with volatility. The lateral earth pressure value of each measuring point increased with the increase of time. At a distance of 0.2 times of the excavation depth below the ground, the measured values of the center, external corner and inside corner were smaller than the calculated values of 42.10%,82.46% and 108.77% respectively; At a distance of 0.5 times of the excavation depth below the ground, the measured value of the middle was 35.21% greater than the calculated. The values of external corner and inside corner were 49.06% and 29.21% smaller than the calculated value respectively. At a distance of 0.8 times of the excavation depth below the ground, the measured values of the center, external corner and inside corner were greater than the calculated values of 6.29%, 40.41% and 23.27% respectively; The settlement of surrounding ground surface was larger when the foundation pit slope settlement was larger.*

Keywords— deep foundation, pit, spatial effect, deformation monitoring.

I. INTRODUCTION

The foundation pit construction project is developed to deep and large direction. The geological conditions and the surrounding environment of the foundation pit are more and more complex. The design theory on deep foundation pit engineering is not perfect at home and abroad. The design method based on of plane strain problem makes supporting structure design of deep foundation pit be not reasonable and result in waste. The finite element method is used to study the spatial effect of deep foundation pit. Because the constitutive model of soil and its calculation parameters are difficult to be determined accurately, the finite element method cannot be used as a practical engineering design method. Dysli et al. [1] (1982) got the conclusion of the ground settlement in the middle part of the retaining wall by the field observation. Ou et al. [2] (1993) Confirmed that the calculated results of the two dimensional were larger than the calculated results and measured values of the three dimensional, and the results of the three dimensional were close to the measured values. It is mainly the existence of pit angle to restrain the development of the displacement of the adjacent area. Liu et al.（1995）[3] considered that the calculation results of the three dimensional finite element could well predict the lateral deformation of the retaining wall below the excavation face, and the two dimensional calculation result was too large, and the pit angle effect could only occur under the excavation face. Fook-Hou Lee et al.（1998）[4] monitored the foundation pit of high-rise building in soft soil region and got the results that the corner of the strengthening effect could significantly reduce the deformation of the supporting structure and ground settlement. Roboski (2006)[5] proposed the method of fitting error function to describe the ground displacement distribution based on the observation data of deep foundation pit supported by an anchor cable. Blackburn et al.(2007) monitored the excavation process of deep foundation pit of the different soft clay ground, and obtained the results that the support forces, soil displacement, and surface displacement had spatial effect. Nie Qingke and

Liang Jinguo et al.（2008）[7], through analysis of field observation data, theoretical study and numerical simulation, studied the deformation and earth pressure distribution of deep foundation pit with double row piles supporting system, and presented to consider the spatial effect of double row piles supporting system design method. Ding Jihui, Yuan Man and Zhang Qin [8-10](2011，2012) introduced utilization coefficient of earth pressure based on elastic resistance method and put forward the calculation method of utilization coefficient of earth pressure on the cantilever and the double row piles retaining structure, and proposed the deformation and internal force of space distribution of supporting structure.

Deep foundation pit is a three dimensional spatial structure system with length, width and depth. The existing design codes or rules can be simplified as two dimensional plane strain problem, which cannot fully reflect the spatial character and size effect of foundation pit. Based on the deep foundation pit engineering of a soil nailing wall and pile anchor support in Shijiazhuang, based on field experiment, the spatial effect coefficient of deep foundation pit is studied in order to provide the basis for the optimization design of supporting structure of deep foundation pit.

II. THE BRIEF INTRODUCTION OF DESIGN OF DEEP FOUNDATION PIT

2.1 The Brief Introduction of Engineering Geology

In the drilling within the depth of 40.0m, there was no groundwater. The main mechanical properties of the soil layer are shown in table 1.

TABLE 1
THE MAIN MECHANICAL PARAMETERS OF EACH LAYER OF SOIL OF THE FOUNDATION PIT SUPPORT

Layer No.	Name of soil layer	Thickness of layer /m	Unit weight / kN/m^3	Cohesive force /kPa	friction angle /°
1	miscellaneous fill	0.70	19.0	10.00	12.00
2	clay soil	1.90	19.5	31.30	14.40
3	silt	4.60	19.1	23.30	17.90
4	silt	2.70	19.3	8.10	24.70
5	fine sand	1.10	18.5	0.00	33.50
6	silt	1.20	19.3	8.10	24.70
7	medium Sand	2.60	18.5	0.00	34.50

2.2 The Brief Introduction of Design of Deep Foundation Pit

The proposed project is located in Shijiazhuang City, the excavation depth is 10m, length 120m, width 77m, the depth of excavation is 10m. The safety level of foundation pit is first class. No load and vehicle can be stacked in the edge of the foundation pit within 3m. The allowable load surrounding is 15kPa.

As shown in Figure 1, according to the surrounding environment, the main supporting way of foundation pit is the soil nailing wall support, the use of pile anchor combination support. The pile diameter of the slope protection pile is 600mm, pile spacing is 1.5m, embedded depth is 3.5m, pile length is 10.4m.The two rows of anchor bolts are set. The first anchor bolt is 16.0m, which the free length is 7.0m and the anchoring length is 9.0m, elevation -2.8m. The free length of the second anchor bolt is 6.0m and the anchoring length is 10.0m, elevation -7.0m .

The soil nail horizontal spacing of the soil nailing wall is 1.2m, and vertical spacing is 1.5m. The first row of soil nailing elevation is -1.0m, the diameter of the hole is 100mm, dip 10 degrees, and the dip angle is 10°.The steel bar net of the surface of the foundation pit is 8@150, and the concrete surface is sprayed with the strength of C20.

2.3 Monitoring Purpose and Arrangement of monitoring points

The monitoring purpose of the foundation pit monitoring is to analyze the influence of space effect on the deformation of deep foundation pit and soil pressure distribution, and analyze the law of foundation pit deformation and soil pressure distribution. Combining with the actual situation, the project decided to monitor the following items: (1) the settlement of the foundation pit slope top; (2) the horizontal displacement of the foundation pit slope top; (3) the horizontal displacement of deep soil; (4) the lateral earth pressure of the pit slope; (5) the surface subsidence around the foundation pit. The monitoring position as shown in Table 2.

TABLE 2
THE POSITION COORDINATES OF THE MONITORING POINT (THE XY PLANE IS BUILT ON THE SURFACE, THE Z AXIS IS DOWN TO THE RIGHT.)

Measuring point number	Coordinate position（x,y,z）/m	Measuring point number	Coordinate position（x,y,z）/m	Measuring point number	Coordinate position（x,y,z）/m
S1	0, 60, 0	S10	73, 126, 0	S19	45, 0, 0
S2	0, 79, 0	S11	76, 122, 0	S20	31, 0, 0
S3	0, 98, 0	S12	76, 103, 0	S21	17, 0, 0
S4	0, 117, 0	S13	76, 84, 0	S22	3, 0, 0
S5	3, 120, 0	S14	76, 42, 0	S23	0, 3, 0
S6	20, 120, 0	S15	76, 23, 0	S24	0, 22, 0
S7	37, 120, 0	S16	76, 4, 0	S25	0, 41, 0
S8	39, 126, 0	S17	73, 0, 0		
S9	56, 126,0	S18	59, 0, 0		
C1	37,-1.5,0	C5	77.5,23,0	C9	39,127.5,0
C2	76,-1.5,0	C6	77,5,84,0	C10	37,121.5,0
C3	77.5,4,0	C7	73,127.5,0	C11	20,121.5,0
C4	77.5,23,0	C8	56,127.5,0	C12	3,121.5,0
P1-1	-0.5,44.25,-3	P2-1	-0.5,21,-3	P3-1	20, 121.5,-2
P2-2	-0.5,44.25,-6	P2-2	-0.5,21,-6	P3-2	20, 121.5,-5
P3-3	-0.5,44.25,-9	P2-3	-0.5,21,-9	P3-3	20, 121.5,-8
P4-1	37,126.5,-2	P5-1	73, 126.5,-2		
P4-2	37, 126.5,-5	P5-2	73, 126.5,-5		
P4-3	37, 126.5,-8	P5-3	73, 126.5,-8		

Table note: S is the monitoring point of pit roof; C is Monitoring point of soil displacement in deep foundation pit; P is the monitoring point of the earth pressure.

III. ANALYSIS OF MONITORING RESULTS OF DEEP FOUNDATION PIT

3.1 Settlement analysis of foundation pit slope

Fig.2 and Fig. 3 are the settlement curve of the north side and south side of foundation pit. It can be seen from figure 2and figure 3:

(1) The interval of settlement curve decreases with time, it can be known that the sedimentation rate is fast, and the later is slow. According to the analysis of the working conditions, the excavation of foundation pit is completed, the soil stress is not fully released, the settlement rate is faster, the release of soil stress at the later stage is basically completed, and the settlement speed is slow. Because of the limiting role of foundation pit on both sides of the pit wall and the supporting structure the settlement of the both sides of the pit wall is smaller than that of the middle part.

(2) On the north side of foundation pit, while in the external corner of the middle of the foundation pit, because the limit of the surrounding soil and the supporting pile is very small, the settlement of the external corner is the maximum settlement and settlement reaches 8.84mm; the monitoring point of the minimum settlement is located at the corner of the end of the foundation pit, and the settlement is 5.33mm; the settlement of the external corner is 48.57% higher than that of the negative angle; the settlement of the external corner of the middle is 65.85% larger than that of the negative angle. On the south side of foundation pit, the settlement is the largest in the middle of the foundation pit, the settlement is 6.73mm; the settlement at the end of the corner is the smallest, and the settlement is 4.81mm. The settlement of the middle part of the foundation pit is obviously larger than that of the end, and the space effect is obvious

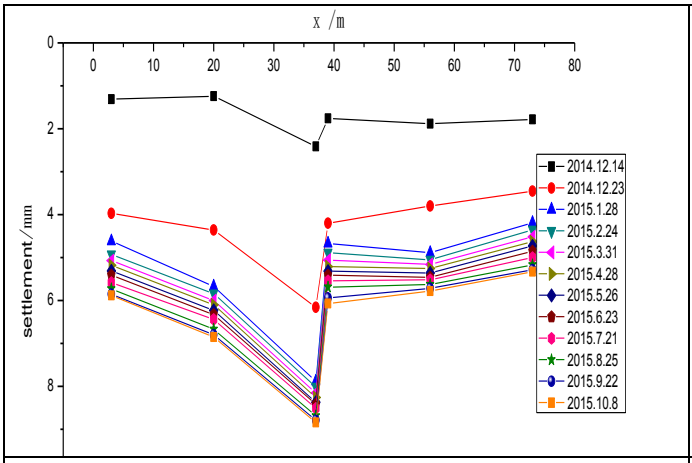

FIG. 2 SETTLEMENT CURVE OF THE NORTH SIDE OF FOUNDATION PIT

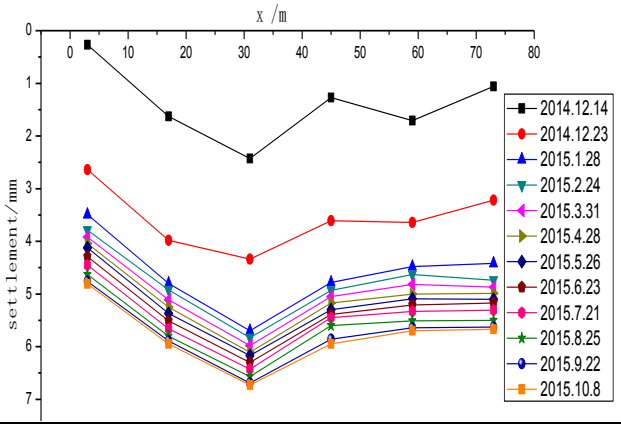

FIG. 3 SETTLEMENT CURVE OF THE SOUTH SIDE OF FOUNDATION PIT

3.2 Analysis of the horizontal displacement of the foundation pit

Fig.4 and Fig. 5 are the horizontal displacement curve of the north side and south side of foundation pit. It can be seen from figure 4 and figure 5:

(1) On the north side of foundation pit, the maximum horizontal displacement appears in the center of the external corner, displacement of 20mm; the minimum displacement occurs at the end of the negative angle; the displacement of the middle part of the center of the external corner is 42.85% larger than that of the negative angle.

On the south side of foundation pit, the horizontal displacement in the middle of the foundation pit is 18mm, and is 28.57% larger than that of the negative angle.

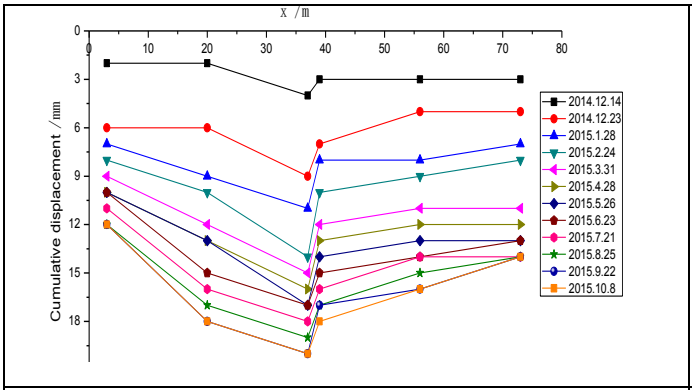

FIG. 4 HORIZONTAL DISPLACEMENT CURVE OF THE NORTH SIDE OF FOUNDATION PIT

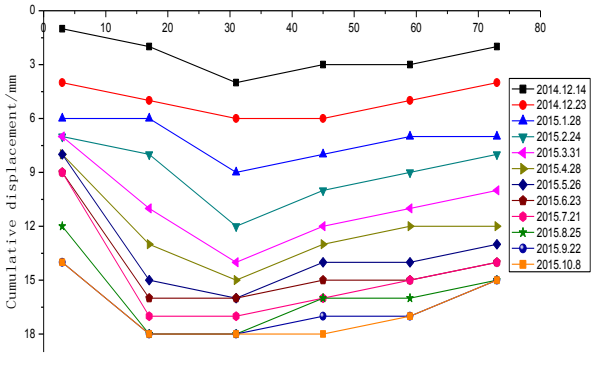

FIG. 5 HORIZONTAL DISPLACEMENT CURVE OF THE SOUTH SIDE OF FOUNDATION PIT

3.3 Horizontal displacement analysis of deep soil in foundation pit

Fig. 6 and Fig.7 are the accumulation level displacement curve deep soil in foundation pit. From Fig. 6 and Fig. 7, the following conclusions are obtained.

(1) The trend of soil body to foundation pit is very obvious, and the curve is basically "spoon shaped" distribution. The maximum point of the horizontal displacement is 1.5 ~ 3.5m under the excavation surface, which is 15% ~35% of the foundation pit depth. This is due to the increase of the stiffness of the top soil, which limits the development of horizontal displacement.

(2) When there is the external angle of the foundation pit is on the north side, the horizontal displacement of the two sides (x=3m and x=73m) of the foundation pit is close. The maximum horizontal displacement at x=37m is located at the north side of the external corner, which is 20.90mm at z=2.5m. The horizontal displacement at z=0.0m is 20.26mm. The maximum horizontal displacement of foundation pit near corner of the south side of foundation pit is

18.44mm mm(x=73m), the maximum horizontal displacement is 19.49mm(x=37m) in the middle of the south foundation pit. The horizontal displacement and the maximum horizontal displacement at the top of the north side of the middle of the north side were increased by 9.87% and 7.23% respectively than that of the south side of the south side. It is found that the presence of external corner does weaken the soil body.

(3) The influence of spatial effect not only exists in the surface, the deep soil is also affected by the spatial effect, and the deep soil displacement in the middle part of the middle part is larger than that of the negative angle.

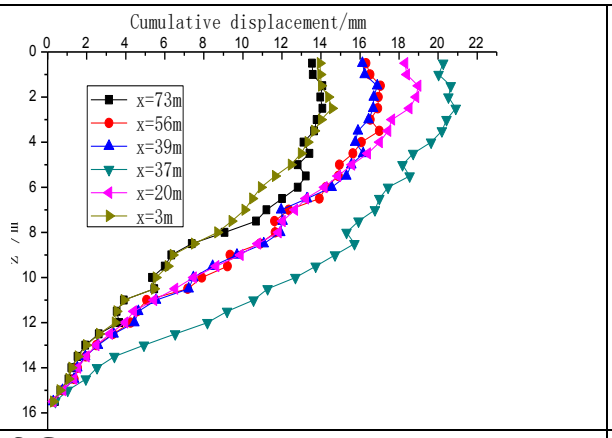

FIG. 6 CUMULATIVE HORIZONTAL DISPLACEMENT CURVE OF THE NORTH SIDE OF FOUNDATION PIT

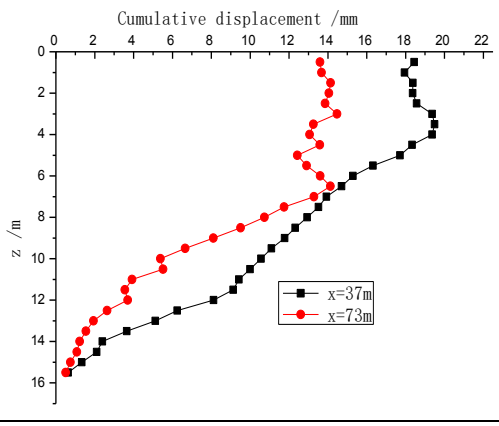

FIG.7 CUMULATIVE HORIZONTAL DISPLACEMENT CURVE OF THE SOUTH SIDE OF FOUNDATION PIT

3.4 Analysis of lateral earth pressure of foundation pit slope

The collected data of the measured data of the fiber grating analyzer are collected and sorted out. It is shown in table 3.

TABLE 3

THE FINAL STABLE VALUE STATISTICS OF THE LATERAL EARTH PRESSURE AT EACH MEASUREMENT POINT

Measuring point number	Coordinate position (x,y,z)/m	soil pressure/kPa	Measuring point number	Coordinate position (x,y,z)/m	soil pressure/kPa	Measuring point number	Coordinate position (x,y,z)/m	soil pressure/kPa
P3-1	20, 121.5,-2	6.6	P4-1	37,126.5,-2	2	P5-1	73, 126.5,-2	-1.0
P3-2	20, 121.5,-5	36.1	P4-2	37, 126.5,-5	13.6	P5-2	73, 126.5,-5	18.9
P3-3	20, 121.5,-8	67.6	P4-3	37, 126.5,-8	89.3	P5-3	73, 126.5,-5	78.4

According to the collated data, the change curve of soil pressure at different measuring point in different locations of the foundation pit is drawn as shown in Fig.8~10. It is can be seen from Fig.8~4.10 that:

(1) The lateral earth pressure changes with volatility. After excavation, there is the disturbance of the supporting structure of foundation pit during the construction of underground works. During the construction period, the influence of soil pressure near the ground is larger, and the effect of soil pressure is smaller at the bottom of the foundation pit.

(2) The lateral earth pressure value of each measuring point increases with the increase of time. The level position of the measuring point is different, and the soil pressure on the profile varies with the depth. In the vicinity of the external and negative angles, the tensile stress zone is near, and the tensile stress zone near the positive angle is larger than that of the tensile stress zone near the negative angle

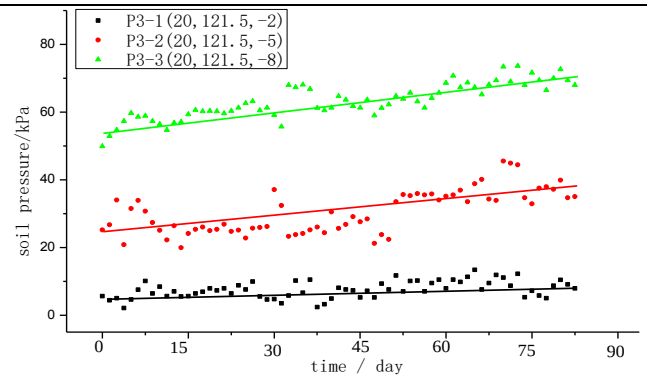

FIG. 8 EARTH PRESSURE CHANGE CURVE(X=20M)

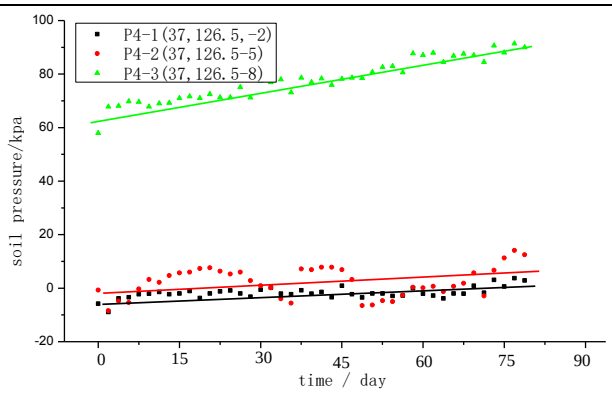

FIG 9 EARTH PRESSURE CHANGE CURVE(EXTERNAL ANGLE X=37M)

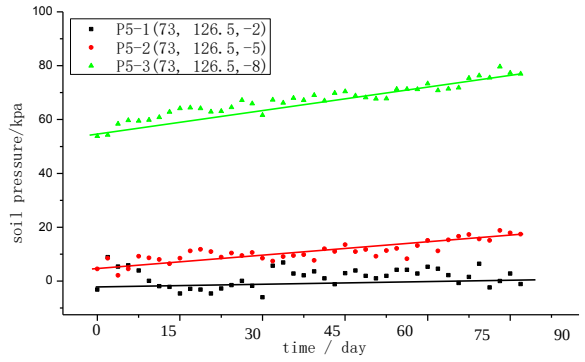

FIG.10 EARTH PRESSURE CHANGE CURVE(NEGATIVE CORNER X=73M)

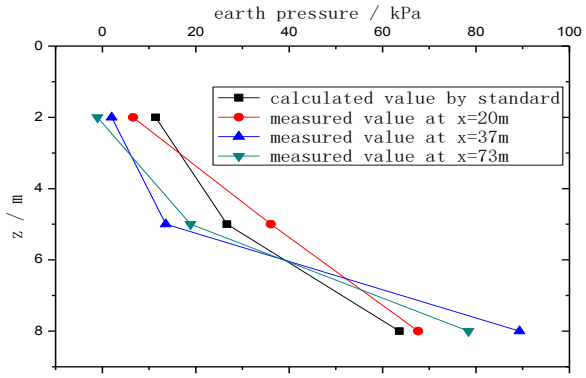

FIG. 11 COMPARISON VALUE OF EARTH PRESSURE BETWEEN MEASURED AND CALCULATED VALUE BY STANDARD

Fig. 4.11 is the comparison value of earth pressure between measured and calculated value by standard. From Fig. 4.11, at 0.2 times the depth of excavation of the ground, the central foundation pit, the positive and negative angle position of the measured values are smaller than the calculated value of 42.10%, 82.46%, 108.77%; at 0.5 times of the excavation depth of the ground, the middle of the foundation pit position of the measured value is greater than the calculated value of 35.21%; the measured values of positive and negative are 49.06% and 29.21 respectively; at 0.8 times the depth of excavation of the ground, the measured values of the the center of the foundation pit, the positive and negative angle position are greater 6.29%, 40.41%, 23.27%than the calculated value respectively.

3.5 Analysis of ground surface settlement around foundation pit

In this monitoring, the settlement of the soil around the foundation pit is monitored. The results show that the surface settlement curve of foundation pit is close to linear, the maximum settlement is 7.26mm, the minimum settlement is 1.86mm, and the surrounding surface settlement of the side corner is less than that in the middle of foundation pit.

IV. CONCLUSION

(1) The monitoring results show that the roof settlement and horizontal displacement of the foundation pit have obvious spatial effect. The middle part of the settlement is larger 40%~65% than that of the corner, and the horizontal displacement of the middle part is larger 28%~42% than that of the side corner. The amplification of the positive angle to the settlement and horizontal displacement is greater than 48% and 11% respectively.

(2) The maximum horizontal displacement of the foundation pit is 15% to 35% in the depth of the foundation pit. Compared to the displacement of foundation pit on the north and south side, the horizontal displacement of the central part is higher than that in the corner. The influence of space effect not only exists in the surface and the deep soil layer is also affected by the space effect.

(3) The lateral earth pressure changes with volatility. The lateral earth pressure value of each measuring point increases with the increase of time. at 0.2 times the depth of excavation of the ground, the central foundation pit, the positive and negative angle position of the measured values are smaller than the calculated value of 42.10%, 82.46%, 108.77%; at 0.5 times of the excavation depth of the ground, the middle of the foundation pit position of the measured value is greater than the calculated value of 35.21%; the measured values of positive and negative are 49.06% and 29.21 respectively; at 0.8 times the depth of excavation of the ground, the measured values of the the center of the foundation pit, the positive and negative angle position are greater 6.29%, 40.41%, 23.27%than the calculated value respectively.

REFERENCES

[1] Dysli, M., and Fontana, A. Deformations around the excavation in clayey soil[C]. Proc., Int. Symp. On numer. Models in Geomechanics, A. A. Balkema, Rotterdam, The Netherlands, 1982: 634-642.

[2] OU, C.Y. HSIEH, P.G. and CHIOU, D. C. Characteristics of ground surface settlement during excavation[J]. Canadian Geotechnical Journal, 1993, 30(5):758-767.

[3] LIU, K.X., Three Dimensional Analysis of Deep Excavation in Soft Clay[D], Master Engineering Thesis National University of Singapore, Singapore,1995.

[4] Fook-Hou Lee, Kwet-YewYong, Kevin C. N. Quan, etc. Effect of Corners in Structted Excavations: Field Monitoring and Case Histories [J]. Journal of Geotechnical Engineering. 1998, 339－349.

[5] Jill Roboski, Richard J Finno. Distributions of ground movements parallel to deep excavations in clay [J]. Canadian Geotechnical Journal 2006, 43:43-58.

[6] J. Tanner Blackburn, Richard J. Finno. Three-Dimensional Responses Observed in an Internally Braced Excavation in Soft Clay [J]. Journal of Geotechnical and Geo- environmental Engineering, 2007, 133(11):1364–1373.

[7] Nie Qingke, Liang Jinguo etc. The Design Theory and Application on Foundation Pit Supporting Structure by Double Row Piles deep [M].Beijing: China Building Industry Press, 2008.

[8] Ding Ji-hui, Zhang Qin. Calculation Method of Soil Pressure Utilization Factor on Cantilever Supporting Structure of Deep Excavation. International Workshop on Architecture[C], Civil and Environmental Engineering, ACEE(Wuhan, China), 2011.4.

[9] Yuan Man, Ding Jihui, Zhang Qin. Analysis of Spatial Effects of Two-row Pile Structure of Foundation Pit Based on Elastic Resistance Method[J], IJCEE, 2011(5): 134-138.

[10] Ding Jihu, Yuan Man, Zhang Qin. The analysis of spatial effect of soil pressure on cantilever reaining structure based on elastic resistance method[J]. Engineering Mechanics, 2012(s1):136-140.