Study on Deformation Characteristics of Soft Soil Deep Foundation Pit under Overload Condition

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***Abstract*—Adjacent overload has a significant effect on the deformation of deep foundation pits in soft soil areas. At the same time, the construction of foundation pits in soft soil areas has obvious time effects, while the classical elastic and elastoplastic models can not reflect this. By establishing a finite element model considering the creep-consolidation coupling effect of soil, the deformation characteristics of deep foundation pit caused by different overload sizes are analyzed and verified by comparison with measured data. The results show that the overloading will reduce the negative excess pore water pressure generated in the surrounding soil due to excavation and unloading. The soil outside the pit is mainly rheological, and the consolidation effect of the soil is almost negligible, while the soil in the pit shows the coupling effect of rheology and consolidation. The effect of overloading on the horizontal displacement of the underground continuous wall is significant. The larger the overload value, the larger the horizontal displacement of the underground continuous wall.The near-overload of the foundation pit increases the maximum settlement of the ground surface behind the wall. The overload action causes the maximum surface settlement of the wall behind the wall to be closer to the retaining wall.**

***Index Terms*—overload, soft soil, deep foundation pit, numerical simulation**

I. INTRODUCTION

With the development and utilization of urban underground space, foundation pit engineering has made great progress and development [1]. There are often dense buildings near this kind of foundation pit, and the overload of adjacent buildings has a significant impact on the deformation of foundation pit engineering [2]. Many scholars [3-5] have studied the influence of adjacent overload on the construction of deep foundation pit, systematically analyzing the influence of adjacent building stiffness, buried depth and distance from adjacent overload to the edge of foundation pit. Due to the special engineering properties of soft soil, foundation pit construction has obvious time effect. There have been studies on consolidation [6] as the main deformation process of soft soil or creep as the main deformation process to establish a constitutive model for calculation and analysis, which will inevitably lead to results inconsistent with the actual. This paper intends to use the finite element software ABAQUS and the extended D-P creep model to carry out the fluid-structure coupling analysis of soil mass, considering the influence of different overload loads on the excess pore water pressure difference, the horizontal displacement of the envelope structure and the surface settlement behind the wall, so as to provide reference for the design and construction of similar projects.

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II. ENGINEERING BACKGROUND

*1.1 Overview of deep foundation p*it

The depth of the foundation pit is 10 m and the width is 20 m. The retaining structure of the foundation pit adopts the support system of underground continuous wall and reinforced concrete inner support. The thickness of the diaphragm wall is 600 mm and the depth of the diaphragm wall is 10 m. The internal support adopts two reinforced concrete jugs with support spacing of 4.5m, and adopts open-cut construction method.

1.2 Calculation Parameter selection

In this paper, the time-hardening creep law in ABAQUS and the D-P yield failure criterion are coupled to the creep model, wherein the plastic yield

The D-P yield surface with a linear meridian is used for the surface. The creep strain rate is the same as the plastic strain rate with the hyperbolic plastic flow potential function.

The physical and mechanical parameters and creep parameters of soil layer in the engineering site are shown in Table 1. In order to simplify the calculation, it is assumed that the soil under study is normally consolidated saturated clay, and the pore water flow conforms to Darcy's law, that is, water and soil are fluid-solid coupled bodies.

Table 1 Physical and mechanical parameters of the Soil layer

Soil layer	Layer thickness/m	Elasticity modulus E/MPa	Poisson's ratio	Cohesive force c/kPa	Internal friction angle φ/°	Fitted creep parameters	Fitted creep parameters	Fitted creep parameters
Muddy clay	16	12	0.4	10	3	4.00×10^{-9}	1.2	-0.7
Gray clay	12	12.3	0.35	18	16	8.00×10^{-9}	1.2	-0.8
Silty clay	13	30.7	0.35	40	20	2×10^{-8}	1.3	-0.9

III. FINITE ELEMENT MODEL

3.1 Construction Conditions

The numerical simulation steps of excavation process are as follows: firstly, gravity load is applied, initial ground stress of soil is calculated, and initial displacement field is set to zero. Generating underground diaphragm wall; Excavate the first layer of soil at a depth of 1.5m; Add the first steel support; Excavate the second layer of soil to a depth of 6 m;

Add a second steel support; Excavate the third layer of soil to a depth of 10 m.

3.2 Numerical analysis model

The shape and force of the strip subway foundation pit are relatively regular, which can be regarded as a plane strain problem. Therefore, two-dimensional finite element analysis is adopted in this paper. In order to eliminate the influence of model boundary on the calculation results, the influence width of foundation pit excavation is set to be 3 ~ 4 times of the excavation depth, and the influence depth is set to be 2 ~ 4 times of the excavation depth. According to symmetry, taking the center line of foundation pit as axis of symmetry, the model is established by taking half of the whole foundation pit.

Model boundary conditions: two sides are X-axis symmetric constraints, the bottom side is X,Y direction constraints. After the excavation of ground and soil, the top surface of the foundation pit is set as the boundary where the excess pore water pressure is 0, that is, the drainage boundary. The soil element adopts the coupled plane strain element CPE4P. According to the survey data, the undrained fixed boundary is set at the bottom of the foundation, considering the symmetry, the symmetric surface of the foundation pit is set as the undrained boundary with horizontal constraint, and the calculated section left boundary can be set as the undrained boundary because it is far enough from the center of the foundation pit.

IV. Analysis of Finite Element Calculation Results

4.1 Analysis of horizontal displacement of underground diaphragm wall

Fig.1 to Fig.2 show the variation curves of the horizontal displacement of the wall in different periods under different overload effects, in which IE3-1 represents the completion of foundation pit excavation,IE3-3 represents the 18th day after the end of foundation pit excavation,IE4-1 represents the 36th day after the end of foundation pit excavation, and IE4-2 represents the 54th day after the end of foundation pit excavatio.

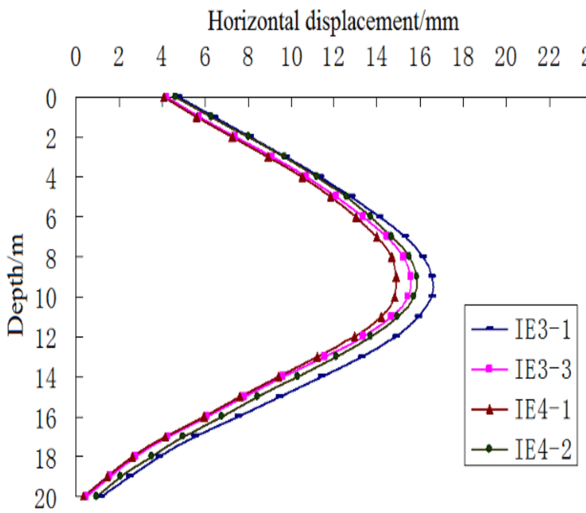

Fig.1 Variation curves of horizontal displacement of wall without overload in different periods

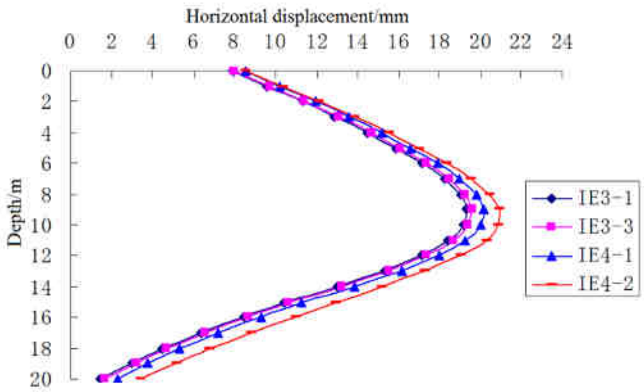

Fig.2 Variation curves of horizontal displacement of wall under 20 kPa overload in different periods

As can be seen from Fig.1 to Fig.2, compared with no overload action, overload near the edge of foundation pit significantly increases the horizontal displacement value of the wall. The horizontal displacement curve of the wall under overload is basically consistent with that without overload. The maximum value of the horizontal displacement occurs near the excavation face of the foundation pit. The horizontal displacement of diaphragm wall increases with the increase of surface overload value. When the overload value is 20 kPa respectively, the corresponding maximum horizontal displacement of underground diaphragm wall is 20.88 mm respectively. It can be seen that surface overload has a significant effect on the horizontal displacement of diaphragm wall. The horizontal displacement of the wall increases with the increase of the ground overload value, but the growth rate of the horizontal displacement of the wall is basically stable under different overload, which indicates that the magnitude of the overload has little influence on the soil rheological rate.

4.2 Analysis of soil settlement behind the wall

Fig.3 to Fig.4 show the variation curves of surface settlement behind the wall in different periods under different overload effects.

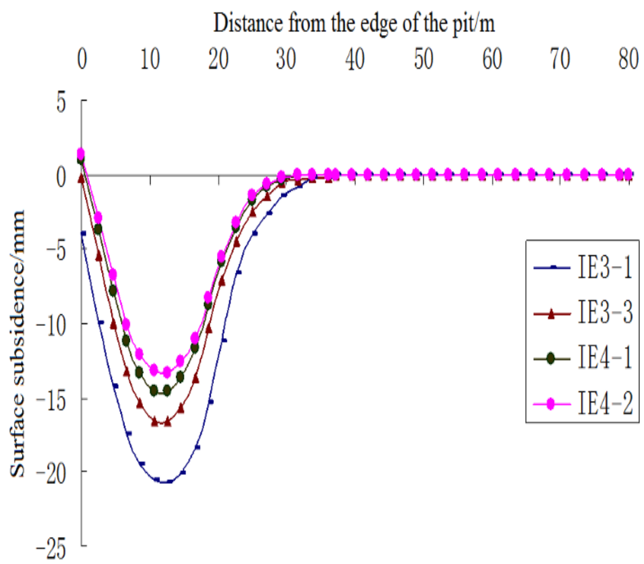

Fig.3 Variation curves of ground surface settlement behind wall without overload in different periods

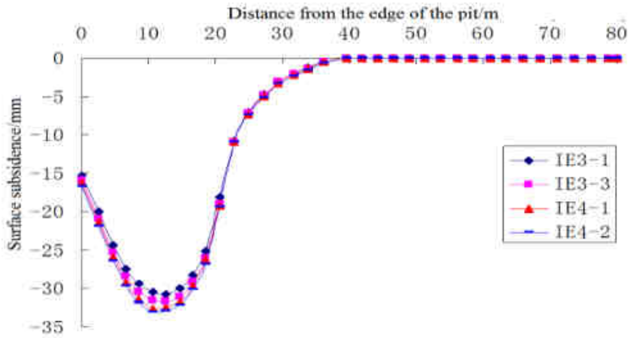

Fig.4 Variation curves of ground surface settlement behind wall under 20 kPa overload in different periods

As can be seen from Fig.3 to Fig.4, when the overload is 0 kPa and 20 kPa respectively, the maximum surface settlement behind the wall at the end of foundation pit excavation is 20.86mm and 30.50mm respectively. It can be seen that, compared with the case without overload, the increment of maximum surface settlement is larger and increases successively with the increase of overload value. Therefore, the overload of adjacent foundation pit has a significant influence on the maximum surface settlement, which is mainly due to the increase of earth pressure in the active area caused by overload, but has little influence on the earth pressure in the passive area. As a result, the pressure difference between the front and back of the retaining wall caused by excavation and unloading keeps increasing, resulting in the increase of the flow trend of soil outside the retaining wall into the foundation pit, and the increase of the maximum surface settlement behind the wall. In addition, the horizontal displacement of the enclosure structure will also cause the increase of the maximum surface settlement behind the wall.

Under the action of overload, the influence range of surface settlement is more obvious, which is about twice the excavation depth of foundation pit. With the increase of overload value, the influence range of settlement increases slightly, but basically remains unchanged. Outside the influence range, the settlement value decreases rapidly and the effect of settlement is weakened. Under the action of overloading, the shape characteristics of surface settlement caused by foundation pit excavation are different from those without overloading. Under the action of overload, the surface settlement curve is spoon-like, and there is an obvious settling trough at a certain distance outside the wall. Under the action of overload, the maximum position of the surface settlement should be closer to the retaining wall, and the surface settlement has a large amplitude within a certain range near the underground diaphragm wall. The surface settlement curve also gradually changes from the original parabola shape to the spoon shape. In addition, it can be seen that the surface settlement behind the wall decreases and the soil rebound occurs within a period of time after the end of excavation without overload, which is most obvious in the first 18 days, and then the rebound rate decreases rapidly. This is caused by the dissipation of negative excess pore water pressure and soil consolidation. In the case of adjacent overload, because overload reduces the consolidation of the soil behind the wall, the rebound of the soil before and after the wall is not obvious, which is consistent with the above analysis of excess static pore water pressure.

4.3 Uplift of soil at bottom of pit

Fig.5 ~ Fig.6 shows the change of soil heave at the bottom of the pit with time after the completion of excavation under the action of overload. Compared with the condition without overload, the soil uplift in the pit shows continuous development, but the difference is that the soil uplift deformation in the pit is larger at the end of the foundation pit excavation under the action of overload. When the overload size is 20KPa, 50KPa, 70KPa and 100KPa, the corresponding maximum uplift of soil in the pit at the end of foundation pit excavation is 42.88mm, 47.72mm, 51.53mm and 54.06mm. The maximum value of uplift in the pit at the end of excavation without overload is 36.22mm. It can be seen that overload has a significant effect on soil uplift in the pit, and the amount of soil uplift in the pit increases with the increase of overload value. This is understandable in theory. We know that there are two main reasons for uplifting soil at the bottom of the pit. On the one hand, the influence of foundation pit excavation on soil at the bottom of the pit is mainly manifested as vertical unloading, which causes upward displacement of soil at the bottom of the pit. On the other hand, the soil outside the pit tends to flow into the pit due to the pressure difference between the retaining wall inside and outside the pit, which causes the uplift and deformation of the soil at the bottom of the pit. With the increase of the overload value, the pressure difference between the soil inside and outside the retaining wall will become larger and larger, which makes the uplift of the bottom of the pit become larger and larger. At the same time, a large plastic zone will be generated around the foundation pit and cause the surface settlement.

From the end of foundation pit excavation to the 90th day, the soil uplift in the pit will continue to develop under different loads. However, the amount of uplift decreases and tends to be stable with the increase of load value. When the overload size is 20KPa, 50KPa, 70KPa and 100KPa respectively, from the end of foundation pit excavation to the 18th day, the maximum soil uplift in the pit is 5.4mm, 5.0mm, 3.9mm and 3.6mm respectively. This is consistent with the distribution of negative excess pore water pressure under overload described above, that is, overload will cause the reduction of negative excess pore water pressure in the soil inside and outside the foundation pit due to excavation unloading. The dissipation of negative excess pore water pressure, that is, the consolidation of soil, also causes the uplift of soil in the pit. Therefore, with the decrease of negative pore water pressure, the consolidation effect of soil becomes weaker and weaker, and the soil uplift in the pit presents a stable growth trend due to the influence of rheology.

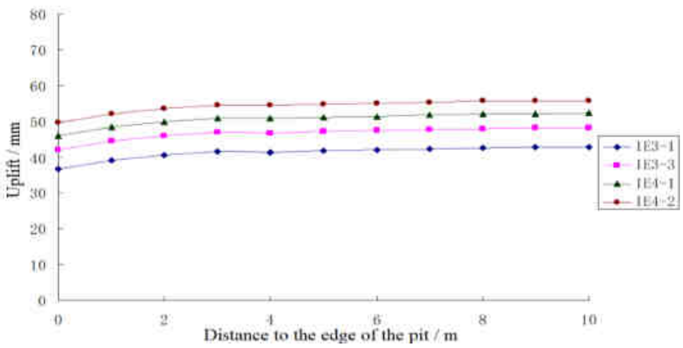

Fig.5 Variation curve of soil uplift in the pit with time under 20KPa load

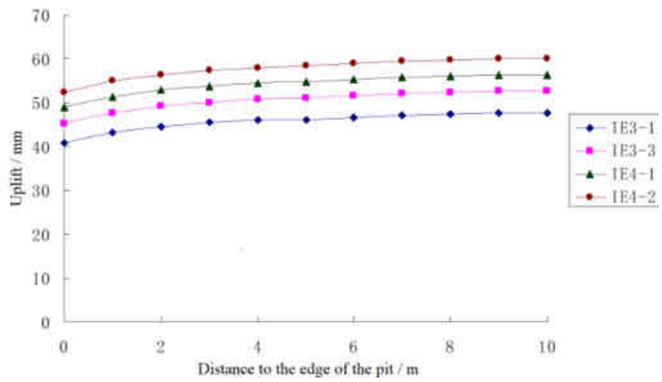

Fig.6 Variation curve of soil uplift in the pit with time under 50KPa load

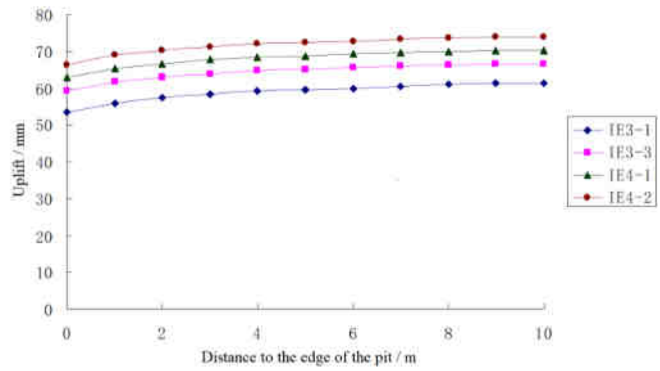

Fig.7 Variation curve of soil uplift in the pit with time under 70KPa load

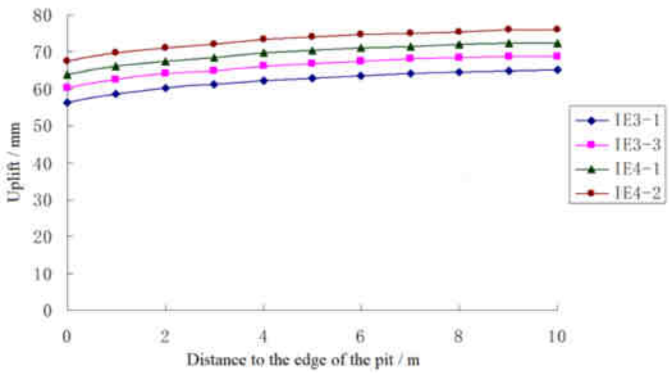

Fig.8 Variation curve of soil uplift in the pit with time under 100KPa load

V. CONCLUSION

Taking the excavation project of deep foundation pit with underground diaphragm wall and internal support as an example, the influence of different overloads on the deformation properties of foundation pit excavation is analyzed through numerical simulation under the condition of considering the coupled characteristics of creep and consolidation of soft soil. The main conclusions are as follows:

1 Overload will reduce the negative excess pore water pressure generated in the pit and surrounding soil due to excavation unloading, and actually accelerate the consolidation effect of soil within the influence range of foundation pit excavation, so as to cause the surface settlement behind the wall and the rebound of the horizontal displacement of the wall, which is beneficial to the foundation pit engineering. However, it will also cause the increase of uplift deformation of the soil in the pit, which is unfavorable to the foundation pit engineering.

2 With the increase of overload value, the horizontal lateral displacement of diaphragm wall also increases, and the maximum horizontal displacement occurs near the excavation face of the foundation pit. With the passage of time after the excavation, the consolidation effect of soil becomes weaker and weaker, which is mainly manifested in rheological properties. As a result, the horizontal displacement of the wall is almost unchanged for a long period of time after the excavation. After that, the horizontal displacement of the wall keeps increasing and the overload size has little influence on the rheological rate of the soil.

3 Adjacent foundation pit overload has a significant influence on the maximum surface settlement. The larger the overload value is, the greater the maximum surface settlement is. Compared with the condition without overload, the position of maximum surface settlement under the action of overload is closer to the retaining wall. During a period of time after excavation without overload, the surface settlement behind the wall will rebound due to soil consolidation, but this rebound is not obvious in the case of adjacent overload.

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