Effect analysis on long-short pile combined with reinforcement in passive zone in deep soft soil excavation

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Abstract. The article introduces long-short pile combined with reinforcement in passive zone support structure about some project in detail and analyzes mechanism of the support briefly.

The influence of long-short pile and reinforcement in passive zone on deformation of support pile, overall stability of excavation, moment of support pile is analyzed by using finite element method. The results show: compared to no reinforcement, the maximum horizontal displacement of support pile is significantly reduced after reinforcement in passive zone, and overall stability safety factor of excavation has a more substantial increase; After setting a certain amount of reinforcement mass, there has a little effect on maximum horizontal displacement of support pile by using short pile, long-short pile and long pile, but it is minimal by using short pile; The setting of long pile is beneficial to improve the overall stability safety factor of excavation, but whether the passive zone reinforces or not has a greater impact on the stability of excavation; When the parameters of reinforcement mass reach a certain range, the parameters of reinforcement mass has little effect on the maximum horizontal displacement of support pile, but it has a certain role in improving the overall stability safety factor of excavation; The height of reinforcement mass has a great influence on the moment of support pile, but the form and width of reinforcement mass have little effect on the moment of support pile.

1. Introduction

Determination of retaining structure and geotechnical design parameters for deep soft soil excavation have always been a difficult problem in the excavation engineering [1]. In order to satisfy the needs of construction, new types of excavation supporting structures are constantly emerging, and the long-short pile combined with passive zone reinforcement support structure is one of them, in which the bottom of the reinforcement mass in passive zone is generally higher than the bottom of the short piles, and the long piles and short piles spacing arrangement (long piles spacing can also be spaced by two or more short piles) are adopted. This kind of support structure is especially suitable for excavation support engineering in deep soft soil area [2]. If necessary, a certain number of concrete internal support can be set up to meet the needs of excavation support with deeper excavation depth. Compared with long piles combined with passive zone reinforcement, long-short piles combined with passive zone reinforcement support structure can also meet the requirements of deformation and stability control of excavation, and has better economy. However, there are few research on the supporting mechanism of this support structure type at present, the determination of support structure scheme is mainly related to engineering experience and lacking of the theoretical basis. Therefore, it is...
of great practical significance to study the working mechanism of long-short piles combined with passive zone reinforcement.

Nowadays, the study of long-short pile foundation [3], long-short pile composite foundation [4-5], and long-short pile excavation supporting technology [6-8] and mechanism [9-11] are carried out, and achieved some results. However, there are few studies on the influence of parameters of long-short pile and passive zone reinforcement on the deformation and stability of excavation, and the supporting mechanism of long-short piles is not clear. For this reason, taking an excavation project as an example, this paper introduces in detail the long-short piles combined with passive zone reinforcement supporting structure used in this project, briefly analyses its supporting mechanism, and finite element method are used to analyze the influence of the parameters of long-short piles and reinforcement mass on the deformation of supporting pile, the overall stability of excavation and the bending moment of supporting pile, in order to get some useful conclusions and practice for the similar engineering.

2. Excavation example of long-short pile with passive zone reinforcement

The excavation’s positive and negative zero is equal to 22.800m, the site leveling elevation is 21.200m, the excavation depth in the main building area is 5.9m, it’s 4.5m in the group building area, the excavation area is 745m, the grade of excavation importance is secondary. According to the analysis of drilling data, in situ test and geotechnical test, In addition to the surface distribution of different thickness of the miscellaneous fill, it is mainly composed of the quaternary holocene alluvial clay and sandy soil, the underlying bedrock is silurian silty sandstone, silty mudstone and mudstone within the maximum exploration depth of 44.30m. The typical engineering geological profile is shown in figure 1.

Figure 2 shows the section of excavation supporting structure(elevation unit is m, all the other units are mm), this project used long-short pile combined with passive zone reinforcement, the long pile and short pile diameter are both 800mm, the length of long pile and short pile are respectively 14.5m and 8.5m, the spacing of long pile and short pile are 1.2m and 4.8m(namely arrange 1 long pile and 3 short piles), high pressure jet grouting piles are set up between piles whose design parameters are φ800mm@1200mm, the passive zone reinforced by single shaft cement-soil mixing pile technology(φ500mm@450mm) whose form is step type, it’s wise to use high pressure jet grouting piles make sure that reinforcement mass stick closely with the retaining pile, the size of reinforcement mass shows in figure 2.

The excavation is completed successfully at present, the settlement of surrounding roads and buildings is small, whose maximum value is 4.9mm; The displacement of the surface is in the normal range, whose maximum vertical value is 39.6mm, and the horizontal value is 13mm; the maximum settlement of the retaining pile is 2.3mm. According to the monitoring data, it’s successful to use long-short pile combined with passive zone reinforcement in this excavation.
3. Two-dimensional finite element numerical analysis model

3.1. Numerical analysis model
The traditional excavation calculation software cannot consider the calculation of long-short pile support structure. This paper intends to establish a long-short pile support excavation model by using finite element numerical analysis software. The model width is 80m and height is 35m. The soil layer is simulated by a quadrilateral plane strain element, and the support pile is simulated by beam element. The model unit size is controlled within 1m, for a total of 3091 units. The long-short piles are simulated according to the principle of stiffness equivalence, with the bottom of the short pile as the demarcation point, and different pile spacing is set respectively. The model is analyzed according to the actual construction conditions, and the stability of the excavation is analyzed by the strength reduction method (SRM) when the excavation is excavated to the bottom. Figure 3 is a two-dimensional finite element analysis model.

3.2. Constitutive model and calculation parameters
Table 1 shows the physical and mechanical parameters of the formation, and the parameters in the table are selected according to the site detailed survey report. The modified Mohr Coulomb constitutive model is adopted for soil, which can consider the unloading characteristics of soil and is more suitable for the numerical simulation of excavation unloading of deep soft soil excavation. The unloading modulus is 2 times the modulus of elasticity of soil.
Table 1. The physical and mechanical parameters

| Layer number | Soil                  | $\gamma$ (kN/m$^3$) | $c$ (kPa) | $\phi$ ($^\circ$) | $E$ (MPa) | $\nu$ |
|--------------|-----------------------|----------------------|-----------|-------------------|-----------|-------|
| 1            | Miscellaneous fill    | 18.5                 | 10        | 8                 | 6.0       | 0.39  |
| 2-1          | Silty clay            | 18.6                 | 17        | 10                | 5.0       | 0.38  |
| 2-2          | Silty clay            | 17.7                 | 12        | 5                 | 3.0       | 0.43  |
| 3-1          | Silty clay mixed      | 17.9                 | 14        | 6                 | 3.5       | 0.41  |
|              | silt soil             |                      |           |                   |           |       |
| /            | Reinforcement mass    | 20.0                 | 30        | 15                | 60        | 0.30  |

3.3. Numerical analysis result

Figure 4 is a numerical analysis result of the supporting situation of short piles with un-reinforcement in the passive zone, and table 2 shows the numerical analysis results. It can be seen from figure 4 that under the condition that the passive zone is not reinforced, the maximum horizontal displacement of the excavation reaches 64.5 mm, and the deformation cannot meet the specification requirements, and the formation failure surface is an arc-shaped sliding crack surface passing approximately through the bottom of the short pile. As can be seen from table 2, compared with the non-reinforcement of the passive area of the excavation, the displacement of the support pile after the reinforcement of the passive zone is significantly smaller, and the safety factor of the overall stability of the excavation is also greatly improved. When a certain amount of soil is reinforced, short piles, long-short pile and long piles have little influence on the maximum horizontal displacement of the supporting piles, and the short piles are the least. The long piles are favorable for improving the safety factor of the overall stability of the excavation, but whether the passive zone is reinforced or not is the main influence factor.

![Figure 4. Results cloud of short pile supporting with no reinforcement in passive zone](image-url)

Table 2. Numerical analysis results

| Passive zone   | Type of supporting pile | Maximum horizontal displacement of supporting pile (mm) | Overall stability safety factor of excavation |
|----------------|--------------------------|--------------------------------------------------------|---------------------------------------------|
| Un-reinforcement | Short pile               | 64.5                                                   | 1.207                                       |
|                | Long-short pile          | 43.9                                                   | 1.309                                       |
4. Effect analysis on parameters of reinforcement mass

4.1. Forms of reinforcement mass

The long-short pile model was used, only change the forms of passive zone reinforcement mass, mainly includes rectangle and step type (the rectangle reinforcement mass is 6.35m in width and 5.3m in height). In order to analyze the influence of the reinforcement mass forms on the deformation and stability of excavation is analyzed. Table 3 shows the calculation results of different reinforcement mass forms and figure 5 shows the bending moment curves of the supporting piles with different reinforcement mass forms. It can be seen from table 3 and figure 5 that the reinforcement mass form has little effect on the maximum horizontal displacement and bending moment of the retaining pile, but it has certain effect on the general stability of the excavation. The results show that the step type reinforcement used in this case can effectively control the displacement of excavation, and its economy is better than that of rectangle reinforcement mass.

| Type of reinforcement mass | Maximum horizontal displacement of supporting pile (mm) | Overall stability safety factor of excavation |
|----------------------------|------------------------------------------------------|---------------------------------------------|
| Step type                  | 28.3                                                 | 1.513                                       |
| Rectangle                  | 28.3                                                 | 1.553                                       |

4.2. Width of reinforcement mass

In order to facilitate modeling and changing parameters, the effect of adding reinforcement mass parameters on deformation and stability of excavation is analyzed. In order to facilitate modeling and changing parameters, the effect of adding reinforcement mass parameters on deformation and stability of excavation is analyzed. In the 4.2~4.3 sections, rectangle reinforcement mass was used for comparative analysis. In this section, the height of the reinforcement mass is set at 5.3m, and only the width of reinforcement mass is changed. The width of the reinforcement mass are analyzed, which are respectively 6.35m, 10.32m and 14.29m. Table 4 shows the calculation results of different reinforcement mass widths, and figure 6 shows the bending moment curve of supporting piles with different reinforcement mass widths. It can be seen from table 4 and figure 6, when the reinforcement mass width is more than 6.35m, the maximum horizontal displacement of the support pile is almost
unchanged, but the integral stability of excavation is improved to some extent. In this case, it is indicated that the width of reinforcement mass is set reasonably. There has not obvious effect on deformation control that the width of reinforcement mass is continuous increased.

| Width of reinforcement mass (m) | Maximum horizontal displacement of supporting pile (mm) | Overall stability safety factor of excavation |
|--------------------------------|------------------------------------------------------|---------------------------------------------|
| 6.35                          | 28.3                                                 | 1.553                                       |
| 10.32                         | 28.3                                                 | 1.641                                       |
| 14.29                         | 28.0                                                 | 1.684                                       |

Fig 6. The moment of support pile under different width of reinforcement mass

4.3. Height of reinforcement mass
In this section, the width of the reinforcement mass is set at 6.35m, and only the height of reinforcement mass is changed. The height of the reinforcement mass is analyzed, which are respectively 5.3m, 8.1m and 11.1m. Table 5 shows the calculation results of different reinforcement mass heights, and figure 7 shows the bending moment curve of supporting piles with different reinforcement mass heights. It can be seen from table 5 that, with the increase of reinforcement mass height, the maximum horizontal displacement of the supporting pile increases slightly. The main reason is that the higher the height of reinforcement mass, the smaller the ratio of width to height, the weaker the ability of the reinforcement mass to resist deformation, but this effect is negligible, and the integral stability of excavation is greatly improved. It can be seen from figure 7 that the reinforcement mass height has a great influence on the bending moment distribution and maximum value of the retaining pile. The higher the reinforcement mass height is, the smaller the maximum bending moment of the retaining pile is, and the position of the maximum bending moment tends to move down.

| Height of reinforcement mass (m) | Maximum horizontal displacement of supporting pile (mm) | Overall stability safety factor of excavation |
|--------------------------------|------------------------------------------------------|---------------------------------------------|
| 5.3                            | 28.3                                                 | 1.553                                       |
| 8.1                            | 28.6                                                 | 1.670                                       |
| 11.1                           | 29.1                                                 | 1.741                                       |
Fig 7. The moment of support pile under different height of reinforcement mass

5. Conclusions
1. Compared to no reinforcement, the maximum horizontal displacement of support pile is significantly reduced after reinforcement in passive zone, and overall stability safety factor of excavation has a more substantial increase; After setting a certain amount of reinforcement mass, there has a little effect on maximum horizontal displacement of support pile by using short pile, long-short pile and long pile, but it is minimal by using short pile; The setting of long pile is beneficial to improve the overall stability safety factor of excavation, but whether the passive zone reinforces or not has a greater impact on the stability of excavation.

2. When the parameters of reinforcement mass reach a certain range, the parameters of reinforcement mass has little effect on the maximum horizontal displacement of support pile, but it has a certain role in improving the overall stability safety factor of excavation; The height of reinforcement mass has a great influence on the moment of support pile, but the form and width of reinforcement mass have little effect on the moment of support pile.

3. In this case, it is appropriate to use long-short pile combined with passive reinforcement, and the parameter design of step type reinforcement mass in passive area is more reasonable, which achieves the basic purpose of safety and economy of excavation. As a successful case, it can provide reference for similar projects.

6. Discussions
The supporting structure of excavation should meet the requirements of deformation and stability control at the same time. In deep soft soil excavation, the longer the supporting pile is, the larger deformation of excavation is and the passive resistance safety coefficient is smaller. Even if the supporting piles are inserted into a better soil for a certain depth, although the stability requirements of excavation are met, the deformation cannot be effectively controlled in most cases. At this time, the advantages of long-short piles combined with reinforcement mass of the supporting structure in the passive area are obvious, which not only can meet the requirements of deformation and stability control at the same time, but also has good economy. The mechanism of action of the support structure can be summarized as the short pile combined with the appropriate volume of the passive zone reinforcement control deformation, the passive zone reinforcement is used to improve the short pile embedded condition, and the short pile deformation is controlled; and a certain number of long piles are set. It is to meet the overall stability control requirements of the excavation and prevent deep slippage of the excavation.
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