A Research on the Stability and Support Technology of Pit in Half Water in the Soft Soil Foundation

Jie Li
STEC Shanghai Road and Bridge (Group) Co, LTD, Shanghai200072, China
Email:75894906@qq.com

Abstract. Semi-shallow water soft soil foundation pit usually have unbalanced earth pressure and soil strength is low. Therefore its support is more difficult in this situation. Anchor-grouting tube technology in geotechnical engineering as a new type of grouting technique has been widely applied in the engineering, this paper applies the technology of soft soil foundation pit supporting, and expounds the concrete application form, whether through site for the application of anchor tube process of soft soil foundation pit respectively for steel sheet pile lateral displacement monitoring, and based on the finite difference method for foundation pit deformation and sliding field is studied. The calculation results show that the technology can effectively control the deformation of foundation pit in soft soil, especially for deformation control.

1. Introduction
With the rapid development of urban construction, the foundation pit excavation support project of underground shopping mall, underground garage, subway station and others are more and more. The construction area and excavation depth of foundation pit project are also increasing. Especially in the city center area of the complex surrounding environment, the difficulty of the excavation and supporting technology is becoming larger because the surrounding buildings are crowded and the underground pipelines are dense. Many new foundation pit support methods have been continuously developed and improved in engineering practice, and the expected support effect has been achieved.

Anchorage tube is perforated or inserted into the soil with a perforated steel floral tube, and then pressed slurry into floral tube the by pressure, the slurry is poured into the soil from the hole, then raised or lowered the flower pipe and grouting continuously. Forming a reinforcement head in soil to improve the strength of foundation. In the construction site, the floral tube is inserted directly into the soil, then hollowed out the silt in the tube and press the slurry into the soil layer through the hole of the floral tube to form a stabilized floral tube-soil anchorage system. Subsequently, the floral tube is welded to the top of the steel sheet pile embedded in the soil to complete the foundation pit supporting system.

2. Soft Soil Foundation Pit Supporting System
Foundation pit support system generally includes baffle, support and necessary wall anchorage. As a foundation pit in soft soil area, floral tube-soil anchorage system is rarely used to support wall. However, with the rapid development of urban construction, the surrounding environment of foundation pit is becoming more and more complicated, and the excavation depth of foundation pit also deepens. The foundation pit excavation not only meet the requirements of rigid support sand the safety of the excavation of the foundation pit, but also increases the control requirements for the deformation of the construction surrounding the surrounding structures. Based on the geological
conditions of soft soil development in Shanghai, this paper proposes a soft soil foundation pit support system for excavation safety and deformation control of foundation pit.

![Figure 1. Soft soil foundation pit supporting system](image)

The foundation pit supporting system in soft soil is shown in Figure 1. The system is formed by the combination of rigid enclosure and directional anchor-grouting technology.

2.1. Rigid Enclosure
As a traditional foundation pit excavation supporting structure, rigid enclosure is responsible for the safety of construction personnel and construction structures during the lifetime of the foundation pit. The main purpose of the rigid enclosure is to prevent the loss of personnel and property caused by collapse of the slope of the foundation pit. Its enclosure structure can include underground continuous wall, soil nailing wall, concrete row pile, steel sheet pile and wall support. For short-term foundation pit in soft soil area, steel sheet pile and transverse bracing structure can be used to form rigid enclosure.

The steel sheet pile is pre inserted into the specified position by the construction machinery before the foundation pit is excavated and reaches the designated depth, and then the complete anti-pressure enclosure structure is formed. Effective links should be made between steel sheet piles to avoid the surrounding groundwater during construction. In the excavation of soil in foundation pit, in order to avoid the large deformation of the steel sheet pile, it is necessary to arrange the transverse bracing in a certain position of the foundation pit to limit the deformation of the retaining structure of the foundation pit effectively. The steel sheet pile in the surrounding structure and the transverse support in the foundation pit have completed the support of the pit wall.

2.2. Directional Anchor Grouting Technology
Anchor-grouting tube technology is widely used in grouting construction of underground works. It is widely used in deep arm grouting because it has good slurry diffusion characteristics and can form a stable anchorage structure in surrounding rock and soil, so the deep hole grouting in geotechnical engineering can be completed effectively. In this paper, directional anchor grouting technology mainly utilized the good grout diffusion and anchorage of the floral tube during the construction process.

After the foundation pit is positioned, anchorage tube is positioned in the pre-set position of the left and right steel plates of the foundation pit in a certain angle with the plumb line. After entering the specified depth, the silt is removed and grouting is carried out according to the predetermined pressure to form a stable anchoring structure of the anchor-grouting and the soil layer. This technique is seldom
used in foundation pit support because of the high requirement on soil geological conditions and the potential effect on construction progress. However, the soil in soft soil area is more viscous and easy to operate. Anchor grouting technology makes the surrounding soil formation whole, and increases the strength of soil cementation, shear resistance and anti-disturbance ability, reduce the plastic flow in the supporting structure so the vertical settlement of the outer surface of the foundation pit can be avoided effectively and reduce the potential active area of soil uplift in foundation pit correspondingly.

3. Deformation and Stability Analysis
The traditional foundation pit support structure usually adopts the design method of stability control to ensure the safety and stability of the supporting structure. With the complication of foundation pit environmental conditions, the design of foundation pit supporting structure is more and more strict, especially the ability of surrounding buildings or underground pipelines to resist deformation and non-uniform deformation is limited. Therefore, the way of strength control design is gradually replaced by the deformation control design in the foundation pit engineering.

In this paper, the method of comparison between foundation pit excavation and numerical simulation analysis (FLAC3D) is applied to analyze the mechanical behaviors such as stress, deformation and failure mode of foundation pit support are comprehensively. And this can provide guidance for the design and construction of foundation pit engineering.

In the construction site, preset and bind the survey pipe to the steel sheet pile at the foundation pit to be tested. Through the regular monitoring and measurement, the horizontal displacement monitoring of the steel sheet pile supporting structure of the corresponding anchored soft soil foundation pit and non-anchored soft soil foundation pit is carried out. FLAC3D uses explicit finite difference scheme to solve differential equations of field.FLAC3D. Using the mixed discrete element model, the yield, plastic flow and even large deformation of the material can be accurately simulated. And it can be closer to the actual construction process of the foundation pit excavation, so as to achieve the purpose of real-time simulation of the construction process.

![Figure 2. Section of foundation pit of construction site](image-url)
At the location of the construction site, two soft soil foundations with the same geological conditions are selected and the 1 row anchorage grouting tube is installed at the top of one plate pile and the anchorage grouting pipe is not installed at the top of another plate pile. The inclinometer tube is placed on the left and right sides of the steel piles and the middle part of the foundation pit. The cutaway drawing of Shanghai Jia min elevated project JMN2-6 section’ foundation pit construction site is shown in Figure 2, the depth of the foundation pit is 7.8m. The anchor rod body adopts hollowed-out floral tube, the outer diameter of the tube is 95mm, the wall thickness is 5mm, and the Angle of the steel sheet pile is 45 degrees. According to geological survey data, the site is mainly composed of earth filling, silty clay, silt clay, sandy clay and gray clay, its mechanical index is shown in Table 1.

The simulated width of the foundation pit is 60m, the simulation height is 21m, and the excavation depth of the foundation pit is 7.8m, and the steel sheet pile depth is 18m. The foundation pit model is divided into 1140 units, each with a size of 1m*1m. The horizontal displacement of the two sides of the model is limited, and the horizontal displacement and vertical displacement are limited.

The ideal elastoplastic model is adopted to simulate the finite difference based on the mohr-coulomb strength criterion.

### Table 1. Soil layer parameter value

| Soil Layer     | Unit weight(KN/m³) | Cohesive force f(kPa) | Friction angle φ(°) | Bulk G(MPa) | Thickness(m) |
|----------------|--------------------|-----------------------|---------------------|-------------|--------------|
| Earth filling  | 17                 | 10                    | 10                  | 2.62        | 1.6          |
| Silty clay     | 18.4               | 18                    | 20                  | 5.14        | 1.7          |
| Silt clay      | 17.6               | 11                    | 15                  | 2.05        | 4            |
| Sandy clay     | 18                 | 6                     | 31                  | 3.6         | 2.7          |
| Gray clay clay | 17.5               | 12                    | 13                  | 8.56        | 11           |

3.1. Numerical Simulation Data Analysis

3.1.1. Analysis of Horizontal Displacement of Foundation Pit. Figure 3 is the horizontal displacement distribution of pit wall under different support conditions. The horizontal displacement of the foundation pit wall shows a curve distribution.

![Figure 3. Horizontal displacement of foundation pit under different supporting conditions](image)
Along the depth of the foundation pit and the maximum displacement usually occurs at the top of the foundation pit and decreases with the increase of depth. The horizontal displacement of the foundation pit wall is obviously decreased with the anti-pull effect of the anchor rod in anchor-grouting tube, but the decreasing amplitude is gradually reduced.

The subsidence distribution law of foundation pit surface is basically the same as that of pit wall horizontal displacement distribution. As shown in Figure 4, the maximum surface subsidence occurs at the pit wall, and the surface subsidence from the crater wall decreases rapidly. When there is no anchorage support, when the pit wall is nearly double the pit depth, the surface subsidence is hardly obvious, and the settlement amount is negligible; When anchorage is supported, the surface subsidence is not obvious when the pit wall is in the depth of half of the foundation pit: It is obvious that the surface subsidence of the foundation pit is lower than that of the condition without the anchor-grouting tube technology. However, it is obvious that the subsidence of the pit wall is less than that with anchorage, but the increase degree is not obvious.

Compared with Figure 3 and Figure 4, the horizontal displacement of the foundation pit corresponds to the surface subsidence, and the larger the horizontal displacement is, the larger the settlement amount is. For the condition of anchor-grouting technology, the surface subsidence rate around the foundation pit is obviously higher than that without the technology: When there is no floral tube support, the subsidence range is twice the depth of foundation pit around the foundation pit; When there is floral-tube support, the construction subsidence range is half the foundation pit depth around the foundation pit because of the strengthening of the soil layer. It is obvious that the anchor-grouting technology is applicable to the complex conditions of surrounding buildings.

**3.1.2. Analysis of Slippage Field of Foundation Pit.** In theory, due to the existence of the anchor-grouting technology, the soil layer anchorage enhancement zone is generated, which reduces the horizontal displacement of the foundation pit wall and the ground subsidence of the foundation pit, and restricts the sliding of the geotechnical body. And also the shear deformation of rock and soil is reduced, the plastic zone of rock and soil is delayed and the range of potential slip area is narrowed. The difference of displacement trend and displacement cloud map under different working conditions will be clearly compared.

Figure 5 shows the horizontal and vertical displacement field and displacement trend of the foundation pit under different supporting conditions. It can be seen from Fig.5 that with the application of anchor-grouting tube technology, the potential plastic strain zone decreases, and the soil layer behind the pit wall is stronger. The horizontal displacement area of the pit wall decreases, the
horizontal displacement of foundation pit decreases, and the slip zone below the steel sheet pile decreases greatly, and the displacement is less than that without support. Therefore, the technology not only reduces the deformation of the foundation pit, but also reduces the potential plastic damage range of the foundation pit. From the comparison of vertical displacement maps, it can be seen that the anchor-grouting tube technology reduces the vertical displacement range in the foundation pit, and has an obvious influence on the vertical displacement range behind the pit wall. It can be seen that the width of the vertical displacement range is obviously less than half that of the condition without the anchor-grouting tube technology.

3.2. Field Measurement and Analysis of Engineering Field

![Displacement trend diagram](image1)

![Horizontal displacement envelope diagram](image2)

![Vertical displacement envelope](image3)

**Figure 5.** Displacement field and displacement trend of foundation pit under different supporting conditions.

Aimed at expanding head of anchor note application of integrated support technology, Shanghai Road and Bridge (Group) construction project in Shanghai jia min overhead JMN2-6 bid construction site chosen two different supporting conditions of foundation pit to pit wall horizontal displacement monitoring, in order to make clear the application of anchor-grouting tube technology for supporting...
technology improvement.

Figure 6 shows the lateral horizontal displacement of the pit wall under different support conditions after the foundation pit excavation is stable. It can be clearly seen from the diagram that every diagonal curve is continuous and complete, and there is a clear horizontal displacement inflection point on both sides of the cross brace. It shows that the horizontal bracing has a good control effect on the horizontal deformation of the pit wall in the rigid enclosure structure. The application of the anchor-grouting technology has a strong effect on the horizontal displacement of the pit wall. In the case of floral-tube support, the maximum horizontal displacement at the top of the pit wall is 344mm, and the maximum displacement of the technology pit wall is 504mm, and the ratio is nearly 7:10. It is obvious that the application of the technology can effectively strengthen the support system, reduce the deformation of the pit wall, and reduce the pressure on the small construction work space.

![Figure 6. Horizontal displacement of pit wall under different support conditions](image)

4. Conclusion
Through the finite element simulation, it is found that the anchor-grouting tube technology strengthens the soil strength after the pit wall, reduces the plastic shear deformation range behind the pit wall, and effectively reduces the vertical settlement range behind the pit wall. The range of the depth of the foundation pit is reduced to half the depth of the foundation pit; Due to anchorage, the soil layer behind the pit wall forms an effective whole, reducing the range of horizontal slip after the wall and the foundation pit.

Based on the measured data from the site of the foundation pit in Shanghai, it is found that the large head anchorage can not only make the soil layer behind the pit wall form an whole effectively, but also reverse the effective anchorage of the pile structure of the foundation pit, which has a significant influence on the horizontal displacement of the pit wall.

For the foundation pit in the soft soil area, the technology can form a stronger support system on the basis of the original steel sheet pile support and transverse bracing support.

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