Research on Deformation Law of Soft Soil Foundation under Load

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Abstract. This study takes a road as the main object of long-term settlement of the road foundation, and analyses the settlement deformation and long-term settlement deformation of the soft soil foundation in the construction process from the aspects of numerical analysis and field test respectively, so as to obtain the long-term settlement characteristics of the road soft soil foundation in Tianjin port area, and further analyse the generation mechanism and key influencing factors of the long-term settlement.

1. Introduction
The long-term settlement characteristics of soft soil foundation are related to the soil layer characteristics and stratum distribution of soft soil foundation, and are also closely related to the construction process and technology of soft soil foundation treatment. According to the numerical model, the characteristics and distribution of soft soil stratum are simulated, and a series of on-site construction processes are restored. Observing and analyzing the stress and strain development process of the foundation in the construction process is the basis for in-depth analysis of the settlement and long-term settlement mechanism of soft soil foundation. At the same time, according to the engineering example analyzed, the field measurement work is carried out and the numerical simulation results are compared with the measured results, so as to verify and correct the selection of key parameters of the numerical simulation and make the numerical analysis results reflect the actual situation in the field as much as possible, which is an essential procedure in the existing numerical analysis process. This study takes a road as the main object of long-term settlement of the road foundation, and analyzes the settlement deformation and long-term settlement deformation of the soft soil foundation in the construction process from the aspects of numerical analysis and field test respectively, so as to obtain the long-term settlement characteristics of the road soft soil foundation in Tianjin port area, and further analyze the generation mechanism and key influencing factors of the long-term settlement.

2. Project overview
A road is a city branch road. The main purpose of the project construction is to serve the liquid bulk storage tank areas on both sides of the road. The construction of the project can provide convenient conditions for the construction of plots on both sides of the road in the next step. This soft foundation
treatment is carried out by vacuum combined with surcharge preloading method, which requires the vacuum degree under the membrane to be kept above 85kPa for about 110 days, the vacuum preloading horizontal drainage channel adopts 400mm thick medium coarse sand cushion, and the vertical drainage channel adopts plastic drainage plates with a spacing of 800mm, square arrangement and a bottom elevation of -14.5m.

The foundation soil of this project is the late Q4 deposited soil and the recent artificial dredger fill. This kind of soil has the characteristics of high water content, high compressibility, low strength and poor permeability due to its short deposition history. At the same time, the foundation soil has not reached full consolidation under its own weight and is in an under consolidated state with poor physical and mechanical properties and cannot meet the use requirements without treatment. According to the drilling data before reinforcement, the foundation soil layer of this project is as follows from top to bottom: silty fine sand: the working cushion layer recently artificially dredged up is mainly silty fine sand, silty clay and silt, and is gray. Silt: it has recently been manually dredged up, grayish brown, highly compressible and plastic flowing. Formed by manual hydraulic fill, this layer is extremely uneven in distribution, and some boreholes contain more silt clay and silty clay. Silty clay: the marine sedimentary soil layer is dominated by silt clay, with silt silty clay and silty clay sandwiched in some boreholes, grayish brown, highly compressible and fluid plastic. Silty clay: marine sedimentary soil layer, grayish brown, highly compressible and fluid plastic. Clay: marine sedimentary soil layer, mainly clay and muddy clay, grayish brown, moderately compressible, soft plastic and rich in shells. Table 1 shows the deformation calculation parameters adopted after the numerical model fitting correction and the vertical permeability coefficient value of the drainage plate foundation after equivalent calculation, which is obtained by simplified calculation with the equivalent permeability coefficient method.

| Soil layer name | Thickness (M) | Elastic Modulus (MPa) | Poisson's ratio | permeability coefficient (cm/s) |
|-----------------|---------------|-----------------------|----------------|-------------------------------|
|                 |               |                       |                | Vertical                      | Horizontal | Equivalent vertical |
| 1 - 1 Dredger   | 6.1           | 0.57                  | 0.2            | 2.15E-07                     | 2.95E-07   | 3.83E-6             |
| 2 - 1 Silty Clay| 2.2           | 6.45                  | 0.24           | 6.67E-07                     | 4.56E-07   | 1.85E-6             |
| 2 - 2 sludge    | 2.7           | 1.14                  | 0.2            | 2.85E-07                     | 4.37E-07   | 1.14E-6             |
| 2 - 3 Silty Clay| 7.8           | 3.52                  | 0.28           | 1.64E-07                     | 3.38E-07   | 5.53E-6             |
| 3 - 1 powder Clay| 6.2           | 8.86                  | 0.34           | 2.7E-08                      | 3.27E-08   | —                   |
| 3 - 3 silty fine sand | 20   | 55.0                  | 0.32           | —                            | —          | —                   |

3. field measurement layout
The field measurement work is divided into two stages, the first stage is the monitoring of soft soil foundation treatment stage, and the second stage is the monitoring of foundation pavement construction and road settlement after foundation treatment. In the soft soil foundation treatment stage, various monitoring facilities such as surface settlement, layered settlement and pore water pressure are respectively arranged in the vacuum treatment area to provide various key data during the foundation treatment construction stage while monitoring various key quality indicators during the foundation treatment process. The second stage of long-term observation after soft soil foundation treatment is mainly based on the observation of foundation surface settlement, supplemented by field survey and soil sampling laboratory tests after reinforcement to provide special stratum parameters for long-term settlement numerical analysis. In the process of foundation treatment, the amount of ground settlement measured on site is shown in fig. 1.
Figure 1 measured curve of ground settlement during foundation treatment construction

As shown in fig. 1, during the foundation treatment, the measured curve of ground settlement at the center is 2079mm during the vacuuming combined loading period, plus the settlement during the slab laying period, the total settlement of the foundation during the final foundation treatment construction is about 2.6m, and the comprehensive consolidation degree of the foundation during the construction period is about 85%.

4. Numerical Calculation Results

In order to fully and accurately reflect the actual situation of the site, the numerical analysis method is used to simulate the construction process and stratum situation. It is necessary to compare the numerical analysis results with the field measured results and to fit and correct the selection of a series of key parameters used in the numerical analysis process, so as to achieve the purpose that the numerical results can accurately reflect and predict the actual situation of the site. During the foundation treatment, the soft soil foundation underwent vacuum combined surcharge preloading. The soft soil foundation underwent drainage consolidation and the soil settlement was obvious. As shown in fig. 2, the total surface settlement during the vacuum combined surcharge preloading period was 2.572m, and the overall compression settlement of the foundation was mainly concentrated in the surface fill 1 - 1 silt layer and the lower original deposit 1 - 2 silt layer. The surface settlement curve showed that the soil was nearly completely consolidated at the later stage of loading.

Figure 2 foundation settlement after vacuum pumping is completed

As shown in result, the surface settlement curve calculated numerically during the vacuum combined loading construction is compared with the field measured curve. Due to the lack of field process observation data during the loading period, the measured curve slightly deviates from the calculated result in the early stage of loading (during the loading period). After vacuuming and fully loading, the numerical calculation results are in good agreement with the measured results, indicating
that the numerical calculation results can fully reflect the actual situation of foundation deformation in the construction period of foundation treatment, and the values of various parameters of the numerical model are reasonable.

During the construction of foundation treatment, the soft soil foundation underwent a series of construction processes, such as inserting plastic drainage boards, pumping air and piling load. The construction period of this foundation treatment is 130 days. During this period, the soft soil foundation realized the reinforcement effect of rapid drainage consolidation under the combined action of pumping vacuum and piling load. The final settlement of the foundation during unloading was about 2.6m, and the comprehensive consolidation degree reached 85%. The pore pressure of soil in the area where the plate is punched in the vacuum zone shows a significant decrease in relation to the static water pore pressure due to the application of vacuuming load, increasing gradually and uniformly from the surface vacuuming pressure of -85kPa downward, conforming to the principle of reducing pore water stress of soil by vacuum preloading to increase effective stress. However, more positive excess pore pressure is distributed below the depth of the drain plate, i.e. in the 3-1 silty clay layer of the underlying layer, indicating that the underlying layer part of the drain plate is still under-consolidated to a certain extent at the end of vacuum pumping.

5. Conclusion
The pore pressure of the soft soil foundation within the drainage plate range rises to close to the static water pore pressure within a short time after vacuum unloading, and then the excess pore water pressure in the soil body is generated under the action of the service life load (road bed construction load and road traffic load), but the excess pore water pressure is quickly dissipated under the action of the drainage plate, indicating that the soil body within the drainage plate range can be consolidated quickly after being subjected to the service load.

Compared with the situation of the soil mass in the underlying layer under the drain plate under the post-construction use load, the pore pressure in the underlying layer is still far from fully consolidated during the vacuuming foundation treatment until the end of vacuuming, and then decreases rapidly after vacuum unloading. Then, under the use load, the obvious excess pore pressure appears in the layer, and the pore pressure dissipates slowly, and it takes time for the entire layer to dissipate to near full consolidation under the use load..

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