Monitoring of Deep Foundation Pit Support and Construction Process in Soft Soil Area of Pearl River Delta

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Abstract. The deep foundation pit supporting technology in the soft soil area of the Pearl River Delta is more complicated, and many factors influence and restrict it. In this project as an example, according to the geological conditions and the surrounding circumstances, the main foundation using bored piles and pre-stressed anchor cable supporting structure + five axis cement mixing pile curtain supporting form; partial use of double row piles supporting structure + five axis cement mixing pile curtain support type. Through the monitoring results of construction show that the foundation pit, the indicators of environmental changes are in the design range, the supporting scheme of deep foundation pit technology is feasible and reliable.

1. Introduction
With the rapid development of China's economic construction, more and more projects involve excavation and support of foundation pit. Deep foundation pit supporting is also developing and improving, such as concrete pouring row piles support, underground continuous wall support, pile anchor support, soil nailing wall support, shotcrete bolt network support, etc. However, no matter how to improve the methods and measures, the basic requirements and setting principles of deep foundation pit support will not change.

According to the design and construction of the actual project, it compares the theoretical foundation pit with practical application, to provide a scientific basis for reasonable and accurate judgment to select the appropriate foundation pit supporting technology, ensure the foundation pit construction safety.

2. General situation of engineering

2.1. project introduction
The Century Square project is located in Zhuhai City, with an area about 21000m², to build a hotel building and two office buildings, the hotel has 21 floors (85 meters), office building has 24 floors (99.6 meters), 3 to 4 affiliated podium layer. Building ±0.00 is tentatively designated as 4.50M, with two basements, and basement floor elevation is -9.20m (relative elevation).

The project site surface relative elevation is about -0.5m, foundation pit slope line total circumference is about 532m, pit area (bottom line) 18490m². The excavation depth of the foundation pit is 9.3m (the partial excavation depth is 12.6 m). The safety level of foundation pit is grade one.

2.2. engineering geology and hydrological conditions
According to the geotechnical investigation report of this site, the upper formation of the site affecting the excavation of the site shall include:
1) miscellaneous fill, number ①
Soil gray, brown, yellow, brown and red and other variegated by granite weathering soil and the demolition of the remaining pieces of bricks, concrete fragments, composed of saturated, less compacted.
This layer is widely distributed in the site, and all boreholes in this survey have been exposed. The thickness is from 1.50 to 6.80m, with an average thickness of 3.58m. The floor elevation is -3.12 ~ 2.12m.

2) gravel sand, number ②
Dark gray, deep gray, gray, brown, yellow, is mainly composed of quartz sand, top part of shell debris containing mud and a small amount of matter, sub-angular, poorly sorted, saturated, slightly dense, loose top, bottom locally dense.
The layer is widely distributed in the site, mostly double layer distribution, sandwiched with silty clay layer ③. All boreholes in this survey have been exposed, the thickness of 4.90 ~ 21.80m, with an average thickness of 12.23m. The floor elevation is -29.90 ~ -2.15m.

3) Silty clay layer, number ③
It is composed of clay and a small amount of gravel sand. The local gravel sand content is high, the cutting surface is rough, the toughness is moderate, the dry strength is moderate, and there is no shaking reaction. It is saturated and plastic.
This layer is widely distributed in the site, and 39 boreholes are exposed in this survey. The thickness is from 1 ~ 12.70m, with an average thickness of 5.06m. The floor elevation is -16.63 ~ -3.43m.

4) Gravel cohesive soil layer, number ④
Brown, yellow brown, brown red, yellowish red, granite residual soil, rock structure has been destroyed, feldspar weathering clay, clay core column, wet, hard plastic ~ plastic.
This layer is widely distributed in the site. 33 boreholes are uncovered in this survey, the thickness is from 2~7.80m, the average thickness is 4.79m, and the elevation of the bottom is -24.21 ~ -17.43m.

The ground water level is stable, the water level is 1.20 ~ 2.50M, the average is 1.69m, and the corresponding elevation is 1.97m ~ 2.57m. Ground water is mainly found in sandy gravel ② deposited by sea land interaction. The annual variation of groundwater level in the field area is about 1 ~ 1.20m.

2.3. surrounding environment
The distribution of pipe network and building around the foundation pit is as follows:
1). The west side of the foundation pit is GangChang Road, and the distance between the road tooth and the basement contour is about 6.1m.
2). North and east of the foundation of municipal roads, road teeth and basement contour line distance is about 4.1m, the other side of the road to the existing buildings, the foundation for the pile foundation, and on the north side of the eastern side of the plant and the basement contour were about 22.0m and 23.0m.
3). The south side of the foundation pit is all the way to Gangyi road. The distance between the road tooth and the basement contour is about 18 ~ 24m. The pit on the south side of GangChang Road along the distribution of cable, cable, water pipes, drains and other underground pipelines, including GangChang Road along a water supply tube from the basement side recently about 4.4m, the pipeline is made of cast iron, the depth of about 1.0m; a port along the road distribution of a communication cable is located the excavation area, then transfer.
3. Foundation pit engineering design

3.1. Support type selection
According to the deep excavation, foundation pit surrounding environment and site formation distribution, \( \Phi 800 \) and \( \Phi 1000 \) pit with two kinds of bored pile retaining pile + mixing pile seam + mixing pile bottom grouting pile with long sealing type pre-stressed anchor + soil cement mixing pile curtain + cement soil.

The construction sequence of the retaining structure is: the construction of five axis mixing pile curtain construction, the construction of cast-in-place concrete pile with cast-in-place concrete piles, and the construction of bored piles.

3.2. Construction technical requirements

3.2.1. Construction of five axle mixing pile
(1) The diameter of the five shaft mixing pile is \( \Phi 650 \)mm, the distance is 450mm, and the method of forming a hole with a hole is adopted.
(2) Mixing pile construction adopts a lifting; mixing into piles, lifting speed shall not be greater than 0.8m/min.
(3) The vertical deviation of the pile is not more than 0.5%, the length of the pile is not more than 5cm.

3.2.2. Construction of plug and mixing piles between retaining piles
(1) The net distance of the support piles is \( \Phi 600 \)mm, \( \Phi 500 \)mm, and the foundation pit adopts the inner support section, and all the other sections of the piles need to be built with two plug mixing piles.
(2) Mixing pile construction adopts four spraying and four stirring process, and the lifting speed shall not be greater than 0.8m/min
(3) The vertical deviation of the pile is not more than 1%, the length of the pile is not more than 5cm.

3.2.3. Bored pile construction
(1) The bored pile has two kinds of diameter: \( \Phi 800 \)mm and \( \Phi 1000 \)mm. The bored pile shall be constructed by jumping pile, and the adjacent pile shall be drilled under the condition that the concrete is filled with 24h, and the two adjacent piles shall not be constructed at the same time.
(2) The bored pile verticality deviation of pile position is less than 0.5%, not more than 50mm.
(3) After complete the construction of top beam bored pile, concrete to reach its design strength can be more than 70% after excavation.

3.2.4. Pre-stressed anchor rope construction
(1) The pre-stressed anchor rope adopts 7 \( \Phi 5 \) steel strand, and the single beam steel strand strength standard value is \( f_{ak} = 1860 \)Mpa.
(2) The anchor hole construction adopts the mechanical drilling, the full casing following pipe drilling technology, and the hole diameter is \( \Phi 150 \)mm.
(3) The tension of anchor cable should be reached 70% of the anchor's solid strength.

3.2.5. Adopting \( \Phi 20 \)mm reinforced soil nailing slope friction, can be directly into the soil and without grouting.

3.2.6. The slope between pile and vertical surface using 8# wire net product, which put the slope grid spacing between piles 200mm * 200mm, 100mm * 100mm vertical surface grid spacing, lap length
not less than 150mm, an anchor-knots aspect reinforcement set net, reinforcement diameter $\phi$ 16mm, length setting.

3.2. The top and bottom of the slope excavation are respectively arranged cut, drain, cut, drain size 350mm * 350mm * 400mm (top bottom width * width * height); around the pit drainage ditch along a cut, set well, the size is 1000mm * 1000mm * 1000mm; the bottom of the slope drainage ditch from the pit edge distance is 500mm and make the appropriate adjustments according to the distribution of pile; foundation pit slope ditch and foundation pit water through sand pool near the rear can be discharged into municipal drainage ditch.

3.3. Pit excavation technical requirements and emergency response plan
Foundation pit earthwork must be in the following post beam pre-stressed anchor cable lock road will be carried out after the staged excavation, the segment length is less than 25m, the section between the interval should be more than 15m, at the ends of earth after the completion of the foundation pit deformation and stability, soil deformation data no abnormal conditions between the open excavation section.

During the excavation, no damage to the retaining structure is allowed.

All the top pit in the range of 16m overload shall not exceed 20kPa.

In the process of slope excavation, foundation pit must strengthen (pile) top horizontal displacement and surrounding ground settlement monitoring, if it is found that the top displacement is too large, should immediately find reasons, and take corresponding measures, emergency of pit earthwork backfilling, such as foundation pit wall leakage, the need for timely and take measures to stop, when necessary after the slope soil by jet grouting. The site should be a sufficient number of standing bag ready for building sand, retaining the necessary auxiliary, equipped with a special inspection of the foundation.

3.4. Overall stability check

![Figure 1. Overall stability check](image)

Calculation method: Swedish strip method
Stress state: the method of total stress; the width of soil strip in strip method: 0.40m
Slip surface data
Overall stability safety factor $K_s = 1.575$; arc radius (m) $R = 13.937$; center of coordinate $X$ (m) $X = -1.940$; center coordinate $Y$ (m) $Y = 6.165$
Checking against stability of overturning - Overturning safety factor:

\[ K_s = \frac{M_p}{M_a} \]

- \( M_p \) — The passive earth pressure and the supporting force of anti-overturning moment of the pile bottom, the inner support pivot by the internal supporting anti pressure; For the bolt or anchor, anchor for pivot bolt or cable tension resistance and the smaller value.

- \( M_a \) — The overturning moment of the bottom of the pile under active earth pressure.

Note: the anchoring force is calculated on the basis of the actual bolt anchorage length calculation.

Working condition 1: excavation depth 1.7 meters

| number | anchor type | material resistance (kN/m) | anchoring force (kN/m) |
|--------|-------------|-----------------------------|------------------------|
| 1      | anchor rope | 0.000                       | 0.000                  |

\[ K_s = \frac{26103.069 + 0.000}{6087.175} \]

\[ K_s = 4.288 \geq 1.250, \text{ meet specification requirements.} \]

Working Condition 2: bracing anchor rope

Note: the anchoring force is calculated on the basis of the actual bolt anchorage length calculation.

| number | anchor type | material resistance (kN/m) | anchoring force (kN/m) |
|--------|-------------|-----------------------------|------------------------|
| 1      | anchor rope | 341.600                     | 407.779                |

\[ K_s = \frac{26103.069 + 4378.347}{6087.175} \]

\[ K_s = 5.007 \geq 1.250, \text{ meet specification requirements.} \]

Working condition 3: excavation depth 4.5 meters

Note: the anchoring force is calculated on the basis of the actual bolt anchorage length calculation.

| number | anchor type | material resistance (kN/m) | anchoring force (kN/m) |
|--------|-------------|-----------------------------|------------------------|
| 1      | anchor rope | 341.600                     | 407.779                |

\[ K_s = \frac{12843.600 + 4378.347}{6087.175} \]

\[ K_s = 2.829 \geq 1.250, \text{ meet specification requirements.} \]

Working Condition 4: bracing anchor rope

Note: the anchoring force is calculated on the basis of the actual bolt anchorage length calculation.

| number | anchor type | material resistance (kN/m) | anchoring force (kN/m) |
|--------|-------------|-----------------------------|------------------------|
| 1      | anchor rope | 341.600                     | 407.779                |

\[ K_s = \frac{12843.600 + 9011.908}{6087.175} \]

\[ K_s = 3.590 \geq 1.250, \text{ meet specification requirements.} \]

Working condition 5: excavation depth 8.5 meters

Note: the anchoring force is calculated on the basis of the actual bolt anchorage length calculation.

| number | anchor type | material resistance (kN/m) | anchoring force (kN/m) |
|--------|-------------|-----------------------------|------------------------|
| 1      | anchor rope | 341.600                     | 407.779                |
Minimum safety factor: working condition 5.
 Minimum security $K_s = 2.077 \geq 1.250$, meet specification requirements.

4. Monitoring of foundation pit support

The excavation of foundation pit earthwork should implement the "information" construction, deal with the horizontal displacement of the slope top, the surrounding ground settlement monitoring; monitoring according to the monitoring of building excavation engineering "technical specifications" (GB50497-2009), foundation pit deformation observation time interval of 1 to 3 days, the initial excavation encryption observation, after the completion of the tunnel observation interval can be lengthened properly. In case of rain or other special circumstances affecting the stability of foundation pit, it needs more monitoring. The monitoring requirements of each foundation pit are as follows.

Deformation monitoring of foundation pit as table 1 shows.

| Monitoring type | Horizontal displacement | Deep displacement | Surface subsidence | Stress of anchor cable | water level |
|----------------|-------------------------|------------------|-------------------|-----------------------|------------|
| Foundation pit | Control value (mm)      | 30               | 40                | 30                    | 80%f       | 1500       |
|                | Alarm value (mm)        | 25               | 30                | 25                    | 60%f       | 1000       |
|                | Rate of change (mm/d)   | 3                | 5                 | 3                     | 500        | 500        |

The surrounding buildings subsidence monitoring as Table 2 shows.

| Monitoring Type | settlement | differential settlement |
|----------------|------------|-------------------------|
| Buildings      | Control value | Alarm value | Control value | Alarm value |
| Buildings      | 20mm       | 15mm                   | 0.002H        | 0.0015H     |

Note: the H in the table is the height of building above the ground.

5. Conclusions

The geological condition of soft soil area in Pearl River delta is complex, deep foundation pit safety is prerequisite to ensure the smooth completion of the project; therefore, the design of deep foundation pit construction should be combined with the actual characteristics of the project construction scheme selection of appropriate and reasonable. At the same time, in the process of deep foundation pit excavation, the real-time monitoring of the foundation pit itself and surrounding environment is
strengthened, so that it can be known in advance and prevent the accident of the deep foundation pit, and ensure the safety of the deep foundation pit and the surrounding environment.

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