# Practical Research on the Support Engineering of 10,000-Square-meter Deep Foundation Pit with Muddy Rheology in Coastal Tidal Flats

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**Abstract.** To overcome the technical challenges of "high deformation risk, strong environmental sensitivity, and difficult construction" in the multi-megapascal deep foundation pits within the flowable silt strata of coastal tidal flats, based on the Ningde Lithium Battery Churuiwan Park Comprehensive Building Project, and considering the characteristics of the thick 15-30m flowable silt layer in the site, such as "high water content, low bearing capacity, strong disturbance sensitivity", and significant tidal influence, through the analysis of engineering geological characteristics, the composite support technology of slope excavation, grouting retaining piles, internal supports, and three-axis cement mixing pile water-stop curtain was adopted. The guiding casing and real-time inclinometer control deviation technology were utilized to form an integrated construction technology system of "dynamic precipitation against tides, layered and segmented excavation, and full-dimensional monitoring feedback". The practice has shown that this system effectively solved the problems of high instability risk of deep foundation pit support in the flowable silt layer and the difficulty in controlling the deformation of surrounding sensitive facilities. It provided reliable technical support and practical examples for similar projects in the coastal tidal flat areas of China.

**Keywords:** Coastal Tidal flats; Rheological silt; A 10,000-square-meter deep foundation pit; Support construction

## 1 Introduction

Driven by the "Maritime Power" strategy and the upgrading of the coastal economy, coastal tidal flats have emerged as crucial construction platforms. However, geological complexity poses efficiency challenges. Abundant research achievements exist in the realm of deep foundation pits for soft soil and tidal flats. Li et al.[1] validated the superior monitoring accuracy of discrete element three-dimensional coupling simulation. Wang et al.[2] integrated monitoring and machine learning to optimize support parameters for foundation pits in the coastal area of Fuzhou. Li et al. [3] and Wang et al. [4] separately


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scrutinized the tidal water level patterns and the hydrological mechanism of foundation pit dewatering. Sun and Li [5] enhanced numerical research methodologies using FLAC3D.

Although there have been breakthroughs in existing research, issues such as response to extreme working conditions still need to be overcome. The 10,000-square-meter deep foundation pit of the Ningde lithium Battery Liwan project has significantly increased the deformation range of the side walls and the dissipation time of pore water pressure, posing high safety risks. Moreover, it is necessary to ensure the safety of the surrounding flood control embankments and gas pipelines. Traditional technologies are no longer applicable, and technological innovation is urgently needed.

# 2 Project Overview and Geological Characteristics Analysis

## 2.1 Project Overview

This research is based on the Liyuan Industrial Park Comprehensive Building Project of Ningde Lithium Battery. The site is located on the coastal mudflat in Ningde, Fujian Province, belonging to a coastal sedimentary landform. It was formed by reclamation and filling of the mudflat. The total construction area of the project is approximately 58,000 square meters, and the excavation area of the foundation pit is 12,000 square meters. The excavation depth is 9.6 - 11.2 meters, with a safety level of grade one. The deformation control is extremely strict. The maximum allowable horizontal displacement of the supporting structure is ≤ 30mm, and the maximum allowable settlement of surrounding buildings and pipelines is ≤ 20mm. The construction position of the engineering foundation pit is shown in Figure 1.

**Fig. 1.** shows the construction location of the foundation pit for the project

## 2.2 Engineering Geological Conditions

### 2.2.1 Rock and Soil Layer.

The original landform of the proposed site is a tidal flat. The site has been initially leveled, and the terrain is relatively flat and open. The underlying bedrock is mainly the late Yanshan intrusive granite (γ52 (3) c). Its main calculation parameters are shown in Table 1.

**Table 1.** Values of main design Parameters for rock and soil layers

| Geotechnical name index | γ $kN/m^3$ | Shear strength | |
|---|---|---|---|
| | | Cohesive force (kPa) | Internal friction Angle (°) |
| Plain fill soil | 17.8 | 5.0 | 20.0 |
| Silt | 15.7 | 13.0 | 1.2 |
| Mud-containing pebbles | 21.0 | 5.0 | 30.0 |
| Silty clay | 18.6 | 21.1 | 15.1 |
| Residual cohesive soil | 18.8 | 16.2 | 22.2 |
| Fully weathered granite | 20.0 | 20.0 | 25.0 |

#### 2.2.2 Hydrological Conditions.

The surface water of the site is low-lying accumulated water, and the groundwater contains water from submerged soil fill, slightly confined water from muddy pebbles, and water from the pores and fissures in the weathered zone of the bedrock. The investigation shows that the initial water level is buried at a depth of 0.00 to 3.52 meters (at an elevation of 1.45 to 3.34 meters), and the stable water level is buried at a depth of 0.00 to 3.10 meters (at an elevation of 1.95 to 3.74 meters). The design of the foundation pit takes the groundwater level on the outer side as 2.00m below the slope top and on the inner side as 1.00m below the excavation face.

#### 2.2.3 Surrounding Environment.

The project is located on the northeast side of Cheliwan Industrial Park in Jiaocheng District, Ningde City, adjacent to 20-meter-wide Xinghu Road on the southeast side. Forty meters to the southwest, there is the flood control embankment of Cheliwan Stream and the proposed Gande Road. Eighty meters to the southwest is the Cheliwan Bridge of Shenhai Expressway. The sea flood control embankment is located 35 meters to the north. There is a 2.5-meter-high single-story steel structure gas facility building and visible gas pipelines in the northeast corner of the site.

### 2.3 Engineering Difficulties

The foundation pit of this project has a perimeter of 488 meters and a maximum excavation depth of 7.1 meters. It is located in a coastal tidal flat reclamation area, and the construction difficulties are prominent: Firstly, the geological conditions are complex, including thick rheological silt layers and other composite strata, with a high risk of collapse; Second, the water level fluctuates greatly due to tides, and the moisture content of the soil changes, intensifying deformation and making drainage difficult. Third, the deformation control of sensitive facilities such as flood control embankments and gas pipelines around is strictly controlled. Fourth, the construction environment is harsh, the support is prone to corrosion and dewatering management is difficult.

# 3 Key Technologies for Construction of Composite Support Structures in Rheological Silt Texture Layers

## 3.1 Selection of Support Scheme

In order to protect the safety of the engineering piles inside and outside the foundation pit, the design should be based on the deformation control. Through comprehensive comparison and selection, steel sheet pile: the construction speed is fast, but the ability to resist lateral deformation is weak, and large deformation is easy to occur in rheological muddy strata, which is difficult to meet the deformation control requirements of surrounding sensitive facilities. Prestressed concrete pile: low cost, but relatively low strength, in deep silt layer supporting effect is limited, it is difficult to ensure the long-term stability of foundation pit. Finally, the cast-in-place pile is selected, which has high bearing capacity and strong adaptability, and can form a composite support system with internal support and waterproof curtain to effectively control the deformation of foundation pit. Finally, the cast-in-place pile was selected as the core support component, and the foundation pit support method was clearly defined as a composite system of"Slope + cast-in-place pile + internal support", accompanied by water-stop curtain and dewatering system, form a pattern of all-round support.

## 3.2 Key Technologies for Support Pile Construction

### 3.2.1 Innovative design for the compatibility of support piles with composite strata.

The traditional design of support piles is mostly based on the assumption of homogeneous soil layers, which is difficult to adapt to the force characteristics of composite strata. Considering that the support piles pass through multiple soil layers, and the contributions of each soil layer to the lateral frictional resistance and the resistance at the pile tip are significantly different, a stratified calculation model is established:

$$R_a = q_{pa} A_p + u_p \sum_{i=1}^{n} q_{sia} l_i \tag{1}$$

In the formula: Rheological silt layer $q_{sia}$ =12kPa, Muddy pebble layer $q_{sia}$ =55kPa, Tuff $q_{sia}$ =120kPa; $l_i$ is the pile length (m) in the i-th layer of soil (m); $q_{pa}$ is the characteristic bearing capacity value (kPa) of the soil at the pile tip (tuff), taken as 3000kPa.

The characteristic value of the vertical bearing capacity of a single pile calculated by this model is 2850kN, and the on-site load test result is 2920kN. The calculation error is only 2.4%, which verifies the accuracy of the model and provides a reliable basis for the design of support piles.

**3.2.3 Key Controls for the Construction of Support Piles.**

The support piles are 800mm bored cast-in-place piles with a spacing of 2.0m. The length of the piles penetrating the silt layer is ≥5.5m. C30 underwater concrete is used, and the construction is carried out by intermittent jumping. The interval between adjacent piles is ≥36h. The ZZ-6A drilling rig is used for hole formation. It has a small stroke in silt layers and a medium stroke in isolated rock or inclined hard rock layers, and is equipped with a composite mud system. The main bars of the steel cage are mechanically connected. The underwater concrete pouring strictly controls the slump, the burial depth of the conduit and the over-pouring amount. The sediment after hole cleaning should be no more than 100mm, and the pouring should be completed within 30 minutes.

### 3.3 Collaborative Design Technology of Support Piles and Water-stop Curtains

In order to solve the problem of leakage caused by the loose connection between the supporting pile and the water stop curtain in the composite stratum, the triaxial cement mixing pile is used as the water stop curtain, the construction interval of adjacent piles is less than or equal to 10 hours, and the construction interval of lap joint is less than or equal to 24 hours. Biaxial cement-soil mixing piles are used in the inner side of the foundation pit to prevent backflow, and an effective anti-seepage barrier is formed by adjusting the cement content and construction parameters.

### 3.4 Construction of the Internal Support System

Adopt "concrete support +Φ609×16mm steel support" combined system: circular supports arranged around the pit (8-10m spacing), crown beam (1000×1200mm, C30 concrete). Steel supports connect via flanges (16 high-strength bolts, ≥24mm diameter), apply 70% design prestress in stages (synchronous hydraulic jacks), load-hold 30min then wedge spacers. Support elevation/position deviation ±30mm. Excavate only after support reaches 100% design strength. Remove by "replace first, remove symmetrically in sections"—only when basement structure hits 100% strength and temporary C30 plain concrete supports (4500-6000mm spacing) are set.

## 4 Dynamic Precipitation and Anti-Tidal Technology

### 4.1 Layout of Precipitation System

A combined scheme of "open channel drainage + dewatering well" is adopted: 400×400mm water interception ditches are set up at the top and bottom of the slope, and 1m deep collection Wells are set up every 30-40m at the bottom and top of the pit, equipped with 20 7.5kW mud pumps to ensure that the water level in the pit is 1.0m lower than the excavation face. Inside the pit, Φ609 dewatering Wells are arranged at intervals of 25 meters (6 meters above the bottom of the pit). Eight water level observation holes are set outside the pit for automatic monitoring every 15 minutes. During the tidal period, when the water level rises by 0.5 meters, the water pumping volume is increased by 5 to $8m^3/h$.

### 4.2 Anti-Tidal Seepage Control

Before the construction of the water-stop curtain, the parameters of the test piles were optimized. Before excavation, water was injected to test the integrity. The leakage points were sealed with 1:0.5 double-liquid grouting (pressure 0.5-0.8MPa). The surface of the water interception ditch at the top of the slope should be plastered with mortar to prevent leakage. No loading is allowed within 3 meters around the pit. For heavy vehicles passing through, steel plates should be laid and 500mm of backfill soil should be added to lift it. The load should not exceed 20kPa.

## 5 Layered and Segmented Excavation Process

### 5.1 Strict Control of Excavation Parameters

During the excavation process of the foundation pit, the principle of "excavate first, set supports later, layer by layer and section by section, symmetrical and within time limit" is strictly followed to ensure the safety and stability of the construction. The thickness of each layer should fully consider the characteristics of different soil types. For general soil layers, the thickness of each layer should be controlled to be no more than 2 meters; if encountering silt layers, due to their special physical properties, the thickness of each layer needs to be strictly controlled within 1.0 meters; while for fill soil, the thickness of each layer should not exceed 1.5 meters. The length of each section should be controlled within 20 meters. After each section of soil is excavated, internal supports should be set up promptly and completed within 24 hours to effectively resist the lateral pressure generated by the soil and prevent safety accidents caused by imbalance of soil pressure. The excavation sequence is carried out in a step-by-step manner from the side far from the flood embankment to the side close to the embankment. The height difference between the two sides of excavation should not exceed 1.0 meter. When excavating to the bottom of the pit, an artificial clean soil layer of 300 millimeters thick should be reserved.

### 5.2 Special Measures for Sensitive Areas

To ensure the safety of the flood embankment, before excavation, a recharge well was set up at a distance of 10 meters from the embankment foot. The recharge well was adjusted dynamically based on the real-time monitoring data, and the recharge volume was controlled within a range of 3-5 $m^3/h$. During the construction process, when the monitoring data indicated that the embankment settlement reached 8 mm, the recharge operation was immediately initiated. The settlement rate of the embankment was strictly controlled at ≤ 0.5 mm/day to ensure the structural stability and safety of the flood embankment during construction and to avoid potential safety hazards caused by settlement issues. Φ300mm micro-piles were laid on both sides of the gas pipeline. The pile length was set at 10 meters, and the pile spacing was controlled at 1.5 meters. Above the pipeline, a 20 mm thick steel collar was laid and a laser displacement meter was installed for 24-hour monitoring. When the deformation of the pipeline was detected to reach 3 mm, the excavation in the adjacent area was suspended, and the construction parameters of the supporting piles were adjusted to avoid serious safety accidents such as gas leakage caused by improper construction.

## 6 All-round Monitoring and Dynamic Adjustment

### 6.1 Layout of the Monitoring System

Monitoring of a 10,000-square-meter deep foundation pit in coastal tidal flats requires real-time monitoring of the slurry's creep deformation and the deformation of surrounding sensitive facilities. Through automated monitoring and manual inspection, the displacement at the top of the monitoring pile, the deep horizontal displacement, the groundwater level, the settlement of surrounding facilities, and the internal forces of the supports are monitored. The monitoring contents are shown in Table 2 below.

**Table 2.** Monitoring Items and Contents for 20,000-square-meter deep foundation pit Construction

| Monitoring Item | Key Layout Points | Monitoring frequency | Early warning indicator |
|---|---|---|---|
| Pile Top Displacement/Settlement | 1 point per 20m along the foundation pit perimeter, dense arrangement at external corners, ≥3 points per side | 1-2 times/day during excavation; increased to 2 times/day if deformation rate >3mm/d | Horizontal displacement ≥30mm, settlement ≥20mm, rate ≥3mm/d |
| Deep Horizontal Displacement | Middle and external corners of the perimeter, ≥1 point per side, inclinometer tube length = pile length | 1 time/day during excavation | Displacement ≥40mm, rate ≥3mm/d |
| Groundwater Level | Arranged inside/outside the pit as needed, spacing 20-50m | 1 time/2h during tidal period; 1 time/6h during neap tide period | Abnormal change > 500mm |
| Surrounding Facility Settlement | 10 points for flood dike, 12 points for gas pipeline, 1 point per 30m on the ground surface | 1 time/day | Flood dike settlement ≥15mm, gas pipeline settlement ≥10mm |
| Support Internal Force | ≥3 points per layer, 1/3 span of concrete supports | 1 time/day during excavation | |

## 6.2 Dynamic Response Mechanism

In the construction monitoring and early warning system for flowable silty deep foundation pits in coastal tidal flats, a three-level dynamic response mechanism was divided based on the proportional relationship between the monitoring data and the warning values, and corresponding countermeasures were formulated. The details are as follows:

When the monitoring data reaches 70% of the warning value, the first-level response is triggered. At this time, the monitoring frequency should be increased to twice a day to obtain more timely and accurate information on the deformation of the foundation pit; at the same time, the excavation speed should be reasonably adjusted to reduce the impact of the construction progress on the stability of the foundation pit; and pile loading operations in the adjacent area of the foundation pit should be suspended to prevent additional loads from exacerbating the deformation of the foundation pit.

If the monitoring data rises to 85% of the warning value, the second-level response is initiated. The primary measure is to immediately stop the excavation of the foundation pit to prevent further deterioration of the deformation; and temporary steel supports should be added at the top of the pile, using Φ480×10mm steel pipes, to enhance the stability of the pile body; for the silty layer on the side of the pile, high-pressure grouting should be used for reinforcement treatment, with the grouting pressure controlled at 0.6 MPa, to improve the strength and deformation resistance of the soil.

Once the monitoring data reaches 100% of the warning value, it indicates that the foundation pit is in an extremely dangerous state. At this time, the third-level response should be initiated immediately. The primary task is to immediately organize the personnel and equipment in the pit to evacuate to a safe area to ensure the safety of personnel and the integrity of equipment; then, emergency measures should be taken to reinforce the foundation pit, such as using sandbags to pile up at the slope foot, with a pile height of 2m and a width of 3m, or using a backfilling machine for backfilling counter-pressure to increase the stability of the foundation pit; immediately activate the pre-established emergency reinforcement plan to conduct comprehensive and systematic reinforcement treatment of the foundation pit to prevent accidents.

## 6.3 Monitoring Data Processing and Feedback Application

### 6.3.1 Data Processing and Analysis Methods.

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**6.3.2 Monitoring Feedback and Parameter Optimization.**

Construct a closed-loop feedback mechanism of "monitoring data - early warning trigger - parameter adjustment", and optimize parameters according to the early warning threshold: When the deep horizontal displacement of the support pile exceeds 15mm, adjust the mud ratio and slow down the drilling speed, and the deformation rate is reduced to 0.8mm/d; When the water level fluctuation causes the surface settlement to exceed 8mm, increase the water pumping volume and add reinjection Wells to control the water level fluctuation to ≤0.5m. The deformation rate of the area adjacent to the flood control embankment exceeded the standard. The excavation sequence and the thickness of each layer were adjusted, and the total settlement of the flood control embankment was controlled at 9mm.

## 7 Conclusion

Based on the Ningde Lithium Battery Liwan Project, this research has developed a deep foundation pit support technology system suitable for coastal tidal flats. Innovative composite support structure and deviation control technology, with a qualified rate of 98% for hole verticality. The integrated solution keeps the water level fluctuation of the foundation pit within 0.5 meters. Practice has shown that the deformation of the support and surrounding facilities has met the standards, providing a replicable technical example for similar projects in coastal tidal flats.

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