Analysis of uplift bearing capacity of pile based on ABAQUS

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Abstract. The uplift bearing capacity of pile in soil foundation is mainly obtained by load test, which is time-consuming and low-efficiency. A small sliding model and the contact pairs in large-scale finite element software ABAQUS are used to simulate the friction between pile and soil, and a good fitting curve of pile foundation bearing capacity is obtained. According to the results of finite element software, the lateral friction of the pile is fully developed, and the stress of the pile gradually reaches the ultimate pull-up capacity with the increase of pile displacement. The finite element software ABAQUS can be used to simulate uplift capacity of pile.

1. Introduction
In recent years, more and more wind power projects have been constructed; large diameter single pile foundation is the most popular type in many types of wind power foundation. Due to the limitation of not having software in the past few decades, the designers of the project rely on the load test to obtain the Data of uplift capacity of the single pile foundation, but this method is easy to be subject by external factors; another side, the experimental level will also cause a lot of uncertainties, although there are many drawbacks of this method, this method has been used today. There is no better way to solve this problem.

Large-scale finite element software ABAQUS specializes in the calculation of various combinations of materials, complex loading processes and varying contact conditions. The geometrical is a special medium with non-homogeneous and non-linear character, arbitrary geometry and discontinuity. This makes it to be most popular finite element analysis software used. In this paper, the software is used to simulate the pull out bearing capacity of single pile, so that the results can guide the engineering design and construction.

2. Project background
The Mohr - Coulomb model was 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.
Mohr-Coulomb theories consider that: the shear stress of a yield surface is against by the material cohesion and the friction, the expression is:

$$\tau = c + \sigma \tan \varphi$$  \hspace{1cm} (1)

$\tau$, $\sigma$ 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:

$$\sigma_i = \frac{2c\cos \varphi + \sigma_2(1 + \sin \varphi)}{1 - \sin \varphi} \frac{1 + \sin \varphi}{1 - \sin \varphi}$$  \hspace{1cm} (2)

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 modulus 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 surface 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:
\[ \tau = \mu p \]  

(3)

\( \mu \) 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 of 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 \( \omega_s \).

![Figure 3](image1.png)\[ Coulomb friction model \]

![Figure 4](image2.png)\[ Pile-soil grid model \]

The results of the numerical analysis are closely related to the mesh shape and mesh density. The more dense of the grid, the higher accuracy of the results, but also increase the time and difficulty of calculation. 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.

3. Result

![Figure 5](image3.png)\[ side frictional resistance of pile \]

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. This is caused by earth pressure, as the pile pulls out more and more, the side friction increases gradually, reaching a peak and suddenly decreasing, at this time, the pile destroyed.
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. Because of the uplift capacity analysis, 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. In this research, lots of data of uplift capacity about this pile, because of the limitation of this space, so this paper will not repeat them.

4. Conclusions
The development and application of the finite element software ABAQUS makes it possible to simulate the uplift capacity of the pile. In this analysis, it is feasible to increase the uplift bearing capacity of the pile by increasing the pile length.

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