Analysis of Super-large Deep Foundation Pit Support and Monitoring Results in Sewage Plant

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Abstract. In order to study the effect of construction sequence of anchor cable on the stability of deep foundation pit**,** Taking the ultra-large deep foundation pit project of Zhong you-fang Sewage Treatment Plant in Hefei City as the background, based on the geological and surrounding environmental conditions and the foundation pit support plan, the supporting structure and surrounding environment during the foundation pit excavation process were monitored and analyzed. The results show that the super-large deep foundation pit support structure has obvious spatial effects. The greater the excavation depth, the more obvious the spatial effect. As the construction proceeds, the axial force of the anchor cables of each layer gradually increases, among which the axial force of the anchor cables of the first layer increases. The force is generally greater than the axial force of the anchor cables on the second and third layers. The average axial force of the anchor cables on the first layer is 6.7kN, which is 67.3% of the design value. Since the axial force of the anchor cables on the second and third layers is not fully utilized, In addition, if water leakage or sand leakage occurs during the construction process, emergency dewatering measures outside the pit must be taken. Although the normal construction of the anchor cables can be ensured, it will have a serious impact on the roads surrounding the foundation pit. During the dewatering period, the maximum settlement of the road outside the pit reached 8mm, accounting for 10% of the total. 86.2% of settlement. The research results can provide reference for similar foundation pit anchor cable construction.

Keywords: deep foundation pit; anchor cable axial force; surface settlement; foundation pit monitoring.

1 Introduction

With the rapid progress of economic development and urbanization construction, the sewage volume in the Ershibu River Basin is gradually increasing. The Zhu zhuanjing Sewage Treatment Plant in the Ershibu River Sewage Treatment System has been running at full capacity and cannot meet the needs of urban development for infrastructure construction [1-2], which has become a bottleneck restricting urban devel-

P. Xiang et al. (eds.), *Proceedings of the 2023 5th International Conference on Hydraulic, Civil and Construction Engineering (HCCE 2023)*, Atlantis Highlights in Engineering 26,
https://doi.org/10.2991/978-94-6463-398-6_37

opment. The completion of Zhong youfang Sewage Treatment Plant will comprehensively boost the water quality of the 20 Bu River, improve the surrounding ecological environment, and do a good job in supporting the construction of the new center in the east of Hefei City.

In recent years, scholars at home and abroad have conducted a lot of research on the ring internal bracing structure system, and accumulated a lot of practical engineering experience [3-15]. Ring beam bracing in deep foundation pit engineering design of internal bracing is more and more widely used. Jun-feng jiang et al.[3] by a set of ring beam support of deep foundation pit as the engineering background, the deep foundation pit supporting structure of the overall mechanical performance of the related problems are studied, the results show that the ring beam has a good effect on foundation pit supporting effect, foundation pit in the column will also be set up to support and pile constraints; Wang Zhanpeng [4] combined with a deep and large foundation pit engineering, such as the use of the force of the ring inside the support structure of numerical calculation and analysis, the results of the study on the section size design and reinforcement of internal support components have a guiding role; Peng Quanmin et al.[5] on the basis of the space bar element coordination model to build the theory of the effect of temperature on the inner support structure, using ANSYS software to simulate the variable temperature conditions, the support structure caused by thermal strain analysis, in order to clear the support structure with the temperature change and presents the linear change rule; Chun-yan wang et al.[6] integration of the ring beam supporting structure system of horizontal stiffness analytical formula, and on the basis of the correction, through the finite element method of empirical research has been clear about the wide applicability of the analytical formula, means that the formula can play a guiding role in the design of the ring beam supporting structure system; Li Song et al.[7], through numerical simulation of the construction process of a deep foundation pit supported by a ring beam, put forward that the process of soil excavation will lead to the displacement rebound effect of underground diaphragm wall. Through the analysis of the numerical simulation results and the field measured data, it is concluded that the displacement rebound effect of underground diaphragm wall will gradually increase with the excavation of foundation pit; Gong Xin et al.[8] put forward the setting principle of ring beam support in deep and large foundation pit by combining with the plane frame calculation of stress deformation value of retaining structure, providing ideas for similar projects; the research content of Chen Zhiping and Huang Xuelong [9] is to study the influence of earthwork excavation sequence of foundation pit on displacement of supporting system, and analyze the disturbance of surrounding environment and deformation of retaining structure by simulating different construction conditions, providing reference for optimizing foundation pit design scheme; Deng Liuyong [10] on the basis of the existing calculation method of ring beam supporting structure, put forward the application of prestressed anchor cable in the ring beam supporting system, and the finite element analysis, in order to clear the positive role of anchor cable to reduce the horizontal displacement of pile. Wu Xichen [11] in wuhan, such as a large deep foundation pit supporting engineering, for example, to carry out the single circular strut and concentric circular ring support structure comparison analysis, the results show that the concentric circular ring support structure can effectively share the support axial force, can effectively control the excavation of wuhan Yangtze river tunnel and the surrounding building, content. Chen Kun et al.[12] took Tianjin City Binhai New District deep foundation pit project as the research background, compared and analyzed the supporting effect of ring beam and straight beam of deep foundation pit, and simulated and analyzed the influence of large-diameter ring beam supporting type on deep foundation pit excavation deformation under actual case by using finite element ABAQUS software, and compared with the influence of straight beam supporting deep foundation pit on surrounding environment. The results showed that large-diameter ring beam supporting system can better control the surrounding soil deformation caused by foundation pit excavation compared with straight beam supporting system. Jiang Jie et al [13] based on a deep foundation pit in NanNing City, the ring beam supporting structure in the case of structural optimization analysis. Using bar removal method, the numerical simulation of the failure of foundation pit supporting structure, and based on redundancy theory to determine the importance of failure bar, and ultimately get the optimized structure. Y.B.Hu et al.[14] studied the entropy-based method of BP-ARMA hybrid model in predicting the displacement of foundation pit ring beam in the application, the hybrid model in the accurate prediction of the displacement of foundation pit ring beam in the performance of good, and has practical reference significance. ZENGF-Y et al.[15] of Shanghai soft soil area of an adjacent two deep excavation at the same time, the supporting structure of the stress and deformation of the study, the analysis pointed out that the uniformity of support layout will affect the lateral deflection of diaphragm wall.

The above research results show that the application of ring bracing system in foundation pit support is very mature, but the influence of anchor cable construction sequence on the stability of foundation pit is less studied. On the basis of the above research, this paper takes the super-large deep foundation pit project of Zhongyoufang Sewage Treatment Plant in Hefei city as the background, designs the anchor cable construction scheme, monitors and analyzes the whole process of the anchor cable construction before and after construction, provides data reference for the construction process of the anchor cable, and studies the stress of the supporting structure and the deformation law of the surrounding environment during the excavation of the deep foundation pit. The design and selection requirements of supporting structure are discussed in order to provide some reference for similar foundation pit engineering support design and construction in this area.

2 Project background

The DBO project of Hefei Zhong you-fang sewage treatment plant project adopts whole-ground buried design, and the ground is landscape greening; the design treatment scale is 100000 cubic meters per day, and the tail water is discharged to the Shi bu River, with a total service area of 31.20km^2. Zhong you-fang sewage treatment plant site is located to the north of the planned Yao-gang Road, east of Barrier Road, west of Zhong you-fang Road, south of Shi bu River; Zhong you-fang sewage treatment plant is arranged as landscape green space on the ground.

This project is a fully buried sewage treatment plant with a large scale, which is quite different from the traditional sewage treatment plant design. The engineering design is more intensive. The water treatment structure, operating space, underground transportation and comprehensive pipelines are all concentrated in an underground box, buried underground, and the deep foundation pit is large in area and deep in depth. The foundation pit is a deep foundation pit engineering, the depth of the foundation pit is 14.1 to 17.2 m, and the maximum depth is 18m. The length of the foundation pit is 299.08m and the width is 97.7m. The excavation area is up to 28000m^2. The layout of foundation pit is shown in Figure 1.

Fig. 1. Layout of foundation pit.

3 Hydrogeological condition

According to the terrain, exposed strata and regional geological data, the microgeomorphology of the proposed site belongs to the Yibu River terrace.

The subsoil composition sequence of the proposed site is from top to bottom:

① Layer mixed fill (Qml) - layer thickness 1.2 ~ 4.7 meters, layer bottom elevation 13.32 ~ 16.27 meters. Brown gray, gray brown, brown yellow and other miscellaneous color, wet, loose to slightly dense state, mainly composed of cohesive soil, including broken brick, gravel, concrete block, concrete floor, domestic waste, construction waste, etc., partial with silt soil. It belongs to the soil with low consolidation and high compressibility.

② Layer of clay (Q3al+pl) - layer thickness 6.6 ~ 10.0 meters, layer bottom elevation 4.44 ~ 7.45 meters. Brown, brown yellow, grayish yellow, hard plastic to hard state, distributed all over the ground, containing kaolin, iron manganese oxide, iron manganese nodules, no shaking reaction, smooth section, high dry strength, high toughness. It belongs to medium low compressibility soil.

③Layer of silty clay (Q3al+pl) - layer thickness 11.3 ~ 15.9 meters, layer bottom elevation -8.79 ~ -5.75 meters. Gray, yellowish brown, grayish yellow, wet, plastic to hard plastic state, distributed all over the ground, containing kaolin, iron manganese oxides, iron manganese nodules, no shaking reaction, slightly coarse section, medium dry strength, medium toughness. It belongs to medium low compressibility soil.

④ Layer of silty clay with silt and silt (Q3al+pl) - layer thickness of 1.7 ~ 5.1 meters, layer bottom elevation of -12.79 ~ -17.75 meters. Yellow-brown, grayish yellow, grayish red, wet, plasticable to hard plastic state, distributed throughout the whole site, containing kaolin, ferrimanganous oxides, ferrimanganous nodules, etc. The layer is mainly composed of silty clay, and locally mixed with silt and silt, the sequence is relatively chaotic, and the soil quality changes are obvious. The whole site is dominated by silty clay. It is of medium compressibility.

⑤ Layer full blown sandy mudstone (K) - layer thickness of 1.5 ~ 5.0 meters, bottom elevation of -15.31 ~ -12.26 meters. Gray brown, black brown, brown red with gray white, wet, dense state, has weathered into hard plastic to hard state of clay or silty clay, sandy and granular gravel, containing argillaceous, quartz, mica and other minerals. It belongs to medium low compressibility soil.

⑥ Layer strong weathered sandy mudstone (K) - layer thickness of 1.9 ~ 4.1 meters, bottom elevation of -18.01 ~ -14.90 meters. Brown red, wet, dense state, the original rock weathered into fragments and sandy soil, weathered cracks developed, containing argillaceous, quartz, mica and other minerals. It belongs to low compressibility soil.

⑦ In the formation of wind-sandy mudstone (K) - this layer is not drilled, the maximum drilling thickness of 13.5 meters. Brown red, hard state, most of the area is sandy mudstone, local argillaceous siltstone, silty or argillaceous structure, thin to medium thick layer structure, argillaceous cement, the main mineral composition is feldspar, quartz and clay minerals, the rock is relatively broken, the rock quality index RQD is generally 65 ~ 75, belongs to the very soft rock, the basic quality grade of the rock is Class V. It is distributed throughout the site. According to the disclosure of this drilling, combined with the regional geological data and the engineering experience in this area, the layer is stable bedrock with large thickness, and no caves, free surfaces and weak interlayers are found in this layer.

Based on the analysis of the results of in-situ drilling, in-situ testing and indoor geotechnical tests, the soil layer distribution and main physical and mechanical indexes within the influence range of foundation pit excavation are shown in Table 1.

Table 1. Soil layer distribution and main physical and mechanical indexes

Geotechnical designation	bulk density(γ)/(kN•m^{-3})	cohesion(C)/kPa	internal friction angle (φ)/(°)
① layer of mixed fill	19.1	5	10.2
② Layer clay	18.8	22.2	11.5
③ Layer of silty clay	17.5	17	10.5

Geotechnical designation	bulk density(γ)/(kN•m^{-3})	cohesion(C)/kPa	internal friction angle (φ)/(°)
④ Layer of silty clay with silt and silt	17.7	17	10.9
⑤ layer of strong weathered sandy mudstone	18.8	7	28.8
⑥ layer of strong weathered sandy mudstone	19.1	6	29.0
⑦ in the formation of wind-sandy mudstone	21.2	5	29.9

4 Foundation pit support design scheme

4.1 Method for determining jacking sequence of multi-row jacking pipes

The excavation area of the foundation pit is large and the excavation depth is deep, so the project mainly considers the convenience and rapidness of construction, adopts the support scheme of pile row plus 3 high-pressure rotary jet prestressed anchor cables, reinforced concrete corner supports, and adopts the deep mixing pile in the passive area at the bottom of the foundation pit to strengthen the middle of the foundation pit [16].

This project uses cast-in pile + anchor cable in the north and the south of the deep foundation pit, and the support system of cast-in pile + Angle brace in the east and the west. The base is designed with prestressed reinforcement anchor for anti-floating. The diameter of the anchor rod is 200mm, and the prestressed threaded steel bar with an interpolated diameter of 1Φ30mm is placed in the center. The corner of the foundation pit adopts Φ1100@1300 type bored pile and a layer of reinforced concrete corner brace as the supporting structure.

In order to comprehensively understand the change of foundation pit stability after the completion of excavation and support, the change law of foundation pit is analyzed by selecting typical measuring points to provide safety guarantee for anchor cable construction. Eight measurement points of horizontal displacement at the top of the supporting structure were selected, namely WY01, WY02, WY03, WY04, WY05, GL01, GL02 and GL03. There are a total of 8 surface settlement measurement lines, each with 3 measurement points, and the outer distance along the foundation pit is 3m, 6m, and 9m in sequence. The ground connection wall side numbers are DB1-1~DB2-3, DB3-1~DB4-3, and the TRD wall side numbers are DB5-1~DB6-3, DB7-1~DB8-3. There are 8 vertical displacement monitoring points at the top of the supporting structure, namely WYC01, WYC02, WYC03, WYC04, WYC05, GLC01, GLC02 and GLC03. The foundation pit supporting structure and measuring point distribution are shown in Figure 2:

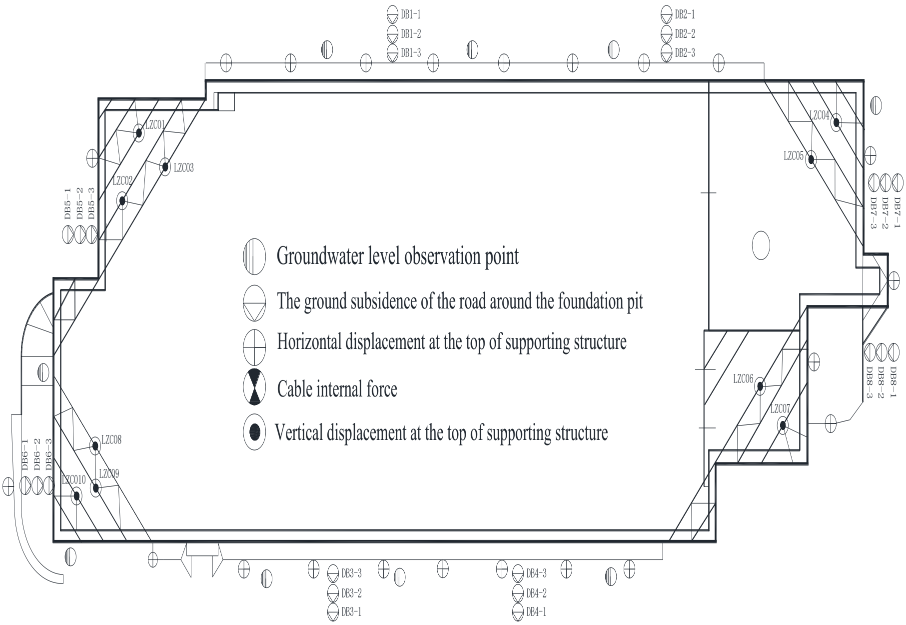


Fig. 2. Supporting structure of foundation pit and plane layout of monitoring points.

4.2 Water stop and precipitation design

In order to prevent the underground continuous wall from collapsing into a trough, the underground continuous wall is first set on both sides of the three-axis mixing pile Φ850×1800mm, a total of 905 pieces, of which the pile length is 20m earth facing surface and 18m pit facing surface, and the construction is based on the hopping type double-hole double-mixing connection. Unconfined compressive strength ≥1.0MPa, permeability coefficient ≤10-6cm/s, cement content 20%, water-cement ratio 1.5 at 28d age of triaxial mixing pile. After the reinforcement of the trough wall reaches the strength requirement, the ground connecting wall shall be constructed.

The ground connecting walls are of two types: 800mm and 1000mm. The wall lengths are 44.2m, 45.2m, 47.2m, 48.2m and 49.2m respectively. The whole steel cage is made with a maximum width of 6.2m and a length of 49.2m. Two high-pressure rotary jet piles with a diameter of 1000mm and a lap length of 500mm are set at the joint positions of each adjacent two ground connecting walls to ensure the water sealing effect at the joint positions. The ratio of cement slurry to cement is 0.8:1~1.5:1, and the shotcrete pressure is 28~30MPa.

4.3 Passive area reinforcement design

In order to improve the soil strength in the passive area and control the deformation of foundation pit, one row of Φ600@500 high-pressure single-pipe rotary jet piles and six rows of Φ850@1800 three-axis mixing piles are used to strengthen skirt edges within the construction plane of the anchor cable. The reinforcement length is about 280 m and the reinforcement depth is 7 m. The typical supporting structure profile is shown in Figure 3.

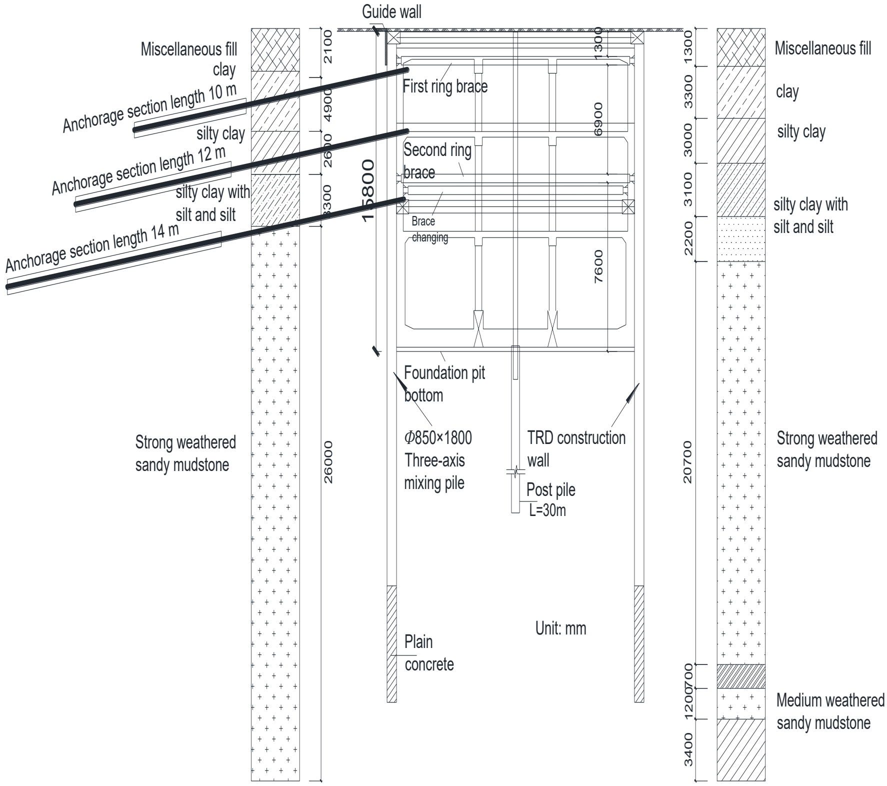


Fig. 3. Foundation pit support design

4.4 Earthwork excavation method

Considering the deformation control and construction efficiency, the excavation is divided into three construction areas. The soil around each layer is excavated first to provide construction work surface for the anchor cable. After the anchor cable is tensed and locked, the soil work in each area is excavated to the next layer of anchor cable construction work surface. In order to reduce the influence of the long side effect of the foundation pit, when the excavation of the south and north sides of the foundation pit reaches the working face of the anchor cable at the third layer (excavation depth 8.7m), after the construction of the anchor cable is completed and the tension is locked, the last layer of soil is excavated by jumping into the silo in the silo mode. After the excavation to the end, the concrete cushion and foundation plate are constructed first. Then excavate the adjacent section to reserve the soil platform and construct the remaining foundation plate.

5 Analysis of measured data

5.1 Horizontal displacement at the top of supporting structure

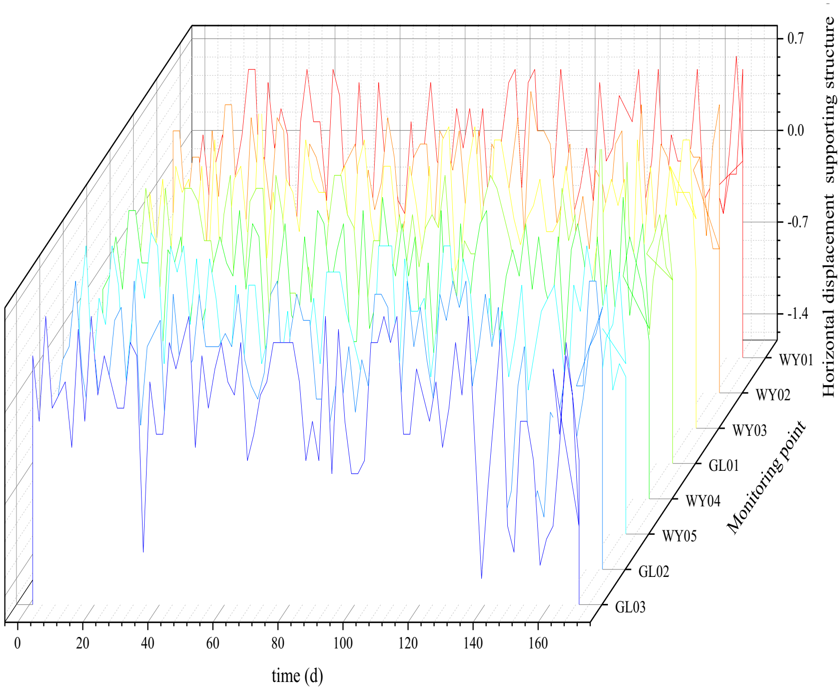


Fig. 4. Horizontal displacement curve of top of retaining pile

Figure 4 shows the horizontal displacement curve of the top of the supporting structure. It can be seen from Figure 4 that at the beginning of excavation, horizontal displacement increments of each pile top increase staggered, and there is no obvious spatial distribution feature. With the increase of excavation depth, the increment of horizontal displacement increases gradually. After the construction of foundation slab, the increment of horizontal displacement gradually becomes stable. The horizontal displacement increment before the Angle strut removal has obvious spatial distribution characteristics, both the long side and the short side show the characteristics of large middle part and small pit corner part. The closer to the pit corner, the smaller the horizontal displacement increment, among which the horizontal displacement increment of WY01 is 0.7mm and that of WY05 is 1.6mm. The average horizontal displacement increment of the long side is larger than that of the short side. According to the mechanism analysis of the spatial effect by Li Dapeng et al. [17], at the corner of the pit, due to the "shielding effect" of the soil arch effect, the earth pressure around the corner of the pit decreases, thus reducing the horizontal displacement of the supporting structure. This effect gradually weakens along the direction away from the corner of the pit.

5.2 Vertical displacement at the top of supporting structure

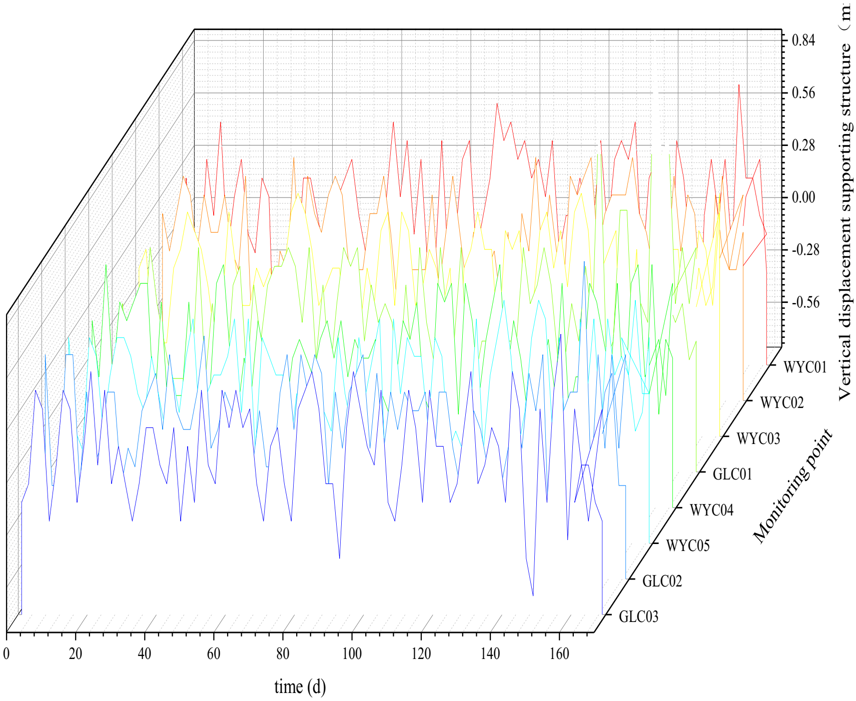
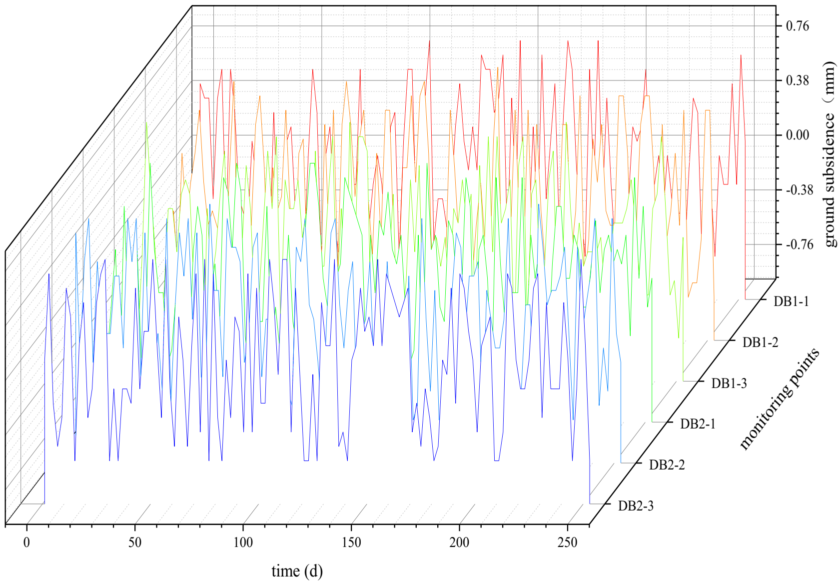


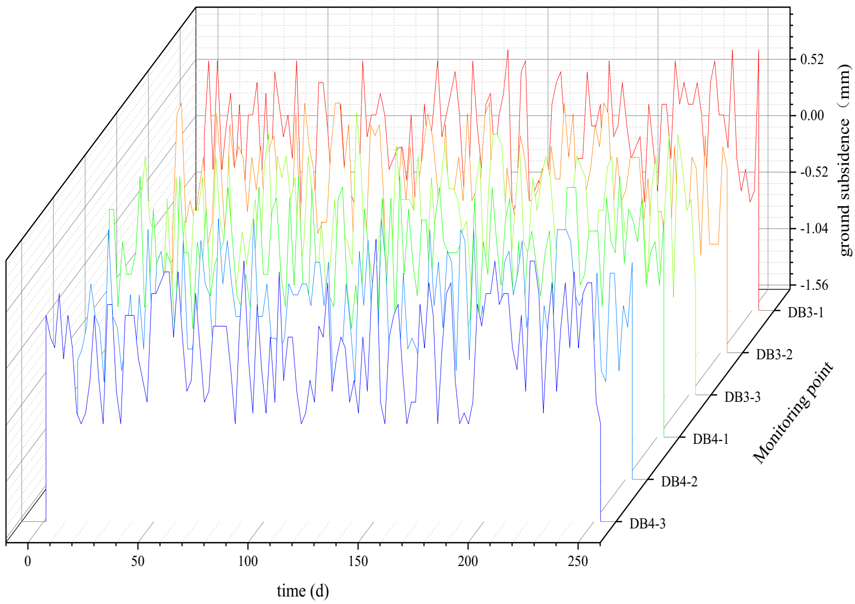
Fig. 5. Vertical displacement variation of pile top

Figure 5 shows the vertical change curve of the top of the supporting structure. As can be seen from Figure 5, the maximum vertical displacement of measuring point WYC01 during earthwork excavation increased by 0.74mm, but the maximum horizontal displacement increment during earthwork excavation of the first layer was smaller than that during earthwork excavation of the second layer. This was because the construction of the anchor cable caused water leakage and sand leakage in the foundation pit, so the dewatering measures outside the pit were taken. The water and earth pressure on the outside of the foundation pit is reduced, and the excavation method of separate silos is adopted, which is conducive to controlling the deformation of the foundation pit. The maximum horizontal displacement of the measuring point GLC02 increased by 0.64mm during earthwork excavation, because the water leakage and sand leakage on the north side of the foundation pit were less than those on the other three sides, and the precipitation range outside the pit was also small, so it had little influence on the deformation of the support structure on the north side.

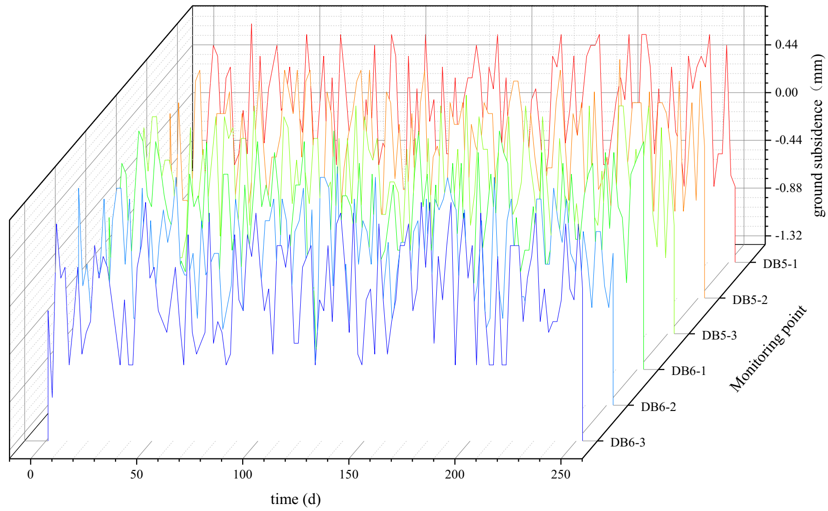
5.3 The ground subsidence of the road around the foundation pit



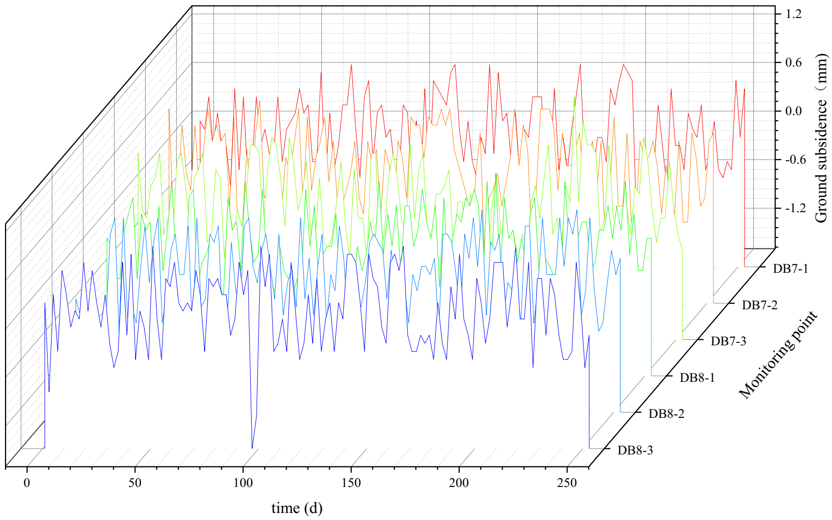
(a)DB1-1~DB2-3



(b)DB3-1~DB4-3



(c)DB5-1~DB6-3



(d)DB7-1~DB8-3

Fig. 6. Surface subsidence under different supporting schemes

Figure 6 shows the surface settlement change curve of the surrounding road. As can be seen from Figure 6, the soil around the foundation pit is mainly settled, and the surrounding soil settlement value slightly decreases compared with the surface settlement value at the end of excavation and support (the maximum value is 1.6mm), mainly due to the long time between the completion of anchor cable construction for each layer and the completion of foundation pit support. The maximum deformation of the foundation pit occurred about 6 m away from the foundation pit and did not exceed the alarm value. The surrounding soil settlement deformation decreases with the increase of the distance from the foundation pit, and the deformation value begins to gradually decrease at about 20m, and the influence range is about 1.5H (H is the depth of the foundation pit).

From the deformation data of measuring points DB1-1 ~ DB4-3 and DB5-1 ~ DB8-3, it can be seen that the vertical displacement of surface monitoring points caused by anchor cable construction has a small variation range, and the average value is about 0.3mm ~ 1mm. Taking the measuring point DB2-12 as an example, the soil vertical displacement changes caused by each step of unbracing are 0.5mm, 0.23mm, 0.52mm, 0.76mm and 0.42mm, accounting for 2.6%, 1.2%, 2.7%, 4% and 2.2% of the final values of the monitoring point.

5.4 Cable internal force

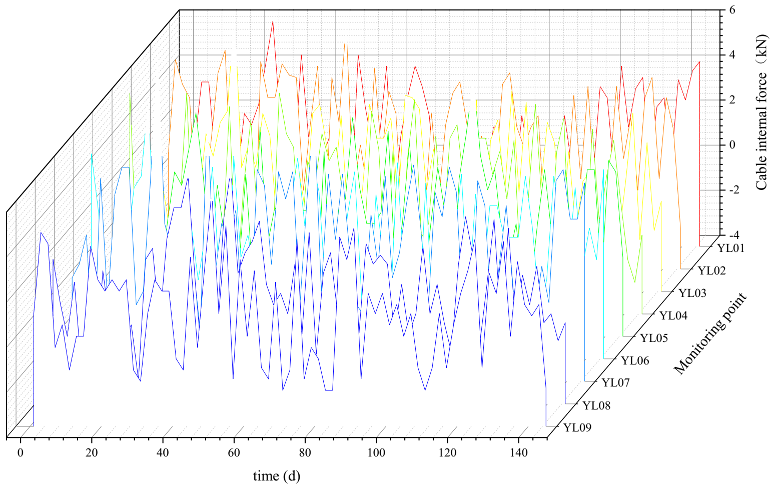


Fig. 7. Change curve of axial force supported by retaining pile

Figure 7 shows the change curve of anchor cable axial force. As can be seen from Figure 7, the axial force of the first layer anchor cable (YL01, YL02, YL03) is generally greater than that of the second layer anchor cable (YL04, YL05, YL06) and the third layer anchor cable (YL07, YL08, YL09), which is because during the construction of the first layer anchor cable, the foundation pit water leakage, sand leakage and precipitation outside the pit lead to the grouting of the anchor cable is not dense and the soil-cement forming is poor. The strength of anchor cable can not be fully utilized, and the water and earth pressure outside the foundation pit is reduced. Compared with the axial force of the second layer during the construction of the third layer, the axial force measured by the second layer anchor cable measurement point decreases to varying degrees, which is consistent with the variation law of the cable axial force obtained in literature analysis [18~22], that is, the application of prestress in the lower layer anchor cable will reduce the axial force of the upper layer anchor cable to a certain extent. The axial force of the anchor cable in the third layer generally changes in a small range, and with the completion of the floor pouring, the axial force of the anchor cable tends to be stable, indicating that the floor plays a key role in controlling the deformation of the foundation pit.

According to the statistical data of all measuring points during the monitoring period, it can be seen that the axial force variation range of the first layer anchor cable is -5.2 ~ 8.5kN, and the average value is 6.7kN, which is 67.3% of the design value. The axial force of the anchor cable in the second layer ranges from -5.8 to 7.5kN, and the average value is 3.8kN, which is 24.7% of the design value. The axial force of the anchor cable in the third layer ranges from -3.1 to 8.1kN, and the average value is 3.2kN, which is 23.1% of the design value. The monitoring results show that the maximum measured axial force of the first floor cable exceeds the design value, and the average measured value reaches 67.3% of the design value. The monitoring of the axial force of the first floor cable should be strengthened in the construction process to prevent the instability of foundation pit caused by excessive axial force.

6 Conclusions

(1) The deep foundation pit of Hefei sewage Treatment plant adopts the ground link wall +TRD construction wall as the enclosure structure, and sets three layers of anchor cable support along the enclosure ring of the foundation pit. The control effect of foundation pit supporting structure is good, and the deformation value is within the allowable range of design. Support pile uplift deformation, part of the envelope structure settlement; The soil in the deep part moves to the pit as a whole, and the maximum deformation is located at 2/3 of the depth of the foundation pit. The whole perimeter of the foundation pit is dominated by settlement, and some sections have uplift.

(2) Field monitoring data show that: During the construction of the second and third layers of anchor cables, the fluctuation range of pile top deformation, deep soil lateral deformation and surface settlement deformation caused by each step is very small, with a fluctuation range of about 0 ~ 4mm. However, due to water leakage, sand leakage and precipitation outside the pit, the anchor cable grouting is not dense, the cement soil forming is poor, and the strength of the anchor cable cannot be fully developed. As a result, the deformation fluctuation is obvious during the construction of the first layer anchor cable, and the monitoring should be strengthened.

(3) Although the precipitation outside the pit can ensure the normal construction of the anchor cable, effectively reduce the water and earth pressure outside the pit, and has an obvious effect on controlling the lateral deformation of the supporting structure of the foundation pit, it is easy to cause excessive settlement around the foundation pit, and should be used with caution under complex and sensitive surrounding environmental conditions. In addition, the horizontal displacement of the supporting structure in the middle of the foundation pit is greater than the horizontal displacement of the corner. Therefore, the deformation monitoring of the central supporting structure should be strengthened during the construction of deep foundation pit.

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