Analysis of uplift bearing capacity of expanded pile

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Abstract. The research on the uplift bearing capacity of expanded pile is less, which lead to develop slowly of mechanism of expanded pile. The finite element software is used to simulate the bearing capacity of expanded pile, and the friction between the pile and soil is simulated by surface contact. The simulations show the ultimate bearing capacity and the distribution of side friction of the expanded pile. Along with the displacement moves bigger, the side friction of upper expanded pile is fully used. When the displacement moves to a special level, the side friction of whole pile is fully used. If the load is bigger than the 25000kPa, the expanded pile will be destroyed.

1. Introduction
The expanded pile is increasing the pile diameter at the pile end of the traditional equal section pile. This method can effectively improve the ultimate bearing capacity of the pile end and the side friction of the pile body, so as to improve the bearing capacity of the whole pile. In recent years, the relevant domestic scholars have done lots of research on theoretical and model test, such as the bearing capacity, pile end resistance, pile side resistance, putting forward a series of important conclusions.

The application of expansion pile in engineering construction has been quite common, but most of the researchers have carried on the theoretical research on the expansion pile. There is little research on the mechanism of the bearing capacity and the side friction resistance of the pile. A small number of scholars are researching on the numerical simulation method of stress characteristics of the expansion pile.

In this paper, the finite element software is used to analyse the pulling capacity of the expanded pile. The distribution of side friction is calculated. The results have some reference significance for designer and constructor of the expanded pile.

2. Project Background
In order to facilitate the simulation of finite element software, the author made a pile in the Daxing Experimental Base of Beijing, experimented with pile diameter D = 1.0m, pile height h = 3.5m, the pile material is the reinforced concrete, pile around with the conventional clay.
3. Simulation of pulling Capacity of Pile

The Mohr - Coulomb model is used to simulate the soil stress, Mohr-Coulomb yield surface is an irregular hexagonal cross-sectioned pyramidal surface in the principal stress space, and is projected into an equiangular equilateral plane in the π plane. There is sharp angle on the yield surface, as shown in Figure 1.

Fig.1 Yield surface on π plane

Mohr-Coulomb theories consider that: the shear stress of a yield surface is against by the material cohesion and the friction, the expression is:

\[ \tau = c + f \sigma_\text{ shear} + \sigma \tan \varphi \]  

\( \tau, \sigma \) are the normal stress and shear stress of the plane, \( c \) is the cohesion, \( f \) is the friction coefficient, and \( \varphi \) is the friction angle.

It can be deduced that when the stress Mohr circle is tangent to the Coulomb criterion line, the rock mass reaches the limit state, and the principal stress should meet the following conditions:

\[ \sigma_1 = \frac{2c \cos \varphi}{1 - \sin \varphi} + \frac{\sigma_2 + \sigma_3}{1 - \sin \varphi} \]  

From the above, it can be seen that the Mohr-Coulomb criterion does not consider the influence of the intermediate principal stress on the strength of rock and soil, but the destruction of material is usually affected by the intermediate principal stress, because of this influence is small, the Mohr-Coulomb criterion is still accurate enough to show the stress level. The result of simulation is very close to the experimental data.

The pile is linear elasticity before the stress reaches the failure strength of material, so it is a linear elastic material in the model. The soil is elastic-plastic material, which is assumed to obey the Mohr-Coulomb criterion. The material parameters are shown in Table 1.

| Name     | Elastic modulus (Pa) | Poisson's ratio | Cohesive force (Pa) | Friction angle | Dilatancy angle | Density (Kg/m$^3$) |
|----------|----------------------|-----------------|----------------------|---------------|----------------|-------------------|
| concrete | 3e10                 | 0.2             | -                    | -             | -              | 2500              |
| Clay     | 4e7                  | 0.35            | 15000                | 30            | 0              | 1800              |

The elastic models of pile and soil are very different. Under the load, there will be relative sliding between pile and soil. In order to ensure the rationality of the calculation results, the coulomb friction contact is used to simulate the contact between the pile and soil. There is a small sliding model in the software and the friction coefficient is 0.3. Then the contact pairs between the pile and soil are established, and the master-slave contact algorithm is adopted.

The selection of the master and slave faces must follow the principle that the meshing of master surface is finer than the slave surface, even the material of master surface is harder, but the mesh density of two faces must be similar. According to the above principle, the surface of the pile face is the master face and the soil surface is the slave face.

Coulomb's law is used to calculate the ultimate shear stress in ABAQUS:

\[ \tau = \mu \sigma \]  

(3)
μ is the coefficient of friction, \( p \) is the stress between the two contact surfaces. When the shear stress between the two contact surfaces reaches the ultimate shear stress, the contact surface will produce the relatively sliding. Because there is the non-ideal frictional contact between the pile and soil, the concept of "elastic slip deformation" is introduced in the finite element calculation. When the surfaces are bonded together, a small amount of relative slip deformation is allowed. As shown in Figure 3, a small slip between the contact surfaces is allowed when the slip displacement is less than \( \omega_s \).

![Coulomb friction model](image1)

![Pile-soil grid model](image2)

Fig.3 Coulomb friction model  Fig.4 Pile-soil grid model

The results of the numerical analysis are closely related to the mesh shape and mesh density. If the results need more accuracy, the grid density must be higher. Therefore, the model should be as far as possible to ensure sufficient accuracy without excessive element, the denser of the mesh close to the pile, the sparser of the mesh away from the pile. Figure 4 shows the pile-soil grid model.

4. Result

![Side frictional resistance of pile](image3)

Fig.5 side frictional resistance of pile

Through the simulation of the friction between pile and soil, it can be seen that along with the length of the pile, the friction resistance is increasing continuously. The expansion head of the expanded pile can bear more loads. If the load is more than the 25000kPa, the expanded pile will be destroyed.

![Strain and stress of pile](image4)

Fig.6 strain and stress of pile

Figure 6 shows the stress chart and strain chart of pile and soil. The maximum stress of the pile occurs at the lower part of the pile, and the stress concentration area is also in the lower part of the pile, even at the part of the expansion head. Because the displacement boundary conditions were
applied at the top of the pile, the whole pile body is the largest displacement area, and the maximum displacement area of the soil occurs in the upper part of the soil. If the soil was damaged, the pile will be failure.

5. Conclusions
The development and application of the finite element software ABAQUS makes it possible to simulate the uplift capacity of the expanded pile.

In this analysis, when the displacement of the expanded pile is very small, the side friction bears the uplift load; when displacement moves to the specific level, the expansion head of the expanded pile bears more load; if the displacement goes on increasing, the pile will be destroyed, the friction between pile and soil will disappear.

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