Construction measuring and deformation analysis of foundation pit in deep silt soil layer under complicated environment

Jianhui Yang[1], Deyi Kong[2,*]

1. School of Civil Engineering, Fuzhou University. Fuzhou 350018, China

2. College of business administration, Fujian Jiangxia University, Fuzhou 350108, China

170584101@qq.com

ABSTRACT. In order to study the deformation law of the underground continuous wall + multi-layer support system of deep foundation pit in Fuzhou soft soil area, the deep foundation pit of the Pan Dun station of Metro Line 6# in Fuzhou soft soil area is used as the engineering research background. The body deformation and the internal force and deformation of the supporting structure and the surrounding surface settlement are dynamically measured and the measuring results are analyzed. The research results show that the horizontal displacement of soil and wall gradually increases with the increase of excavation depth. The maximum displacement occurs about 6m away from the basement, then gradually decreases, and the final deformation curve is "bulging type". The measured subsurface settlement is a parabolic type of lateral surface settlement. The maximum settlement occurs at 7m away from the foundation pit wall. The maximum settlement is about 0.29Hm, which is 0.3%Hm. The longitudinal surface settlement is roughly linear; the multi-layer support is supported. The supporting axial force in the structural system changes dynamically with the earthwork excavation of each layer, the pouring, installation and removal of adjacent supports. The axial force of the upper and lower layers is obviously smaller than that of the intermediate support. The research results verify the reliability and rationality of the design of the deep foundation pit supporting structure-underground continuous wall + multi-layer support system, and have certain reference for the design and construction of other subway line sites and similar foundation pit projects in Fuzhou area.

RÉSUMÉ. Pour étudier la règle de déformation de la paroi continue souterraine + système de support multicouche de la tranchée de fondation profonde dans la zone du sol mou de Fuzhou, la tranchée de fondation profonde de la station PanDun de la ligne 6 du métro dans la zone du sol mou de Fuzhou est utilisée comme fond de recherche en génie. La déformation du corps et la force interne ainsi que la déformation de la structure porteuse et du tassement de la surface environnante sont mesurés de manière dynamique et les résultats de mesure sont analysés. Les résultats de la recherche montrent que le déplacement horizontal du sol et des murs augmente progressivement avec l'augmentation de la profondeur d'excavation. Le déplacement maximal se produit à environ 6 m du sous-sol, puis diminue progressivement, et *la courbe de déformation finale est de «type bombé». Le tassement mesuré sous la surface est un type de tassement parabolique de la surface latérale. Le tassement maximum a lieu à 7 m du mur de la tranchée de fondation. Le tassement maximum est d'environ 0,29 Hm, ce qui correspond à 0,3% Hm. Le tassement longitudinal de la surface est à peu près linéaire; le support multicouche est prise en charge. La force axiale de support dans le système structural change de manière dynamique avec l'excavation de terrassement de chaque couche, la coulée, l'installation et le retrait des supports adjacents. La force axiale des couches supérieure et inférieure est évidemment inférieure à celle du support intermédiaire. Les résultats de la recherche vérifient la fiabilité et la rationalité de la conception de la structure de support de la tranchée de fondation profonde, comprenant une paroi continue souterraine + un système de support multicouche, et ont certaine référence pour la conception et la construction d'autres sites de lignes de métro et de projets similaires de tranchée de fondation dans la zone de Fuzhou.*

KEYWORDS: *deep foundation pit, deep silt layer, monitoring, deformation analysis.*

MOTS-CLÉS: *tranchée de fondation profonde, couche de limon profond, surveillance, analyse de déformation.*

DOI:10.3166/ I2M.17.167-185

1. Introduction

Deep foundation pit construction may face various risks. Foundation pit structure type, engineering geological conditions, hydro-geological conditions, support structure design and construction plan have a direct impact on the safety of foundation pits and surrounding structures. Deformation rules of deep foundation pits are different because of different geological and hydro-logical conditions and support designs. Then the focus of monitoring is different, but monitoring data analysis is a necessary means to study the spatial effects of deep foundation pits. Xiong and Wang (2009) introduced the design and monitoring of a foundation pit support structure. By analyzing the measured monitoring data, they explained the mechanism of the dangerous situation and put forward the reinforcement measures, which have obtained good results. Liu *et al*. (2014), Hu *et al*. (2014), and Liao *et al*. (2015) analyzed various monitoring data during the excavation process of deep foundation pits under different regions and different texture conditions, and summarized the deformation rules to provide suggestions and references for similar engineering design and construction. To date, there are few studies on deep foundation pit engineering with deep silt layer under complex environment in coastal areas. The completed 1# and 2# lines in Fuzhou and the 3#, 5#, 6# currently under construction as well as several planned subway lines are mostly under such environmental conditions. Therefore, it is necessary to dynamically monitor the base pit support wall, soil deformation and support axial force, groundwater level and surrounding structure deformation of soft and muddy soil layer, and analyze the test data and summarize the deformation rules. It is expected to provide suggestions and reference for the design and construction of other subway stations and other similar foundation pit projects in Fuzhou.

2. Project overview and geological conditions

2.1. Project and design overview

The Pandun Station of Fuzhou Metro Line 6# is an underground three-story island station located at the traffic junction of Pandun Road and Linpu Road in Cangshan District (as shown by the red line in the photo of Figure 1). The excavation depth of the foundation pit is large (with 205m length, 16.4~33.2m width, and 22.56~24.16m depth), and the surrounding environment is complex. The north side of the station is the Century Jinyuan Building, Yonghui Supermarket, etc. The west side plot is the construction site of the Red Star Meikailong project. The south side plot is the construction site under construction, the planned river course and the prefabricated demolished residential building. The east side plot is the Bund commercial residential building under construction. There is no grading space. The soil in the stratum is weak and complex, and the groundwater level is high.

Figure 1. Phase I location photo of pandun station

2.2. Engineering geological conditions

According to the engineering geological survey report, the soil layers are mainly described from top to bottom as follows:

(1) Plain fill: gray, under consolidation ~ consolidation, slightly wet, mainly sandy clay, mixed with a small amount of gravel, hard impurities content of about 10% to 30%. A total of 11 holes in this layer have been exposed. Exposure layer is 0.90 ~ 4.40m deep, with different density and uniformity, low shear strength, low load bearing capacity and poor engineering performance.

(2) Miscellaneous fill: mainly grayish yellow and loose. yellow and loose. The composition is mainly consisted with cohesive soil, gravel and block stones. A small amount of construction waste contains, and 50% to 70% hard impurities. Large different density, uneven, and mainly filled by labors. Landfill time is about 8 to 10 years. A total of 19 holes in this layer have been exposed. Exposure layer is 1.40 ~ 5.50m deep, with different density and uniformity, low shear strength, low load bearing capacity and poor engineering performance and uniformity.

(3) Sludge: dark gray, gray, flowing plastic, mainly composed of clay and powder. Partially containing a small amount of sandy components and humus, smelly, easy to soil, high dry strength, high toughness, no shaking reaction, slightly shiny surface, cause of sea accumulation. According to the results of geotechnical test and the sensitivity of on-site cross-plate shear test, the sensitivity is 3.1-7.2, which is a highly sensitive soil. 103 holes in this layer were exposed. The exposed thickness is 1.00-26.60m, with low bearing capacity is low and poor engineering performance.

(4) Muddy soil: dark gray, fluid-like, saturated, composed mainly of clay and powder, with uniform soil, a small amount of humus and sand, medium dry strength, toughness, no shaking reaction, slightly cut surface glossy, marine formation. 23 holes in this layer have been exposed, with 1.00 - 12.60m thick, low carrying capacity and poor engineering performance.

(5) Mid-fine sand (with mud): grayish yellow, gray, loose-compact, saturated, poor grade, the composition is mainly quartz particles, the shale content is about 15-20%, and the content of local clay is higher. High, mainly composed of fine sand and medium sand, containing a small amount of silt, smelly, marine accumulation. This layer is exposed in all boreholes, the exposed thickness is 0.60 - 25.7m, with general bearing capacity and engineering performance.

(6) Silty clay: grayish yellow, light gray, plasticizable, composed mainly of sticky and powdery particles, containing a small amount of sandy components, medium toughness, medium dryness, lustrous soil surface, no shaking reaction, sea formation. 48 holes have been exposed, with 0.90 ~ 7.10m thick, general bearing capacity, medium compressibility, and general engineering performance.

Table 1. Physical and mechanical parameters of soil layers

Layer	Quality density ρ (g/cm3)	Moisture content w/%	Natural void ratio e	Shear strength (24h Consolidation shear)	
				Cohesion/kPa	Internal friction angle/(°)
Plain fill	1.8		0.779		
Miscellaneous fill	1.75		0.845		

Sludge	1.60	62.30	1.523	11.7	5.5
Muddy soil	1.71	47.20	1.321	13.7	6.1
Silty clay	1.90	28.7	0.847	17.0	32.2
Medium fine sand	1.80		0.650		21.5
Strong weathered granite	1.93			32	28

(7) Sand-like strong weathered granite: grayish yellow, grayish white, composed of quartz, incompletely weathered feldspar particles. Most of the weathered minerals such as feldspar have been weathered into secondary bauxite minerals. The core is loose, which is easy to soften and disintegrate when it meets water. It is extremely soft rock, the rock mass is extremely broken, the basic quality grade of rock mass is V, medium to low compression, and the strength is generally higher. 98 holes in this layer have been exposed, with 1.60-12.93m thickness. This layer reveals a boulder (middle weathered granite) of 1.00 to 1.70 m in the boreholes MFZ3-S1-046 and MFZ3-S1-070. Table 1 shows the main physical and mechanical properties of the layer.

2.3. Hydro-geological conditions

The groundwater depth of the site is about 1.00 and 2.0 m. Loose rock pore-bearing water mainly stores in medium-fine sand and fine sand layer with medium-strong permeability and pressure bearing. The lateral recharge among the aquifers has a certain hydraulic connection with the Minjiang River. The upper part and the lower part of the confined aquifer are generally covered with silt and silt soil with a certain thickness of water barrier, which has little effect on the excavation of the foundation pit, and is weakly corrosive to the steel bar in the reinforced concrete structure in the case of alternating wet and dry conditions.

3. Foundation pit support scheme and construction condition

3.1. Foundation pit support scheme

After comparison and optimization of the scheme, it is finally determined that the foundation pit support structure is a composite structure type: he outer pit of in the large foundation pit chooses the 850SMW construction pile + inner support, the inner pit uses 1m thick underground continuous wall (the inner pit continuous wall is also used as an anti-floating, 47m long); the small foundation pit area uses 1m thick underground continuous wall (the inner pit continuous wall is also used as an anti-floating, 47m long)+ inner support envelope form (see figure 1). Except for the

51-52 axle, which adopts the internal support form of four concrete supports, the rest adopts two raft supports + four steel support inner support forms. The foundation pit sets a row of temporary center pillar, which serves as a permanent structure and anti-floating.

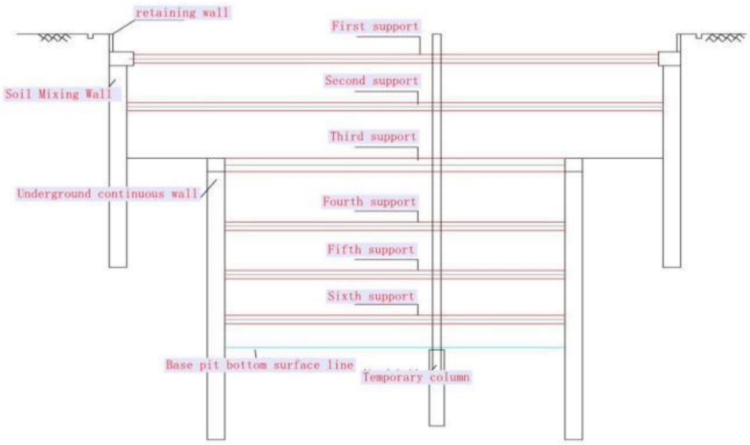

Figure 2. Sectional view of the foundation pit support structure

3.2. Construction condition

Foundation pit excavation adopts segmented, blocked and layered excavation, and excavation is carried out layer by layer. And concrete or steel pipe support is set layer by layer. After the earthwork excavation reaches the design base elevation, construction of each station layer structure was done from bottom to top. And the temporary support at each level was also torn down correspondingly.

4. Monitoring level, project and measure point arrangement

4.1. Monitoring level

Engineering monitoring level should be determined according to the factors of engineering risk level, surrounding environmental risk level, geological condition complexity based on design documents and Urban Rail Transit Engineering Monitoring Technical Specification GB 50911-2013. In this paper, the risk level of the foundation pit is first grade, the surrounding environmental risk grade is first grade, and the geological condition is very complex. Hence, the monitoring level of the foundation pit project is comprehensively determined to be level one.

4.2. Monitoring project

According to the importance of foundation pit, surrounding environment condition and monitoring level, the monitoring items of foundation pit include: settlement of surrounding structures, outside ground settlement of foundation pit, vertical and horizontal displacement of retaining structure, vertical and horizontal displacement of column, supporting internal force, horizontal displacement of deep soil, groundwater level.

4.3. Measure point arrangement

A total of 46 wall slope points, 26 soil slope points, 78 surface settlement observation points, 26 groundwater level observation points, 8 column displacement measurement points, and 108 concrete beam, steel tube support axial force measure points were set along the perimeter of the foundation pit with 10m~20m spacing. The concrete beam and steel pipe support axial force measurement points (see Figure 3) are used to monitor the deformation of the retaining structure, surrounding structures, and foundation soil uplift during the construction process. They are used to monitor the deformation of the envelope structure, surrounding structures and foundation soil uplift during the construction process.

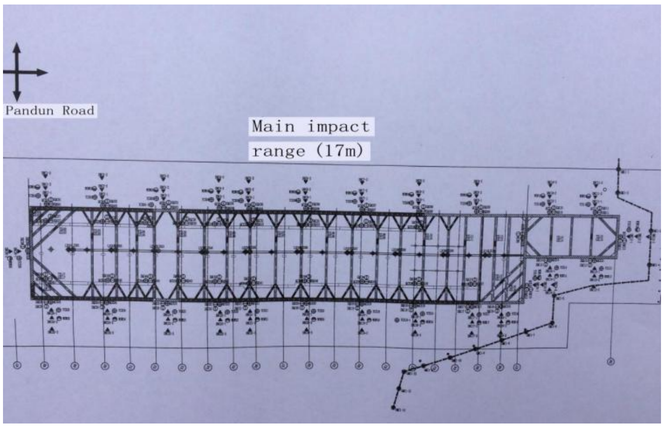

Figure 3. Monitoring point layout plan

4.4. Arrangement principles

Monitoring points are placed at the middle of each part of the foundation pit, the corner, depth change part, the adjacent building (structure) and underground pipelines as well as other important environmental parts and complex geological conditions.

5. Monitoring period and monitoring frequency, early warning control value

5.1. Detection cycle

The monitoring period of this station should start from the completion of the precipitation excavation construction of the foundation pit supporting structure project until the back-filling. It should be completed after the deformation tends to be stable (usually half a year). The monitoring of the surrounding environment of the pit with special requirements should be continued as needed.

5.2. Monitoring frequency

Foundation pit safety rating is level one. According to Technical specification for urban rail transit engineering monitoring GB 50911-2013 and Fuzhou Rail Transit Line 6 Project Work Contact Form [No.: E-S201482-055(2017)], the excavation depth of the foundation pit of Pandun Station on Line 6 is about 22.56~24.16m, so the monitoring frequency of this project is determined as shown in Table 2 below.

Table 2. Monitoring frequency of the foundation pit project

Construction process		Frequency
Foundation pit excavation depth (m)	≤5	Once/3d
	5 ~ 10	Once/2d
	10 ~ 15	Once/2d
	15 ~ 20	Twice/1d
	>20	Twice/1d
Time after pouring the bottom plate(d)	≤7	Twice/1d
	7 ~ 14	Once/1d
	14 ~ 28	Once/1d
	>28	Once/3d

Note:

① The monitoring frequency before excavation of the foundation pit project shall be determined according to the actual needs of the project;

② After the bottom plate is poured, the monitoring frequency can be adjusted according to the change of monitoring data;

③ The monitoring frequency should be increased within 3 days after the removal of the supporting structure and after the completion of the removal;

④ When the monitoring data reaches the early warning, the monitoring frequency should be increased appropriately;

⑤ If there are unfavorable geological conditions not found in the survey, and the monitoring frequency should be appropriately increased;

⑥ If the monitoring frequency should be increased or decreased as appropriate in the case of sudden large settlement of adjacent buildings (structures);

⑦ If there should be other abnormal conditions affecting the safety of the foundation pit and the surrounding environment, and the monitoring frequency should be increased;

⑧ When there are signs of dangerous accidents, real-time follow-up monitoring should be carried out.

5.3. Monitoring range

The surrounding monitoring range of the project from the outer pit line is 17m (0.7H, H is the excavation depth of the foundation pit; for safety reasons, we consider the deepest point of about 24m). Internal engineering itself as well as surrounding underground, ground construction (structure), underground pipelines, earth surface and roads.

5.4. Warning control value

Table 3. Monitoring and control value of the foundation pit project

Monitoring project	Control value	
	Change rate (mm/day)	Cumulative change (absolute value) (mm)
Horizontal displacement of support pile (wall)	3	25
Vertical displacement of support pile (wall)	3	25
Horizontal displacement of support pile (wall) body	3	30
Surface subsidence	3	30
Deep horizontal displacement of soil	3	30

Monitoring project		Control value		
		Change rate (mm/day)	Cumulative change (absolute value) (mm)	
Underground pipeline	Natural gas pipeline	2	10	Differential settlement (absolute value) (mm)
				0.25%lg
	Power line	2	30	0.3%lg
Groundwater level		500	1000	
Column vertical displacement		2	20	
Column horizontal displacement		2	20	

The monitoring control indicators of this project are determined in accordance with the Technical Specification for Urban Rail Transit Monitoring (GB 50911-2013) and Fuzhou Rail Transit Line 6 Contact List Project E-S201482-2005. Building (structure) crack observation is based on the provisions in Table 3.4.5 of the Concrete Structure Design Code GB50010-2010. The specific control indicators are shown in Table 3 below.

5.5. Stopping test standards

First, each monitoring project measures the initial value before the start of construction, and starts monitoring after the construction starts according to the on-site construction conditions and the corresponding detection frequency. When the construction of the project is completed, the influencing factors of construction safety are basically eliminated. After the deformation of the monitoring object tends to be stable, the application for suspension of the test is submitted to the supervisors and designers, and the corresponding monitoring work can be stopped after approval.

Second, the foundation pit monitoring should not be less than half a year after the completion of the underground structure construction. When the settlement speed of the important buildings (structures) in the last 100 days is less than 0.04mm/d, it can be considered that the settlement of the building (structure) is basically stable and monitoring can be stopped. If the important building (structure) in the surrounding area is still not stable after half a year, it should continue to be monitored until it is stable.

5.6. On-site inspection

5.6.1. Inspection content

① Foundation pit excavation section, stratification height and slope, excavation surface exposure time; ② Whether the column and the support rod are obviously deformed or loosened; ③ Type, characteristics, self-stability of excavation face rock soil, and whether there is leakage; ④ Heaping condition around the foundation; ⑤ Whether the foundation pit pile (wall) has obvious deformation; ⑥ Whether the pile (wall) with has water leakage; ⑦ Surface cut and drainage measures and effects on the side wall and surrounding area of foundation pit, whether there is water accumulation in the pit edge base; ⑧ whether clear settlement or ground cracking on the surface outside the pit.

5.6.2. On-site inspection frequency

On-site safety inspections should be carried out during on-site monitoring work. Safety inspection must be done once a day. And increase inspection frequency under special circumstances. Record the inspection results in detail in the on-site inspection table.

5.7. Monitoring focus and difficulties

The excavation depth of the foundation pit is 22.56m-24.16m, with high risk and wide the influence range. There are a certain number of buildings (structures), underground pipelines, electric towers, and important trunk lines and main roads in the affected area. The complicated surrounding environment adds difficulty and risk to the construction monitoring of the project. The difficulty of monitoring lies in the underground pipelines. The 7m and 14m surface settlement observation points are located on the two main trunk roads of Linpu Road and Pandun Road, and the 2m surface settlement observation points are located on the intra-field transportation passage. Monitoring work is highly disrupted and there is a significant risk of traffic safety. The key point of monitoring is to grasp the changes of the horizontal displacement, support axial force and soil uplift of the retaining wall in real time to prevent the foundation pit retaining structure, the displacement or deformation of the base soil beyond a certain limit, threatening the safety of the foundation pit. At the key points of the construction, the monitoring frequency can be increased, and the daily inspection of the surrounding environment can be strengthened.

6. Analysis of monitoring results

6.1. Groundwater level

The upper part of the confined aquifer in the site has a depth of about 12m, and the middle and coarse sand layer has a depth of 42m. Below the basement is a deep impervious layer-sludge layer. According to experience and design calculation, there will be no piping or sand drift in the foundation pit. Since the upper part of the foundation pit is made of 850 SMW, the water isolation effect is good. The deep impervious layer of the basement (muddy soil layer) and the underground continuous wall are relatively isolated from the confined water in the lower middle coarse sand layer. The influence of precipitation in the foundation pit on the soil deformation around the foundation pit is virtually negligible. Therefore, no water level observation points are buried in the foundation pit. There was no precipitation outside the foundation pit and no leakage of the retaining structure was found during daily inspection. The actual depth of the groundwater level changed greatly. However, the changes at each observation point are relatively stable after the water level is lowered or increased (see Figure 4). The water level in the upper backfill soil is affected by atmospheric precipitation and surface subsurface infiltration. The water level and water volume vary greatly with the seasons. In the spring and summer rainy season, the upper stagnation water is richer, and the water volume in the dry seasons of autumn and winter is smaller. The roadbed around the foundation pit is prime backfill, miscellaneous backfill, deep silt, and heavy traffic. The groundwater level changes by nearly 5m, which is one of the reasons for the super-warning settlement of ground surface. Due to poor drainage of the site, WSW4, WSW24, and WSW26 are often flooded by surface water, and the water level change of the 3 holes is negligible.

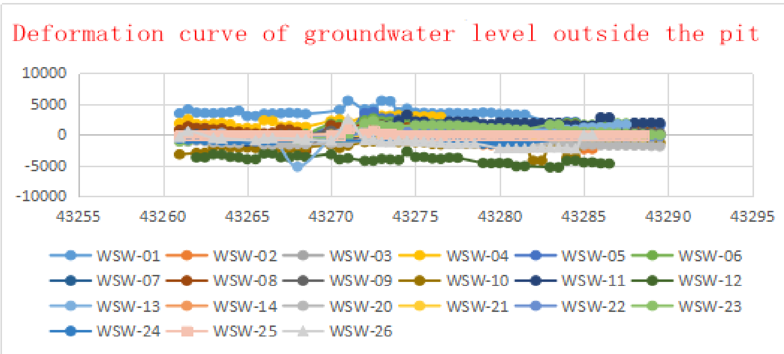

Figure 4. Deformation curve of groundwater level outside the pit

6.2. Horizontal displacement of deep soil

In this paper, the displacement curve of the horizontal displacement of deep foundation soil with small depth and working condition is taken as the representative. It can be seen from Fig. 5 that the horizontal displacement of the soil outside the foundation pit gradually increases with the increase of the excavation depth, and the displacement has a “bulging” shape with the depth deformation curve, and the structure is stable after completion. The maximum displacement occurs near the fifth support, the distance from the base is about 6m, the maximum displacement is inclined to the base pit by about 37mm, exceeding the early warning control value of 30mm, and the soil deformation control exceeds the design requirements, which can cause the surrounding surface super-warning settlement.

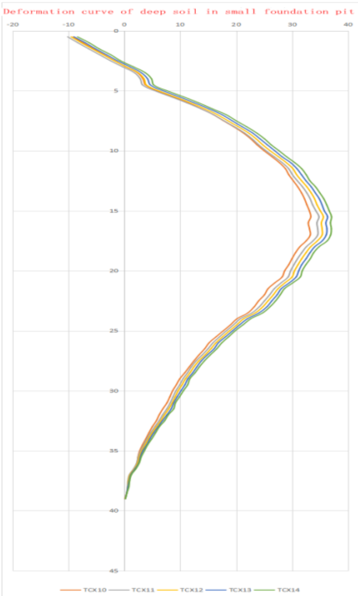

Figure 5. Deformation curve of deep soil in small foundation pit

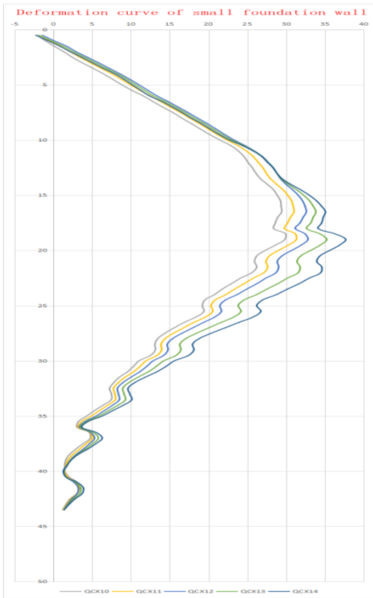

Figure 6. Deformation curve of small foundation wall

6.3. Horizontal displacement of the wall

In this paper, the displacement curve which changes with the depth and working conditions of the horizontal displacement of the small foundation pit retaining wall is taken as the representative. It can be seen from Fig. 6 that the horizontal displacement of the supporting wall at the top of the foundation pit is relatively small. As the foundation pit is excavated down layer by layer, the displacement changes in a "bulging" shape. The maximum horizontal displacement of the wall occurs about 6m away from the bottom of the foundation pit, and the maximum displacement is about 35mm, which exceeds the warning control value of 30mm.Deformation control exceeds the design requirements, which can cause super-warning settlement of the surrounding surface, which is smaller than the relationship curve δhm/Hm (0.5%~3.0%) between the maximum settlement and the maximum horizontal displacement of the wall of the confined wall proposed by Mana and Clough (1981), which is between 0.5% and 3.0%.

The maximum displacement curve of the wall and soil deformation is basically consistent with the results of Li *et al*. (2007), that is, the maximum deformation of the soft soil foundation pits in Shanghai and Hangzhou gradually decreases with the increase of the excavation depth of the foundation pit, and the final maximum deformation position is stable at a certain depth above the excavation surface.

6.4. Support axial force

Figure 7 shows the variation curve of the measured axial force of the foundation pit under different construction conditions. The reinforced concrete support (TZL) axial force is measured by a steel bar gauge, and the steel pipe support (GZL) is measured by an axial force meter. It can be seen from the figure that the axial force changes with the excavation of the foundation pit soil accordingly. The axial force monitoring value basically meets the warning control value. The influence of temperature change on the support axial force is very large. At the same time, the axial force of the concrete support is more affected by the temperature change than the support of the steel pipe. In addition, the influence of temperature change on the axial force of the second support is larger than that of the first support, which is basically consistent with the conclusion of Liu *et al*. (2016).

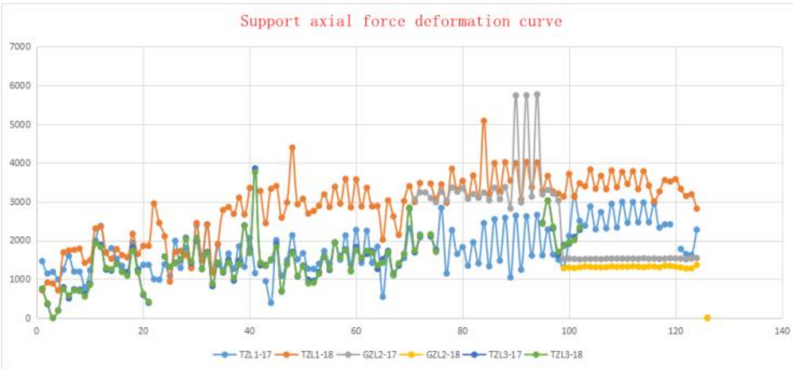

Figure 7. Support axial force deformation curve

6.5. Ground Settlement curve

Through the analysis of the measured values of surface subsidence, we get the deformation of the surrounding surface (formerly municipal road) caused by the construction of the deep foundation pit (see Figure 8).

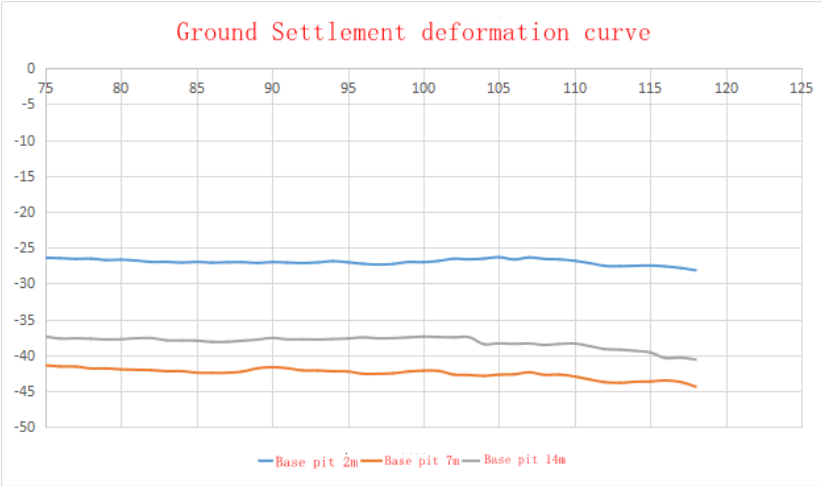

Figure 8. Ground Settlement deformation curve

It can be seen from the above monitoring data that the settlement of the foundation pit surrounding the foundation pit is large except for 2m. Because heavy vehicles and the super load are not allowed to travel within 2m from the foundation pit, the settlement value of the 2m monitoring point is within the early warning control value. 7m is the intra-vehicle transportation channel and 14m is the main road for municipal traffic. The maximum settlement value is about -45mm, which exceeds the warning control value. Wang (2010) pointed out that the settlement of deep foundation pits in Shanghai soft soil area is 1.5Hm~3.5Hm away from the foundation pit. Wang pointed out that the settlement impact range of the deep foundation pit in soft soil area of Shanghai is 1.5Hm ~ 3.5Hm distance from the foundation pit. The maximum settlement of the surface is between 0.1% Hm and 0.8% Hm, and the maximum surface settlement occurs within the range of 1.0 Hm. The maximum settlement measured on the surface of the foundation pit is about 7m away from the foundation pit wall,which is about 0.29Hm. The maximum settlement is about 0.18%Hm, which is less than the analysis result 1.07%Hm of a foundation pit in soft clay by Moorman (2004) and is located within 0.1%Hm~0.8%Hm of the maximum settlement range of the surface indicated by Wang *et al*., However, the surface subsidence monitoring range around the project is 17m (0.7H), and the variation curve does not fully reflect the parabolic shape (Ying *et al*., 2011).

6.6. Vertical displacement of the column

The vertical displacement of the column (base soil uplift displacement) is shown in Figure 9.

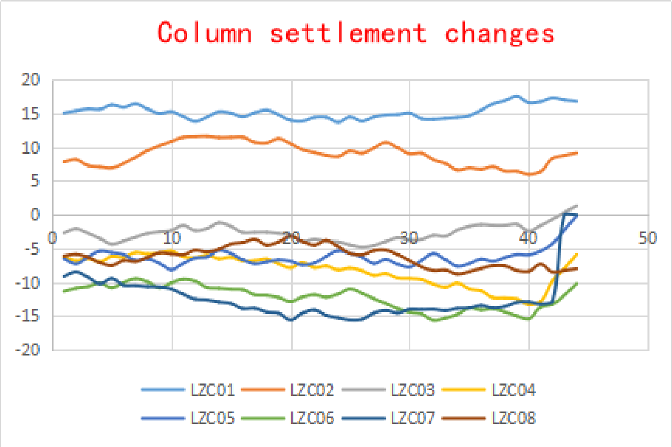

Figure 9. Column settlement changes

It can be seen from the measured data in the figure that the base soil uplift displacement within 45 days of foundation pit excavation is small, and the deformation is within 20 mm of the early warning control value. Although the vertical displacement of the column of the foundation pit is within the early warning control value, since the column is poured in the large-diameter concrete punching pile, the concrete punching pile is self-important, and the pile itself has a certain anti-pull effect. Moreover, the support of each layer is erected on the column, which is equivalent to the additional overload. The vertical displacement of the column cannot fully reflect the actual change of the uplift displacement of the base soil, to which attention should be paid to. In the subsequent engineering practice, the column should be set separately.

6.7. Daily inspection

Not found: construction in violation of design conditions; cracking of the supporting structure; large settlement or severe cracking on the surrounding ground; large settlement of the surrounding buildings, uneven settlement or severe cracking; leaks or quicksands appear on the bottom and side walls of the foundation pit.

Found: partial daily earthwork stratification excavation exceeds the norm and the determined value of the plan; overload stacking around partial foundation pit; partial groundwater did not fall to 500mm place above the bottom of the pit more than.

7. Conclusions

According to the actual monitoring data of the construction process of the project and combined with similar monitoring experience and related research of foundation pit engineering, the following conclusions are drawn:

(1) Although the maximum deformation displacement of the supporting wall, soil and surrounding surface exceeds the early warning control value, it is still less than the design control value and related research results. Combined with other project experience, and no abnormalities were found during the construction site inspection, it can be determined that the foundation pit project is safe. It is feasible to use the 850SMW construction method pile +1m thick underground continuous wall + 6 inner support structures for the foundation pit supporting structure.

(2) The influence of surrounding stratum deformation caused by the excavation of large foundation pits in deep soft clay foundations should not be neglected.

(3) The horizontal displacement of soil and wall gradually increases with the increase of excavation depth. The maximum displacement occurs about 6m away from the basement, and then gradually decreases. The final deformation curve is "bulging". After the construction of the bottom plate is completed, the deformation gradually stabilizes. In similar engineering support designs, the maximum displacement wall, the support stiffness or the vertical distance of the support can be strengthened, and the horizontal displacement of the support structure can be reduced so as to decrease the influence on the surrounding structures.

(4) The parabolic distribution of the lateral surface settlement is measured around the foundation pit. The maximum settlement which is about 0.29Hm occurs about 7m away from the foundation pit wall, and the maximum settlement is about 0.3%Hm. Longitudinal surface settlement is roughly linear. The surface settlement around the foundation pit is only monitored for the impact range of 17m (0.7Hm), which is obviously less than other relevant research results, that is, the area where the obvious settlement occurs is generally within 2 times of the excavation depth of the foundation pit, and the follow-up works should be paid attention to.

(5) When the periphery of the foundation pit is the municipal traffic main road, the support with large rigidity can effectively control the deformation of the foundation pit. With earth excavation, pouring, installation and dismantling of adjacent supports, the axial force of each layer supported by the multi-layer support structure system is continuously and dynamically changed, and the axial force of the intermediate support is obviously larger than that of the upper and lower layers. The structure of the deep foundation pit with multi-layer support is relatively complicated, and is affected by the comprehensive factors such as the foundation soil layer, the support spacing, the distance between the last support and the substrate, the back cover time and the temperature changes. The factors affecting the axial force and the envelope structure of the foundation pit and the seasonal temperature change need further study.

(6) In this paper, the water level observation point is not designed in the foundation pit, it is impossible to determine the influence of precipitation in the pit on the support wall, the horizontal displacement of the soil and the changes of the axial force of the support. Previous researches results show that due to the effect of seepage, the effective stress and void water pressure around the foundation pit will change, which not only affects the endurance and deformation of the foundation pit supporting structure, but also aggravates the settlement of the surface around the foundation pit and the basement bulge. Therefore, it is suggested that the groundwater level observation point of the follow-up subway foundation pit project in Fuzhou should be designed to further study the influence of foundation pit precipitation on the support wall, soil horizontal displacement and support axial force variation.

(7) In this paper, the water pit, soil and wall displacement observation points are symmetrically arranged in the same section, and the actual measurement results are also relatively close. Therefore, the subsequent projects can use the correlation between the monitoring points to reduce the number of measuring points.

(8) Bottom soil uplift observation column shall be independently set up in the deep foundation pit project. In the deep soft soil layer and the foundation pit which contains confined water, 2-3 observation points should be set along the mid-line of the foundation pit length. Inspection should start from the excavation to 5-8m distance to the bottom until the construction of the bottom plate is completed, so as to avoid foundation pit inability without timely predict the uplift of the soil at the bottom of the pit.

References

Hu H. Y., Zhang Y. C., Liu H. K., Luo Y. D., Rao C. Q. (2014). Case study of super-deep foundation pit of Pingan IFC. *Chinese Journal of Geotechnical Engineering*, Vol. 36, No. 1, pp. 31-38. http://dx.doi.org/10.11779/CJGE2014S1005

Li L., Yang M., Xiong J. H. (2007). Analysis of the deformation characteristics of deep excavations in soft clay. *Chinese Journal of Geotechnical Engineering*, Vol. 40, No. 4, pp. 66-72. http://dx.doi.org/10.3321/j.issn:1000-131X.2007.04.012

Liao S. M., Wei S. F., Tan Y. (2015). Field performance of large-scale deep excavations in Suzhou. *Chinese Journal of Geotechnical Engineering*, Vol. 37, No. 3, pp. 458-469. http://dx.doi.org/10.11779/CJGE201503009

Liu C., Zhang Y. L., Zheng G., Zheng J. C., Sun Y. N. (2016). Effects of seasonal temperature change on a large excavation project. *Chinese Journal of Geotechnical Engineering*, Vol. 38, No. 4, pp. 627-635. http://dx.doi.org/10.11779/CJGE201604006

Liu H. T., Wu X. G., Wang Z. (2014). The construction safety control analysis of super-deep and super-large foundation excavation for Wuhan greenland center project. *Construction Technology*, Vol. 43, No. 17, pp. 21-25.

Mana A. I., Clough G. W. (1981). Prediction of movements for braced cuts in clay. *Geotechnical Special Publication*, Vol. 107, No. 118, pp. 1840-1858. http://dx.doi.org/10.2514/3.56113

Moorman C. (2004). Analysis of wall and ground movementsdue to deep excavations in soft soil based on a newworldwide database. *Soils and Foundation*, Vol. 44, No. 1, pp. 87–98. http://dx.doi.org/10.3208/sandf.44.87

Wang J. H., Xu Z. H., Wang W. D. (2010). Wall and ground movements due to deep excavations in Shanghai soft soils. *Journal of Geotechnical & Geoenvironmental Engineering*, Vol. 136, No. 7, pp. 985-994. http://dx.doi.org/10.1061/(ASCE)GT.1943-5606.0000299

Xiong Z. B., Wang Q. Y. (2009). Monitoring horizontal displacements of support structure for a complicated planar foundation pit and its reinforcement. *Rock and Soil Mechanics*, Vol. 30, No. 2, pp. 572-576. http://dx.doi.org/10.1016/S1874-8651(10)60073-7

Ying H. W., Yang Y. W., Hu A. F., Xie K. H. (2011). Analysis on observed performance and environmental effect of a deep excavation in soft clay. *China Civil Engineering Journal*, Vol. 44, pp. 90–93.