Support technology of deep foundation bracing and quality control

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Abstract: Ruibai Times Project lies in the central city area of Jinzhou District, Dalian. With the abundant underwater, the geological condition is quite complex. Underground public transportation, old brick-concrete buildings and converting station are all around the construction site. The deep foundation excavation exceeds 17m. The support design adopts a combination of pile anchor system and internal support, which better solves the problems concerning safety, construction period, and cost. The quality is controlled during the construction process, and the monitoring results show that the support method is safe and reliable.

1. Introduction
In recent years, with the rapid development of modernization in China, a great number of large-scale projects such as high-rise buildings have emerged. The density of buildings in contemporary cities is relatively high. Many buildings have basements or underground garages of 1 to 3 floors. The corresponding depth of foundation pit excavation is therefore large. When adjacent buildings or underground structures exist, the traditional slope excavation would be difficult to implement. As the depth of the foundation pit increases, the amount of excavated earthwork increases, which is not very applicable from an economic point of view. With the continuous innovation of scientific and technological means as well as that of mechanical equipment, support and excavation technology is currently widely used. It not only solves the problem of narrow construction sites, but also has a stronger guarantee in terms of engineering safety and economic efficiency. Under the condition that safety is ensured, choosing an economical and reasonable support combination would be an important task for construction engineering design and construction units.

With a planned construction area of 12,813 square meters and a total construction area of 143,760 square meters, the Ruibai Times Project belongs to the city center renovation project. The construction site of the project is located on the south side of Shengli Road, the east side of Beishan Road, and the west side of Jinwan Road in the Jinzhou District, Dalian. On the north, west, and east sides of the site are municipal roads, and the south side is adjacent to the 7-story brick-concrete residential building. The red line is approximately 5.70 meters away from the building, and the red line at the southeast corner is only 1.00 meters away from the residence on the south side. The planned building is a rectangular 30-storey residence, two 29-storey apartments, a 4-5 story public podium and an overall four-storey basement. The depth of the foundation pit is 17.0m, which is a deep foundation pit, and the safety level of the sidewall of the foundation pit is level 1. In order to ensure the safety of the underground structure construction and the surrounding environment of the foundation pit, the
foundation pit needs to be supported.

2. Geological conditions and design options

2.1. Engineering geological condition

According to the geotechnical engineering survey report of this project, the site stratum within the scope of the supporting structure is as follows:

① Miscellaneous fill: gray-brown, loose, partially dense and slightly wet. It is mainly composed of construction waste, gravel and silt. The gravel content is about 30%, the particle size is generally 2-15cm, angular, and the backfilling time is more than 10 years. This layer is generally distributed in the site with a thickness of 1.10~5.80m.

② Silty clay: gray-black-gray-green, plastic, soft and plastic in the shallow layer, medium dry strength and toughness, slightly shiny on the cut surface, no shaking response, fine sand and clay lenses are seen locally. This layer is common in the venue distribution, and the distribution thickness is 3.00~6.90m.

③ Gravel-containing silty clay: yellowish brown, plastic, partially hard plastic, high dry strength, medium toughness, slightly shiny cut surface, no shaking response, mixed with about 20% pebbles, particle size 2-12cm, quartz, Sub-circular shape. The layer is generally distributed in the site with a distribution thickness of 3.30~9.80m.

④ Coarse sand: yellowish brown, wet, slightly dense, the main component is feldspar, quartz, the particle size is equal, the content of clay particles is higher, and there are local gravels and clay clumps. This layer is discontinuously distributed on the site, and locally appears as a lens, with a thickness of 1.10~3.20m.

⑤ Crushed stone-containing silty clay: reddish-brown-yellow, plastic, partially hard plastic, high dry strength, medium toughness, no shaking response, gravel content about 30%, high local content, quartz, and sub-angular. The particle size is generally 2~8cm. This layer is generally distributed in the site with a thickness of 2.30~10.20m.

⑥ Fully weathered diabase: yellow-brown, the core is soil columnar, and hard plastic. The structure is faintly discernible, can be drilled by dry drilling, and is softened by water. This layer is generally distributed in the site with a thickness of 1.20~18.60m.

⑦ Strongly weathered lime-greenstone: yellow-brown, massive structure, diabase structure, most of the structure is destroyed, and the mineral composition changes significantly. The core is gravel and fragmented, and the massive core can be broken by hand. This layer is generally distributed in the site with a thickness of 3.30~16.20m.

⑧ Moderately weathered green rock: gray-green, massive structure, diabase structure, partially destroyed. The rock core is short columnar and massive, the hammering sound is not clear and crisp, and it is relatively easy to break. It is softer and relatively broken. The basic quality of the rock mass is Grade IV. This layer of massive core can be broken by hand. This layer is generally distributed in the site with a thickness of 3.30-16.20m.

⑨ Moderately weathered limestone: off-white, metamorphic structure, layered structure. The rock core is columnar, the length of the column is generally 10~20cm, and the maximum length is 36cm. The hammering sound is relatively crisp and not easy to break. It is harder and relatively complete. The basic quality of the rock mass is Grade IV. The exposed thickness is 1.80~8.30m.

2.1.1 Hydrogeological condition

During this investigation, the boreholes on the west side of the site were found to have groundwater distribution, and the water level was 1.90~3.30m deep. The type of groundwater is upper stagnant water, which is mainly supplied by the leakage of municipal water pipelines and drainage pipelines. According to the investigation, there is a water well on the west side of drilling ZK51 on the site. The well depth is more than 100m, and the stable water level is about 3m. The type of groundwater belongs to the fissure water of confined bedrock with abundant water.
2.1.2 Design scheme selection

Since the project is located in the center of the city, there exist a great number of surrounding pipe networks, large traffic flow, and several external constraints. For instance, there are underground passage entrances and exits on the northeast side of the foundation pit as well as 7-storey old brick-concrete houses on the south side of the foundation pit. The distance from the red line is about 5.7m. There is a well on the west side and a substation at the northwest corner, which is about 10m away from the red line. On the whole, the characteristics are the depth of the pit, strict requirements for slope top deformation, and the presence of confined water at the bottom of the pit. The pile-anchor support system commonly used in Dalian is difficult to meet the deformation restriction requirements of local sections. After repeated program comparison and selection, combined with external constraints and construction planning, the following support methods are adopted for each section: AB, CDEF, HIJKLMNA sections adopt upper grading, supporting pile, crown beam, prestressed anchor cable, and sprayed concrete. BC, FGH sections adopt upper slope, supporting piles, steel column, internal support, prestressed anchor cable, and sprayed concrete. (See Figure 1 for details.)

![Figure 1: general layout of supporting structure of foundation pit](image)

2.2. Construction key points

2.2.1 Construction process

According to the characteristics of this project, the overall construction procedures are as follows: leveling the site, entering the site of materials and equipment, erecting temporary construction → grading and first layer of earth excavation → construction of supporting piles, crown beams, column systems and first layer support systems → Start of foundation pit monitoring → excavation of earthwork layer by layer, layer-by-layer application of support system and anchor rod (cable) system, layer-by-layer application of concrete spraying between piles → soil excavation to the base, construction of blind drainage ditch → foundation pit layer by layer Backfill, apply the support layer by layer, remove support system layer by layer → backfill earth to the planned elevation, precipitation continues → stop precipitation construction

2.2.2 Supporting pile construction

2.2.2.1 Hole forming process
Considering the site conditions, geological conditions and hydrogeological conditions comprehensively, this project uses a long auger drill to form holes. In the construction, the method of jumping and driving is adopted, and the construction is carried out one pile apart.

2.2.3 Reinforced cage production, steel cage hoisting
After the concrete is filled with the pile holes by the pressure pump ascending with the auger, the steel cage is then hoisted. When installing the steel cage, the operation is required to be stable to prevent the steel cage from deforming; when lowering the steel cage, align the center of the hole gently and slowly. It is strictly forbidden to rise and fall or forcefully lower to prevent tilting, bending or collision with the hole wall.

After spot welding, the steel cage crane can be inserted into the concrete to a certain depth by its own weight in the living room. When the cage is longer by its own weight or cannot be pressed in, a vibrator can be used to shake it in.

2.2.4 Problems that easily occur during the construction process and their prevention measures

(1) Blocking pipe
There are two drill doors on both sides of the long spiral drill bit. The drill doors are closed during construction to prevent drill cuttings from entering the drill pipe and causing the drill pipe to block. When the concrete is pumped, the two drill doors are opened as the pump pressure increases, so that the concrete is poured into the hole. Once the drill door cannot be opened when the drill is lifted, there will be no concrete in the drilled hole, which will cause serious consequences. Therefore, it is required to check whether the drill door is stuck before and after each drilling. If a cohesive soil layer with high plasticity appears, the drilling tool rotary pump concrete method is used, which is to make the drilling tool rotate in the forward direction under the lifting while the concrete is pumped, so that the mud squeezed on the drill door becomes loose or falls off, so that the pump Press down to open the drill door.

(2) Stuck
In the process of long auger drilling, if the drill tool is lowered too fast, the drill cuttings will not be brought out of the hole in time, and the backlog between the drill pipe and the hole wall will result in a serious accident. If the accident is minor, we shall turn off the rotary power supply immediately, lift the drilling tool at the lowest lifting speed and re-drill it; if the accident is serious, first bolster the lower beam of the rig tower with machine sleepers, and then pull the drilling tool at the lowest lifting speed.

2.3 Construction of prestressed anchor cables

2.3.1 Construction process
Place anchor cable point → anchor cable drill in place → drill rig → anchor cable grouting → anchor cable waist beam production and installation → anchor cable tension

2.3.2 Key points of drilling rig
(1) Before drilling a hole, it is necessary to investigate the stratum of the site, underground obstacles and adjacent buildings, and determine the hole position and mark according to the design requirements.

(2) When the anchor cable is positioned, the horizontal hole pitch error should not exceed 50mm, and the vertical hole pitch error should not exceed 100mm.

(3) The anchor rod body adopts high-strength steel strand. The cutting length of the anchor cable rod body is: the length of the free section plus the length of the anchoring section 0.6~0.7m jack working length.

(4) The special anchor cable drilling rig is in place on the working platform 0.5m below the anchor
cable elevation, and the angle and flatness of the drilling rig are adjusted according to the designed anchor cable inclination. The hole diameter is 130mm.

(5) Strictly control the elevation of the anchorage working platform, avoid over-excavation or under-excavation, and ensure that the working surface is level.

(6) To ensure the grouting pressure of the anchor cable, a grouting device is installed at the junction of the free section of the bolt and the anchor section.

2.4 Reinforced concrete internal support

2.4.1 Construction process
Earthwork excavation → formwork construction → steel bar binding → concrete pouring → maintenance

2.4.2 Construction of internal support formwork
The beam formwork support system is erected with φ 48 × 3.5 steel pipe (about 300 mm in length). The longitudinal distance of steel pipe column is 1000mm, and the horizontal distance is 500mm. A horizontal bar is set as a sweeping bar. The beam formwork is made of 18mm thick polyester varnish smooth plywood and laid on the joist. The joist is made of 50 × 100 mm square timber with a spacing of 200-300 mm. Because the support height of beam formwork is only 300 mm, it is not necessary to calculate the stability of beam formwork.

2.4.3 Reinforcement works
Binding of beam and waist beam reinforcement: the binding joint position between longitudinal stressed reinforcement of beam shall be staggered with each other. From the center of any binding joint to 1.3 times of the lap length L1, the percentage of the cross-sectional area of the stressed reinforcement with the binding joint to the total cross-sectional area of the stressed reinforcement shall not exceed 25%, and the compression area shall not exceed 50%.

2.4.4 Concrete pouring
Before the concrete pouring, the sundries in the formwork and the oil stain on the reinforcement must be cleaned up. The gaps and holes of the formwork should be blocked tightly and watered, but there should be no ponding. During the concrete pouring process, the personnel should be sent to observe to prevent the deformation of the formwork. When pouring the beam concrete, the elevation control should be done well, and the concrete vibration time (generally 10 ~ 15 seconds) should be strictly controlled. The concrete vibrator should be inserted quickly and pulled out slowly. The appropriate spacing should be 400mm. Follow up the pouring direction to ensure that the elevation is accurate and the surface is smooth after the concrete pouring. After the concrete pouring, straw bags should be covered and watered for maintenance.

3. Deformation monitoring

3.1 Monitoring purpose

3.1.1 Check the correctness of various assumptions and parameters adopted in the design and guide the excavation of foundation pits and the construction of supporting structures.

3.1.2 Ensure the safety of the foundation pit supporting structure and adjacent buildings and provide a basis for reasonable formulation of protective measures.

3.1.3 Accumulate engineering experience to provide a basis for improving the overall level of foundation pit engineering design and construction.
3.2 Monitoring method
The on-site monitoring of foundation pit engineering should adopt the method of combining instrument monitoring and patrol inspection.

3.3 Monitoring content
According to the specific conditions of this project, in accordance with the relevant specifications and the foundation pit support design plan and the construction unit's relevant requirements for foundation pit monitoring, this foundation pit monitoring includes the following contents:

- Monitoring of the surrounding environment of the foundation pit mainly includes monitoring the settlement of the surrounding roads.
- Monitoring of support structure of foundation pit mainly includes horizontal displacement monitoring of support structure.
- Groundwater level observation mainly includes water level observation in foundation pits. The specific detection point layout is shown in Figure 2.

![Figure 2: Layout of Foundation Pit Monitoring System](image)

3.4 Monitoring results
The above monitoring content should be filled out carefully after each observation using a special form and reported to the construction unit and the supervision unit every week.

The monitoring results of the vertical displacement and deep horizontal displacement of the foundation pit are shown in Table 1 and Table 2 respectively.
Table 1: Vertical displace

| No. | Measured value of current observation (m) | Measured value of previous observation (m) | Initial value of vertical displacement test (m) | Current settlement value (mm) | Accumulated settlement (mm) |
|-----|----------------------------------------|-------------------------------------------|-----------------------------------------------|------------------------------|-----------------------------|
| JC1 | 3.0853                                 | 3.0865                                    | 3.1031                                        | -0.2                         | -16.8                       |
| JC2 | 3.1209                                 | 3.1209                                    | 3.1373                                        | 0.0                          | -16.4                       |
| JC3 | 3.0405                                 | 3.0405                                    | 3.0580                                        | 0.0                          | -17.5                       |
| JC4 | 3.0360                                 | 3.0362                                    | 3.0541                                        | -0.2                         | -18.1                       |
| JC5 | 3.0528                                 | 3.0530                                    | 3.0696                                        | -0.2                         | -16.8                       |
| JC6 | 3.0852                                 | 3.0934                                    | 3.1095                                        | -0.2                         | -16.3                       |
| JC12| 3.0785                                 | 3.0786                                    | 3.0953                                        | -0.1                         | -16.8                       |
| JC13| 3.0745                                 | 3.0745                                    | 3.0932                                        | 0.0                          | -18.7                       |
| JC14| 3.0647                                 | 3.0647                                    | 3.0831                                        | 0.0                          | -18.4                       |
| JC15| 3.0756                                 | 3.0757                                    | 3.0938                                        | -0.1                         | -18.2                       |
| JC16| 3.0913                                 | 3.0915                                    | 3.1102                                        | -0.2                         | -18.9                       |
| JC17| 3.0842                                 | 3.0843                                    | 3.1124                                        | -0.1                         | -18.2                       |
| JC18| 2.9663                                 | 2.9664                                    | 2.9863                                        | -0.1                         | -20.0                       |
| JC19|                                       |                                           |                                               |                              | -17.9                       |
| JC20|                                       |                                           |                                               |                              | -17.8                       |
| JC21|                                       |                                           |                                               |                              | -17.1                       |
| JC22|                                       |                                           |                                               |                              | -17.5                       |
| JC23|                                       |                                           |                                               |                              | -17.0                       |

This area has been backfilled
Table 2: Monitoring of deep horizontal displacement of foundation pit

| Hole No. SX1 | Pile depth - displacement curve | Depth (m) | Current Displacement | Accumulated Displacement |
|--------------|---------------------------------|----------|----------------------|--------------------------|
|              |                                 | -11.50   | -64.12               | -68.52                   |
|              |                                 | -12.00   | -68.27               | -78.52                   |
|              |                                 | -12.50   | -60.01               | -78.81                   |
|              |                                 | -13.00   | -81.20               | -81.75                   |
|              |                                 | -13.50   | -54.94               | -80.79                   |
|              |                                 | -14.00   | -58.83               | -85.53                   |
|              |                                 | -14.50   | -55.02               | -90.55                   |
|              |                                 | -15.00   | -49.51               | -99.91                   |
|              |                                 | -15.50   | -47.00               | -96.80                   |
|              |                                 | -16.00   | -39.65               | -95.29                   |

Note: the positive value is the change to the inside of the foundation pit, and the negative value is the change to the outside of the foundation pit. Control value: 30mm; warning value: 25mm, continuous 2mm / 4.

4. Conclusion
The supporting form adopted in this project is mainly traditional supporting piles and pre-stressed anchor rods (cables), combined with steel structure columns and reinforced concrete internal supports. This combined supporting form is adopted to better ensure the basement The safety of construction and foundation construction, as well as the surrounding adjacent buildings, roads and underground pipelines and other public facilities, while reducing the project cost. In addition, the reinforced concrete internal support is not limited by the lack of space during the construction process, and can be carried out simultaneously with other processes, thus speeding up the construction speed. In this project, two problems including internal support removal and groundwater treatment were also innovatively solved.
4.1 Removal of inner support
In the design of the foundation pit support project, the characteristics of the main structure are fully considered to avoid the conflict between the internal support and the main structure column and shear wall as far as possible. The strength of the internal support concrete is the same as that of the shear wall concrete. Under the condition of multi support in the foundation pit, the construction cost can be reduced, and the foundation structure can be ensured to meet the safety requirements.

In this project, the traditional construction technology of supporting first and then dismantling is abandoned. Instead, the main basement is constructed to the internal support position. Through precise calculation, some steel structure auxiliary supports are added to break some supporting beams which affect the construction. Some of the supporting beams which conflict with the structural columns and shear walls are drilled in the beams, and the reinforcement of the wall columns is penetrated through the holes. After the concrete pouring, this part of the supporting beams becomes a part of the wall columns. The support is not removed layer by layer, but is removed after the basement construction is completed and the foundation pit is backfilled.

4.2 Groundwater treatment
The project has abundant groundwater. After the site was excavated to the basement, piping occurred in many places, and water seepage in the site was serious. The traditional construction technique is to set up dewatering wells around the foundation pit for deep dewatering. However, due to the abundant groundwater in this project and the poor permeability of the soil on the site, the surrounding dewatering wells have a small influence radius, which cannot completely solve the piping phenomenon in the site. However, if a large number of dewatering wells are required in the site, it will affect the on-site construction and the cost will be higher.

Through analysis and experimentation, after excavation to the elevation of the base, according to the location of piping and site conditions, the project will excavate criss-cross trenches in the base, place PVC pipes, set water inlet holes and wrap them with gauze, and then place the trenches Backfill to channel the water in the site to the drainage ditch around the foundation pit. The effect is very good, which not only solves the situation of on-site piping, but also saves the construction cost.

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