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Application of Bored Pile Technology Under Complex Geological Conditions

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Abstract. The paper systematically explores the application and optimization strategy of bored pile construction technology in light of the intricate and dynamic surrounding environment, challenging geological conditions, and significant potential damage, based on extensive research conducted for a subway station construction project. The entire process, from lofting measurement to final hole formation, hole clearing, steel cage fabrication, underwater concrete pouring, and post-grouting construction, is comprehensively detailed. Furthermore, the key control points of bored pile construction are further extracted and summarized. In-depth analysis and discussion are conducted on the two core technical challenges in this project case: reasonable mud proportion control to ensure hole wall stability and prevent the risk of collapse; as well as scientific installation and arrangement of grouting pipes to guarantee grouting quality and subsequent effectiveness. Through comprehensive case analysis and in-depth exploration of key technologies, this paper aims to provide meticulous and practical construction strategies as well as a solid reference framework for similar underground projects, thereby enhancing the quality and efficiency of bored pile construction under complex environmental conditions.

Keywords. Complex geology, bored pile, construction technology, technology application

1. Introduction

As a common foundation reinforcement technology, bored pile construction technology has the advantages of strong bearing capacity, good adapt ability and good settlement control effect [1-5]. At present, there are many factors to be considered in the construction of bored piles, especially in complex geological environment, and environmental factors can easily have a great impact on the construction. Therefore, it is necessary to carry out in-depth discussion on the construction of bored piles under complex geological conditions, clarify the construction process and construction technology, and improve the construction quality [6-11].

2. Project Profile

This article is based on the Jinan Urban Rail Transit Line 6 project. This project is in a complex and changeable site environment. Its stratigraphic sequence is rich in various soil types, including but not limited to gravel soil, variegated medium-dense soil, silty clay mixed ginger stone, cemented sand layer, pebble layer, pure clay layer, gravel-containing silty clay layer, uniform sand layer and gravel sand layer. These strata show significant diversity, which poses a substantial challenge to the construction of bored piles, especially in the area of medium-fine sand layer with a depth range of 12 to 18 meters, pebble layer with a depth range of -8 to -2 meters and cemented sand layer.

Groundwater condition and activity: Although there is no obvious sign of surface water distribution on the surface, there is a widespread Quaternary pore confined water layer, which has a non-negligible impact on the stability of the pile foundation. The recharge sources of groundwater mainly include the infiltration of atmospheric precipitation and the backing effect of underlying karst water bodies, showing high dynamic activity.

Specific bearing layer characteristics: The bearing layer at the pile end is mainly composed of silty clay layer. For pile foundation projects with high bearing capacity design standards, it is very important to ensure that the pile end fully enters the preset depth.

The complex and changeable site background: the project area was originally villages, farmland and untreated fish ponds. After the demolition and backfilling, the topography and geomorphology have changed significantly, resulting in complicated geological conditions. The original soil layer structure was destroyed, and the artificial filling soil layer with irregular thickness and poor mechanical properties was formed, which aggravated the technical difficulty of construction.

The heterogeneity of geological sequence: The geological section covers a variety of soil units such as loose artificial fill, cemented silty clay, cemented sand, mixed soil with different gravel content and organic soil layer. It is particularly noteworthy that the medium-fine sand layer is easy to cause the difficulty of pore formation and the risk of hole collapse due to the large gap between the particles and the strong fluidity; at the same time, due to their different physical and mechanical properties, the cemented sand layer and the organic soil layer pose special challenges to the pore forming technology and the bearing capacity respectively.

Summary of geological unfavorable factors: the site also faces the problem of soil stability decline caused by groundwater erosion, and the abrupt change of the mechanical properties of the interface between the hard cemented conglomerate layer and the adjacent weak stratum, which increases the difficulty of pile extraction and implantation.

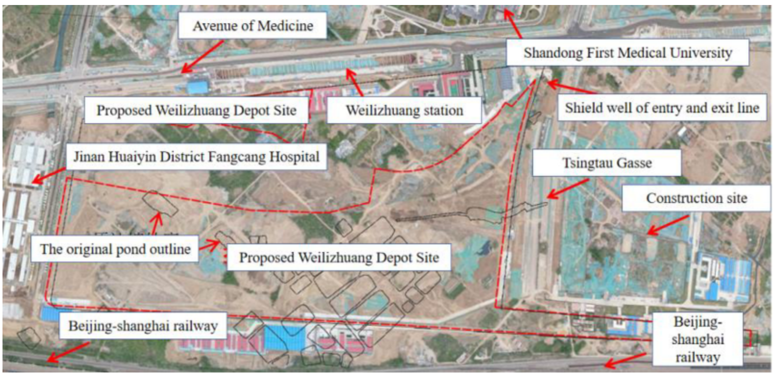

Figure 1. Aerial photo of the proposed site environment

Potential major environmental risks : As the project is close to the existing Beijing-

Shanghai railway line and the under-construction Weilizhuang station, its environmental risk level has been assessed as level 2, which means that any negligence in construction operations may lead to potential damage to the surrounding infrastructure. The site environment is shown in Figure1.

3. Conceptual design

The main section of the subway station in this project adopts the design grade of class A foundation, the design grade of class A building pile foundation, and the bored pile and cap foundation with a diameter of 800 mm. It is estimated that the total number of piles is 5000, and a small part of them are test piles and engineering piles. Before construction, the geological treatment of medium and fine sand is carried out. The bottom elevation of the pile cap is 1.5 m below the bottom elevation of the pile cap, which is replaced by Sanqi lime soil, and the layer is compacted. The thickness of the layer is 250 ~ 300 mm, and the compaction coefficient is not less than 0.96.

To fully consider the economic applicability and on-site bearing requirements. The engineering pile foundation adopts the retaining wall bored pile, and there are two kinds of pile types. Pile type one: pile diameter 800mm, pile length 37.1m, 38.1m, single pile bearing capacity characteristic value is 3200kN ; pile type 2: pile diameter 800mm, pile length 45m, 48m, single pile bearing capacity characteristic value is 4200kN. The pile end and pile side are treated by post grouting technology. Two pile end grouting valves are set at the pile end. The cement model is P.O 42.5, and the grouting amount of single pile is not less than 2.5 t. The concrete is underwater concrete C35, and the filling coefficient of cast-in-place pile is not less than 1.05. The reinforcement cage reinforcement is HRB400, the main reinforcement is 16 HRB400 diameter 22 reinforcement bars, and the longitudinal reinforcement in the 1 / 3 pile length range at the bottom is 8 HRB400 diameter 22 reinforcement bars. The stiffener is HRB400 diameter 20 mm reinforcement bar, and the spacing is 2000 mm. The spiral hoop is HRB400 diameter 10 mm reinforcement bar. According to the specific construction conditions, the spacing is determined to be 100 mm or 200 mm. The range of 4000 mm below the pile top and the range of 2400 mm above the pile bottom is 100 mm in the encryption area, and the other areas are 200 mm. The layout of pile foundation is shown in Figure 2.

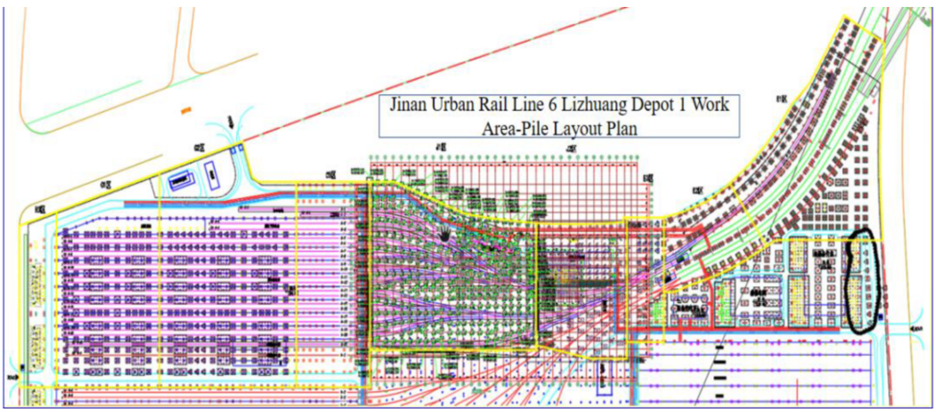

Figure 2. Pile foundation plan of the work area

4. Bored pile construction technology

4.1. Pile position measurement and casing burying

In the early stage of construction, precision measurement technology is used to ensure that the pile position deviation is less than 10 mm, and the pile position identification is set up. Before the casing is buried, multiple retests are carried out, the elevation of the casing is determined by the level, and the position of the bored pile is accurately calibrated by the cross positioning method. The height of the casing is ≥ 3 meters, the wall thickness is 8 millimeters, and the inner diameter is 20 centimeters larger than the pile diameter to ensure its stable installation on a solid foundation. The effective burial depth is more than 1.5 meters, and the total length reaches 4 meters.

4.2. Drilling construction and hole wall stability management

During the construction of the drilling rig, the alignment accuracy of the drill bit and the cross positioning line is strictly controlled to be ≤ 100 mm to ensure the stable operation of the rotary drilling rig. In view of the soil layer which is easy to collapse, the deformation of the hole wall is inhibited by adjusting the proportion of mud, slowing down the drilling speed and using the mud circulation system. In the high leakage risk soil layer, the stability of the hole wall is enhanced by increasing the mud density, adding sawdust or increasing the viscosity. In order to ensure continuous operation, the mud preparation capacity needs to be greater than the drilling demand, and each drilling rig is equipped with enough mud equivalent to the volume of a single pile to fully support the hole wall.

4.3. End hole and hole cleaning process

Based on the design hole depth and geological report, the drilling depth was planned and recorded in advance, and the soil change was analyzed by collecting drilling slag. Collect samples at the turning point of the formation, accurately record the drilling process, and ensure that the geological conditions meet the design requirements. After the end of the hole, the hole bottom cleaning operation is carried out, and the flat head dredging bit is used to strictly control the sediment thickness at the bottom of the hole ≤ 50 mm. In the hole cleaning stage, the effective replacement of mud and cuttings in the hole is realized by appropriately slowing down the drilling speed and replacing the high-quality mud. Before and after the installation of the reinforcement cage, the hole was cleaned twice, and the thickness of the sediment at the bottom of the hole was strictly controlled to be less than 50 mm, and the specific gravity of the mud was maintained within the range of 1.1 to 1.25.

4.4. Reinforcement cage production and underwater concrete pouring and post grouting

The steel cage is welded with HRB400 steel bars to ensure that the positioning bars are set correctly to control the uniform thickness of the concrete protective layer. The reinforcement cage is assembled in the hole after the whole welding on the ground, and the welding specification is strictly complied with. During the hoisting process, attention should be paid to prevent deformation and ensure that it is firmly embedded in concrete as shown in Figure.3. Underwater concrete pouring adopts continuous construction to control the buried depth and lifting speed of the pipe to ensure the quality of concrete pouring. The final grouting volume is 0.8 ~ 1.0m, and the concrete material parameters are in accordance with the specifications. After 12 hours of concrete pouring, the cast-in-place pile was treated with clear water plug opening method. After 7 days, post grouting was carried out. P.O 42.5 cement was selected and grouting operation was carried out according to the design pressure and flow rate. During the whole grouting process, the specific sequence and interval are followed to ensure that the total amount of grouting meets the design requirements. At the same time, the grouting strategy is flexibly adjusted according to the actual situation until the total amount of grouting reaches more than 75 % of the total design amount and the grouting pressure exceeds the design limit.

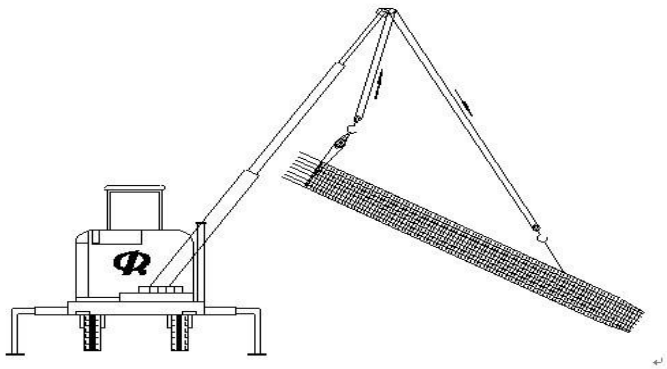

Figure 3. Reinforcement cage hoisting process

5. Key technology

5.1. Mud specific gravity control

Dynamic geological responsiveness adjustment strategy : According to the geological exploration results and on-site construction feedback, the construction team implemented a strategy to flexibly adjust the proportion of slurry for different geological levels. In the process of construction, in view of the geological conditions such as medium-fine sand layer, pebble layer (12 ~ 18m) and cemented sand layer (-8 ~ -2m) which are easy to collapse, the specific control measures of mud specific gravity are adopted, that is, on the basis of conventional specific gravity of 1.10 ~ 1.20, The specific gravity of the mud should be increased to a higher limit of 1.25 in a timely and appropriate manner, and the auxiliary means such as sawdust and tackifier should be added to enhance the wall protection ability of the mud in a specific soil layer and effectively prevent the necking and collapse of the hole wall.

Fine mud performance parameter control: The fine management of mud performance parameters based on geological characteristics is implemented. By monitoring and adjusting the key parameters such as the specific gravity, sand content and viscosity of the mud, it is ensured that the mud has good rheology and permeability stability while meeting the side pressure of the balanced formation. Especially in the soil layer which is prone to mud leakage, the construction team innovatively applied the methods of increasing the proportion of mud and adding additional substances, such as adding sawdust or fiber materials and using tackifier, which not only maintained the stability of the hole wall, but also reduced the risk of environmental pollution caused by mud loss.

Real-time monitoring and feedback optimization: A real-time monitoring and feedback optimization system was established during the construction process. The sensor was used to detect and collect key data such as the proportion of mud in the construction process, and timely analysis was performed to evaluate the construction status. And adjust the proportion of mud in time to ensure that the mud performance always meets the changing needs of geological conditions. This includes the analysis of slag samples taken at different stages of drilling, as well as the regular measurement of mud performance indicators to ensure that the specific gravity of the mud is always within the specified range, and timely adjustments are made according to the actual reaction of geological conditions.

5.2. Grouting pipe installation and grouting process

The scientific installation and reasonable arrangement of grouting pipe is the key to ensure the quality of grouting and the effect of grouting in the later stage. It not only involves the number and position of grouting pipe, but also the design and installation of grouting valve. By precisely pre-embedding the grouting pipe and installing a special grouting valve, it is possible to ensure that after pouring concrete, the pile end and pile side can be efficiently re-grouting to increase the bearing capacity and durability of the pile foundation.

Grouting pipe layout: In the application of pile end and pile side grouting technology, the project adopts a fine grouting pipe layout strategy. Two grouting valves are set at the pile end to ensure the effectiveness and comprehensiveness of pile bottom grouting. For pile side grouting, a differentiated layout scheme is formulated according to the different pile lengths: two annular grouting valves are set up for pile types with pile diameter of 800 mm, pile length of 37.1 m and 38.1 m, and three annular grouting valves are set up for pile types with pile length of 45 m and 48 m. This layout can better adapt to the grouting needs of piles at different depths, so as to achieve a full range of pile quality enhancement as shown in Figures 4-5.

Grouting pipe connection and fixation: The connection between the grouting pipe and the steel cage adopts the advanced wire connection technology, which ensures that the grouting pipe will not be displaced or leaked during the concrete pouring process, and enhances the stability and reliability of the grouting system. In addition, the grouting pipe is firmly tied inside the reinforcement cage, ensuring the stability and safety of the grouting pipe in complex construction environments as shown in Figure 6.

Quantitative grouting technology optimization: According to the pile length and design requirements, the project accurately controls the grouting amount of single pile. For example, for the pile with a length of 35 m, the grouting amount of single pile is set to not less than 2.8 tons, while for the pile with a length of 45 m, the grouting amount is increased to not less than 3.5 tons. This quantitative grouting strategy is based on rigorous mechanical calculations and geological characteristics studies to achieve optimal pile tip and pile side reinforcement effects.

Intelligent dynamic grouting parameter controlling: In the grouting process, the project introduced a dynamic grouting pressure control mechanism. The grouting pressure range was set between 1.2 and 4.0 MPa, and the grouting flow was strictly controlled to not exceed 75 L / min. By adjusting the grouting pressure and flow rate in time, the double optimization of grouting efficiency and grouting quality is realized, and the limitation of traditional grouting technology that it is difficult to balance the grouting effect and grouting rate is overcome.

Grouting process: Grouting construction follows a scientific time node and sequence. For example, after 12 hours of concrete pouring, clear water plugging technology is used, and then grouting construction is carried out. Grouting operation and hole forming operation point maintain a safe distance (at least 8-10 meters). In addition, the compound grouting sequence of pile side and pile end is also implemented, and the appropriate interval time (such as 2 hours) is set in the adjacent grouting interval to ensure that the grouting slurry can be evenly distributed and fully consolidated in the pile body.

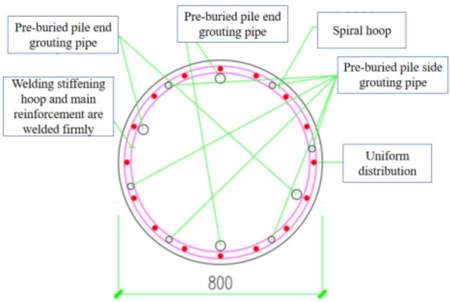

Figure 4. Installation position of pile end grouting pipe(45m, 48m pile type).

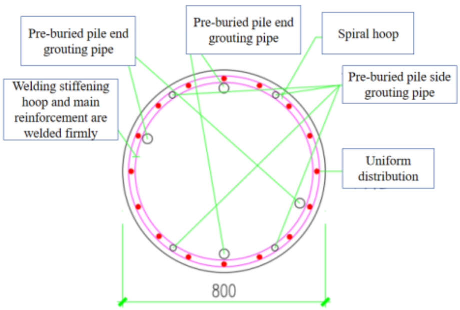

Figure 5. Installation position of pile end grouting pipe(37.1m, 38.1m pile type).

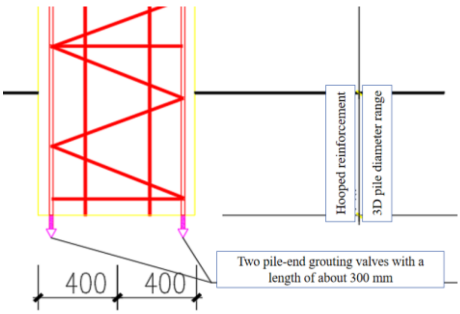

Figure 6. Installation position of pile end grouting valve.

6. Conclusion

In view of the complex environment and significant construction disturbance in this project area, as well as the complicated geological conditions and difficult construction, in order to meet the strict bearing demand and minimize the adverse impact on the surrounding environment, the bored pile technology is adopted for foundation reinforcement. Based on the specific geological exploration results, two types of large-diameter bored piles were selected, and the whole construction process and key control points from design to implementation were elaborated. In the process of construction technology optimization, special attention is paid to the effective regulation of slurry proportion to ensure the stability of hole wall and prevent the risk of hole collapse, as well as the precise installation and arrangement of grouting pipe to improve the quality of grouting and the overall efficiency of pile foundation. Through the application of the above specialized construction scheme and key technical means, this project has successfully realized the effective response and solution to the construction problems of large-diameter bored piles under complex geological conditions.

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