Deformation analysis of retaining structure of deep foundation pit in soft soil under over-excavation

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Abstract. In the construction of deep foundation pits in soft soil areas, over-excavation of foundation pits and failure to set up support in a timely manner often occur. Due to the creep properties of soft soil, the envelope structure will be sharply deformed and cause engineering accidents. With the secondary development program of the elastic-viscose-plastic constructive model, simulate the conditions of normal construction and over-excavation of foundation pit in Soft clay area, analyze the time change regulation of retaining structures and safety state of foundation pit, in order to achieve effective control of the deformation and protect the buildings adjacent to foundation pit.

1. Introduction

In a deep foundation pit with a rheological soil layer, the rheological characteristics of the soil not only affect the safety of the deep foundation pit, but also play an important role in the deformation control of the deep foundation pit, which is especially prominent in the deep foundation pit engineering which requires high deformation control. Soft soil has very complex mechanical properties. With the development of theoretical research and the improvement of experimental level, for the constitutive model of soft soil and its application in foundation pit engineering, there have been many research results[1-3].

Due to the limitation of construction period, overexcavation often occurs in the construction process of deep foundation pit. As a result, the support fails to be set in time, the additional stress increases, and the deformation of the retaining structure increases. It is reasonable to understand the variation law of deformation with time of deep foundation pit retaining structure under various working conditions, as well as the safety characteristics of deep foundation pit, which will be helpful to make a scientific construction plan, and effectively control the deformation of foundation pit from the perspective of safety and economy, so as to ensure the safety of foundation pit and protect the surrounding environment.

Based on the research results of constitutive relation of the soft clay, this paper realizes the secondary development of elasto-viscoplastic constitutive model in FLAC3D, and it conducts finite element simulation analysis for two cases of normal excavation and timely support in the construction process of deep foundation pit in soft soil area[4-5].

2. Elasto-viscoplastic model of soft soil

Borja established an elasto-viscoplastic model to describe the stress-strain-time characteristics of clay with high moisture content on the basis of Cambridge model by introducing lag deformation term. Its expression is:
\[
\begin{align*}
\Delta p &= K(\Delta \varepsilon_v - \Delta \varepsilon'_v - \Delta \varepsilon'_p) \\
\Delta q &= 3G(\Delta \varepsilon_v - \Delta \varepsilon'_v - \Delta \varepsilon'_p)
\end{align*}
\]

3. Analysis of the deformation of the retaining structure

3.1 Project profile

There is a subway station with a two-story frame structure underground, the length is about 365m, the width is about 21.5m for the standard section. The main body of the station is enclosed by underground diaphragm wall. The standard section adopts 800mm thick underground wall with a wall depth of 30.8m, foundation pit excavation depth of about 17m, and five 609 steel tubes for support. There are a primary school, a middle school and some multi-storey residential buildings on the south side of the construction area. There are several buildings near the foundation pit on the north side of the construction area. There are many municipal pipelines under the traffic trunk road. The construction site is narrow, the foundation pit is long and deep, and the surrounding environmental protection requirements are high, therefore, the station foundation pit is designed, and the deformation control is carried out according to the first grade foundation pit, a total of 34 monitoring points of horizontal displacement of underground diaphragm wall are arranged, as shown in fig.1.

Fig.1 Schematic diagram of the layout of the wall measuring slope

The main characteristics of soil layer distribution in the site are: The upper layer (②、③、④1) is normally distributed, affected by the ancient river cutting, ⑥ layer dark green clay (hard soil) missing, ⑦ layer of soil buried deep, about 49m. ⑤ layer is larger for the aggregate thickness, In particular, the distribution of ⑤2-2 layers of sandy silt is relatively stable, and the ⑤2-2 layer is connected to ⑦ layer. The shallow groundwater of the site belongs to the divining type, and the water level is generally 0.5-1.5m deep. The micro-confined water aquifer is distributed in ⑤2-2 layers, and the head depth of confined water is generally 3~6m.

3.2 Deformation characteristics of the retaining structure

There are dozens of measuring points along the depth direction of each inclined hole, and the points corresponding to the maximum deformation are different under different working conditions. For normal deep foundation pit construction, the point corresponding to the maximum deformation of each working condition plays a decisive role in the safety character of the foundation pit at this moment. The measured results show that in each stage of excavation without support, the wall deformation increases sharply, and the deformation increases with the increase of excavation layers. The deformation value of the wall gradually tends to be stable after each soil layer is excavated and supported.

3.3 Numerical analysis model

Due to the large length of the foundation pit and the longitudinal symmetry of the standard section of the foundation pit, in order to simplify the calculation, only half of the standard section of the foundation pit with a width of 18m is taken for numerical analysis. The computational grid division is shown in figure 2. The width of half of the foundation pit is 10m, the width of the underground diaphragm wall is 0.8m and the depth is 31m, and the length of the soil body outside the pit is 51m, and the depth of the model is 51m. The model is divided into 19188 units and 23,180 nodes. Three contact surface elements are set at the contact point between the diaphragm wall and the soil mass, the support is simulated by beam element, the diaphragm wall is simulated by solid element, and the
support and the diaphragm wall are assumed to be elastomers. The lateral constraints around the model are as follows: movable bearing boundary conditions are used to constrain the horizontal displacement; fixed bearing boundary types are used to constrain the horizontal and vertical displacement on the bottom surface. The parameter values of the soil are shown in Table 1.

3.4 Results analysis

3.4.1 Calculation process
In the construction of deep foundation pit, the excavation of soil is not completed at one time, but step by step. Therefore, in the numerical simulation analysis, according to the actual situation of the project, the incremental method is adopted to simulate each working condition of the foundation pit, which can not only reflect the stress-strain situation of a certain stage in the construction process, but also use the elasto-viscoplastic constitutive model to better reflect the change of soil mass with time, truly simulate the excavation and support process of the foundation pit.

For the two cases of timely bracing and overexcavation construction, the calculation is carried out according to five working conditions, as shown in Table 2, the normal construction is to dig a layer of soil, and add support for one day. Another layer of soil was dug five days later, and so on. However, for the calculation condition of overexcavation, one step is to directly excavate to the depth of foundation pit analyzed.

| Calculation condition | Digging depth /m | Support position/m | Calculating time/d |
|-----------------------|------------------|--------------------|--------------------|
| Add the first support  | 3                | 1                  | 10                 |
| Add the 2nd support   | 6                | 5                  | 10                 |
| Add the third support  | 9                | 8                  | 10                 |
| Add the 4th support   | 12               | 11                 | 10                 |
| Add the 5th support   | 15               | 14                 | 10                 |

3.4.2 Adding support calculation result analysis
Fig. 2 is the time history calculation curve of lateral deformation of the retaining structure when normal excavation is carried out and support is added in time. As can be seen from the figure, for the first working condition (adding the first bracing), the wall deformation is 0.9mm after the first layer of soil is dug for 24h. At 48h, that is, 24h after bracing, the wall deformation increases to 2.37mm. At the 64h, the wall deformation has gradually become stable, and the maximum value is 2.96mm. For the second working condition, after digging the second layer of soil for 24h, the wall deformation is 3.83mm. At 48h, the wall deformation increased to 5.38mm. At 68h, the wall deformation has gradually become stable, and the maximum value is 2.96mm. For the third working condition, after digging the third layer of soil for 24h, the wall deformation is 8.98mm, and the wall deformation increases to 9.6mm at 48h. At 72h, the wall deformation has gradually become stable, with a maximum value of 10.3mm. For the fourth working condition, after digging the fourth layer of soil for 24h, the
deformation of the wall is 13.47mm. At 48h, the wall deformation increased to 14.01mm. At the 76h, the wall deformation has gradually become stable, with a maximum value of 14.43mm. For the fifth working condition, after digging the fifth layer of soil for 24h, the deformation of the wall is 17.63mm. At 48h, the wall deformation increases to 18.4mm. At the 84h, the wall deformation has gradually become stable, with a maximum value of 19.32mm.

After soil excavation, the deformation of the wall increases greatly, especially when the stress level is high, and the increase of the curve is more obvious. After adding the support, the slope of the deformation curve of the wall immediately decreases, and after a period of time, the deformation tends to be stable, close to the line parallel to the time axis.

![Fig.2 timely plus support wall deformation time history curve](image1)
![Fig.3 Time history curve of deformation wall without support](image2)

### 3.4.3 Analysis of calculation results without support

Under the condition of no support, the horizontal deformation of the wall changes with time when the deep foundation pit is dug for 3m, 6m, 9m and 12m. Under each excavation condition, draw the curve of the maximum point of wall deformation over time, as shown in figure 3. It can be seen from the figure: under the condition of 3m deep foundation pit excavation, at 86h, the wall deformation is 4.2mm, and the safety control index value of wall deformation is reached when the depth reaches 3m. This means that the deep foundation pit can only be placed for 86h under the condition of 3m, and support must be added; otherwise, the foundation pit will start to be in a dangerous state. As the placing time increases, the deformation increases. At 240h, the wall deformation is 13.09mm. When deep foundation pit excavation is 6m, the wall deformation is 8.4mm at 71h, and the wall deformation safety control index value reaches 6m. As the placing time increases, the deformation gradually increases. At 240h, the wall deformation is 75.4mm. Under the condition of deep foundation pit excavation at the 62h, the wall deformation is 12.6mm, and the safety control index value reaches 9m. As the placing time increases, the deformation rapidly increases. At the 240h, the wall deformation is 138mm. Under the condition of deep foundation pit excavation for 12m, the wall deformation is 16.8mm at 58h, and the safety control index value reaches 12m. With the increase of placing time, the deformation increases sharply. At 240h, the wall deformation is 216mm.

Under the condition of no bracing, when the excavation depth is shallow, the wall deformation is in a state of slow development. However, the deeper the excavation is, the greater the lateral stress of the soil body outside the pit is, the greater the wall deformation rate is, and the shorter the time to reach the corresponding safe control index value of the excavation. The deep foundation pit may be damaged due to the continuous creep of the soil body in a relatively short time.
4. Conclusion
(1) In the process of deep foundation pit construction in soft soil area, the slope of deformation curve of the wall immediately decreases after adding support. After a period of time, the deformation tends to be stable, and the deep foundation pit will always be in a safe and controllable state.

(2) Without bracing, with the increase of excavation depth, the greater the wall deformation rate is, the shorter the time to reach the corresponding safety control index value, and the deep foundation pit may be destroyed in a relatively short time.

(3) During the excavation of deep foundation pit in soft soil, the influence of time effect cannot be ignored, and over excavation shall be strictly prohibited during construction. When the excavation reaches the predetermined depth, the support should be completed as soon as possible to prevent the further development of deep foundation pit deformation, avoid the adverse impact on the foundation pit itself and the surrounding environment caused by long-term exposure.

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