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Analysis of Deep Foundation Pit Construction Monitoring for Subway Station in Shenyang

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ABSTRACT

In order to further study the horizontal displacement of the pile, the supporting axial force and the ground settlement deformation law during excavation of the foundation pit, the real-time monitoring and data processing of the monitoring items were carried out based on the construction of the Metro Line 10 Hunnan Road Station. The study results indicated that: when the foundation pit is excavated to the basement, the horizontal displacement curve of the pile is parabolic and the maximum displacement of the pile appears at 1/2 of the excavation depth of the foundation pit.And the supporting axial force reaches the maximum and tends to be stable,The first support is affected by the temperature more obvious.The ground surface subsidence curve is close to the concave shape, and the maximum point appears at about 10m from the edge of the foundation pit.

1. INTRODUCTION

With China's rapid development and the increasing population,urban space above ground can no longer meet the needs of urban economic development,the development and utilization of underground space has become an inevitable choice.(Wang Y 2013)As an important development of underground space,subway construction plays an important role in alleviating urban crowded traffic and driving urban infrastructure development.As the largest city in Northeast China, Shenyang has become an inevitable development of subway projects.At present, Shenyang Metro has entered a phase of rapid development.Subway construction will bring many influences to Shenyang City, such as relieving urban traffic pressure, driving rapid economic development, bringing convenience to people's travel, raising the visibility of cities, etc.When the subway construction is completed, Shenyang will enter a new stage of development.

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2. PROJECT OVERVIEW

The deep foundation pit of Shenyang Subway Line 10 Hunnan Road Station is located at the east side of the intersection of Hunnan East Road and Changqing Street,the main body of Line 10 is constructed using open-cut method.The excavation length of the station is 215.45m,the excavation width is 22.9m, and the excavation depth is 23.75m.The station is built along the north-south direction,and the main body adopts underground three-level island platform.Six security entrances are set up at the station.On the east side of the station are two high-rise residential houses, and on the south side is the Hunnan Road.The light rail is about 20m south of the pit.The west side of the pit is the residential area of Fengtian Jiuli Community under construction,and the residential buildings of the community are high-rise buildings.In the excavation area of the foundation pit, pipelines, electricity, and gas pipelines are densely distributed, making it difficult to excavate.

2.1 Engineering Geological Conditions

The deep foundation pit of Shenyang Subway Line 10 Hunnan Road Station is located in Hunnan District , Shenyang . The exploration shows that the construction stratum is mainly composed of Quaternary soil. The specific physical parameters of the soil layers are shown in Table 1.

Serial number	Formation name	γ(KN/m³)	Cq(kPa)	φc(°)	E0 (Mpa)
1	Silty clay	18.4	33.8	11.4	3.5
2	Silty clay	19.6	40.8	14.3	4.5
3	Silty clay	19.3	39.1	14.1	4.2
4	Silty clay	18.5	39.5	14.5	6.0
5	Silty clay	19.0	39.6	14.7	6.0
6	Fine sand	17.0	0	21.5	10.2
7	Fine sand	17.4	0	23.5	11.0
8	Fine sand	18.8	0	30.9	17.0

Table .1 Composition and mechanical properties of main soil layers

2.2 Hydrogeological Conditions

The groundwater in the shallow part of the construction site belongs to diving type.,the main source of it's recharge is atmospheric precipitation and surface runoff of the Hunhe River. The water level changes with the seasons, and the groundwater does not corrode the concrete.The groundwater flow is generally from east to west, but due to the influence of artificially-mined groundwater, the local groundwater flow direction will change.In the excavation area of the excavation area, the aquifer has strong permeability, the soil permeability coefficient k is between 30~100m/d, and the groundwater hydraulic slope is 1.0‰~2.0‰.

3. FOUNDATION PIT SUPPORT STRUCTURE PLAN

The main body of the station building adopts ¢1000mm@1400mm bored reinforced concrete cast-in-place piles,The length of the piles is about 32m, and the depth of the piles in the soil is about 8m. The bottom of the pile is inserted into the cobble soil. The concrete of the pile is C30, the thickness of it's protective layer is 70mm, the middle retaining plate is C25 concrete, and the cushion is C15 concrete.The inner pit support uses inner diameter ¢ 600 mm Q235 steel pipes with a thickness of 16 mm, a horizontal spacing of 3.5 m, and a horizontal spacing of 3 to 4 m in the local area.

4. FOUNDATION PIT MONITORING PROGRAM

4.1 Monitoring Purpose

By monitoring the horizontal displacement of piles,the axial support force of steel support and the stress of steel bars, the deformation and force of the envelope can be found.(Tan Y C 2009)When the monitoring data exceeds the design control value, it shall be fed back to the construction unit in time and take appropriate measures to prevent accidents from occurring.Through the data processing and analysis of the horizontal displacement of the piles, it provides real-time information guarantee for the smooth excavation of the foundation pit and guarantees that the foundation pit is in a safe state during excavation.(Ran J X 2009)Through the monitoring of ground settlement, the monitoring of the surrounding buildings , it is possible to find out the deformation of buildings and structures.(Hu C M 2009)By comparing the monitoring data with the control values, analyze whether the construction plan is reasonable and provide reference for the subsequent excavation of the foundation pit.(Liu J 2010)

4.2 Monitored Items

The foundation pit monitoring items mainly includes horizontal displacement of piles, axial support force of steel support, ground settlement, and settlement of surrounding buildings.Through the analysis of the monitoring data, the excavation dynamics of the foundation pit will be mastered to provide the basis for the construction of the next-step foundation pit.(Qian T H 2012)The frequency and control values of the monitoring items are based on the "Urban rail transit project monitoring technical specifications".The monitoring items layout is shown in Fig. 1

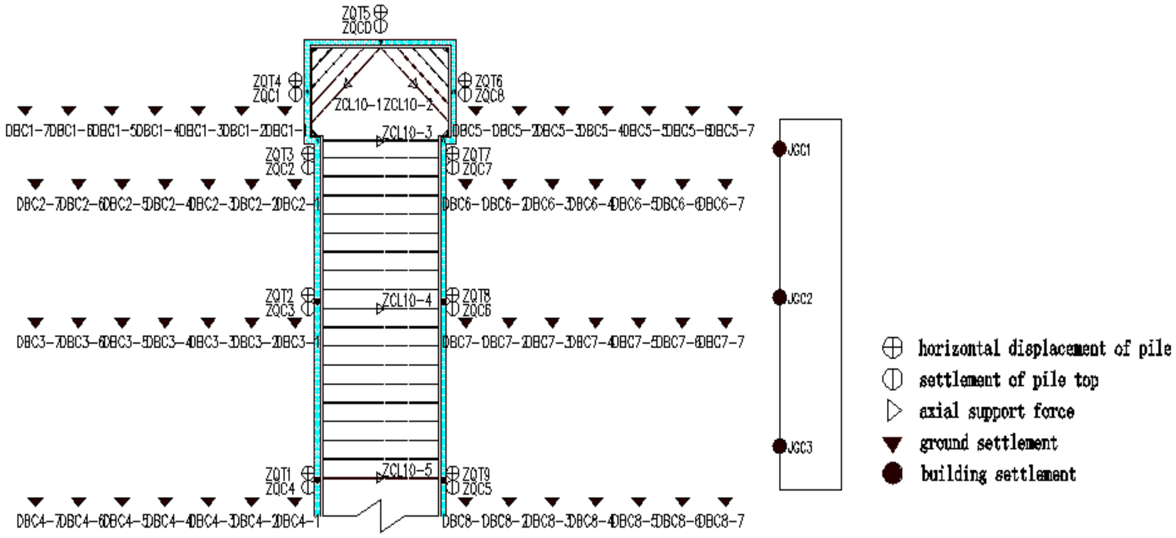


Fig. 1 Subway line 10 excavation layout plan

5. MONITORING DATA ANALYSIS

5.1 Horizontal Displacement of Pile

The horizontal displacement of the envelope structure directly reflects the stability and safety of the supporting structure of the deep foundation pit.The excavation of excavation engineering results in the deformation of the enclosing structure. The deformation of the enclosing structure results in the settlement of the ground surface outside the pit and the uplifting of the bottom of the pit. The displacement of the soil outside the pit affects the structures in the ground.(Yang X H 2014)This article selects four monitoring points ZQT3, ZQT5, ZQT7, ZQT9 to analyze the horizontal displacement curve of the piles.H represents the pit excavation depth, "+" represents the inclination to the inside of the pit, and "- ”represents the inclination to the outside of the pit.

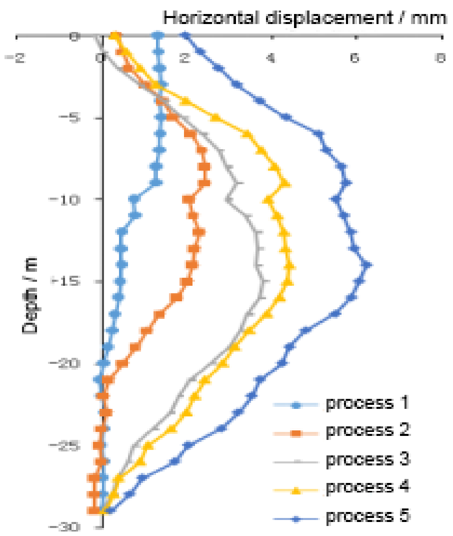


Fig. 2 Horizontal deformation of ZQT3 pile

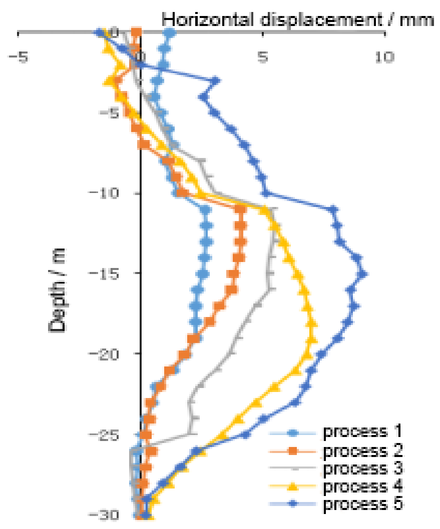


Fig. 3 Horizontal deformation of ZQT5 pile

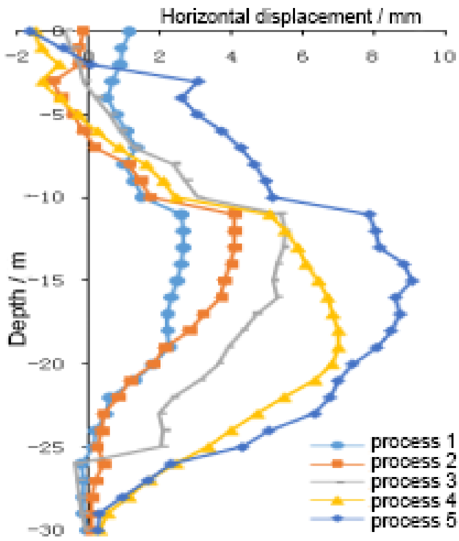


Fig. 4 Horizontal deformation of ZQT7 pile

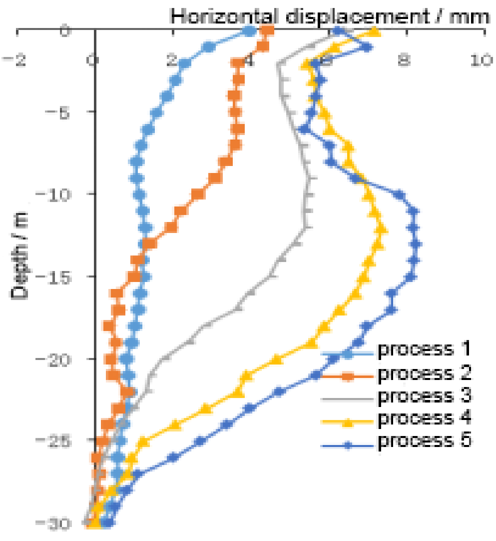
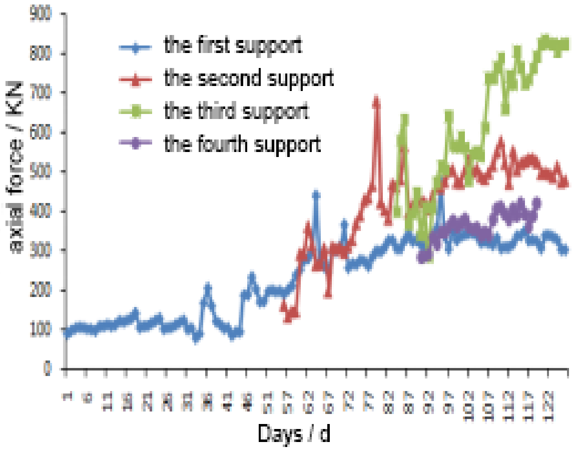


Fig. 5 Horizontal deformation of ZQT9 pile

As can be seen from Fig. 2 to Fig. 5,in process 1,the pile horizontal displacement curve of each inclinometer is relatively uniform, and the displacement of the ZQT9 hole is relatively large, which is about 3.82mm,the horizontal displacement of other holes is basically 0.5~2.5mm.The vertical elevation corresponding to the maximum displacement of each inclining hole shown in the figure appears at the 0m elevation of ZQT9 hole.In process 2,the displacement of each inclinometer hole increases rapidly. Among them, the ZQT5 inclinometer has the fastest growth rate, which increases by about 2.3mm. At this stage, the ZQT5, ZQT7, and ZQT9 hole displacements all reach 3.5mm, and the ZQT3 hole displacement is about 2mm,which is relatively slow.In process 3,at this stage, the horizontal displacement continues to increase, the ZQT5, ZQT9 hole displacement reaches 5mm, and the other hole horizontal displacement is within 4.5mm.In process 4,the ZQT5, ZQT7, and ZQT9 holes have a large horizontal displacement, the ZQT3 hole has a relatively slow angular displacement, and the ZQT9 hole has the largest displacement of 7.37mm. The maximum displacement occurs in the middle of the pit excavation..In process 5,the displacements of the inclinometer bores vary greatly, the displacement of the ZQT57 bore increases by about 3 mm, and the horizontal displacement of other bores increases by about 1 to 3 mm. At the final excavation, the ZQT1, ZQT5, ZQT9 hole horizontal displacement will have a slight increase, ZQT7 hole horizontal displacement has a larger increase. The horizontal displacement curve of each inclinometer tube shows a parabolic shape at the end of the final excavation.

5.2 Axial Support Force

Analyzing the monitoring data of supporting axial force not only can understand whether the support structure is safe and stable, but also can judge the force behavior of the support structure, and provide necessary basis for the design optimization and improvement of the follow-up support.(Zhang X T 2014)This article selects the ZCL10-1 and ZCL10-2 two supporting monitoring sections. The following figure shows the changes of the supporting axial force over time.



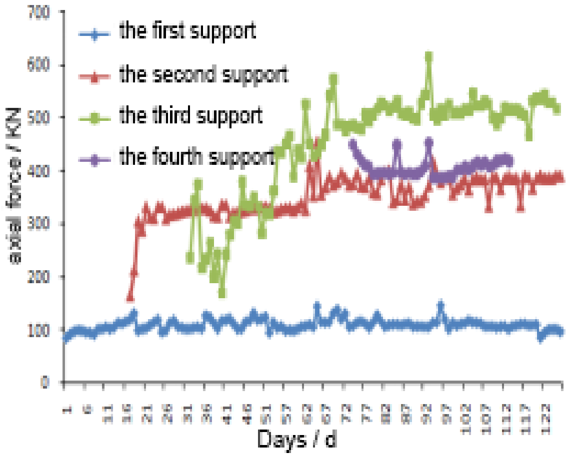


Fig. 6 ZCL10-1 axial force curve

Fig. 7 ZCL10-3 axial force curve

Fig. 6 to Fig. 7 show the variation of the axial support force of each support with the excavation time of the foundation pit.The support of the ZCL10-1 and ZCL10-2 cross section is 18.3m diagonally supported by the steel pipe,the support of the ZCL10-1 section is 21.3m steel straight support, and the support of the ZCL1-4 section is 21.3m steel straight support,these four supports are all steel support.For the first support, the axial force of each support member increases during the second excavation;When the third excavation is carried out, the axial forces of the first and second supports will have a fluctuating increase.In the fourth excavation, the axial forces of the support increase significantly;In the fifth excavation, the axial forces of the support increase slightly; the axial force of the second supporting ZCL10-1 is the largest, reaching 680.91 KN.For the third support, from the fourth to the fifth excavation, the axial forces of the support still change greatly, and after the bottom plate is poured, the axial forces of the support gradually decays and tends to stabilize.In the third support, Zl10-1 has the largest axial force, reaching 971.93 KN.For the fourth support,during the fifth excavation, the axial support forces slightly increase and then stabilized. The ZCL10-2 has the largest axial force, reaching 1023.66 KN.In the fifth support, the ZCL10-1 has the largest axial force, reaching 271.51 KN. During the fifth excavation, the axial forces of the fifth support change little and are relatively stable compared to other supports.

5.3 Ground Settlement

The surrounding ground settlement can not only reflect the influence of the excavation of the foundation pit on the surrounding environment, but also serve as an important indicator of the safety of the foundation pit.(Yang B 2013)The following figure shows the seven ground settlement points on the monitoring section of the foundation pit. During the actual construction process, the outermost monitoring point is covered by steel and cannot be monitored. Only six monitoring points can be monitored.

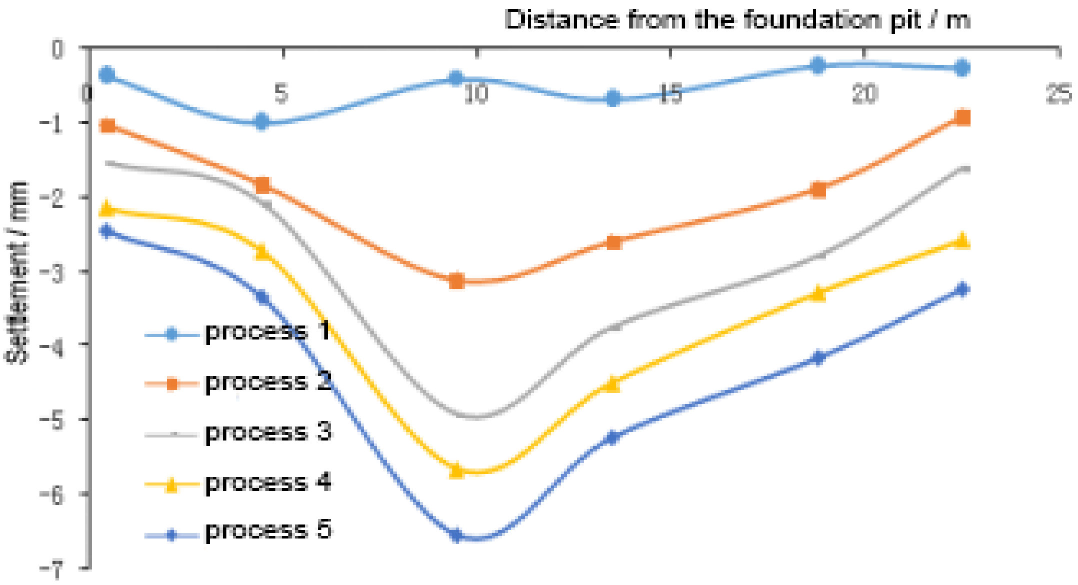


Fig. 8 Ground settlement monitoring curve

It can be seen from Fig. 8 that the deformation trend of the ground settlement curve continuously decreases as the excavation depth of the foundation pit increases.In process 1,the ground surface settlement outside the pit is not obvious, the maximum settlement is -0.99mm, and it appears at the outer edge of the pit 4m.In process 2,the ground settlement is more obvious than that in process 1. Near the pit, the ground settlement curve moves downwards as a whole. The maximum settlement is -3.12mm, and the abscissa with the largest settlement is 10m away from the pit.In process 3,the maximum settlement has a large increase of -4.92mm.In process 3 to process 5,the ground settlement curve continued to sink, and the ground settlement curve eventually stabilized at -6.53mm.During the excavation of the foundation pit, the nearest point near the pit is continuously sinking, but the settlement is stable, and the maximum settlement occurs at a distance of 10m from the pit.

5.4 Building Settlement

The settlement of the building directly reflects the influence of the deformation of the foundation pit on the surrounding buildings, and it is an item that must be measured in the monitoring.(Li B 2016)A total of 3 vertical settlement points are laid out for the settlement of buildings, all located on the east side of the foundation pit.The following figure shows the trend of the three settlement points of the building with the excavation of the foundation pit, in which the negative value represents the downward settlement of the building.

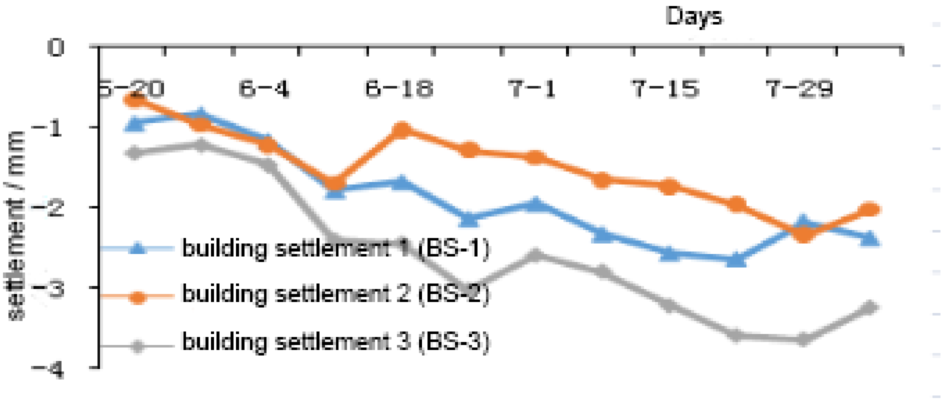


Fig. 9 Building settlement monitoring deformation curve

As can be seen from Fig. 9:In the constant construction of foundation pits, the monitoring points of various buildings are continuously sinking over time.During the subsidence of the building, the envelope structure was affected to the inside of the pit. However, from the figure above, the maximum point BS-3 of the settlement was found to be -3.58 mm, which is much smaller than the warning value.With the settlement of the building, the envelope structure was affected and tilted to the inside of the pit, but from the figure above, the maximum point BS-3 of the settlement was found to be -3.58 mm, which is much smaller than the warning value.The overall trend of BS-1 shows a downward settlement,during the construction process, there is also a small fluctuation in the settlement of BS-1, with a small increase in settlement, and the maximum settlement is -2.63mm.The change trend of BS-2 was first sinking, rising on June 11 and then generally showing a decline, with a maximum settlement of -2.34 mm.The accumulated settlement of BS-3 is always the largest of the three, and there is fluctuation in the subsequent construction.,the cumulative maximum value is -3.58mm.Building settlement can directly reflect the impact of excavation of the foundation pit on the surrounding environment. In the process of excavation of the foundation pit at this station, excavation of the foundation pit has little impact on the safety of the building, and the building is always in a safe state.

6. CONCLUSIONS

By analyzing the data of horizontal displacement, axial support force, ground settlement, and building settlement of piles, the following conclusions are obtained:
(1) As the excavation depth increases, the maximum displacement of the pile and the corresponding vertical elevation will gradually move downward.When the foundation pit is excavated to the base, the horizontal displacement of the pile reaches a maximum value, and it generally shows The shape of the parabola, the corresponding elevation appears in the lower part of the pit excavation.

(2) The axial force of the support is affected by changes in temperature and weather. During the construction of the rainy season, the axial force of the support will increase significantly; applying pre-stress to the support can reduce the horizontal displacement of the pile; the maximum value of the axial force of the support appears on the third support and coincides with the maximum displacement position of the pile body.
(3) ground settlement is an auxiliary indicator for monitoring of foundation pits. The effect of excavation process on the surrounding environment can be seen from the ground settlement curve. Especially when there are buildings in the surrounding area; the building is continuously sinking as the foundation pit excavates, and the maximum value of accumulated settlement meets the specifications and design requirements.

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