Research on Construction Technology of cast-in-situ bored pile under Complex Geological Conditions

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Abstract: Under complex geological conditions, the use of rotary drilling rigs to excavate pile foundations to form holes, unfavorable factors such as silt and groundwater will bring problems such as deviated holes and collapsed holes. Research on construction technology is required to overcome these difficulties. In this paper, the technology of rotary excavation and hole formation in a thick seam and high groundwater area of a seashore is studied. The influence of mud parameters and drilling speed on the quality of hole formation is explored. An efficient drilling rate and an economical and reasonable mud parameters are obtained.

1. Introduction
With the development of national economic construction, high-quality land resources are gradually reduced, so construction land is gradually transferred to somewhere with complex geological conditions. In the meanwhile, there are more and more pile foundation projects, and the construction environment for pile foundations becomes increasingly demanding. Due to the fast construction speed, simple operation, and high bearing capacity, cast-in-situ bored piles are suitable for a various of complicated stratum, and is therefore widely used in pile foundation engineering of various bridges. Rotary drilling machine has the characteristics of highly centralized integration of machine, electricity and fluid, optimized design of working system and flexible shift of pile machine, which makes the rotary drilling machine technology has the characteristics of fast hole forming speed, high efficiency and simple operation, so it is widely used.

Construction team will often encounter deep and soft silty soil layers and loose sandy soil layers for the complicated geological conditions in the coastal areas. Construction through such soil layers is liable to suffer hole collapse, necking, and mud trapping if improper construction measures are taken, which will result in the insufficient bearing capacity of the pile foundation, causing a huge safety hazard and a large economic loss. In this paper, the technology of rotary excavation and hole formation in areas with thick groundwater and high groundwater is studied. Through improving the construction process, adjusting the mud parameters, and adjusting the drilling speed and so on, we can cope with the problems of deviated holes and collapse caused by unfavorable factors such as silt and groundwater.
1.1. Test pile conditions

The pile foundation project of Wanqingsha station of a traffic project in Guangzhou is located in Nansha District, Guangzhou City. The number of test piles for the project is 3, and the pile numbers are SJ-1, SJ-2, SJ-3. The design pile length is 47 ~ 60m, and the pile diameter is 1m. See Table 1 for information on cast-in-situ bored pile:

| Number | Design pile length (m) | Pile diameter (m) | Holding layer   |
|--------|------------------------|-------------------|-----------------|
| SJ-1   | 43.7                   | 1                 | Light weathering|
| SJ-2   | 59.9                   | 1                 | Strong weathering|
| SJ-3   | 41.7                   | 1                 | Moderate weathering|

SJ-1, SJ-2 and SJ-3 are representative in terms of geological selection. The bearing layers of test pile are light weathering, strong weathering and moderate weathering. Through three geological samplings of the test piles, it is found that the geological conditions of the three test piles are almost the same. The sequence of soil layers is that the backfill soil layer is less than 2m, the silt layer is 2~20m, the medium sand layer is 20~24m, and 29m (24 ~ 38m for SJ-3) is a muddy soil layer, 29 ~ 33m is a silty clay layer, 33 ~ 50m is a coarse round gravel soil layer, and further down is a weathering holding layer. The order is basically the same for three test piles.

Through the actual geological conditions obtained from the test pile holes, it can be found that during the construction of the pile foundation project of the Wanqingsha station, the unstable layers that need attention are silt layers, medium coarse sand, silt fine sand and coarse round gravel soil layers. In the process of pile hole drilling, different drilling speeds and mud parameters need to be adjusted for different formation conditions to adapt to the actual conditions of the formation.

2. Effect of drill parameters on hole forming quality

2.1. Rotary drilling machine selection

The Sanyi SYC6028R rotary drilling rig used by SJ-1 is suitable for drilling pile foundations with a hole depth of less than 50 meters. The rig has no pressure device and the drilling speed is obviously slow for the deeper and harder coarse round gravel soil layer and weathered rock strata. In shallow geological layers, that is, above the coarse round gravel soil layers, SJ-1, SJ-2, and SJ-3 have average drilling speeds of 0.53, 0.51, and 0.51m/min, respectively, which is little difference. In deeper geological layers, compared with SJ-1, the average drilling speed of SJ-2 is 4.6 and 6.75 times as fast as SJ-1 in coarse round gravel soil layer and strong weathering formations, respectively. In strong weathering formations, the average drilling speed of SJ-3 is 9 times that of SJ-1. It can be found that Jintai SH36 rotary drilling machine performs better than Sanyi SYC6028R in deeper soil layers. The maximum drilling depth of Jintai SH36 rotary drilling machine is 75m, which can meet all pile foundations of Wanqingsha station. In order to improve the construction speed and efficiency, it was decided to choose Jintai SH36 rotary drilling machine in this project.

| Number | Drill type | Coarse round gravel soil layer | Strong weathering |
|--------|------------|--------------------------------|-------------------|
| SJ-1   | SYC6028R   | 0.1                            | 0.04              |
| SJ-2   | SH36       | 0.46                           | 0.27              |
| SJ-3   | SH36       | 0.36                           |                   |

2.2 Drilling speed control

In unstable geological layers such as the boundary of the stratum and sand layers, excessive drilling
speed will be prone to cause deviations and collapses. Based on the experience of 3 test piles, the drilling speed should be controlled at 0.3 ~ 0.5m/min in sand and coarse round gravel soil layers, while silt and silty clay soil layers should be controlled at 0.5 ~ 0.8m/min.

The lifting drill speed can be controlled in two stages. Within 20 meters of the hole depth, the lifting drill speed can be appropriately improved and can be controlled between 0.4 to 0.6m/s. While the hole depth is deeper than 20 meters, due to the mud in the drill pipe, lifting the drill too fast will result in the overflowing of mud from the top of the drill pipe, causing pollution and mud waste. Most unstable soil layers locate deeper than 20 meters, so if the drill lifts too fast, a large mud flow velocity will generate around the drill, which will impact the mud guard arm, and be harmful to the stability of the hole wall. Therefore, it is appropriate to control the lifting drill speed between 0.3~0.45m/s when the hole depth is deeper than 20 meters.

3. Effect of mud parameters on pore-forming quality

3.1. Test pile mud deployment
During the test pile process, starting from SJ-2, the density and viscosity of the mud were gradually reduced. Until SJ-3, the density and viscosity had been reduced from the initial 1.15g/cm³, 30.29s to 1.07g/cm³, 22.7s. In the three test pile construction process, no hole collapse occurred, so the parameters of 3rd test pile, the most economical mud parameters, was selected for large-scale construction.

3.2. Mud parameters control during drilling
There are many types of unstable stratum in the construction area, which is relatively thick. It’s necessary to adjust the mud parameters in real time and reasonably during the process of drilling. The reasonable proportion of mud can effectively improve the quality of cast-in-situ bored piles and reduce the probability of engineering problems.

During the test pile construction, the density and viscosity of SJ-2 was controlled in 1.14g/cm³, 30~35s; to SJ-3, it was controlled in 1.11~1.12g/cm³, 21~23s. The hole didn’t collapse when change the mud parameters, indicating that the mud control during the drilling process was more reasonable and the stability requirements of the hole wall were met. Combining practicality and economy, the SJ-3 mud parameters is selected, with a density of 1.11g/cm³ and a viscosity of 22s, which can meet the construction requirements and save costs. The mud flowing out of the hole during the pore forming process should also meet the requirements of the specification, the density of the mud should be between 1.1~1.2g/cm³. The density of the circulating mud flowing out of the hole of SJ-2 and SJ-3 was 1.13g/cm³ and 1.11g/cm³, which are all in the range of specification requirements.

| Table 3. Density of mud (g/cm³). |
|------------------|------------------|------------------|
| Number | Density | Specification requirements |
| SJ-2 | 1.13 | 1.1~1.2 |
| SJ-3 | 1.11 | 1.1~1.2 |

4. Hole formation detection

4.1. Detection equipment
SJ-1, SJ-2, and SJ-3 all use RSM-HGT (B) ultrasonic hole formation detector for hole formation detection.

In the process of hole formation detection, three main problems occurred. First, the twisted wires were not collected neatly, which caused the probe to skew. Second, stuck and slipping occurs during the take-up process. Third, the probe cannot reach the bottom of the pile hole.

The hole forming detector is a twisted pair type. During three pile tests, we found that the probe will stop when it reaches nearly 30 meters, and the take-up process has the phenomenon of stuck slipping and the twisted wire isn’t uniform, which makes the probe skew and difficult to measure. To solve the
problem, in the testing process of SJ-3, workers were guided by the manufacturer's experts on the spot. When the instrument was used, it was completed by three people. One for arranging the wires, one for the control of the winch, one for the control of the display screen, and the phenomenon of stuck and slipping during take-up process are problems of the instrument itself. As for the problem that the probe cannot reach the bottom of the hole, according to the product description of the hole forming detector, the maximum mud density applicable to the ultrasonic probe is 1.30g/cm³. According to the adjustment records of the mud in the drilling, the mud density at the bottom of SJ-1, SJ-2 and SJ-3 holes is all heavier than 1.30g/cm³, which makes it impossible for the probe to further dive.

4.2. detection result

The hole formation detector only generates inspection images on the SJ-3 with a detection depth of 36 meters. The results of the hole formation detector are shown in Table 4. It was found that the maximum and minimum pore diameters of the pile holes were 1365mm and 1003mm, the average pore diameter was 1055mm, and the perpendicularity was 0.01%, which met the requirements of the designed bore diameter and perpendicularity. The quality of hole formation was satisfactory.

| Number | Design hole diameter (mm) | Maximum hole diameter (mm) | Minimum hole diameter (mm) | Average hole diameter (mm) | Verticality (%) |
|--------|---------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------|
| SJ-3   | 1000                      | 1365                        | 1003                        | 1055                        | 0.1%            |

![Figure 1. Detection result.](image-url)
5. Conclusions
In this paper, the technology of rotary excavation and hole formation in areas with thick groundwater and high groundwater is studied. To solve the problems of deviated and collapsed holes caused by unfavorable factors such as silt and groundwater, the effect of mud parameters and drilling speed on hole forming quality and the best parameters were discussed. Some engineering experience was obtained, which provided some references for other similar projects.

(1) In order to prevent the problems of hole collapse and deviation due to too fast drilling speed, the drilling speed should be controlled at 0.3–0.5m/min in sand layer and coarse round gravel soil layer, and 0.5–0.8m/min in silt and silty clay soil layers.

(2) The lifting drill speed can be controlled in two stages. In the hole depth below 20 meters, we can appropriately improve the lifting drill speed, which was controlled between 0.4–0.6m/s. The lifting drill speed should be controlled between 0.3–0.45m/s when the hole depth is more than 20 meters.

(3) When carrying out cast-in-situ bored pile construction in unstable places (such as silt layers, medium coarse sand, silt fine sand and coarse round gravel soil layers), the density and viscosity of the mud should be controlled at 1.11g/cm³ and 22s, which can meet the needs of on-site construction and economy.

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