Research on construction settlement of different soft foundation under vacuum preloading condition

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Abstract: Vacuum preloading, rigid foundation, raft foundation and piled raft foundation are more commonly used in soft foundation treatment. PLAXIS is large finite element software of rock and soil, which can simulate the influence of different foundation forms. After the vacuum preloading treatment, the foundation settlement is reduced by 80%, the raft foundation settlement is reduced by 60%, the pile raft foundation settlement is reduced by 40%. It is suggested that the vacuum preloading is used to deal with the foundation of the building. If the time limit, the pile raft foundation is used as the foundation form of the foundation is better than others.

1. Introduction
As you know, Soft foundation has low bearing capacity, it is easy to deformation under loading, and the soft soil is difficult to meet the design requirements. There are many kinds of soft soil foundation treatment methods, but drainage consolidation method and pile foundation method are wide range of applications. The vacuum preloading method is suitable for large area soft foundation treatment, this method is easy to operate by the simple equipment, but the processing time is longer than other methods. When the thickness of soft soil layer is more than 40m, it is difficult to carry out deep treatment in large area, and the piling method can be used for increasing soil bearing capacity. All kinds of soft ground treatment methods have their own advantages and disadvantages, how to play the advantages of soft soil treatment methods and how to have good economic benefits will become a hot spot of research [1].

In this paper, a project in Tianjin Binhai New Area as an example, different treatments of soft soil have different stress and strain, such as the rigid foundation, raft foundation and pile raft foundation of building [2].

2. Project overview
The project site is located in Tianjin Binhai New area. The proposed project is office building. The site is located in the North China Plain, which belongs to alluvial plain and low sea plain. According to the origin in the soil can be divided into seven layers, because the clay parameters are small difference, the mean performance parameters of clay. During the investigation, the static water depth is 0.50m ~ 0.80m.

The project area is the soft foundation, although it has obvious advantages and characteristics of various methods of foundation treatment and foundation form, but simulation of the foundation is
necessary. The three basic forms include rigid foundation, raft foundation and pile raft foundation are selected to compute the foundation settlement, based on the finite element simulation of excavation process and construction process.

3. Basic parameters
The finite element analysis software PLAXIS 3D is used to simulate the interaction between building and foundation. Take the basic clay depth is 40m, length and width were 150m; take the building's length and width were 18m as the foundation; the weight of the superstructure is applied as surface load; in order to save computing time, take 1/4 of the basis of the building and construction as whole finite element model, along the line of symmetry applied to symmetric boundary conditions; the calculation is divided into three conditions, rigid foundation, beam slab foundation and pile raft foundation[3]. Gravity acceleration is 9.81m/s², the calculation of the material parameters as shown in table 1.

| Name                               | Clay (after compression) | Clay (before compression) | Building | Floor | The side wall | Pile/column | Beam | Emb pile |
|------------------------------------|--------------------------|---------------------------|----------|-------|---------------|-------------|------|----------|
| Natural severe (kN/m³)             | 19                       | 17                        | 50       | 15    | 15.5          | 24          | 6    | 6        |
| Saturation severity (kN/m³)        | 20                       | 18                        | —        | —     | —             | —           | —    | —        |
| Elastic modulus/E’(kN/m²)          | 5E3                      | 1E3                       | 3E7      | 3E7   | 3E7           | 3E7         | 3E7  | 3E7      |
| Poisson ratio/ν’                   | 0.3                      | 0.3                       | 0.15     | 0.15  | —             | —           | —    | —        |
| Cohesive force/c’ (kN/m²)          | 10                       | 10                        | —        | —     | —             | —           | —    | —        |
| Friction angle/ψ (°)               | 30                       | 30                        | —        | —     | —             | —           | —    | —        |
| dilation angle/ψ (°)               | 0                        | 0                         | —        | —     | —             | —           | —    | —        |
| Horizontal stress coefficient/K₀   | 0.5                      | 0.5                       | 1        | —     | —             | —           | —    | —        |
| Thickness/ (m)                     | —                        | —                         | —        | 0.5   | 0.3           | 1.5         |      |          |
| Sectional area/ (m²)               | —                        | —                         | —        | 0.49  | 0.7           | —           |      |          |
| Moment of inertia₁ (m⁴)            | —                        | —                         | —        | 0.02  | 0.058         | —           |      |          |
| Moment of inertia₂ (m⁴)            | —                        | —                         | —        | 0.02  | 0.029         | —           |      |          |

4. Simulation Analysis and comparison
The vacuum preloading method is arranged in vertical plastic drainage belt or sand well in soft clay, covering with sand, then covered with closed membrane, making the drainage belt and sand in partial vacuum, elimination of moisture in soil, making the soil pre consolidation and to reduce the foundation settlement.

4.1. Rigid foundation
Rigid foundation refers to the materials whose compressive strength is larger and bending strength, shear strength is smaller such as brick, stone, lime, concrete, are used to be the foundation. According to the actual situation establish the rigid foundation model as shown in figure 1.
The results show that the maximum stress of the rigid foundation is 95.84kN/m², the minimum value of stress is -854.2kN/m², and the maximum value of the displacement is 0.2059m, which occurs at the lower edge of the rigid foundation.

4.2. Raft foundation

The raft foundation is composed of the bottom plate and beam, it connect independent foundation and strip foundation with the beam. When the load of the building is large, the bearing capacity of the foundation is weak, and the concrete floor is often used to bear the load of the building, forming the raft foundation. Generally speaking, the raft foundation can be selected when the bearing capacity of foundation is uneven or the foundation is weak. And the raft plate foundation is shallow, and even cannot be buried deep foundation.

The results show that the maximum stress of raft foundation is 837.1kN/m², and the minimum value of stress is -5029kN/m²; the maximum value of the total displacement is 0.1029m, which occurs at the lower edge of the raft foundation.

4.3. Pile raft foundation

Pile raft foundation is composed of pile foundation and raft foundation. The pile foundation is artificial foundation rather than structure, and the raft is part of the structure. The pile foundation has the characteristics of high bearing capacity, small settlement and more uniform, almost can be applied to various engineering geological conditions and various types of engineering, especially suitable for construction in the soft foundation.

According to the calculation results, the maximum stress of pile raft foundation is 1318kN/m², and the minimum value is -5271kN/m². The maximum value of the displacement is 0.0834m, which occurs in the pile raft foundation.

4.4. Comparative analysis of calculation results
Table 2 Summary of calculation results of stress and strain

| Foundation condition | Basic form   | Maximum stress (kN/m²) | Maximum displacement (m) |
|----------------------|-------------|------------------------|--------------------------|
| Vacuum preloading    |             |                        |                          |
| Rigid foundation     | 95.84       | 0.2059                 |                          |
| Raft foundation      | 837.1       | 0.1029                 |                          |
| Pile raft foundation | 1318        | 0.0834                 |                          |

All kinds of foundation treatment of maximum stress and settlement of the simulation results in Table 2, according to the simulation results show that the settlement from big to small is rigid foundation, raft foundation and pile raft foundation; Based on the rigid foundation, the settlement of the foundation was reduced by 80% after vacuum preloading, the settlement of the raft foundation was reduced by a factor of 60%, and the settlement of the piled raft foundation was reduced by about 40%.

5. Conclusion
According to the different foundation form of building finite element simulation, the settlement decreased obviously after vacuum Preloading, the settlement of pile raft foundation is decreased more than 40%.

If the funds and construction time permits, the vacuum preloading treatment of building foundation is necessary; if the time is limited, the pile raft foundation can reduce uneven settlement of buildings after construction.

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