Analysis of the conventional vacuum preloading method

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Abstract. The conventional vacuum prepressing method is to reinforce the soft soil foundation. The process is to lay a certain height of horizontal sand cushion layer on the surface to form a horizontal drainage channel, and then set up a plastic drainage plate and connect it with a pumping pipe to form a vertical drainage channel. This paper analysed the conventional vacuum preloading method with in-site test method, and the foundation reinforce effect was evaluated by monitoring the surface settlement, variation of pore pressure and layered settlement.

1. Introduction

The conventional vacuum preloading method is used to reinforce the soft soil foundation based on the consolidation theory. Consolidation of soil means that the internal water oozes slowly under the action of load, gradually reducing the volume and increasing the strength. With the consolidation of soil, the applied pressure is transferred from pore water to the soil skeleton correspondingly, and the compression deformation and strength of soil gradually increase. Consolidation of soil is one of the basic subjects in soil mechanics.

For saturated soils, the current consolidation theories of formation: Terzaghi consolidation theory $^{[1]}$ proposed the classical one-dimensional consolidation theory, which combined the compaction and permeability of soil and derived the one-dimensional consolidation partial differential equation. It reflects the consolidation mechanism of soil properly and is accurate in one dimension. Then Rendulic$^{[2]}$ generalized them to the three-dimensional case, forming a quasi-three-dimensional consolidation theory. According to the partial differential equation, the analytical solutions under various conditions are given, including boundary permeability and impermeability, linear increase of load with time, conditions of change of soil thickness with time, and so on. Barron$^{[3]}$ consolidation theory based on Terzaghi’s one-way consolidation theory, Barron established a basic axisymmetric differential equation. Its assumption is basically the same as Terzaghi’s consolidation theory, except that consolidation compression is caused by radial pore water seepage. Under the condition of free strain and equal vertical strain, the analytical solution of consolidation equation is obtained. In 1941, Biot$^{[4]}$ derived the correlation between the dissipation of pore water pressure and the deformation of the skeleton from the relatively strict consolidation mechanism, and proposed a relatively complete three-dimensional consolidation theory. It is generally called "true three-dimensional consolidation..."
theory”, while Terzaghi consolidation theory is called "quasi-consolidation theory". By using Biot consolidation theory, it can not only solve the distribution of pore water pressure, but also give the distribution of displacement field. The conventional vacuum preloading method was put forward by Prof. W. k. jellman[5] of the royal Swedish institute of geoscience (kjellman) at the meeting of MIT in 1952.

This paper analysed the conventional vacuum preloading method with in-site test method, and the foundation reinforce effect was evaluated by monitoring the surface settlement, variation of pore pressure and layered settlement.

2. Engineering case

This project is located in the reclamation of land which is relatively flat topography, surface as weakness of reclaimed soil, ground stability is good, there is no landslide, collapse, empty, such as adverse geological processes, in which a representative borehole columnar graphs, the distribution of soil and the physical and mechanical parameters as shown in Table 1.

The surface of the test site area is laid with 0.5 m thick medium coarse sand. The plastic drain board adopts a standard plate with a distance of 1 m, a square layout, and a depth of 18 m. The design vacuum requires 85 kPa, and the effective vacuum time is 150 days.

| Layer          | Thickness (m) | Weight (kN/m³) | Sub-weight (kN/m³) | Cohesion (kPa) | Internal friction angle (º) |
|---------------|--------------|----------------|--------------------|----------------|----------------------------|
| Dredger fill mud | 6.1          | 15.9           | 5.9                | 14.1           | 7.92                       |
| Mud           | 2.2          | 16.2           | 6.2                | 14.57          | 7.67                       |
| Silty clay    | 2.7          | 18.5           | 8.5                | 18.93          | 12.13                      |
| Silty         | 7.8          | 19.3           | 9.3                | 5.23           | 28.97                      |
| Clay          | 6.2          | 18.8           | 8.8                | 20.71          | 10.42                      |

3. Test results

3.1. Surface settlement

In the process of soft soil foundation reinforcement, the monitoring instrument of field burial depth in the test areas was used to make real-time dynamic observation of foundation reinforcement. The settlement of the surface fill ground mainly includes the settlement during the insert period and the settlement during the vacuum preloading period. The settlement during the insert period is the settlement caused by the consolidation of soil during the insert period, while the settlement during the vacuum preloading period is the settlement caused by the soil under the action of vacuum load after the installation of drainage plate. The surface settlement is shown in Table 2 and the variation of settlement is in Fig.1.

| Settlement in the plate stage /mm | Settlement in the preloading period/mm | Total Settlement /mm |
|-----------------------------------|---------------------------------------|----------------------|
| 630                               | 1777                                  | 2379                 |
Since the surface of the test area is unconsolidated blow-fill soil, which has a larger settlement than other soil layers under the action of vacuum load, monitoring the surface settlement of the test area can effectively evaluate the reinforcement effect of different construction techniques. Fig.1 shows the settlement increases gradually with the change of depth.

3.2. Pore pressure
Pore water pressure refers to the excess hydrostatic pressure generated by soil in the process of vacuum preloading, and its growth and dissipation process reflect the characteristics of drainage consolidation and effective stress change law of soft soil foundation, which has important research significance. There are 6 pore pressure monitors installing in different depths. The variation of pore pressure is shown in Fig.2.
The pore water pressure of soil layers at 2m depth is not measured accurately due to the complexity of field construction. The pore pressure at 5m, 8m, 11m, 14m and 17m is changing with time. The value of pore pressure is changing with the soil depth, the value of pore pressure at 17m is the larger than the value at 14m, which is larger than the value at 11m, which is larger than the value at 8m, which is larger than the value at 8m.

3.3. Layered settlement
In order to accurately grasp the settlement deformation of foundation during the process of vacuum preloading reinforcement, it is also necessary to monitor the layered settlement of foundation. Layered settlement monitors are arranged in three test zones to monitor the settlement of soil layers at different depths during the process of foundation reinforcement. There are 5 settlement monitors installing in different depths with 3 m intervals. The development of layered settlement is shown in Fig.3.

Figure 3 shows that layered settlement at 5m, 8m, 11m, 14m and 17m is changing with time. The value of layered settlement is changing with the soil depth. The value of layered settlement at 17m is the smallest and the value at 5m is the largest.

4. Conclusions
This paper analysed the conventional vacuum preloading method with in-site test method, and the foundation reinforce effect was evaluated by monitoring the surface settlement, variation of pore pressure and layered settlement. The main conclusions are as followed.

• Since the surface of the test area is unconsolidated blow-fill soil, which has a larger settlement than other soil layers under the action of vacuum load, monitoring the surface settlement of the test area can effectively evaluate the reinforcement effect of different construction techniques. Fig.1 shows the settlement increases gradually with the change of depth.

• The pore water pressure of soil layers at 2m depth is not measured accurately due to the complexity of field construction. The pore pressure at 5m, 8m, 11m, 14m and 17m is changing with time. The value of pore pressure is changing with the soil depth, the value of pore pressure at 17m is the larger than the value at 14m, which is larger than the value at 11m, which is larger than the value at 8m, which is larger than the value at 8m.
• The layered settlement at 5m, 8m, 11m, 14m and 17m is changing with time. The value of layered settlement is changing with the soil depth. The value of layered settlement at 17m is the smallest and the value at 5m is the largest.

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