Combined Application of Multiple Support Forms in Design of Large Deep Foundation Pits

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Abstract. With the constant exploitation of underground space, the single support pattern is not able to meet the needs of the foundation ditch design. This paper is based on a design case of the large-deep foundation ditch in Hangzhou and took the different geological environment requirements into consideration. In this paper our research team put forward the composite design of support pattern which adopts steel support, bored grouting pipe, soil nailed wall etc. We hope this paper can provide suggestions and references for other analogous projects.

1. Project Overview
A project is located in Yuhang District of Hangzhou City, with Chuangjing Road on the east side and Haishu Road on the south side, Yuhang Tanghe South Road on the north and Wangqiao Port on the west. The project is a large-scale building foundation pit with multiple high-rise residential buildings and their supporting houses, covering an area of about 65653.3m², the basement is 1st floor, the excavation depth of the foundation pit is 4.70m~6.25m, and the perimeter of the foundation pit is about 1064m, the maximum axial force of the designed column bottom is about 4000kN, and the pile foundation is adopted.

2. Project address and hydrological conditions
The stratum of the site can be divided into top-down types according to the genetic type: ① miscellaneous fill, layer thickness 0~2.80m. ④ Clay, soft plastic, partially hard plastic, partially silty clay, layer thickness 0~7.30m. ⑤1 clay, hard plastic, local soft plastic, layer thickness 6.50 ~ 14.00m ⑤2 silty clay, soft plastic, local soft plastic, layer thickness 1.10 ~ 6.20m. ⑤3 gravel sand, medium dense, mainly composed of gravel, sand and a small amount of cohesive soil, containing a small amount of round gravel, pebbles content of about 18%, gravel content of about 30 to 40%, sand content of about 25%, the mother rock is mainly tuff and sandstone, grinding roundness is general, secondary sub-circular, and the rest of the viscous soil filling, and the degree of cementation is general. The layer thickness is 1.30 to 7.00 m. ⑥ round gravel, medium dense, mainly composed of gravel, sand and a small amount of cohesive soil, containing a small amount of round gravel, pebbles content
of about 25%, gravel content of about 35 to 45%, the sand content is about 20%, the mother rock composition to tuff and sandstone, grinding roundness is slightly better, it is sub-circular, and the rest of the cohesive soil filling, and the degree of cementation is general. The layer thickness is 2.10 to 8.10. ⑩2 strong weathered argillaceous siltstone is slightly hard, silty sand structure, massive structure, core is short column and fragmented, weathering fissure is relatively developed, and partially sandwiched weathered rock block. The thickness is 0.50 to 6.00m. ⑩3 the middle weathered argillaceous siltstone is hard, with silty structure and massive structure, and the core is relatively complete, mostly short columnar, joints are not developed, and local is glutenite. The thickness is controlled from 3.00 to 9.20 m.

Three layers of groundwater are mainly distributed in the proposed site. The nature of the upper groundwater belongs to diving, and the nature of the lower groundwater is confined water and bedrock fissure water. During the exploration period, the water level is buried in the depth of 0.30 ~ 3.10m, and the water level elevation is between 2.13~2.58m. The diving water level is controlled by the terrain, and has obvious dynamic changes with the season and climate, and has certain hydraulic connection with the surface water body. This aquifer is closely related to foundation pit enclosure, precipitation and anti-floating design. The confined water is mainly distributed in the ⑤3 gravel sand, and its overlying viscous soil layer constitutes a relatively waterproof confined roof. The confined water is not obviously affected by climate, and its main supply source is lateral diving, and the lateral runoff is slow. Generally, artificial deep well mining is the main drainage route. According to the regional hydrogeological data, the distribution of the aquifer in the survey area is not continuous, and the site confined water level is the elevation of the water head is about 3.00m. The confined water has little influence on foundation anti-floating and engineering dewatering, and has certain influence on the pile foundation of the bored pile. It should be paid attention to during the design and construction. The corresponding wall protection measures should be taken when necessary. The bedrock fissure water occurs in the bedrock weathering and joint fissures, and the joint fissures have good closure properties, poor permeability and poor water-richness. It is mainly affected by lateral replenishment and upper confined water infiltration replenishment, and the water volume is weak, which has little impact on pile foundation design and construction.

3. Foundation pit support design scheme

3.1. Characteristics and difficulties of foundation pit support

Through the engineering overview and geological conditions, the foundation pit project has the following characteristics: ① The surrounding conditions of the foundation pit are complex, and adjacent to the building (structure), need to consider the influence of foundation pit excavation on the surrounding building (structure); ② geological conditions are general, mainly clay and silty clay, and the physical and mechanical properties are more general; ③ the excavation scope is large, the excavation area of the foundation pit is large, 410×120m, and the deepest depth is 6.25m; ④ there is a pit in the pit problem, the second excavation depth is 2.35 ~ 2.80m; ⑤ the groundwater level of the site is higher, the excavation process should focus on doing a good job in waterproof and drainage work, and focus on preventing the damage caused by the deformation of the soil caused by the drop in water level.

3.2. Foundation pit type selection analysis

Considering factors such as the geological conditions of the project and the depth of excavation of the foundation and the characteristics of the surrounding environment, combined with the experience in design and construction of similar projects in the region, the specific foundation pit support scheme is given as follows: ① The north side of the foundation pit adopts φ600@1100's bored pile support, the northwest side is combined with four-way steel gussets, the northeast side is combined with 7-way steel gussets, steel section mainly H350×50×2×9; ② the east and west sides of the foundation pit
adopt two rows of φ600@1100's bored pile support; ③ the south side of the foundation pit is open space, and the soil deformation requirements are small, using 20@1000L soil nail wall support; ④ base pit north and south 2 1-storey basements pits need pit excavation, using natural slope support; ⑤ foundation pit water stopping scheme: After the foundation pit support pile, the φ650@450 three-axis mixing pile is used to stop the water.

**Figure 1. Schematic diagram of foundation pit layout**

![Foundation Pit Layout Diagram](image)

**Figure 2. Sectional view of foundation pit**

![Sectional View Diagram](image)

4. Construction technical measures

4.1. Prestressed steel support construction

Prestressed steel supporting construction sequence: deepening design→construction preparation→measuring positioning→H-shaped steel column pile construction→excavation crown beam and cow-leg earthwork→crown beam construction→welding cow-leg and force transmission connecting plate (welding with pouring pile main rib )→Cow-leg installation→Installing the first circumference purlin→welding the force transmission component→Installing the second circumference purlin→Installing the bracket and the beam→Installing the support beam→Pre-stressing→Foundation pit earth excavation→End of foundation pit excavation→Construction pouring concrete cushion, floor, side wall, roof and concrete support → basement structure, roof, side wall and concrete support strength to reach design strength → remove combined steel support.

This foundation pit of the project adopts the support form of cast-in-place bored pile and prestressed steel combined support, and the three-axis mixing pile also serves as the water stop curtain. Combined with the planar shape of foundation pit, the planar form of Angle brace is adopted. H350×350×12×19 section steel (Q345) is used as the standard part of internal support,
H400×400×13×21 section steel (Q345) is used as the circumference purlin of section steel, and H300×300×10×15 (Q235) is used as the supporting column.

Before support installation, the pre-splicing should be carried out on the ground according to the deepening drawing. The support center line error of the splicing needs to be controlled within the design range, no more than 2mm. At the same time, the elevation error of support should not exceed 20mm, and the overall deflection of the support should be controlled. If necessary, additional beams are required to reduce the deflection of the support. During the supporting assembly process, the installation of the auxiliary members such as the support cover is interspersed, so that the multi-bed support is formed integrally. When setting the cow-leg, the elevation angle of the cow-leg should be 90~95 degrees and should not be less than 90 degrees. The planar positioning error of the column should be controlled within 20, and the verticality should be controlled within 1/200. After the support assembly is completed, 70% of the total amount of pre-stress is applied, and in the later stage, the pre-stress is gradually applied according to the deformation of the foundation pit excavation. After the steel support is prestressed, tighten the loose bolts again.

After each components of the combined steel support are arranged, first check whether the connection of the bolts of each component is tight, whether the connection state between the force transfer member and the enclosure system is correct, and then by the Angle brace from the inside out one by one pressure. Before the prestressing is applied, check the hydraulic jack and other equipment in advance and ensure that it is qualified; with the application of the newly installed supporting prestress, the supporting stress after the previous loading will gradually decrease, and therefore, need to set the re-stressing device; In the process of prestress application, the connection of each node should be checked to prevent eccentric compression and uneven force. At the same time, the prestress of the support shall be applied in strict accordance with the axial force provided on the design drawing. Do not allow loading is not in place or overloaded, and the data in the whole process must be recorded and archived.

Figure 3. Details of steel support

4.2. Technical requirements for construction of three-axis cement mixing pile
The cement mixing pile adopts three-axis mixing equipment with a diameter of 650. It is constructed in a standard continuous way with a lap connection of 200. P•O 42.5 grade ordinary Portland cement and SN201 admixtures were used, cement incorporation 20%, empty stirred cement content was 10%, water-cement ratio 1.5; If the unconfined compressive strength of cement mixing pile is no less than
1.0mpa for 28d and the age of the pile reaches 28 days, a certain number of piles shall be selected for coring to test their strength as required by relevant regulations. The number of sampling should not be less than 2% of the total number of piles.

The cement used should be fresh, dry and without agglomeration, and the organic matter composition and content of the foundation soil should be investigated. If necessary, admixture should be used to ensure the quality of the pile.

The deviation of pile positioning shall not exceed 2cm, the deviation of pile diameter shall not exceed 2cm, and the deviation of perpendicularity shall not exceed 0.5%.

The pile body adopts one stirring process. The cement and the undisturbed soil must be evenly mixed, do not flush and sink. The sinking and lifting are all gunite mixing. In order to ensure the cement mixing evenly, it is necessary to control the sinking and lifting speed of the drilling tool. The drilling speed of the drilling rig is generally 1m/min, and the lifting mixing speed is generally 1.0-1.5m/min. Repeated stirring and grouting in the lower part of the pile, the lifting speed should not be too fast, avoiding vacuum negative pressure and hole wall collapse phenomenon. The construction of piles must be continuous, and the interval between adjacent piles must not exceed 12 hours. If it is inevitable for special reasons, it shall be reinforced and marked with location. The amount of grouting during drilling is generally 70% to 80% of the rated slurry volume, and should be re-mixed in the 2m area of the pile top. In the construction of the cold joint, two three-axis cement mixing piles are added on the outside to strengthen. During the construction of the mixing pile, the settlement and displacement around the foundation pit must be monitored, and according to the monitoring data, the pressure resistance, grouting speed and grouting pressure of the mixing head during the construction of the mixing pile should be reasonably controlled.

4.3. Soil nails wall construction

Construction sequence of soil nailing wall: excavation work surface according to design requirements → trimming slope → the hole forming → installing connecting parts → tying steel mesh → embedded shotcrete thickness control mark → shotcrete surface layer.

Foundation pit excavation and soil-nailing wall construction shall be carried out in sections and layers from top to bottom according to design requirements. After mechanical excavation, artificially trimming the slope surface shall be supplemented, overexcavation is strictly prohibited. Before the concrete is sprayed on the slope, the virtual soil on the slope should be removed.

The soil nails are made of 20 steel bars. The soil nailing shall firstly form holes and then implant the rebar. The pore size of the pores must not be less than the design pore size (diameter 150). The hole forming depth should be greater than 0.50m of the anchor bolt depth, and then immediately put into the steel bar and grouting. The grouting adopts low-pressure grouting, the grouting pressure is controlled at 0.4-0.6Mpa, the grouting shall be made of 42.5 cement, the water-cement ratio is 0.5, the cement dosage for grouting shall be no less than 25kg/m, and the grout should be evenly mixed, mix and use at any time, and the cement slurry for each mixing is used up before initial setting.

The soil nail surface layer is C20 shotcrete, 100mm thick, the shot concrete mix ratio is preferably 1:2:3.5 (cement: sand: gravel weight ratio), the stone particle size is 10~15mm, and The top layer bone is added with steel bars is 14, The mesh reinforcement is 6.5@300×300 bidirectional.

The soil nails shall be tested for pull-out resistance according to the specifications. The maintenance time of the test nails shall not be less than 15 days. The pull resistance of soil nails should not be less than 15kN per meter, and the number of soil nail pullout tests should not be less than 1% of the total number of soil nails.

The number of holes should be 100m wall area, each group should not be less than 3 points, and the allowable error is ±10mm.
5. Conclusion

The monitoring results of the surrounding displacement of the foundation pit after foundation pit excavation show that the displacement of the whole foundation pit is very small during excavation, which meets the requirements of “Technical specification for building foundation pit engineering monitoring” GB50497-2009, and satisfactory effect of various support forms in deep foundation pits For near around the building, and the deformation during the course of the foundation pit engineering construction demanding, the foundation pit support design can select different schemes according to the boundary conditions, adjust the excavation sequence and optimize the construction organization design, improve the safety of the engineering construction, greatly improve the economic and social benefits of the engineering construction, and provide better construction experience and technical reference for the future construction of similar large-scale foundation pit projects.

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