Finite Element Analysis of Bearing Capacity on the Composite Foundation of Group Pile

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Abstract. In order to study the bearing characteristics on the composite foundation of group pile, the influences of variation of pile length, elastic modulus, spacing and cushion thickness on the bearing capacity for the composite foundation of group pile were investigated by finite element method. This paper presented the laws of the displacement and additional stress of pile with different parameters. The results showed that pile length, elastic modulus and spacing had great influence on the composite foundation of group pile; however, cushion thickness had less effective. Finally, this paper gave the optimal parameters, which provide a reference for practical engineering applications.

1. Introduction

Compared with natural foundation, composite foundation has high bearing capacity and small settlement, which is beneficial to the bearing potential of pile and soil. The numerical simulation method considered to be a very effective method was also used to analyze composite foundations in combination with actual engineering. The large-scale composite foundation of group pile of natural gas tanks after 40 years of service was subjected to on-site horizontal load test and finite element analysis by Shuntaro Tramoto et al.[1]. Using the numerical simulation analysis method by Li et al.[2], the effects of the bearing performance on composite foundation of group pile with different pile elastic modulus in presence or absence of the cushion layer were conducted, and the idea of using the cushion layer to optimize composite foundation was also proposed. Under vertical load with the influence of various influencing factors, the law of axial force and settlement characteristics of rigid pile composite foundation (group pile) was analyzed using ANSYS finite element program by Chi et al. [3]. The influence of cushion thickness and deformation modulus on bearing behavior of rigid pile composite foundation was studied by Liu et al. [4]. Combined with actual engineering site static load test, bearing capacity, load transfer performance and deformation characteristics of piles in deep mixing pile and high pressure rotary grouting piles in backfill ground by finite element calculation method were studied by Zhao et al.[5].

At present, theoretical research on composite foundations lags behind engineering practice. Existing field tests or numerical simulation studies are only a small part of the research of composite foundations, and there are relatively few theoretical studies on composite foundations. Therefore, in order to study the bearing performances on the composite foundation of group pile, combining a
specific project, ANSYS software was used to carry out certain finite element calculations, and the bearing characteristics on composite foundation of group pile were also analyzed for the different factors. Finally, the optimal parameter values were given.

2. Numerical modelling procedure

Deformation characteristics and stress distribution on composite foundation of group pile were studied deeply through a representative composite foundation calculation model. The finite element analysis calculation model was simplified, as followed:

- The pile was selected as a linear elastic material; in addition, the Drucker-Prager material model was used for the analysis of the soil between the piles.
- It was assumed that the pile and the soil were both homogeneous and isotropic.
- In composite foundation of group pile, no contact surface was set between piles and soil.
- Considering symmetry, the 1/4 circular section model was adopted for group pile.

The solid45 8-node unit was used for the element of the pile and the soil, as well as the cushion layer. The rigid link constraint was applied on each side surface of foundation perpendicular to the side, the vertical rigid link constraint was applied on the bottom surface, and the symmetrical constraint was applied on the symmetry plane of the pile and the soil. The physical and mechanical parameters of each material of the composite foundation were shown in Table 1.

![Table 1. Physical and mechanical parameter list of materials.](image)

| Scheme | Pile length(m) | Pile spacing(m) | Pile elastic modulus(MPa) | Cushion thickness(mm) |
|--------|---------------|----------------|---------------------------|-----------------------|
| 1      | 12            | 12             | 60                        | 300                   |
| 2      | 12            | 12             | 180                       | 300                   |
| 3      | 12            | 12             | 240                       | 300                   |
| 4      | 12            | 12             | 480                       | 300                   |
| 5      | 12            | 12             | 960                       | 300                   |
| 6      | 12            | 12             | 1200                      | 300                   |
| 7      | 12            | 12             | 2400                      | 300                   |
| 8      | 12            | 12             | 4800                      | 300                   |
| 9      | 12            | 12             | 9600                      | 300                   |
| 10     | 12            | 12             | 12000                     | 300                   |
| 11     | 12            | 12             | 24000                     | 300                   |
| 12     | 12            | 12             | 48000                     | 300                   |
| 13     | 12            | 12             | 96000                     | 300                   |
| 14     | 12            | 12             | 120000                    | 300                   |
| 15     | 12            | 12             | 240000                    | 300                   |
| 16     | 12            | 12             | 480000                    | 300                   |
| 17     | 12            | 12             | 960000                    | 300                   |

3. Results and conclusions

3.1. Influence of pile elastic modulus on the deformation and bearing characteristic of group pile
The curves of the displacement and stress of center pile for the different pile elastic modulus were shown in Fig.3. As can be seen from the displacement curve, the displacement of the pile reduced continuously along the pile, and the displacement of pile at the pile head was 396mm when the pile elasticity modulus was 60MPa, which was twice that of 191mm when the modulus was 1200MPa. In the upper part of pile, with the increase of the pile elastic modulus, the displacement of pile decreased gradually, while this order was reversed around 5m below the pile tip.

Fig.3. Displacement and stress of center pile for the different pile elastic modulus

As shown in the stress curve (Fig.3b), the stress values of pile increased firstly and then decreased with increased depth, and finally closed to zero at the pile bottom. Moreover, the maximum stress position of pile was 1.2m below the top of pile. With pile elastic modulus increased from 60Mpa to 1200Mpa, the stress curve dropped slowly, and the maximum stress of pile increased by 219% from 0.43Mpa to 1.37Mpa. The results show that the increase of pile elastic modulus will enhance the load carrying capacity of pile, improve the load transfer performance of pile, and help to improve the bearing capacity on composite foundation of group pile. Furthermore, when pile elastic modulus was large, the maximum stress value of pile increased slightly with the increase of pile elastic modulus.

According to the above discussion, the increase of pile elastic modulus can greatly improve the bearing capacity on composite foundation of group pile. Based on the economy and the distribution characteristics of the displacement and stress of pile, the measures to reduce pile elastic modulus of the lower part and increase that of the upper part can be considered according to actual situation.

3.2. Influence of pile length on the deformation and bearing characteristic of group pile

The curves of the displacement and stress of center pile for the different pile lengths were shown in Fig.4. The displacement of pile gradually decreased with the increase of the pile length, even the decline became slower. As the graph illustrated, the displacements of the pile head of 0.042m, 0.037m and 0.036m were corresponded to the pile lengths of 6m, 12m and 18m respectively, and this means that the displacement was reduced by 12% when pile length increased from 6m to 12m, while that was lessened by 3% when pile length added from 12m to 18m. These reductions were mainly due to the increase of the side friction with the augment of pile length. The results show that there is an optimal pile length, and displacement of pile can be effectively reduced by increasing pile length within that.
Fig. 4. Displacement and stress of center pile for the different pile lengths

The maximum stress position of pile was not at the top of the pile, while about one-tenth below the top of pile as shown. Taking center pile as an example, the maximum stress position of pile was at 0.6m, 1.2m and 1.8m below the top of pile when the pile length was 6m, 12m and 18m respectively. Besides, the corresponding maximum stress values of pile were 538kPa, 498kPa and 500kPa respectively, and the maximum stress of pile was decreased by 7% when pile length increased from 6m to 18m. These data show that the stress of pile is less affected by pile length.

3.3. Influence of pile spacing on the deformation and bearing characteristic of group pile

The curves of the displacement and stress of center pile for the different pile lengths were shown in Fig.5. As the pile spacing increased from 0.8m to 1.6m, the displacement at the pile head was increased by 96.3%, and the maximum stress of pile at the time was increased by 94%. The results indicate that the displacement and maximum stress of pile were dramatically increased with the increase of pile spacing. With the increase of pile spacing, the constraint of the soil on piles was reduced, and then the load carrying capacity of pile was able to be given full play. Inversely, with the decrease of pile spacing, the corresponding displacement and stress of pile decreased at the pile head, in addition, the phenomenon of stress concentration gradually disappeared. Therefore, this paper gives the most reasonable pile spacing of 1.2m after taking into account such factors as the load carrying capacity of pile, the phenomenon of stress concentration, the settlement of pile top and economy.

Fig. 5. Displacement and stress of center pile for the different pile spacing
3.4. Influence of cushion thickness on the deformation and bearing characteristic of group pile

![Displacement and stress of center pile for the different cushion thickness](image)

a. the relationship of the depth and displacement of the pile
b. the relationship of the depth and stress of the pile

Fig.6. Displacement and stress of center pile for the different cushion thickness

The curves of the displacement and stress of center pile for the different cushion thickness were shown in Fig.6. The displacement curve in Fig.6 showed that cushion thickness had no effect on the displacement of pile, while the stress curves showed that the influence of cushion thickness on the stress of pile was concentrated in the shallow layer, where was about 3m below the pile. Within this range, with the increase of cushion thickness, the maximum stress of pile decreased slightly. For distance, the maximum stress of pile decreased by 0.026MPa on average when the cushion thickness increased from 100mm to 500mm. The effect of further increase of cushion thickness on the pile-soil load ratio of composite foundation was limited.

4. Conclusions

Based on practical engineering, a series of finite element calculations were conducted to obtain better knowledge of the bearing capacity of composite foundation of group pile. Based on the results of the calculations presented herein, the following conclusions can be drawn:

- The elastic modulus of pile was one of the important factors affecting the bearing capacity of the composite foundation. With the increase of pile elastic modulus, the load transfer behaviour of pile and the bearing capacity on composite foundation of group pile were all greatly improved.
- The increase of pile length was beneficial to the bearing capacity of group pile. The optimal pile length proposed in this paper was 12m.
- The increase of pile spacing remarkably enhanced the load carrying capacity of group pile; however, the settlement of pile top decreased and the phenomenon of stress concentration enlarged. An optimal pile spacing of 1.2m therefore was recommended in this paper.
- The thickness of cushion had no effect on the settlement of composite foundation.

Acknowledgments

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Conflict of Interest

The authors confirm that this article content has no conflict of interest.

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