# Construction Design of Pile Anchor Support in Deep Foundation Pit Excavation

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**ABSTRACT**

This paper briefly introduced the deep foundation pit and deep foundation pit pile anchor support technology and then made a numerical simulation on the deep foundation pit excavation and pile anchor support structure of a high-rise building project in Xuantan community, Qianzhou street, Jishou, Hunan province, China. In addition to the original pile anchor support scheme, an optimization scheme was proposed in the case analysis. The height of the second row of anchors was adjusted from - 6 m to - 7 m, and the third row of anchor cable was adjusted from - 9 m to - 11.5 m. The simulation results showed that the error between the simulated value and measured value under different working conditions in the original scheme was within 1.22% ~ 2.21%, which had a high reference value in the engineering analysis, and the calculation model was effective. With the advancement of the working conditions, the overall horizontal displacement of the cast-in-place pile under the two schemes increased, and the original scheme had more increase, the horizontal displacement of the cast-in-place pile under the same working condition was smaller, and the position where the maximum horizontal displacement occurred moved up. The maximum settlement displacement of the surrounding surface of the foundation pit under the two schemes increased with the advancing of the working condition, the original scheme increased more. The maximum settlement displacement of the optimization scheme was smaller under the same working condition.

## 1. INTRODUCTION

In the process of urbanization, although the number of buildings has increased, the area available for construction in an area is limited [1]. When the building cannot expand horizontally on the ground, people begin to expand vertically, that is, to build high-rise buildings and underground buildings [2]. On the one hand, the surface construction area is limited; on the other hand, it benefits from the development of building materials science. Building materials with better mechanical properties can support the vertical expansion of buildings. The increase of building height makes its self-weight increase. When building a house, first of all, it is necessary to dig a foundation pit of appropriate size on the ground surface. Usually, the pit depth is determined according to the design height of the building; the higher the building is, the deeper the pit is. The function of foundation pit is to carry part of the structure buried in the ground, so that the building is more stable [3].

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In modern buildings, buildings with a height of 10 m are everywhere; therefore, in order to ensure the stability of the building, the foundation pit will be dug deep. In the process of excavation, deep foundation pit will be affected by factors such as soil quality and groundwater in the construction site. One of the manifestations is the loose soil at the edge of the pit, which will result in geological instability around the pit and cause geological changes such as ground subsidence and pit bottom uplift. It will not only increase the risk of construction, but also reduce the stability of the building. Therefore, it is necessary to pay attention to the structural reinforcement when excavating deep foundation pit, and the deep foundation pit support technology is a kind of reinforcement technology [4]. Tang et al. [5] took a deep foundation pit project in Xuzhou as an example, established the FDM numerical model of foundation pit supporting pile and ground deformation under different supporting modes by using FLAC-3D software. The experimental results showed that the pile spacing was the main factor causing the foundation pit deformation, which was mainly reflected in the lateral displacement of supporting pile and the settlement around the foundation pit, while the row spacing had little effect on the deformation. Li et al. [6] analyzed the influence of reinforcement on the deformation of supporting pile, the overall stability of foundation pit and the bending moment of supporting pile by using the finite element method, and the research results showed that the maximum horizontal displacement of supporting pile after reinforcement significantly reduced and the overall stability safety factor of foundation pit greatly increased compared with that without reinforcement. Liu et al. [7] made a simulation calculation on the support structure using FLAC ~ (3D) simulation software, compared the result with the field measured value, and found that the simulation value was basically consistent with the measured value and the numerical simulation result was reliable. In this study, the deep foundation pit and deep foundation pit pile anchor support technology were simply introduced. Then, a numerical simulation was carried out on the deep foundation pit excavation and pile anchor support structure of a high-rise building project in Xuantan community, Qianzhou street, Jishou, Hunan, China, using ABAQUS software. In addition to the original pile anchor support scheme, an optimization scheme was proposed in the case analysis. The height of the second row of anchor cable was adjusted from - 6 m to - 7 m, and the height of the third row of anchor cable was adjusted from - 9 m to - 11.5 m.

## 2. DEEP FOUNDATION PIT AND SUPPORT

Before building construction, it is often necessary to dig a foundation pit in the designated area. The depth of the foundation pit depends on the height of the building and architectural design requirements [8]. With the decrease of usable area of surface buildings, in order to improve the effective utilization rate of the building area, the building begin to expand longitudinally. Both the increase of building floors and the demand for the basement of buildings promote the foundation pit depth of the building foundation engineering to increase gradually [9]. Compared with the general shallow foundation pit, the construction of deep foundation pit is more difficult. After the part of soil layer is removed during the excavation of deep foundation pit, the stress balance of the original soil layer will be broken. According to the nature of soil layer, under the influence of self-weight and vibration during construction, it will deform towards the center of the foundation pit. When the deformation exceeds the critical point, the deep foundation pit will collapse, causing personnel and cost loss and slowing down the progress of subsequent construction projects [10].

Therefore, before the excavation of deep foundation pit, it is necessary to fully investigate the geology of the construction site in order to develop reasonable protective measures.

The supporting structure of deep foundation pit has the following characteristics during excavation:

- The supporting works are carried out together with the excavation works, so the longitudinal depth of the supporting works is also as large as that of deep foundation pit;
- The supporting works are incremental, regional and risky in the construction process; incremental means that the excavation works are not excavated to the target depth at one time, but layer by layer, therefore the supporting work is also layer by layer; regional refers to that the supporting technology types will be affected by the environment of the construction site; risky is because that the probability of emergency is large due to the long cycle of excavation works and supporting works [11].

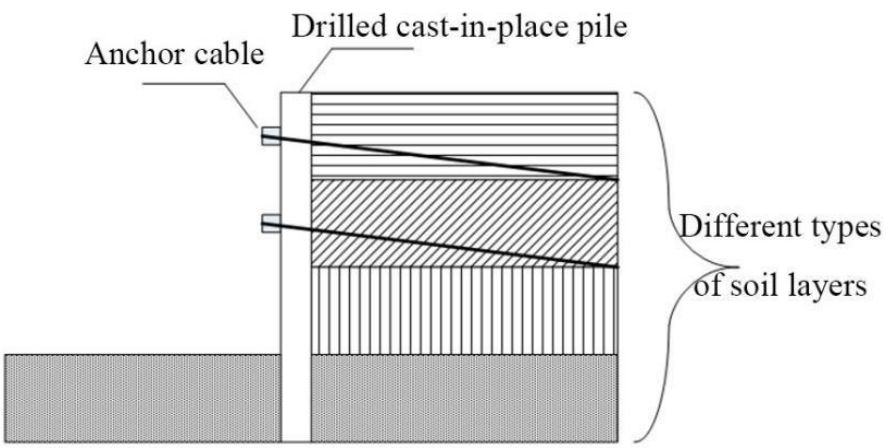


Figure 1 Schematic diagram of pile anchor support for deep foundation pit

As shown in Figure 1, the pile anchor support structure consists of cast-in-place pile and anchor cable [12]. The cast-in-place pile is a pile formed by drilling and pouring concrete into the ground through a drilling machine before the excavation of a deep foundation pit and then solidifying; the anchor cable is a structure that uses steel strands to stabilize the pile after drilling on the wall of the foundation pit. In Figure 1, with the increase of the excavation depth of the earth, it will pass through different types of soil layers, and the specific types will change according to the different construction areas. The construction process of pile anchor support for deep foundation pit is as follows.

1. Firstly, a drilling machine is used to drill holes on the ground. The hole diameter and depth are determined according to the needs of the building, and the spacing between holes is kept at about 1 m;
2. The reinforcement cage in the pre-made column pile is put into the drilling hole, and then concrete is gradually poured into the hole. After the concrete is solidified, the deep foundation pit excavation project starts [13].
3. The excavation works need to be carried out layer by layer in stages to ensure safety. When the earthwork is excavated to the preset depth, the anchor hole is positioned.
4. According to the positioned anchor cable hole, a drilling machine is used for drilling, and the depth of hole is determined by the design objective.
5. After drilling, the hole is cleaned. Anchor cable is made using steel string according to the hole depth, and anti-corrosion treatment is carried out for the anchor cable.
6. The anchor cable is installed in the drilling hole, and the earthwork excavation continues after the anchor cable is connected with the column pile. The above steps are repeated after reaching the designed depth.

## 3. EXAMPLE ANALYSIS

### 3.1. Engineering Overview

A high-rise building project in Jishou, Hunan, China was taken for instance analysis. The total floor area of the building was about 4000 m2, and the building surface height was 14 m. In this construction project, the depth of the foundation pit was 14 m, and the area was about 3860 m2. In the process of foundation pit excavation, pile anchor support technology was used to stabilize the deep foundation pit.

The soil structure of the area where the deep foundation pit of the construction project was located is shown in Table 1. There were four types of soil layers, miscellaneous fill soil layer, coarse sand layer [14], silty sand layer and silty clay layer [15], from top to bottom, and the parameters are shown in Table 1.

The supporting scheme of deep foundation pit in the construction project is as follows. The supporting form of bored pile combined with anchor cable was used, that was, the pile anchor supporting structure, in which the section diameter of bored pile was 600 mm, the pile spacing was 1.8m, the pile length was 18 m, and the elastic modulus was 2□104 MPa, and Poisson's ratio was 0.25. Three rows of anchor cables were used, and the relevant parameters of each row of anchor cables are shown in Table 2. The first row of anchor cables refers to the anchor cables of the first group of auxiliary cast-in-place piles set in the process of digging down from the ground surface, the second and third rows and so on. The anchor cable positioning hole height refers to the position of drilling holes on the pit wall before setting the anchor cables. The construction scheme of the supporting structure in the deep foundation pit excavation is as described above, and the foundation pit was monitored and data recorded during the construction process [16], including the horizontal displacement of the cast-in-place pile at different depths and the settlement of the ground around the foundation pit (such data was used for comparison with the numerical simulation data later).

Table 1. Structural parameters of soil layer in the area where deep foundation pit locates

| **Soil layer number** | **1** | **2** | **3** | **4** |
|---|---|---|---|---|
| Soil type | Miscellaneous fill | Coarse sand | Silty sand | Silty clay |
| Thickness of soil layer/m | 2 | 3 | 3 | 6 |
| Weight of soil layer kN/m$^3$ | 18.2 | 20.1 | 19.6 | 19.1 |
| Modulus of elasticity/MPa | 15 | 30 | 28 | 40 |
| Internal friction angle/° | 10 | 28 | 26 | 9 |
| Cohesion/kPa | 10 | 2 | 3 | 21 |

Table 2 anchor cable parameters of pile anchor support scheme

| **Row of anchor cable t** | **One row** | **Two rows** | **Three rows** |
|---|---|---|---|
| Anchor cable positioning hole height/m | -3 | -6 | -9 |
| Length of anchor cable/m | 20 | 23 | 22 |
| Length of free section/m | 8 | 9 | 7 |
| Length of fixed section/m | 12 | 14 | 15 |
| Axial tension/kN | 230 | 280 | 290 |

### 3.2. Numerical Simulation

In this study, ABAQUS software [17] was used for numerical simulation. Moreover, the optimization scheme was proposed: the distance between the first row and the second row of anchor cables was expanded from 3 m to 4 m, the distance between the second row and third row of anchor cables was expanded from 3 m to 4.5 m, and the other parameters remain unchanged. The calculation model is shown in Figure 2. The deep foundation pit area was 30 m long, 20 m wide and 14 m deep. The whole calculation model was 30 m wide, 90 m long and 40 m high. In this study, Mohr-Coulomb plastic model [18] was used to simulate the soil layer where the foundation pit was located, and the physical parameters of the soil layer are shown in Table 1. For the convenience of calculation, the cast-in-place pile was equivalent to the continuous braced wall, and the elastic model was used; the truss element was used for the anchor cable [19]. The boundary constraints were: horizontal constraints at the left, right, forward, and back and vertical and rotation constraints at the bottom [20], and the other boundary displacement is free.

The change of the soil around the foundation pit is related to the excavation process. Therefore, when numerical simulation was conducted for the support structure of the deep foundation pit, it was necessary to simulate the construction process of the deep foundation pit at the same time. The process was as follows: working condition 1: excavate to 3.5 m below the surface, and then carry out the construction of the first row of anchor cables; working condition 2: excavate to 7.5 m below the surface, and then carry out the construction of the second row of anchor cables; working condition 3: excavate to 11 m below the surface, and then carry out the construction of the third row of anchor cable; working condition 4: excavate to 14 m below the surface.

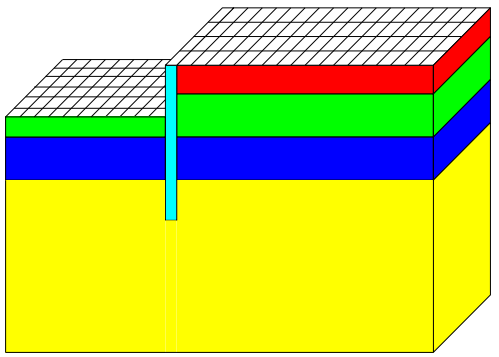

Figure 2 Numerical calculation model of deep foundation pit support structure

### 3.3. Simulation Results

In this study, ABAQUS software was used to simulate the pile anchor support structure of deep foundation pit, and the corresponding calculation model was designed. In order to verify the validity of the calculation model, the horizontal displacement of the cast-in-place pile calculated by the numerical simulation of the four working conditions under the original support scheme was compared with the actual monitoring data, and the error between them is shown in Figure 3. It was seen from Figure 3 that the error between the simulated value and measured value under different working conditions and different depth of the cast-in- place pile had volatility, but its fluctuation was relatively stable. On the whole, the error between the simulated value and measured value increased gradually with the process of the working condition of deep foundation pit excavation. The average error between the simulated value and measured value in working condition 1 was 1.22%, the average error in working condition 2 was 1.78%, the average error in working condition 3 was 1.96%, and the average error in working condition 4 was 2.21%. Although the calculation model designed in this study had some errors with the actual values, the average error of 1.22% ~ 2.21% had a high reference value in the engineering analysis, and the calculation model was effective.

After the numerical simulation of the original support scheme and optimized support scheme, the change of the horizontal displacement of the cast-in-place pile with the progress of the working condition is shown in Figure 4. On the whole, the horizontal displacement of the cast-in-place pile increased with the advance of the construction conditions. The maximum horizontal displacement was 9 mm and 2.5 mm respectively under the original scheme and optimized scheme in working condition 1, 12 mm and 7 mm respectively in working condition 2, 18 mm and 9 mm respectively in working condition 3, and 26 mm and 11 mm respectively in working condition 4. The increase amplitude of the original scheme was larger, that is to say, after adopting the optimized pile anchor support scheme, the earth excavation of the deep foundation pit has less impact on the supporting pile, and the pile anchor support has a greater effect on the stability of the deep foundation pit wall. As to the depth of the cast-in- place pile which happened the maximum horizontal displacement, the depth under the original scheme was about 10 m, and the depth under the optimized scheme was about 8 m. It showed that the change of the second and third rows of anchor cable position in the optimized scheme made the position of the maximum horizontal displacement move.

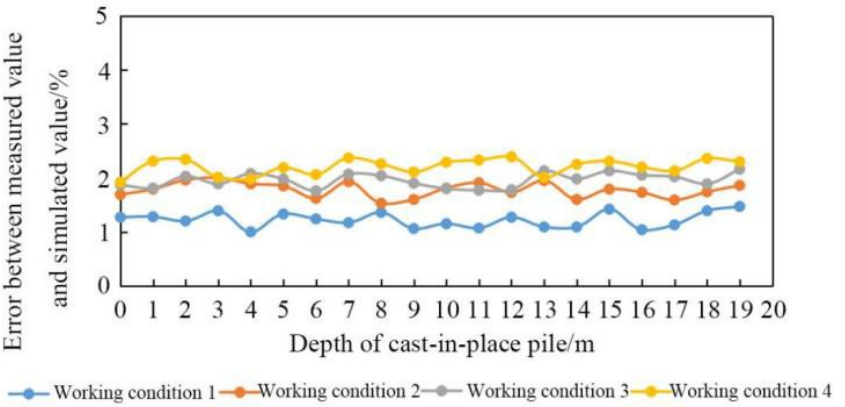


Figure 3. Numerical simulation error of horizontal displacement of cast-in-place pile under different working conditions under the original support scheme

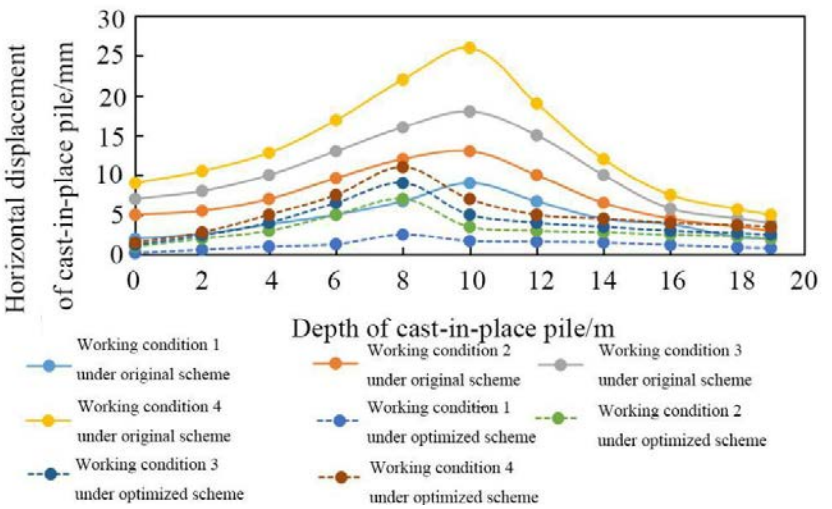


Figure 4. Changes of horizontal displacement of different depth of cast-in-place pile under different working conditions in two schemes

In the process of earthwork excavation of deep foundation pit, in addition to the horizontal displacement of the cast-in-place pile in the support structure, the surface around the foundation pit was also affected, mainly manifested as the ground settlement. The change rule of the settlement depth was that the surface increased with the distance with the foundation pit wall, and the settlement depth increased first and then decreased. Through the numerical simulation of the original support scheme and optimized support scheme, the change of the maximum settlement depth of the surface around the foundation pit during the excavation is shown in Figure 5.

It was from Figure 5 that the maximum settlement depth of the surface around the foundation pit increased under the two schemes with the increase of the excavation depth of the foundation pit, and the original scheme not only had a larger maximum settlement depth, but also had a larger increase amplitude.

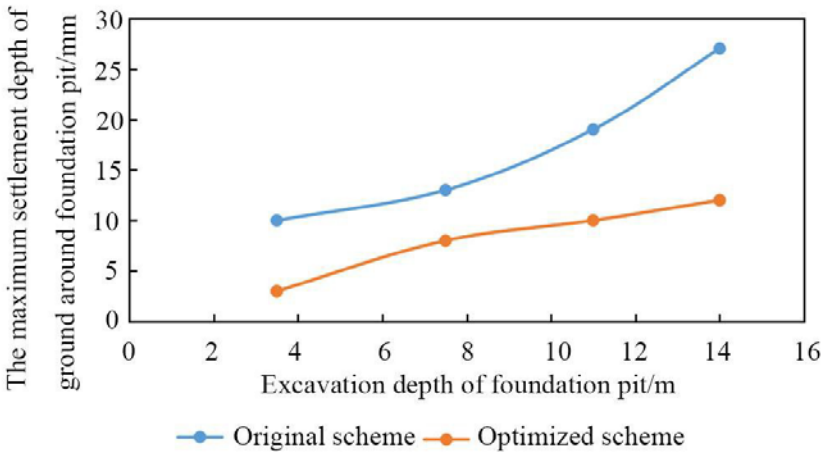


Figure 5. Variation of the maximum settlement depth of the ground around the foundation pit with the increase of excavation depth under the two schemes

## 4. CONCLUSION

In this study, the technology of deep foundation pit and deep foundation pit pile anchor support was simply introduced. Then, the deep foundation pit excavation and pile anchor support structure of a high-rise building project in Xuantan community, Qianzhou street, Jishou, Hunan, China was simulated using ABAQUS software. In addition to the original pile anchor support scheme, an optimized scheme was proposed in the case analysis. The height of the second row of anchor cable in the optimized scheme was adjusted from - 6 m to - 7 m, and the height of the third row of anchor cable was adjusted from - 9 m to - 11.5 m. The data simulation results are as follows. (1) In the original scheme, although the average error between the simulated value and actual value was 1.22% ~ 2.21% under different schemes, it had a high reference value in the engineering analysis, and the calculation model was effective. (2) With the advance of construction conditions, the maximum horizontal displacement of the cast-in-place pile in the two schemes increased, in which the maximum horizontal displacement after optimization increased less, and the location of the maximum horizontal displacement of the cast-in-place pile after optimization moved up from about 10 m underground to about 8 m underground. (3) With the advance of construction conditions, the maximum settlement depth of the ground around the foundation pit increased under the two schemes. The original scheme not only had a larger maximum settlement depth, but also had a larger increase amplitude.

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