TEST Engineering & Management

July - August 2020
ISSN: 0193-4120 Page No. 6057 - 6063

Simulated Analysis and Research on the Force of Slope Foundation Pit Support Pile and Its Reinforcement Effect

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Article Info
Volume 83
Page Number: 6057 - 6063
Publication Issue:
July - August 2020

Article History
Article Received: *25 April 2020*
Revised: *29 May 2020*
Accepted: *20 June 2020*
Publication: *28 August 2020*

Abstract

The simulation analysis research technology of the force of the supporting piles of the slope foundation pit and its reinforcement effect effectively solves the problems of the force and stability of the supporting piles of the construction engineering site. The force is fixed by applying the indirect parabola criterion The supporting pile. The successful development of the simulation analysis and reinforcement effect of slope foundation pit supporting piles has corresponding parameter constraints, and on-site simulation reinforcement is carried out to achieve the expected effect.

Keywords: *Slope Foundation Pit, Force of Supporting Pile, Force and Deformation, Simulation of Reinforcement Effect, Hybrid Genetic Algorithm;*

1. Introduction

Foundation pit engineering can be said to be a geological engineering designed for soil conditions. It is necessary to consider the hardness of the ground at the excavation site, as well as whether the soil will deform and shift due to environmental influences, and whether the soil conditions can withstand the foundation pit support Structure, each process complements each other to achieve the conditions of site excavation[1-3]. In foundation pit engineering, in order to ensure that the underground excavation space can be safe and the water control and environmental systems meet the standards, a side pit foundation pit supporting pile bearing structure appears in the pit foundation engineering construction[4-6]. In the construction of the foundation pit, it is often considered to excavate with a more cost-effective method, but it is severely treated by a variety of realistic conditions. In this case, the force mechanism of the slope foundation pit supporting pile is used to simulate the scenic spot through the supporting system The site environment provides a safe and secure environment for the construction site.

2. Features and working principle of pile-anchor supporting system for slope foundation pit

2.1. Features of pile-anchor supporting system

Since the 1990s, especially since entering the 21st century, with the construction of large-scale high-rise buildings, bridges and underground spaces, theoretical research on deep foundation pit engineering has attracted attention, and the depth of foundation pit excavation has increased rapidly. Take Tianjin as an example. Since the beginning of the 21st century, there have been hundreds of deep foundation pit projects every year in just over 10 years. The excavation depth of the foundation pit has rapidly developed from less than 10m to more than 30m, so the support of deep foundation pits has become An increasingly important issue. Row piles have also been widely used as a form of support.

Since the foundation pit supporting piles are

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ISSN: 0193-4120 Page No. 6057 - 6063

arranged at intervals, with the continuous excavation of the foundation pit, the tendency of the soil outside the pit at the empty surface between the two piles to move into the pit gradually increases, and the soil inside the pit is blocked by the piles. Will produce horizontal soil arching. The design concept of supporting piles is to adopt a discontinuous structure, using the arch effect formed by the strength of the soil itself to transmit the active soil pressure of the soil between the piles to the pile to achieve the purpose of supporting. The formation of this arching effect is essentially the result of stress adjustment caused by uneven soil deformation. In reality, generally arch structures are first arched and then strong, while soil arches are first strong and then arched, which is spontaneously formed, so it must be more reasonable It is called "reasonable arch axis". Soil arching is a unique spatial effect exhibited by soil. Generally, this soil arching effect is conducive to the stability of the foundation pit support system. However, this is not considered in the current deep foundation pit excavation and support design. This kind of spatial effect, but with the deepening of engineering practice, many scholars believe that it is more and more necessary to consider the soil arching effect to simulate the reinforcement effect of the foundation pit support system.

Pile-anchor support is a relatively common form or support method for slope protection and row piles combined with single-anchor or multi-anchor foundation pit support. It is a statically indeterminate structure with good stability and high safety performance. The pile-anchor supporting system uses the friction between the anchor rod anchoring section and the soil layer, and the supporting force provided by the supporting pile embedded in the soil layer to maintain the stability of the entire supporting structure. It can be applied to most slope foundation pit and super slope foundation pit projects, including some projects with poor engineering geological conditions and strict surrounding environment control requirements.

Analyzing the stress characteristics of soil arches, the arch top and arch toe are the most vulnerable places. The force characteristic of the vault is that the external load is perpendicular to the arch section, which is prone to shear failure; the soil at the arch foot is mainly subjected to pressure and bears the force of two adjacent soil arches, which is prone to plastic failure. There are two typical failure modes of soil arches: the first is the shear failure of the soil at the top of the arch when the soil displacement behind the pile is too large, resulting in the destruction of the entire arch structure; the second is that the soil at the arch foot is affected by adjacent two. The compression of the soil arch force achieves plastic failure. Soil particle model diagram and soil particle velocity vector diagram when soil arching fails. It can be seen that the soil velocity at the arch top is relatively uniform as a whole, and there is no sign of mutual shear dislocation, so it can be considered that the soil at the arch top does not undergo shear failure. And the arch foot is due to the soil behind the pile. Excessive squeezing results in a large difference in the speed of the soil mass. The soil mass will undergo large shear deformation here, and the soil mass will locally reach plastic yield. As the plastic zone gradually expands and develops, the soil mass at the arch foot will eventually be oriented. Extrusion failure between piles. Terzaghi obtained the conditions for the soil arching effect through the movable door test: ① There is uneven displacement between the soil bodies; ② There is an arch foot as a support. In addition to the above two conditions, Jia Haili and others pointed out The soil arching effect should also meet the third condition: the shear stress in the soil where the arch is formed is less than its shear strength. Therefore, when the soil at the arch foot behind the pile is squeezed out, its supporting effect Greatly weakened, the soil arch also failed.

2.2. Working principle of pile-anchor support system

The piles of foundation pit support have a blocking effect on the soil in the active area. Due to the existence of the rigid boundary of the pile, the displacement of the soil between the piles and the

Published by: The Mattingley Publishing Co., Inc.

TEST Engineering & Management
July - August 2020
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soil of the pile diameter will be inconsistent. When the relative displacement reaches a certain level, the soil in the active area The stress direction of the pile is deflected, and a certain range behind the pile will produce a horizontal soil arch between adjacent piles.The soil pressure is finally transferred to the pile through the soil arch. The existence of the soil arch is an important guarantee for the effect of the supporting pile.

Using the particle flow method to carry out the numerical simulation of the soil arching effect between piles can intuitively observe the microscopic phenomena such as the stress distribution, soil particle displacement and velocity during the formation, development and failure of the soil arch. In addition, from the analysis in the article, the simulation of the soil The failure of the arch is due to extrusion plastic failure of the soil at the arch foot.

Researchers believe that when the free end of the anchor rod in the pile-anchor support system is subjected to force, it is transmitted to the anchoring section through the anchor rod. Since the anchoring section is anchored with the soil layer, the friction between the anchors can be used to reduce the force. The external force is transferred to the surrounding soil to achieve the purpose of stress release. The force mechanism of the pile-anchor protection system is shown in Figure 1.

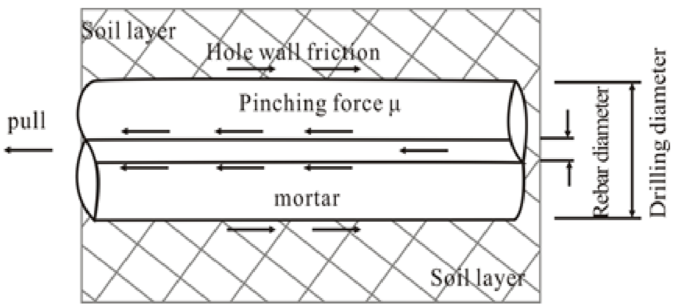

Figure 1. Schematic diagram of the force mechanism of the pile-anchor supporting system.

3. Finite element analysis of pile-anchor supporting system for slope foundation pit

3.1. Project overview

Wuhan Donghu Chunshuli Foundation Pit (Phase III) support project, according to the calculation depth provided by the construction unit, is 11.0m, and the elevation of the bottom of the foundation pit is 15.00m. According to the site survey and measurement, the ground elevation of the site is considered as 26.00m, then The overall depth of foundation pit excavation is about 11.0m. The engineering design of foundation pit support is shown in Figure 2.

3.2. Establishment of finite element model

(1) Model assumption

The following assumptions are made for the established finite element model:

1) Simplify all supporting structures into plane strain problems;

2) Anchor cables and supporting piles are completely elastic bodies, supporting piles are modeled by pile elements, and anchor cables are modeled by anchor cables and solids;

3) The soil is an ideal elastoplastic material, which conforms to the relevant flow laws and large strain deformation modes.

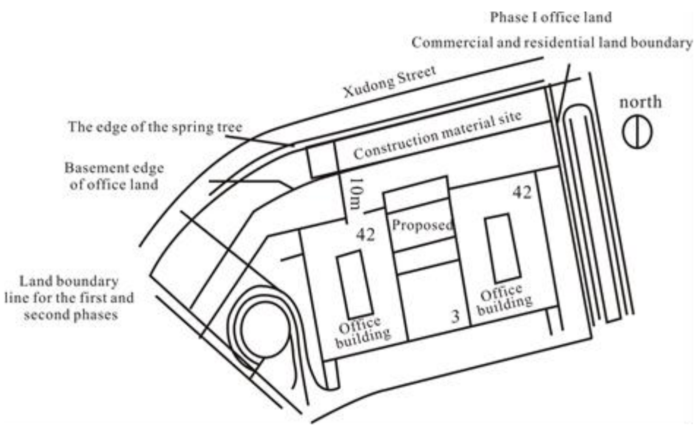

Figure 2. Schematic diagram of Chunshuli foundation pit support project.

According to the relevant engineering survey report, the surface layer within the depth range exposed by the survey site is mixed fill and plain fill, and the bottom is silty clay, gravel with medium coarse sand, etc. The mechanical parameters of each soil layer are shown in Table 1.

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Table 1. Mechanical parameters of each soil layer.

Soil layer number	Soil layer name	Severe $\gamma/(kN \cdot m^{-3})$	Cohesion c/kPa	Internal friction angle $\phi/(^\circ)$
A6,A12,A18	Fill soil	18.52	11	7
A5,A11,A17	Silty clay	19.45	29	15
A4,A10,A16	Silty clay	19.56	43	16
A3,A9,A15	Silty clay	19.26	44	17
A2,A8,A14	Gravel with medium coarse sand	20.02	0.0	31

(2) Model size

According to the engineering construction experience and the corresponding finite element simulation calculation results, it can be seen that the influence range of the excavation of the foundation pit on its width is about 3 to 4 times the depth of the foundation pit excavation, and the influence range of the depth is about 2 to 4 times the depth of the excavation. Times. The size of the three-dimensional finite element model used in this paper is 50m×45m×50m.

(3) Establishment of finite element model

Based on the above model assumptions and simulation size settings, a finite element model of the foundation pit is established.

In this model, layers A2, A8, and A14 are gravel with medium coarse sand, A3, A9, and A15 are silty clay layer I, A4, A10, and A16 are silty clay layer II, and A5, A11, and A17 are silty clay layers. The third layer of high-quality clay, A6, A12, and A18 are fill layers.

According to the designed foundation pit construction plan, the entire foundation pit simulation process is divided into the following six steps:

The first step is to establish a model according to the design plan and calculate the initial ground stress before excavation.

The second step is to impose corresponding boundary constraints.

In the third step, the foundation pit was excavated. Each step was digging down 2m, and the two steps were 4m in total.

The fourth step is to apply anchor rods at 22.3m.

In the fifth step, continue to excavate the foundation pit downwards. Each step is 2m, and the two steps are 4m in total.

In the sixth step, continue to excavate the foundation pit downwards. Each step is 3m, and a total of 3m is excavated.

For situations that are not valid for evaluation, if the evaluated complex loading mode is found to be relatively effective for evaluation through analysis and adjustment, the new complex loading mode is effective for evaluation compared to the original complex loading mode. The conversion formula is:

$$\begin{cases} x_0' = \theta^0 x_0 - x^{0-} \\ y_0' = y_0 + s^{0+} \end{cases} \tag{1}$$

Among them, (x_0', y_0') is the "projection" of (x0, y0) corresponding to the complex loading pattern j0 on the relative effective surface of the evaluation.

3.3. Simulation results and analysis

When the second step of the excavation of the foundation pit (start excavating the soil layer, excavate two steps to -4m), because the anchor unit has not yet played its role, the maximum horizontal displacement of the pile is at the top of the pile.

When the foundation pit is excavated in the third step, the pile displacement gradually increases, and the anchor rod plays a role at -4.2m; when the

Published by: The Mattingley Publishing Co., Inc.

July - August 2020
ISSN: 0193-4120 Page No. 6057 - 6063

foundation pit is excavated to the bottom of the pit, the pile displacement continues to increase. At this time, the displacement of the pile top is 16.4mm, the maximum horizontal displacement of the pile body is 21.4mm, and the maximum displacement point is at -8m; as the excavation depth continues to increase, the x-direction stress of the supporting structure also continues to increase, and the x The change of the axial stress is not great, but the x-direction stress of the pile body is relatively large. It can be seen that it is necessary to strengthen the monitoring of the support structure of the foundation pit, find the abnormal deformation of the foundation pit in time, find and fix it early, to avoid adverse effects on the construction period and project safety.

4. Simulation of reinforcement effect of pile-anchor supporting structure of slope foundation pit

Structural reinforcement effect simulation means that the designer combines the design requirements and uses mathematical analysis to obtain several feasible schemes among all possible structural design schemes, and then selects one of these design schemes according to the predetermined requirements of the designer the best. The simulation of the reinforcement effect of the slope foundation pit support project mainly needs to consider the safety of the support project and the project cost. The process of establishing an optimal mathematical model mainly includes selecting design variables, determining constraints and establishing objective functions.

It can be concluded that the maximum load sharing ratio of the pile and the ultimate load of soil arching decrease with the increase of the pile spacing, and increase with the increase of the friction coefficient of the soil particles. As for the cross-sectional shape of the pile, the soil arching effect The impact is derived from the above analysis: when other conditions are the same, because the effective retaining area of the square pile is larger than that of the round pile, the arch foot is more stable, it is easier to form a soil arch, and the mechanical performance is better than that of the round pile. The soil arching ultimate load of the pile is greater than that of the round pile, and the difference between the two cross-section piles is greater than that when the pile spacing is small.

4.1. Selection of design variables for pile-anchor supporting structure

(1) Embedded depth of supporting piles

1) The depth of the embedded soil layer is not enough, the pile itself is affected by the surrounding earth pressure, and the bottom of the pile undergoes horizontal displacement under the force, which makes the whole pile deviate.

2) The earth pressure at the bottom of the pit does not fully reach the passive earth pressure, and the stability of the lower part of the pile can be maintained. At this time, the bottom end of the supporting pile has only rotating bending moment but no displacement, so it can still be regarded as a simply supported structure.

3) The embedded depth continues to increase. At this time, the part of the bottom end of the pile that enters the soil not only has no displacement, but its rotation is also restricted, and a reverse bending moment is formed there, which greatly reduces the bending moment and deformation between the upper span of the pile In this case, the working state of supporting piles is ideal, and it is also the state that can play the role of pile supporting most.

4) The embedded depth further increased, and the bending moment and deformation between spans did not significantly continue to decrease, and the embedded depth was too large at this time.

(2) Diameter and spacing of supporting piles

For supporting piles, the pile diameter cannot be too small, otherwise the reinforcement cannot be carried out. Under normal circumstances, the pile diameter of supporting piles should be greater than 400mm. For foundation pits with a buried depth of less than 12m, the pile diameter should be selected to be 400~800mm. When the buried depth of the foundation pit exceeds 12m, 800~1200mm should be selected. Pile diameter.

Published by: The Mattingley Publishing Co., Inc.

TEST Engineering & Management

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ISSN: 0193-4120 Page No. 6057 - 6063

The spacing of supporting piles is also one of the important parameters in the design of pile-anchor supporting structure. A reasonable spacing of supporting piles should not only make the possible spalling area of the soil between the piles within the allowable range, but also make the soil arching effect between the piles fully exerted.

(3) Parameter design of anchor rod

The inclination angle of the bolt and the nature of the soil layer have a great influence on the ultimate bearing capacity of the bolt. When the length of the anchor rod is fixed, increasing the inclination angle can increase the ultimate bearing capacity of the anchor rod without increasing the diameter of the anchoring section, which can reduce the engineering cost. In actual engineering construction, measures to increase the length of the anchor rod anchorage section in the pile-anchor support system are usually used to improve the mechanical properties of the anchor rod.

4.2. Establishment of objective function

We can multiply the project cost (c) by a certain characteristic coefficient (al) to express the cost (c •a1) borne during the construction period, then the comprehensive project cost is (c+c • a1). Among them, if a1>0, it means that the construction period of the support plan is longer and increases the entire project cost; on the contrary, a1<0, it means that the support plan shortens the construction period and reduces the entire project cost. Therefore, for some influencing factors, the project cost (c(X)) of the plan (X) can be multiplied by a certain coefficient (an) to characterize the impact of each target on the comprehensive project cost (ct), then the objective function can be established for

$$c_t(X) = c(X) \cdot (a_1 + a_2 + \cdots + a_n) \tag{2}$$

Hybrid genetic algorithm, in the sense of probability, seeks the optimal solution of the problem in a random manner, so it is possible to obtain a local optimal solution within a certain local range, so it is necessary to run the program multiple times to increase the search for the global Chance of optimal solution. In this paper, the program compiled by the Chunshuli foundation pit project was run, and four optimal design schemes appeared, removing the local optimal solution retrieved in the optimization process, and finding the true global optimal solution. The detailed design parameters of the final reinforcement effect simulation scheme are shown in Table 2.

Table 2. Comparison table of detailed design parameters for optimized front and rear support schemes.

Program	Set parameters	Pile design parameters	Number of supporting piles	Crown beam section	Total cost/(ten thousand yuan)
Optimization	Pile diameter: 0.9m/1.2m Pile center distance: 2.9m/3.2m Pile margin: 2m Pile length: 12m Embedded depth: 1m	16@2000 Concrete grade: C25 Protective layer thickness: 50mm Reinforcement method: evenly distributed reinforcement along the circumference Longitudinal steel bars: hot rolled Φ22@32 Spiral stirrup: Φ8@200 Positioning rib: Φ	58 piles of Φ900, Φ1200 pile 2	Width: 1.4m Height: 0.4m	212.724

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Current plan	Pile diameter: 0.9m/1.2m Pile center distance: 2.4m/2.7m Pile margin: 1.5m Pile length: 12m Embedded depth: 1m	16@2000 Concrete grade: C30 Protective layer thickness: 50mm Reinforcement method: evenly distributed reinforcement along the circumference Longitudinal steel bars: hot rolled Φ22@22 Spiral stirrup: Φ8@250 Positioning rib: Φ 16@2000	66 piles of Φ900, Φ1200 pile 2	Width: 1m Height: 0.5m	257.903

It can be seen from Table 2 that the optimized pile-anchor support plan saves 17.16% of the cost of the actual support plan, and the optimization effect is better.

5. Conclusion

Numerical simulation methods have been widely used in foundation pit engineering, but the main difficulty in numerical simulation of foundation pit engineering is to determine the parameters, and the parameter selection in the numerical simulation process of this paper is mainly based on the preliminary geotechnical survey report of the project, and the simulation results are in The shape and value are in good agreement with the monitored displacement value. Although the simulated soil displacement is slightly larger than the monitored displacement, the error is within the allowable range. This paper also uses a hybrid genetic algorithm to optimize the pile-anchor support scheme of the slope foundation pit to create the objective function of the lowest engineering cost. The results show that the optimized pile-anchor support scheme is cheaper than the actual support scheme. 17.16%, the optimization effect is good.

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