Monitoring and Analysis of Ultra-wide and Deep Foundation Pit Deformation in Complex Environment

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Abstract: Taking the deep foundation pit of Foshan Zongde Service Center as the research background, the on-site monitoring data of the deep horizontal displacement, supporting axial force, horizontal displacement of the wall and the settlement of the column pile during the excavation process of the deep foundation pit are analyzed. The results show that during the excavation process of the deep foundation pit, the envelope structure is basically not affected by the excavation of the soil within the pit after the excavation surface is less than 10m; the reasonable arrangement of the support position can effectively reduce the displacement amplitude of the wall body; encryption monitors the change of the axial force of the adjacent support, and prestresses the upper support to improve the safety of the foundation pit; the greater the depth of the foundation pit is, the uplift of the column under the combined action of the pile side frictional resistance and the support of ballast and self-weight - sedimentation rate. The larger the amount of change is, the more the ballast is applied to the support when the support is poured, the amount of rebound of the column is reduced, and the continuous excavation of the earth can be effectively reduced to reduce the peak of the column uplift and prevent the column from being unstable due to the large difference between the settlement and the uplift. Endanger the safety of the support system in the pit.

1. Introduction

The construction of large-area deep foundation pit is a high-risk construction project with the characteristics of complex construction and many unpredictable factors. It is particularly important to strengthen the monitoring of deep foundation pit. With the acceleration of urbanization process, there are more and more large-scale deep foundation pit excavations and support projects, and foundation pit projects are often adjacent to buildings and underground pipelines. In order to ensure the safety of surrounding buildings, underground pipelines and trunk lines, foundation pit excavation will cause horizontal and vertical deformation of the retaining structure, resulting in changes in the surrounding environment. In order to ensure the safety of construction and further improve the construction technology, the whole process of construction is monitored, and the stability of excavation and support of deep foundation pit is evaluated from different angles. According to the analysis of actual monitoring data, the safety status of foundation pit is monitored, which provides a basis for the smooth implementation of this project.

Combinied with the deep foundation pit project of Foshan Zongde Service Center, this paper analyses the monitoring data, studies the variation law of horizontal deformation, column settlement and support
2. Engineering survey

2.1 Engineering Brief
Foshan Zongde Service Center is located in Foshan Sino-German Industrial Service Zone, with a total floor area of more than 320,000 square meters. The project consists of high-end foreign-related super-A office building, hotel-style international apartment and German style commercial street. Another 3-storey underground building with a total area of about 72,000 square meters connects the three buildings above ground to achieve full three-dimensional access.

Three towers with a maximum of 56 stories and three basements will be built on the site. Pile foundations will be adopted for the foundation. The basement floor elevation is -10.80m, the foundation pit elevation is -12.00m, the construction road around the site before foundation pit excavation will be leveled to 5.60m, and the design depth of foundation pit excavation is 17.60m. The foundation pit of this project is roughly strip-shaped, with the maximum size of 360 m in the North-South direction, 80 m in the east-west direction and 880 m in the circumference. The section of the foundation pit is shown in Figure 1.

The deep foundation pit is constructed with inner support and diaphragm wall, i.e. side support and side excavation, which can effectively reduce the deformation of foundation pit and surface cracking and settlement, and ensure the safety of surrounding buildings and underground pipeline network. The construction conditions of the end of the foundation pit are shown in Table 1.

2.2 Geological condition
The geomorphic unit of the site is the alluvial plain geomorphic unit of the Pearl River Delta. The site is cultivated land and banana land. Some of the sites have been filled and the subway crossing the site is under construction. The physical and mechanical indexes of each soil layer are shown in Table 2.

2.3 Hydrological conditions
Groundwater in the site mainly consists of upper phreatic water and bedrock fissure water. The silty sand, fine silt, medium-coarse sand and gravel sand in the site are aquifers. During the survey period, the groundwater depth ranged from 2.00m to 4.70m. The groundwater in the site is mainly porous groundwater in the Quaternary alluvial sand layer, followed by fissure water in the bedrock fissure zone. Sand layers are widely distributed and groundwater is abundant. The recharge of groundwater is mainly vertical recharge of atmospheric precipitation and lateral recharge of surface runoff. The stable groundwater level measured during the survey is 2.00m~4.70m, with an average of 3.27m. The variation of groundwater level has little effect on seasonal variation. Groundwater in site is mainly surface water, pore water in sand layer and fissure water in fissure zone of bedrock.

2.4 Surrounding environment
The project site is located in the south of Tianhong Road, east of Baihe Road, north of Yuhe Road and west of Yongxing Road in Foshan New Town. Cement pavement leads to the proposed site, which is convenient for traffic. The surrounding environment of the site is more complex, with villages in the East and houses still to be demolished in the village. The west side is close to the planning and design of Lily Road section, Lily Road as a temporary site for only one year, and the west side of Lily Road is planning to start construction plots. There is a subway construction site in the south, and the diaphragm wall of this project is only 14.2m away from the diaphragm wall of the subway. The existing end of Tianhong Road crosses the site on the North side, which needs to dismantle the road surface and migrate pipelines. The foundation pit on the north side is close to the planning and design of Tianhong Road Section. In the middle of the foundation pit, a river runs through the foundation pit from east to west, and there are still parts to be demolished and leveled. In the Southeast corner, there are fish ponds and
shacks.

2.5 Foundation pit plane and measuring point arrangement
Considering the factors such as super-deep excavation, complex geological conditions and the importance of adjacent subway stations under construction, the monitoring grade of will lead to serious consequences and foundation pit is one-level. The layout of monitoring points in foundation pit construction site is shown in Fig. 2.

3. Monitoring results and analysis

3.1 Monitoring and Analysis of Deep Horizontal Displacement of Ground-connected Wall
With the excavation of foundation pit by stages and layers, the release of earth pressure caused by excavation unloading makes the displacement change of supporting structure very complicated. Fig. 3 is a curve of horizontal displacement of wall with the depth and time of excavation of foundation pit, and the displacement of wall is positive to the pit.

Figure 3 (a) shows that there is no obvious horizontal displacement of diaphragm wall when it is excavated to 2.5m from the first support. With the increase of excavation depth, the lateral water and soil pressure on the wall increases, and the displacement along the excavation depth increases gradually. When the foundation pit is excavated to 6.3m, the displacement in the middle of the wall increases obviously, and the displacement at the excavation site is the largest. The horizontal displacement of the soil is larger than 10 meters below the excavation site. Under the action of water and soil pressure on both sides, the displacement of the wall below the excavation surface decreases gradually along the depth direction. When the foundation pit is excavated to 10.5m, the horizontal displacement of the top of the wall increases suddenly, and the overall displacement of the wall increases. The change trend is similar to that of the previous excavation. Because of the existence of end restraint and the effect of water and soil pressure on both sides of the wall below the foundation, the horizontal displacement of the top and the bottom of the wall changes slightly. With the excavation of the foundation pit to the bottom of the pit, the lateral water and soil pressure on the wall reaches the maximum. The displacement along the excavation depth reaches the maximum, and the maximum displacement of the wall occurs at the depth of 11m.

It can be seen from the graph that the maximum displacement occurs near the excavation face during the excavation of foundation pit. Finally, the displacement curve of the wall shows the phenomenon of large in the middle and small at both ends.

From figs. 3 (b), (c), it is also known that when shallow excavation of foundation pit is carried out, the increase rate of wall displacement along depth direction is small, and the maximum displacement of wall appears below the excavation surface; with the increase of excavation depth, the displacement of whole wall increases obviously, and the increase rate of displacement increases, reaching the maximum near the maximum displacement; and in figs. 3 (b), (c), the maximum displacement of wall appears. The two sides of the support position show that the existence of the support weakens the peak displacement of the wall, and the retaining structure is basically not affected by the excavation of the soil in the pit below 10m of the excavation surface.

During the excavation of the foundation pit, the wall body will be displaced laterally under the excavation face, and the rate of increase above the excavation face will be slower. The displacement of the soil below the excavation face will decrease at a higher rate in the depth direction. The depth increases and increases; the horizontal displacement of the wall gradually increases with the depth of the excavation, and the maximum horizontal displacement position also gradually moves downward.

3.2 Axial Force Monitoring of Foundation Pit Support
In the first stage of construction, the excavation depth of foundation pit is shallower, the earth pressure behind the wall is smaller, and the increase of the axial force of the first support is slower, basically showing a slow growth. When the second supporting concrete is loaded, the axial force of the first
supporting layer decreases, which indicates that the setting of the second supporting layer bears part of the earth pressure of the upper soil, thus reducing the pressure of the first supporting layer. With the increase of excavation depth, the axial force of the second supporting layer increases. Due to the use of mechanized construction in the whole excavation process, the construction progress is faster. After the third support is completed, the axial force of the second support tends to rise smoothly, and the axial force of the first support decreases as a whole. The earth pressure behind the wall is mainly borne by the second and third support. When excavated to the bottom of the foundation pit, the axial force of the third support reaches its maximum and tends to be gentle, while the axial force of the first and second support decreases slightly. With the completion of the pouring of the foundation floor concrete, the axial force of each support decreases.

It can also be seen from Figure 4 that after the removal of the third support, the earth pressure outside the pit is mainly borne by the second support, and the axial force of the first support increases rapidly without obvious change. When the second support is removed, the axial force of the first support decreases gradually. In the whole process of foundation pit construction, the spacing of support in the middle of foundation pit is adjusted, which makes the second and third supports bear most of the earth pressure, more effectively exerts the effect of materials, and controls the deformation of supporting piles; monitors the change of the adjacent support axial force before dismantling the support, and prestresses the upper support, so as to prevent serious support damage caused by excessive support force. Consequently, improve the safety of foundation pit.

3.3 Horizontal Displacement Monitoring of Foundation Pit Wall Top
The whole foundation pit excavation works are carried out from south to north. The southern end is first excavated to the bottom of the pit. Six measuring points are selected for analysis. The horizontal displacement of the top of the wall under different working conditions is shown in the figure. The positive number in the figure indicates that the top of the wall moves into the foundation pit.

Fig. 5 (a) shows that the top crown beam of the foundation pit wall moves towards the pit due to the release of water and soil pressure in the initial excavation stage, and the horizontal displacement of the top of the wall increases slowly due to the restriction of support; because the southern end is first excavated, C6 is less affected by the adjacent soil excavation, and the horizontal displacement is very small at the initial excavation stage of C2 and C4 ends. The displacement of the top wall increases slowly due to the effect of support restriction and end restraint. After 14 weeks of excavation, the excavation depth increases gradually, and the stress of the soil at the bottom of the pit releases continuously. The earth pressure behind the wall at C4 is much greater than that behind the wall at C2. Because C2 and C4 are at both ends of the end oblique support, C4 moves gradually into the pit, while C2 moves out of the pit. It can effectively reduce the increase rate of the displacement of the long side wall at the end, reduce the displacement of the top of the short side wall, and improve the stability of the foundation pit. Therefore, prestressing the support can effectively reduce the displacement of the top of the wall and the settlement of the ground and buildings around the foundation pit.

When excavation takes 23 weeks, excavation begins at C6 and super deep excavation is carried out at C2 and C4 ends, the horizontal displacement of the top of the wall increases rapidly. With the increase of excavation depth, the displacement of the top of the wall increases gradually. When the foundation pit is excavated to the bottom of the pit, the horizontal displacement of the top of C4 and C6 walls tends to be stable, and the soil behind the stabilized wall moves into the pit and unloads under the action of short-term construction materials and large-scale machinery. After loading, it returns to its original stable position. The soil behind the C2 wall continues to move into the pit under the action of material surcharge and heavy machinery for a long time, which increases the horizontal displacement of the short end.

As shown in Fig. 5 (b), in the initial excavation, the horizontal displacement rate of the top of the wall to the pit is relatively high because there is no support or support has not played a role; when the support plays a role, it hinders the displacement of the top of the wall and slows down the movement rate to the pit; after excavation for about 21 weeks, the displacement of C9 reaches its maximum, the
excavation face is near the bottom of the pit, and the excavation of C9 places is locally super-deep, resulting in large soil pressure on the side of the wall. When C10 and C11 are excavated locally, the wall moves rapidly into the pit, and C10 and C11 move out of the pit in the opposite direction because of the support restriction; when excavated to C10 and C11, the displacement of the top of the wall increases rapidly; therefore, in large-scale and ultra-wide foundation pit engineering, the displacement of the top of the wall should be the same from the middle of the pit to both sides. When excavating, it can prevent the displacement of the top of the wall from abruptly changing, which will affect the safety of the foundation pit.

3.4 Settlement Monitoring of Pillars in Foundation Pit

Settlement analysis is carried out at three measuring points at the north end and the middle of the foundation pit. Figure 6(a) shows that unloading of soil during foundation pit excavation causes soil rebound and uplift in the pit. Pile piles are moved upward by the upward frictional resistance of soil at the side of the pile. The initial excavation depth is shallow and the uplift of the pillar is small. When the first support is erected, the pillar piles bear the gravity load and self-weight of the support. Settlement is small because of friction; with the increase of foundation pit excavation depth, column piles show upward uplift displacement, while the support of the erection makes column piles more loaded, resulting in settlement displacement, and with the number of support, the settlement of column piles increases; when the third support is erected, the settlement of column reaches the maximum; when the foundation pit is excavated to the bottom of the pit, the settlement of column piles reaches the maximum. Soil stress release is very large, the column quickly uplifts upward, until the bottom of the pit is poured, the column uplift tends to be stable, and the column settlement-uplift ends. During the whole excavation-support process of foundation pit, the uplift and settlement alternately change under the combined action of self-weight, supporting load and side friction.

As shown in Fig. 6 (b), the change trend of the middle pillar of foundation pit with the excavation of foundation pit is similar to that of the end pillar; compared with (a), the "amount" and "difference" of the uplift-settlement of the middle pillar of foundation pit are larger than that of the end pillar; due to the excavation of earthwork at LZ15, the settlement of the soil around LZ15 under large mechanical ballast makes LZ15 subjected to downward frictional resistance, and then due to the opening of the pillar. The excavation began to uplift, and LZ15 reached its peak value earlier than the others.

In the 30th week, due to weather and other factors, the excavation of foundation pit was stopped for a period of time. The column settled under self-weight and supporting ballast. After the 32nd week, the construction resumed. In the 34th week, the third support began to be erected. Therefore, the pillar uplift did not reach the maximum peak due to the stoppage, and similar situation occurred around the 13th week.

Therefore, the greater the excavation depth of the foundation pit, the greater the stress release of the soil in the pit, the higher the uplift rate of the pillar and the larger the uplift amount of the pillar; therefore, in the process of ultra-deep excavation of the foundation pit, the settlement-uplift change of the pillar is closely monitored to prevent the instability of the pillar caused by the large difference of settlement-uplift, which endangers the stability of the supporting system in the foundation pit; reducing the continuous excavation earth can effectively reduce the uplift of the pillar. Peak value.

4. Conclusion

1) During the excavation of deep foundation pit, the enclosure structure is not affected by the excavation of soil in the pit when the excavation surface is less than 10m. During the excavation of ultra-deep foundation pit, the number of supports should be increased near the bottom of the pit, and the floor should be poured in time after the excavation, so as to reduce the large displacement of the retaining structure near the bottom of the pit under the water and soil pressure, and to arrange the support position reasonably, which can effectively reduce the displacement and deformation amplitude of the wall.

2) In the whole process of foundation pit construction, the earth pressure in the middle and lower part of the foundation pit is the largest, so the support should be reasonably arranged to bear most of the
earth pressure on the second and third layers of the support, so as to play a more effective role of materials and control the deformation of the support structure; the change of the adjacent support axial force should be monitored before the dismantling of the support, and the prestressing force should be applied on the upper support to prevent the support from breaking due to the excessive support. The bad will lead to serious consequences and improve the safety of foundation pit.

3) Therefore, in practical engineering, the material stacking around the foundation pit and the residence time of large-scale construction machinery should be reduced as far as possible. In local ultra-deep excavation, the monitoring frequency of the displacement of the top of the foundation pit wall should be increased to prevent the excessive displacement of the top of the wall from affecting the safety of the foundation pit.

4) The greater the excavation depth of foundation pit is, the greater the stress release of soil in the pit is, the faster the upheaval rate of the pillar is, and the larger the upheaval of the pillar is. Therefore, in the process of the excavation of the foundation pit, the settlement-uplift change of the pillar is monitored by infilling. When the support is completed, a certain amount of ballast is applied on the support to reduce the rebound of the pillar, and the continuous excavation earth can effectively reduce the peak of the upheaval of the pillar and prevent the cause. The large difference between settlement and uplift results in the instability of the column and endangers the safety of the supporting system in the foundation pit.

Figure 1. Sectional view of the foundation pit (unit: m)

Table 1. Construction conditions

| Working date (2015) | Construction contents                                      |
|---------------------|-----------------------------------------------------------|
| 1  06-09            | Foundation pit excavation 2.3m, erecting the first support|
| 2  07-11            | Foundation pit excavation 4.5 m with second support      |
| Striatigraphic code | Layer number | Geotechnical property | Compression modulus Es (MPa) | Natural severity $\gamma$ (KMN/m$^3$) | Cohesion C (KPa) | Internal friction angle $\Phi$ (°) |
|---------------------|--------------|-----------------------|-----------------------------|---------------------------------|----------------|-------------------------------|
| $Q_{ml}$            | ①           | Prime fill            | 1.8                         | 18.0                            | 6              | 6                             |
|                     | ②③          | Medium sand           | 4.0                         | 18.0                            | 0              | 25.0                          |
|                     | ②④          | Coarse sand           | 6.0                         | 18.5                            | 0              | 31.0                          |
| $Q_{al}$            | ③①          | Muddy Siltstone       | 8.0                         | 20.0                            | 43             | 22.0                          |
|                     | ③②          |                       | /                           | 22.0                            | 0.6            | 32.0                          |

Figure 2. Measured curve of horizontal displacement of shaft X1 of underground continuous wall with depth and time
Figure 3. Axial force-time curve of steel support in the middle of foundation pit

Figure 4. Horizontal displacement of the ground wall with depth versus time
Figure 5. Horizontal displacement-time curve of the wall crown beam measurement point

Figure 6. Settlement-time curve of foundation pit column

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