Construction Technology of Partition Water Control Support for Water-rich Deep Foundation Pit

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Abstract. The water-rich deep foundation pit in complex site is restricted by factors such as narrow space, shallow groundwater development, diverse excavation conditions and deep excavation in the pit. Single support and drainage technology is difficult to ensure construction safety. Based on the project of Hainan National Emergency Medical Rescue Base, this paper proposes a zoning water control support technology. According to the excavation depth, surrounding environment and stratigraphic hydrological conditions, four construction zones are divided, and differentiated support structures are configured. Combined with pipe well dewatering, pit top water interception, open drainage in the pit, local drainage and other measures, the coordinated control of support and precipitation is realized. The numerical analysis shows that the deformation of the foundation pit is concentrated in the shallow layer behind the wall and the excavation contour, and the slope top loading will enlarge the deformation of the soil. This technology can provide reference for similar water-rich confined foundation pit projects.

Keywords: water-rich deep foundation pit; partition support; collaborative drainage; pile anchor support; pit-in-pit

1 Introduction

With the continuous improvement of urban underground space development intensity and the continuous increase of underground structure volume of large public buildings, deep foundation pit construction has become the core link of underground engineering construction[1-3]. The safety and stability of foundation pit excavation directly determines the construction conditions of the subsequent main structure, the efficiency of process connection and the overall construction quality of the project. There are many difficulties in the construction of deep foundation pit in complex sites : surrounding roads, existing buildings and narrow sites, which put forward higher requirements for support selection and excavation deployment[4] ; at the same time, the occurrence of groundwater, uneven stratum and local deep excavation conditions make the support force, dewatering and drainage in the pit and construction conversion mutually coupled and restricted[5]. Under the condition of limited site, different working conditions in each section and strict groundwater control standards, it is difficult for a single support or a single drainage scheme to meet the requirements of safety, adaptability and continuous operation at the same time[6]. Therefore, it is urgent to systematically sort out

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the construction method of coordinated control of support and drainage in combination with engineering practice.

Based on the National Emergency Medical Rescue Base (Hainan) project, this paper proposes a zoning water control support technology for the engineering conditions of water-rich strata, limited construction space and no water-stop curtain, and focuses on the support system adaptation, pile-anchor section stable hole-forming process, rapid construction conversion of pit-in-pit, collaborative drainage measures and numerical analysis of typical sections.

2 Engineering Overview and Difficulties

The National Emergency Medical Rescue Base (Hainan) project is located in Guilinyang, Haikou City, with a total construction area of 68088.26 m^2 and an underground construction area of 44546.26 m^2. It has two basements. The surrounding area of the foundation pit is adjacent to the road under construction, existing projects and temporary facilities, and the working space is limited.

2.1 Stratum and Groundwater Conditions

According to the site survey data, the main strata stratification from top to bottom is as follows:

1)Plain fill : the layer thickness is 1.20-3.50 m, loose to slightly dense, mainly composed of sandy clay, gravel and construction waste, and the permeability is medium.

2) Clay : layer thickness of 2.10-5.60 m, plastic-hard plastic state, small permeability coefficient, relatively impermeable ;

3) Coarse sand : the thickness of the layer is 2.30-8.80 m, medium-density compacting, which is the main phreatic aquifer of the site, with good connectivity, strong water abundance and high permeability ;

4) Silty clay : the thickness of the layer is 2.60-8.00 m, the plastic is hard plastic, the permeability is weak, and it is the relative aquiclude under the aquifer.

The site mainly contains phreatic aquifer, and the aquifer is mainly coarse sand layer, which is recharged by atmospheric rainfall and regional surface water. The stable groundwater level is 1.60-5.60 m. The water level fluctuates obviously with seasonal rainfall, and the water level rises by about 1.0 -1.5 m in rainy season.

2.2 Technical Difficulties

Strong constraints around the site; groundwater is shallow, and the risk of quicksand and water inflow is high; the support profile conditions vary greatly; the anchor cable passes through the water-bearing sand layer, and the hole grouting is easily disturbed by groundwater. The connection requirements of deep excavation process in pit are strict.

3 Partition Water Control Support Construction Technology

3.1 Subsection Support Matching Technology

The excavation depth, surrounding constraints and groundwater influence of each section of the foundation pit of this project are significantly different, and it is not suitable to use a single support. According to the excavation depth, surrounding constraints, groundwater sensitivity and local deep excavation conditions, it is divided into four zones:

1) Conventional slope area : section 3-3, 3a-3a, 3b-3b and 6-6, open site, shallow excavation, using 1 : 1 pure slope support ;

2) Slope reinforcement area :sections 1-1, 2-2, 5-5, 7-7, 9-9, 10-10 and 11-11 have construction loads on the top of the slope, which are supported by slope + soil nailing.

3) Pile-anchor control area : sections 4-4 and 8-8 , adjacent to buildings, deformation control is strict, using pile-anchor composite support ;

4) Pit-in-pit deep excavation area : the secondary excavation unit inside the foundation pit, the bottom of the pit to expose the coarse sand aquifer, no peripheral corresponding section, using SP-IV Larsen steel sheet pile + corner brace enclosure.Different support types and their corresponding relationships are shown in Table 1.

Table 1. Different support sections and corresponding support methods

The support type	represents the section	support method
Slope support	3-3, 3a-3a, 3b-3b, 6-6	1 : 1 slope
Slope + soil nailing support	1-1, 2-2, 5-5, 7-7, 9-9, 10-10, 11-11	1 : 1 slope + soil nailing
Pile-anchor composite support	4-4, 8-8	Cast-in-place pile + anchor cable + slope

Note: Table 1 is the statistics of the supporting section of the foundation pit. The deep excavation area of the pit in the pit belongs to the internal local deep excavation unit, as shown in Section 3.3.

For the 3-3,3a-3a, 3b-3b and 6-6 sections with gentle excavation conditions and working face can be expanded, 1 : 1 slope support is adopted, and the construction control focuses on slope forming, layered excavation and slope drainage. Rigid support should not be excessively increased in this type of section, and excavation stability should be ensured by controlling slope rate, slope closure and pit top drainage. The typical section of slope support is shown in Fig.1.

For the 1-1, 2-2, 5-5, 7-7, 9-9, 10-10 and 11-11 sections that are sensitive to slope conditions but still have slope space, 1: 1 slope combined with soil nailing support is adopted. In addition to controlling the geometric shape of the slope, this type of section also needs to improve the integrity of the slope through soil nailing, steel mesh and shotcrete to avoid local slip of shallow soil due to seepage, excavation disturbance and slope top load. The typical section of slope combined with soil nailing support is shown in Fig.2.

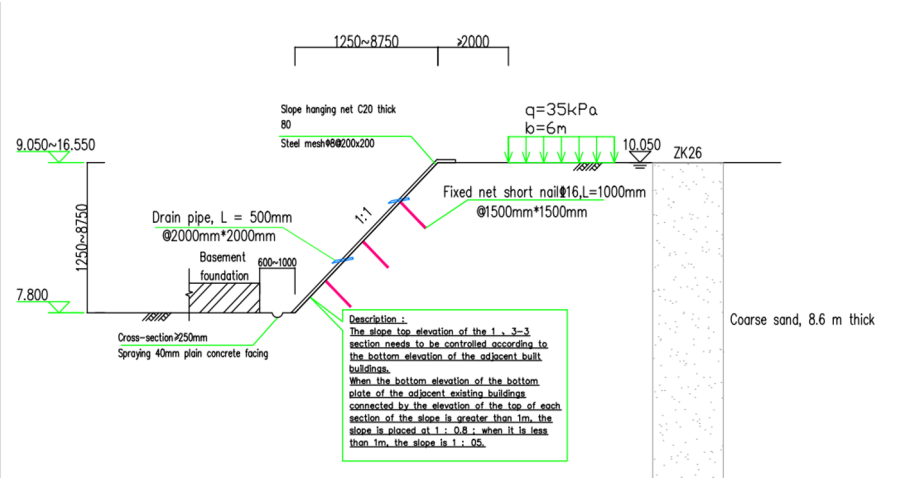


Fig. 1. Typical section of slope support (3-3 section)

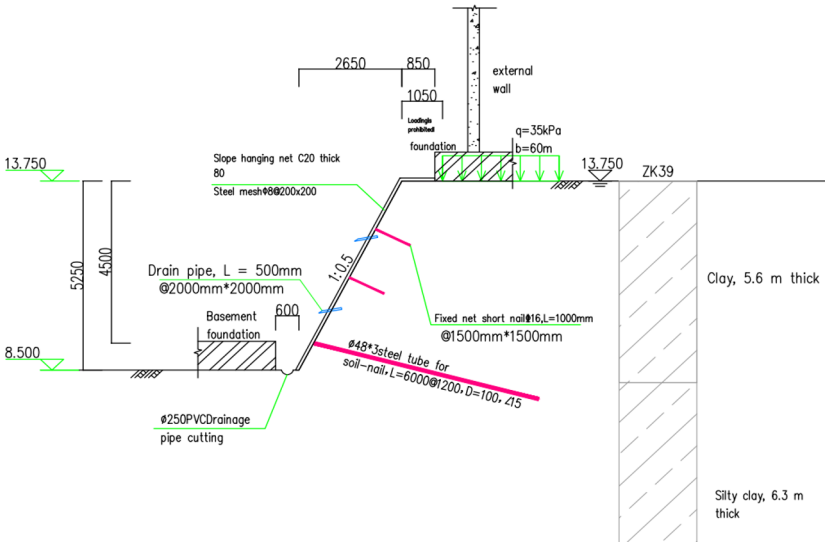


Fig. 2. Typical profile of slope combined with soil nailing support (9-9 profile)

For the 4-4 and 8-8 sections, the surrounding constraints are stronger and the deformation control requirements are higher. The combined support of cast-in-place pile, anchor cable and slope is adopted. In this type of section, the retaining pile bears the main lateral restraint, the anchor cable limits the displacement of the wall, the crown beam and the waist beam coordinate the pile anchor force, and the slope treatment is carried out simultaneously with the excavation. Compared with the slope and soil nailing section, the control focus of the pile-anchor section is changed from slope stability to pile-anchor cooperative force, anchor hole quality and wall deformation control.

3.2 Key Section Control Deformation and Stable Hole Forming Technology of Pile Anchor

The 4-4 and 8-8 sections are the key sections of the pile anchor with high deformation control requirements for this project. The 8-8 section adopts the combined support of cast-in-place pile, three prestressed anchor cables and slope, as shown in Fig.3. The risk of this section is concentrated in the displacement development of retaining piles after excavation and unloading, the disturbance of anchor cable hole formation and the superposition of groundwater seepage, especially when the anchor cable passes through the water-bearing sand layer, it is prone to water gushing, sand leakage and hole collapse. Therefore, this project adopts the coordinated control method of "layered excavation, casing hole preservation, secondary grouting and local water control."

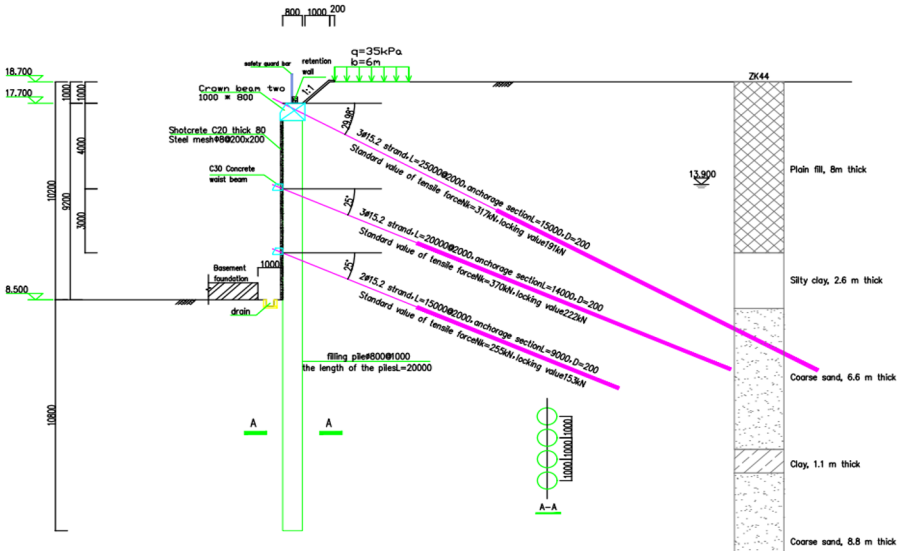


Fig. 3. Supporting structure diagram of key section of pile anchor (8-8 section)

The pile-anchor section is constructed according to the principle of ' first enclosure, layered excavation, layered anchorage and step-by-step restraint '.After the completion of the retaining pile and the top beam, the layered and partitioned excavation is carried out. After each layer is excavated to the elevation of the anchor cable, the hole forming, cable lowering, grouting, waist beam construction and tension locking are completed in time, and then the next layer of excavation is carried out. The anchor cable drilling is the key process. When crossing the water-bearing sand layer, the casing is used to follow up the drilling, and the problems of hole wall collapse and water and sand gushing are controlled. After the hole is formed, the hole is cleaned and grouted immediately. The cement slurry wall protection process needs to clean the bottom of the hole before grouting to ensure the anchoring performance. The anchor cable construction control is detailed in Figure 4.

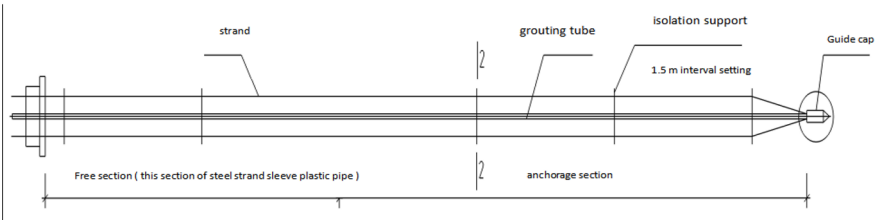


Fig. 4. Large sample of anchor cable and grouting structure

The anchor cable adopts the secondary grouting process to improve the anchorage compactness: the primary grouting fills the pores, and the secondary high-pressure grouting enhances the compactness of the slurry and the interface bonding force. The primary grouting pressure of this project is 0.5 ~ 0.8MPa, and the secondary grouting pressure is ≥ 2.5MPa.After the initial slurry strength reaches 5.0MPa, the grouting hole is set at the end of the anchorage section, and the cast-in-place pile, grouting body and ring beam are tensioned and locked after reaching the standard.

The pile-anchor section forms a complete set of technologies for layered excavation, casing hole formation, secondary grouting, and local water control. The supporting force, hole forming quality, anchoring performance, and groundwater control are integrated to effectively avoid the risk of anchor hole instability, anchoring failure, and enclosure deformation superposition in water-rich sand layers.

3.3 Pit-in-pit Steel Sheet Pile Corner Brace Fast Conversion Technology

There are two pit-in-pits in areas 7 and 8 of the basement in the middle of the project, with dimensions of 21.6 m×14.7 m and 14.7 m×14.7 m, respectively. The excavation area is small, but the deep excavation process is compact, and the enclosure, excavation, cushion, floor pouring and dismantling support need to be closely connected. The core of pit-in-pit construction does not rely on expanding the scope of support, but relies on closed enclosure and internal support to control deformation and ensure rapid structural construction.

The pit-in-pit support adopts the form of SP-IV Larsen steel sheet pile and corner brace. The purlin adopts double-assembled HM298 × 201 × 9 × 14 H-shaped steel, and the inner support adopts Φ400 × 8 steel pipe. The steel sheet pile forms a closed enclosure boundary along the periphery of the pit. The purlin is used to coordinate the force of the sheet pile and provide support connection conditions. The corner brace is used to limit the lateral deformation after local deep excavation. The technical focus of the structure is the closure of the enclosure boundary, the clear force of the support and the removal of the components, which can meet the requirements of rapid prototyping and subsequent structural connection in local deep excavation sections. The supporting structure of the pit is shown in Fig.5.

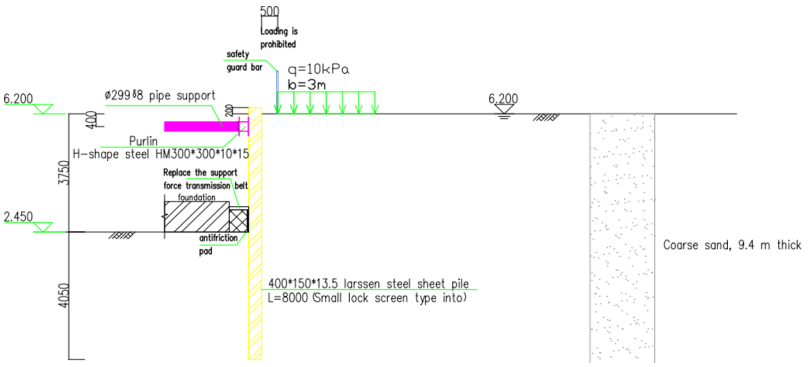


Fig. 5. Pit-in-pit steel sheet pile corner brace support structure diagram

The construction of the pit in the pit is controlled by the closure of the steel sheet pile retaining, the timely installation of the internal support and the formation of the foundation plate as soon as possible. The specific process relationship is shown in Figure 6. This method continuously connects temporary enclosure, internal support installation, staged excavation and foundation structure construction, which can reduce the adverse effects of support lag after local deep excavation, long-term exposure of pit bottom and pile pulling disturbance on the constructed structure.

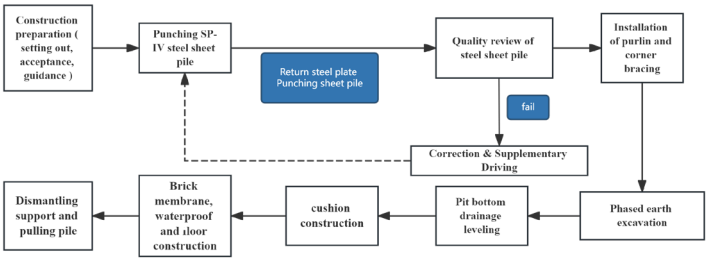


Fig. 6. Flow chart of steel sheet pile corner support construction in pit-in-pit

4 Collaborative Drainage Technology Under the Condition of No Water-Stop Curtain

4.1 Pre-dewatering and Drainage Diversion Technology of Pipe Wells Around the Pit

There is no waterproof curtain in this project. Groundwater, surface runoff and open water in the pit are easy to act on the slope surface, slope foot and pit bottom together during the excavation stage. In order to avoid the concentrated discharge of water after entering the excavation surface, this project adopts the diversion control technology of ' pipe well pre-dewatering + pit top water interception + pit bottom open drainage ', and integrates groundwater, surface water and pit open water into different drainage paths.

Pipe well pre-dewatering is used to control the groundwater level within the influence range of excavation in advance. The dewatering well should be arranged in the post-pouring zone of the raft foundation as far as possible to reduce the influence on the subsequent foundation construction. The diameter of the tube well is 600 mm, and the diameter of the steel cage filter is 400 mm. One is arranged every 25 m around the foundation pit, and one is arranged every 30 ~ 35 m around the post-pouring zone. The depth of the well is 15 m(According to ' Code for Groundwater Control Technology of Building and Municipal Engineering ' JGJ 111-2016 5.3.6.), and the depth of precipitation is controlled to not less than 0.50 m below the bottom of the foundation(According to ' Code for Groundwater Control Technology of Building and Municipal Engineering ' JGJ 111-2016 5.2.1). The dewatering in the pit is started before the excavation of the foundation pit, and the number of pipe wells is adjusted according to the excavation progress, rainfall and the amount of water in the pit, or the open drainage of the sump is supplemented. The main control parameters are shown in Table 2.

Table 2. Pre-dewatering and drainage control parameters of tube well

controlled member	Control structure	key parameter
groundwater	tube well precipitation	The hole diameter is 600 mm, the filter diameter is 400 mm, and the well depth is 15 m.
Water level around foundation pit	Pipe well around the pit	About 25 m around a mouth
Water level near post-pouring zone	Encrypted tube wells	About 30 - 35 m.
Water level at the bottom of foundation	Pre-precipitation control	Not less than 0.50 m below the bottom of the foundation
surface water	Cut-off ditches, water collecting wells	The top of the pit is continuously arranged, and the ground is closed.

The pit top drainage system is used to dredge the surface water body. The intercepting ditch and collecting well are set up around the foundation pit and on the top of the slope, and the ground of the intercepting ditch area is closed to reduce the infiltration of rainwater and construction wastewater. The system is independently arranged with the open drainage system at the bottom of the pit, and the water flow at the top of the slope can be directly intercepted and discharged, so as to avoid pumping after the catchment enters the pit. This measure can not only alleviate the slope erosion and soil softening of the slope and soil nailing section caused by rainfall, but also reduce the adverse effects of surface water on the soil behind the retaining wall and the construction surface of the anchor cable.

4.2 Continuous Drainage Technology of Open Water in Pit

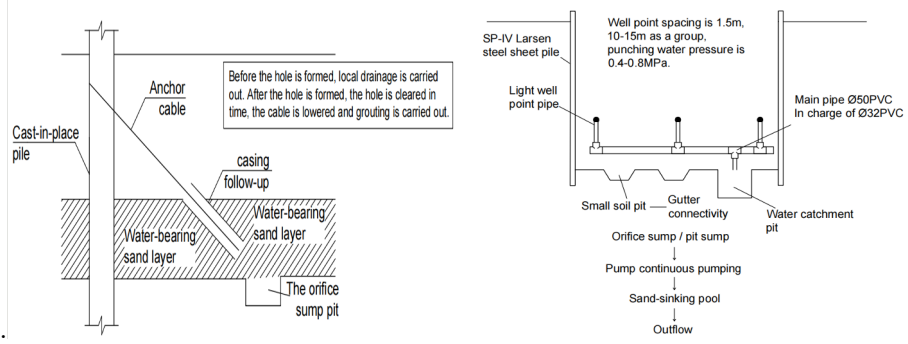
The pre-dewatering of the foundation pit tube well cannot completely isolate the slope seepage, rainfall catchment and sand layer seepage. The accumulated water is easy to

soften the base and hinder the cushion construction. The project adopts the open water treatment scheme of ' laying drainage channels first and then excavating in a large area ', and integrates the drainage ditch, water collecting well, water pump and grit chamber to form a closed-loop drainage system.

The foundation pit is matched with masonry and finished resin drainage ditch, and the water collecting well is set up according to the specification and the drainage slope is controlled. Drainage facilities are arranged before earthwork excavation, and pumping pumps are added on demand. The water in the pit is discharged after precipitation by the three-stage grit chamber to avoid pipeline clogging and ensure the stable construction of cushion, waterproof and floor.

4.3 Local Drainage of Key Sections and Light Well Point Strengthening Technology

The conventional pipe well pre-dewatering and pit bottom open row can meet the general water control requirements of large-scale excavation, but the water level control objects in the pile-anchor section and the pit-in-pit section are more concentrated. The risk of the former is concentrated on the water gushing, sand leakage and hole collapse when the anchor cable passes through the water-bearing sand layer, and the risk of the latter is concentrated on the water accumulation at the bottom of the pit after local deep excavation. In view of the above parts, this project adopts local drainage of anchor holes and light well points in pits to strengthen water control, and the control relationship is shown in figure 7.



(a)Pile-anchor section (b) Pit-in-pit section

Fig. 7. Local drainage control diagram of key section

The pile-anchor section adopts a complete set of hole control technology of ' drainage-casing-clearing ': before the construction of the anchor cable, the water pressure of the orifice is drained, the casing is followed up to avoid the collapse of the quicksand, and the hole is cleared immediately after the hole is formed. Grouting, centralized control of water and sand leakage in the anchor hole, to ensure the anchoring density.

The pit-in-pit relies on the linkage drainage of the light well point inside the steel sheet pile + the open row at the bottom of the pit, and the dewatering zone is arranged along the inner side of the support. The linkage sump reduces the groundwater level in

the deep excavation area and eliminates the interference of accumulated water on the floor construction.

The light well points are arranged in a group of 1.5 m spacing and 10 ~ 15 m, and the standard PVC pipeline is matched. The punching water pressure is 0.4 ~ 0.8MPa, the bottom of the hole is ultra-deep 500mm, the hole is filled with sand and gravel filter layer, and the wellhead clay is sealed. The parameters are shown in Table 3.

Table 3. Local drainage control parameters of key sections

Control link	Core process Single point pumping	Key parameters
Pile-anchor section	Local drainage before drilling + casing follow-up drilling	Temporary drainage near the orifice, timely hole cleaning, cable laying and grouting after hole forming
Pit-in-pit section	Light well point belt precipitation + pit bottom open row connected drainage	The well point spacing is 1.5 m, and 10 ~ 15 m is a group.
Well point branch pipe	Connected water delivery within the group	Φ32 PVC pipe
Well point main pipe	Water punching into holes	Φ50 PVC pipe
Punching into a well	Sand filter layer + clay sealing	The water pressure is 0.4 ~ 0.8 MPa, and the aperture is 300 ~ 350 mm.
Filter layer and sealing	The sand and gravel filter layer + clay sealing	filter layer is 60 ~ 100 mm, sealing 1.0 ~ 1.5 m.

The focus of the above-mentioned local dewatering strengthening technology is on fixed-point water control. The pile-anchor section aims at the stability of the anchor hole and the grouting quality, and the pit-in-pit section aims at the stability of the local deep excavation working surface. The two work together with the pre-dewatering of the pipe well and the open row at the bottom of the pit to ensure the continuous connection between the key section support and the structural construction.

5 Auxiliary Numerical Analysis of Typical Section

5.1 Numerical Modeling

This numerical simulation uses the midas GTS NX geotechnical finite element software, and selects the 8-8 section (JK section) with strong constraints and large excavation depth as the research object. The enclosure is C30 bored cast-in-place pile, which is equivalent to 0.62m thick continuous wall according to the principle of equivalent bending stiffness. The model is 60m wide, 30m deep, and the excavation depth is 8.7 m. Three anchor cables are set behind the wall. The soil is dominated by a quadrilateral mixed grid with a unit size of 1.0 m. The size of the retaining wall and the anchor cable

unit is 0.5 m. The bottom of the model is completely fixed, the horizontal degree of freedom is constrained and the vertical degree of freedom is released on both sides, and the surface is set as a free boundary. The Goodman contact element is set between the equivalent retaining wall and the soil. The normal stiffness $K_n = 1\times10^8$ KN/m^3, and the tangential stiffness $K_s = 1\times10^7$ KN/m^3 . The value is referred to the recommended experience range of the midas GTS-NX interface element manual. The interface friction angle is 0.7 times the internal friction angle of the adjacent soil layer. The anchor cable adopts the truss element. The first and second anchor cables are configured with 3Φ15.2 steel strands, and the axial stiffness EA = 8.13×10^4 KN. The third anchor cable is configured with 2Φ15.2 steel strands, and the axial stiffness EA = 5.42×10^4 KN. The stiffness is calculated according to the specifications of the steel strands in the profile drawings, and is calculated by the elastic modulus and the total nominal cross-sectional area of the steel strands. The prestress of the three anchor cables is taken from the design locking load of the support construction drawing, which is 191 kN, 222 kN and 153 kN respectively. The soil adopts a four-layer Mohr-Coulomb constitutive model, and the initial ground stress balance, excavation completion, and 30 kPa additional load on the top of the slope are calculated in turn. The material parameters and calculation models are shown in Table 4 and Figure 8.

Table 4. Soil material parameters table

soil horizon	ρ / kg·m^{-3}	E / Pa	v	c / Pa	φ / °	Ψ / °
1	1800	1.0×10^7	0.33	1.0×10^4	15	0
2	1900	2.0×10^7	0.35	2.5×10^4	18	0
3	2100	8.0×10^7	0.28	8.0×10^4	28	5
4	2300	3.0×10^8	0.23	2.0×10^5	38	8

Note : ρ is soil density, E is elastic modulus, v is Poisson 's ratio, c is cohesion, φ is internal friction angle, Ψ is expansion angle.

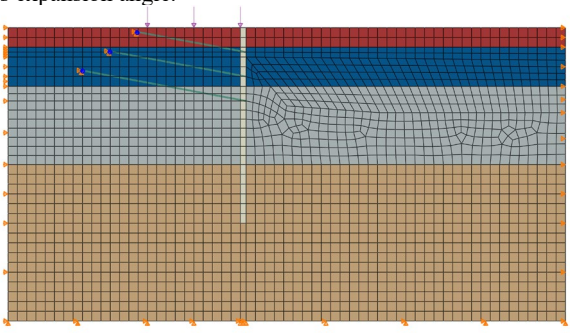
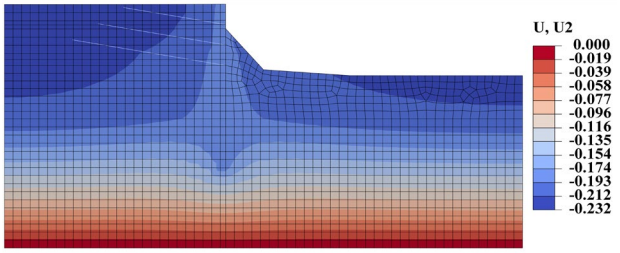


Fig. 8. The schematic diagram of typical section finite element model

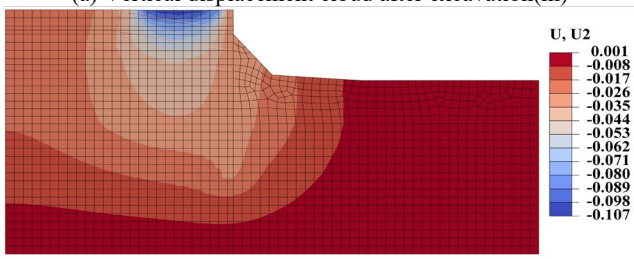
5.2 Numerical Calculation Results

From Figure 9, it can be seen that the deformation of the foundation pit is concentrated in the shallow layer behind the wall, the slope break and the excavation side line ; the

slope top load only aggravates the displacement of shallow soil. The numerical results confirm the control focus of the partition water control support in this paper.



(a) Vertical displacement cloud after excavation(m)



(b) Vertical displacement cloud diagram after external load(m)

Fig. 9. Numerical calculation results

6 Conclusion

Based on the water-rich deep foundation pit project in Hainan, this paper proposes a zoning water control support technology, which divides the foundation pit support zone according to the working conditions and supports differentiated support and comprehensive precipitation water control measures. The numerical analysis shows that the slope break of the foundation pit and the shallow layer behind the wall are the key control areas of deformation, which verifies the rationality of the technical zoning management idea.

This process can effectively solve the construction problems of water-rich deep foundation pits with limited sites and no water-stop curtains. For projects with abundant confined water and extremely high surrounding deformation control standards, it is still necessary to add water-stop structures and improve the calculation and whole-process monitoring system of confined water.

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