Study on Creep-consolidation Coupling Characteristics of Soil of Deep Foundation Pits in Soft Clay Regions

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Abstract. This paper starts from the mechanism of the coupled effect of consolidation and creep of soft soil, regarding the effect of time, adopting time hardening and Druker-Prager yield criterion coupled creep model, studies the variation law of the excess pore water pressure of soil with time after foundation pit excavation through numerical simulation. The results show that unloading of foundation pit excavation will produce negative excess pore water pressure in the pit bottom and surrounding soil, and the maximum pore water pressure (absolute value) will occur in the center of the foundation pit; after the excavation completion of the foundation pit, the pore water pressure is continuously dissipated, and the pore pressure of the soil before the pit is dissipated faster, while the soil behind the pit is relatively slow. The excess pore water pressure after dissipation is basically the same as the ultra-static pore pressure when the excavation is completed; due to the impermeability of the underground continuous wall, the pore pressure boundary is very complicated, resulting in a sudden change of the excess pore water pressure behind the wall front wall.

1. Introduction
Soft soil has the engineering characteristics of large natural water content, high compressibility and poor permeability. The foundation pit construction in the soft soil foundation has obvious time effect. During the excavation of the foundation pit, the soil stress is released due to excavation unloading, which causes the rebound and uplift of the soil at the bottom of the pit[1,2]. During the excavation interval, due to the special engineering characteristics of soft soil, there are two processes of consolidation and creep in the compression process of soft soil, the consolidation and creep of soil are unified, and the consolidation deformation is included in creep deformation. The deformation of the foundation pit bottom and surrounding soil is caused by the coupling of the two processes[3].

Regarding the consolidation effect and creep effect of the soil in deep foundation pit engineering in soft soil area, the previous studies have been carried out separately. However, there is relatively little research on the coupling between the two. In this paper, the time-hardening and Druker-Prager plastic coupled creep model is used to study the creep-consolidation coupling characteristics of soft soil through numerical simulation, and to explore the influence law of deformation and stability of deep foundation pit.

2. Constitutive model of soft soil
In this paper, the ABAQUS finite element software is used to analyze the fluid-solid coupling characteristics of soil using the extended D-P model.
3. Finite element analysis of reference examples

3.1 Basic assumptions of the calculation model.

- According to the plane strain model, the symmetry is used to take the half section for analysis.
- It is assumed that the soil studied is a normally consolidated saturated clay, and the flow of pore water conforms to Darcy's law, that is, water and soil are fluid-solid coupling bodies.
- The initial stress of the soil is assumed to be the earth pressure at rest.
- The constitutive model of soil uses time hardening and Druker-Prager plastic coupled creep model.

3.2 Calculation diagram of reference example

Figure 1 is the simplified diagram of two dimensional excavation calculation of foundation pit engineering. The standard section width of foundation pit of reference example is 20m, the excavation depth is 10m, the underground continuous wall is supported, the thickness of underground continuous wall is 0.6m, and the depth of the inserted soil is 10m. Two-layer concrete horizontal support is provided. The first layer supports is 1.5m from the ground, the support spacing is 4.5m, and the second support is 4.0m from the bottom of the pit.

![Figure 1. Calculation diagram of the reference example](image)

3.3 Calculation parameters

Soil: it is assumed that the soil is a homogeneous isotropic material in order to reduce the parameters and simplify the analysis. The permeability coefficient of the soil in each layer is taken as 1.0×10^-6 cm/s. The other parameters of the soil layer refer to literature[4]. The specific data is shown in Table 1.

| Soil layer number | Layer thickness/m | E/MPa | u | c/kPa | φ/(°) | γ/(kN/m³) | A | n | m |
|--------------------|------------------|-------|---|-------|-------|-----------|---|---|---|
| layer 1            | 14               | 6.384 | 0.45 | 5 | 25 | 16.8 | 5.0×10^-9 | 1.2 | -0.8 |
| layer 2            | 12               | 12.32 | 0.35 | 18 | 16 | 17.3 | 8.0×10^-9 | 1.2 | -0.8 |
| layer 3            | 4                | 30.76 | 0.35 | 40 | 20 | 19.8 | 2.0×10^-8 | 1.3 | -0.9 |
| layer 4            | 16               | 38.2  | 0.35 | 3 | 31.5 | 19.4 | 5.0×10^-8 | 1.5 | -0.9 |

Space enclosing structure: the concrete parameters of C35 are taken for underground continuous wall. The thickness is 0.6m, the modulus of elasticity is 5000MPa, the Poisson's ratio is 0.167.

Support: the two layers of support are made of reinforced concrete. The support spacing is 4.5m, the elastic modulus is 25000MPa, and the Poisson's ratio is 0.167.

Table 1. Parameter calculation table for each soil layer
3.4 Computational model
According to the results of finite element calculation and engineering experience, the width of influence of foundation pit excavation is 3~4 times of the depth of excavation, and the depth of influence is 2~4 times of the depth of excavation. According to symmetry, the half section of calculation area is taken for analysis. The calculation range taken in the analysis is 80m×48m.

The creep model is calculated according to the coupling of time hardening and D-P plasticity. The contact relation between underground continuous wall and surrounding soil is friction contact relation. The main contact surface is underground continuous wall, and the left and right soil is subordinate contact surface, tangential given friction coefficient, and the normal direction is set to hard contact, that is, the two contact surfaces do not intrude into each other.

3.5 Implementation steps of numerical Simulation of excavation process
The specific implementation steps of complex processes such as partial excavation and construction interval are as follows:
- Apply a gravity load, calculate the initial ground stress of the soil, and set the initial displacement field to zero.
- Form underground continuous wall.
- Excavate the first layer of soil with excavation depth of 1.5 m.
- Add the first steel support.
- Excavate the second layer of soil with excavation depth to 6m.
- Add the second steel support.
- Excavate the third layer of soil with excavation depth to 10m.

4. Analysis of results
4.1 Calculation condition and its finite element mesh
The mesh layout is shown in Fig. 2. The constraint condition is that the two sides are X-axis symmetric constraints, and the bottom surface is X and Y direction constraints. The top surface of the foundation pit after the ground and soil excavation is set as the boundary of the excess pore pressure of 0, that is, the drainage boundary. The soil unit uses a coupled plane strain unit CPE4P. Considering the symmetry, the symmetric surface of the foundation pit is set as a horizontal undrained boundary. The left boundary of the calculation section can be set as the undrained boundary because it is far enough from the center of the foundation pit.

4.2 Initial stress balance analysis
Figure.3 shows the geostress balance results of the equilibrium stress analysis step in the excavation of the foundation pit simulated by ABAQUS. Among which, the maximum vertical displacement U2 is 3.653e-03m, which proves that the initial stress balance is proper, the initial displacement of the
calculation result is guaranteed to be close to 0, thus meeting the accuracy requirements of the model.

4.3 Calculation results and Analysis of excess pore pressure

4.3.1 Excess pore pressure distribution

The reference example ignores the change of groundwater level, assuming that the groundwater level is maintained at the surface, and using the finite element software ABAQUS to perform consolidation-creep coupling analysis on the reference example. According to the calculated results, the contour diagram of excess pore water pressure is drawn, see Figure. 4-Figure 7.

From figure 4, it can be seen that the excess pore water pressure caused by excavation and unloading is negative in the whole calculation area, the negative excess pore water pressure in the area below the bottom of the pit is larger in numerical value, and the negative excess pore water pressure in the area outside the pit is smaller numerically. The maximum value of negative excess pore water pressure (absolute value) occurs in the center of foundation pit, near the interface between soil layer1 and soil layer2.

Figure 4 to Figure 7 show the excess pore pressure contours after 9 days, 36 days, and 54 days after the completion of the excavation of the foundation pit. It can be seen from the figure that the negative excess pore water pressure behind the pit in front of the pit is dissipating and the dissipation rate is slower and slower with the passage of time. Therefore, the velocity of pore water pressure dissipation in the soil in front of the pit is faster, and the pore water pressure in the soil behind the pit is relatively slow. There are two main reasons why the dissipation rate is so slow: on the one hand, the permeability coefficient of soil is small; on the other hand, the rheological behavior of soil slows down the velocity of negative excess pore water pressure dissipation, and the smaller the permeability coefficient, the more significant the influence of rheological behavior.

4.3.2 Dissipation of excess pore water pressure

In order to analyze the dissipation law of excess pore water pressure at different locations after foundation pit excavation, four representative points A, B, C and D were selected. The specific
position is shown in Fig. 8.

![Figure 8. Position of analysis point](image)

![Figure 9 Comparison of excess pore water pressure dissipation after excavation](image)

It can be seen from Fig. 9 that the absolute value of the negative excess pore water pressure at the end of excavation is A>B>C>D, the dissipation rate at point A is the fastest, and the dissipation rate at point D is the slowest. At point A and B, the pore water pressure dissipation rate is the fastest in the first 10 days after the completion of the excavation, and then the dissipation rate begins to decrease slowly. For the points C and D, the pore water pressure dissipation from the end of the excavation to the 54th day has been very slow. It can be seen that the negative excess pore water pressure generated by the excavation and unloading of the foundation pit is mainly concentrated in a certain range under the pit in front of wall, and the excess pore water pressure caused by the excavation and unloading of the soil outside the pit is very small. This is mainly due to the impermeability of the underground continuous wall, which results in a sudden change of the excess pore water pressure behind the wall and in front of wall.

5. Conclusion

The main conclusions are as follows:

- Foundation pit excavation and unloading produces negative excess pore water pressure in the bottom of the pit and surrounding soil. The distribution of negative excess pore water pressure in the area below the bottom of the pit is more concentrated and the value is larger, but the value outside the pit is smaller.
- Due to the influence of soil rheological behavior, the negative pore water pressure dissipates slowly over time, that is, the soil consolidation is weaker. From the entire dissipation process of the negative excess pore water pressure, the dissipation rate has been very slow.
- Due to the impermeability of the underground continuous wall. The negative excess pore water pressure is mainly concentrated in a certain range below the bottom of the pit, and the excess pore water pressure of the soil outside the pit is very small.
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References
[1] MENG Y, ZHOU S. (2016) Discussion on the Engineering Properties of Soft Soil and Treatment Measures for Soft Foundation in Shenzhen. Resources Environment. 30: 450-453.
[2] LIU S P, LI J Y, ZHANG X S, HE Z Y. (2018) Excess Pore Water Pressure Caused by Driving Pile in Ko Consolidated Saturated Soils. Chinese Journal of Underground Space and Engineering. 02: 430-435.
[3] XIE X D, LIU G B. (2012) Analysis on Deformation Temporal Characteristics of Retaining Structures in Deep Foundation Pit. Chinese Journal of Underground Space and Engineering. 06:1261-1266.
[4] GUO H Z, ZHANG Q H, GUO J(2008) Application Study on Time Hardening and Druker-Prager Yield Criterion Coupled Creep Model of Soil. Structural Engineers. 3: 117-121.