Influence of Excavation of Complex Foundation Pit on Surrounding Environment

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Abstract. In order to study the deformation of the complex foundation pit, based on an engineering example, the influence of the excavation of foundation pit on adjacent buildings with different supporting structures is analyzed by the finite element software MIDAS GTS/NX especially for the fragile soil. The supporting structure is simplified by the principle of equivalent flexural rigidity, and the model of theoretical calculation with better accuracy and efficiency is established. The results show that the northern foundation pit with combined support structure of double row pile with inclined bracing and pile anchor first carried out by stratified excavation has great influence on the deformation of the building. When the foundation pit is excavated to -2.80m, the rate of settlement deformation and the rate of horizontal deformation of the retaining structure are larger. After the excavation of the northern foundation pit, the settlement of the building has reached 4/5 of the total settlement. The later southern foundation pit with the supporting structures of inner support has little influence on the settlement deformation of adjacent buildings. In this paper, the effects of deformation of the two supporting structures are compared and analyzed in order to provide technical reference for the similar engineering of foundation pit about selection and construction of supporting structure.

1. Introduction

With the rapid development of urbanization, foundation pit engineering is gradually developing in the direction of deep, large, close and tight. During construction, the surrounding environment including surrounding buildings, underground pipelines and surrounding traffic arteries must be ensured. Therefore, the selection of excavation procedures and supporting schemes should be more cautious.

Many scholars and engineers at home and abroad have done research on the deformation of buildings caused by excavation of foundation pit. According to the geological conditions in Beijing area, Zhang Yakui [1] made a preliminary study on the relationship among the deformation of foundation pit structure, the displacement of surrounding strata and the deformation of buildings at different distances during the excavation of deep foundation pit. Using the numerical simulation method, Jiang Zheng [2] analyzed the influence of excavation process on the settlement of adjacent buildings, and compared with the monitoring data. Based on the actual monitoring data of excavation of a key foundation pit in central Beijing, Liu Jian-rong [3] was calculated by using FLAC-3D three-
dimensional finite difference method, and analyzed the variation characteristics of surrounding structure and building monitoring data after excavation of foundation pit. Based on a specific engineering example in a soft soil area, the deformation characteristics of adjacent buildings after excavation of foundation ditch are analyzed by the finite element software MIDAS GTS/NX.

2. General situation of Engineering and Geological conditions

2.1 Engineering survey
The excavation of foundation pit No. 1 is located on the north side of Jinan Road in Xicheng District of Dongying City and in the hospital of Shengli Oilfield Central Hospital on the west side of Xicheng Road, adjacent to the north side of the building. It is a 24-story internal medicine building and an underground garage. The whole shape of the foundation pit is rectangular, the length of east and west is about 107 meters, the width of north and south is about 70 meters, the circumference of foundation pit is about 360 meters, and the excavation depth of foundation pit is about 7 meters. The No. 2 foundation pit next to the south side of the building is a new medical technology building, which wants to be connected with the first excavation. The foundation pit includes two parts: the new medical building and the underground garage. The length of the foundation pit is about 69m in the north and south, 108.5m in the east and west, and the excavation depth of the foundation pit is 6.4m. The buried depth of building foundation is about 1.50m. The composite foundation is treated with powder jet pile (the relation between foundation pit and adjacent building is shown in Fig. 2-1).

2.2 Engineering geological conditions
The proposed site landform unit is the Yellow River Delta alluvial plain. Within the scope of construction site, the formation is Quaternary strata, mainly mixed fill, silty clay and some silt.

2.3 Main supporting forms of Foundation Pit
The support forms of 1-1, 2-2, 3-3 and diagonal brace section are as shown in Fig.2-2, 2-3, 2-4 and 2-5, respectively. The specific parameters of the bolt are shown in Table 1.
Table 1. Parameters of prestressed anchor cables

| Cable number | Anchor cable model | Anchor cable Length | Free segment length | Anchorage length | Prestress | Axial force standard value |
|--------------|--------------------|---------------------|---------------------|------------------|-----------|---------------------------|
| MG1          | 32/20anchor arm    | 21m                 | 6m                  | 15m              | 150KN     | 388KN                     |
| MG2          | 32/20anchor arm    | 18m                 | 5m                  | 13m              | 100KN     | 329KN                     |

3. Model building

MIDAS GTS/NX finite element software is used to simulate and analyze the model. The overall size of the model is: 208m × 176m × 24.9m. The excavation depth of 3 to 5 times is taken as the distance from the retaining body to the boundary of the model. The material of surrounding rock and soil is homogeneous and homogenous continuous medium, assuming it is an ideal elastic-plastic material. Based on macroscopic material behavior, the rock and soil are modeled by Moore Coulomb elastoplastic model, and the solid element is used to simulate the soil. The inclined brace, column, anchor cable and waist beam are simulated by line element, and some loads are applied to the building foundation model to replace the existing building. The calculation model is shown in figure 3-1.

3.1. Structural models

For ease of calculation, in this paper, the pile row is equivalent to the underground continuous wall by the principle of equivalent flexural stiffness. As shown in figure 3-2, the diameter of the row pile is expressed by D, the net distance is expressed by t, and the length of the diaphragm wall is the net distance of the pile row with the diameter of the pile. If the thickness of the equivalent ground connection wall is h, it can be obtained:

\[
\frac{1}{12} (D+t)h = \frac{1}{64} \pi D^4 \\
\Rightarrow h = 0.838 D \sqrt[3]{\frac{1}{1+\frac{t}{D}}}
\]

3.2. Calculation model parameter

The mechanical parameters of each material are shown in Table 2.

Table 2. Material physical mechanics parameter table

| Serial number | Item          | Thickness / m | Bulk density gamma (kN/m³) | Compression modulus Es (MPa) | Poisson's ratio v | Cohesive force c(KPA) | Internal friction angle φ k |
|---------------|---------------|---------------|-----------------------------|------------------------------|------------------|------------------------|---------------------------|
| 1             | Plain fill    | 1.10          | 18.0                        | 15.00                        | 0.41#            | 6.00                   | 15.00                     |
| 2             | Silty soil    | 3.40          | 19.2                        | 28.00                        | 0.31#            | 7.00                   | 25.20                     |
3.3. Calculation boundary conditions
Vertical and horizontal constraints are adopted at the bottom of the calculation model, horizontal constraints are adopted on the side, and the upper surface is set as a free surface. The vertical constraint is adopted for the column and the fixed constraint for the bottom is adopted.

3.4. Simulation working condition for excavation of foundation pit
By setting up the stage management in the finite element software, the corresponding activation and passivation of soil and supporting structure are used to simulate the construction conditions. Specific excavation simulation construction conditions are shown in Table 3.

Table 3. Simulated construction conditions of foundation pit excavation

| Simulated construction condition | General description of construction                        |
|----------------------------------|------------------------------------------------------------|
| North foundation pit             |                                                            |
| 1                                | Initial stress field displacement clearing                  |
| 2                                | Construction of retaining piles and connecting beams       |
| 3                                | Slope excavation in inclined bracing area to the bottom of the pit |
| 4                                | Excavation of the first layer of soil to -2.800 m, and installation of the first Anchorage cable and waist beam at -2.500 m |
| 5                                | The second layer of soil is excavated to -5.300 m and used as the second Anchorage cable and waist beam at -5.00 m. |
| 6                                | Excavate to the bottom of the pit -7.00m and apply it to the concrete floor |
| 7                                | Make oblique brace, and excavate inclined brace area to the end. |
| South foundation pit             |                                                            |
| 8                                | The south foundation pit is used as retaining pile, inner bracing and pillar. |
| 9                                | Excavation of the South Foundation Pit.                    |

4. Analysis of deformation characteristics of adjacent buildings in excavation of Foundation Pit
According to the results of 3D numerical simulation, the deformation of buildings under 8 different working conditions can be obtained. According to the influence of different working conditions on the deformation of buildings, the cloud map of building deformation and final profile deformation cloud map and the deformation cloud map of building foundation are only extracted under the condition of working condition 3/4/5/6/7/9 (see figure 4-1).
By extracting the results of numerical analysis, the following conclusions can be obtained: Under three-dimensional numerical simulation, the results of different profiles under different working conditions are obtained. The maximum horizontal displacement at the top of the supporting structure and the settlement value of the building are within the range of the control value required by the design, and are in accordance with the law of foundation pit excavation deformation. The results show that the 3D numerical simulation can well reflect the actual excavation conditions (the displacement of the supporting pile is shown in figure 4-2).
During the excavation of foundation pit, due to the influence of many factors such as excavation and unloading of the inner soil mass of the enclosure structure, the stress situation of the lower soil changes, which leads to the rebound of the soil in the bottom of the pit, and the springback of the soil in the bottom of the pit will inevitably lead to the movement of the surrounding soil. In addition, the stress on both sides of the enclosure structure loses its original balance, which leads to the horizontal displacement of the enclosure structure. (see Table 4 for the deformation of the building.)

Table 4. Deformation of adjacent buildings under different working conditions (differential settlement = South-North)

| simulated condition | building | Vertical maximum settlement | North-South differential settlement |
|---------------------|----------|----------------------------|-----------------------------------|
| 3                   | north    | -1.95                      | -0.30                             |
|                     | south    | -2.25                      |                                   |
| 4                   | north    | -6.01                      | -0.75                             |
|                     | south    | -6.76                      |                                   |
| 5                   | north    | -7.16                      | -1.01                             |
|                     | south    | -8.17                      |                                   |
| 6                   | north    | -7.96                      | -0.99                             |
|                     | south    | -8.95                      |                                   |
| 7                   | north    | -8.12                      | -0.88                             |
|                     | south    | -9.00                      |                                   |
| 9                   | north    | -10.00                     | -0.70                             |
|                     | south    | -10.70                     |                                   |

Fig 4-3. Deformation curve of buildings under different working conditions

Fig 4-2. Displacement diagram of support pile
5. Conclusions
Through the above research, we can draw the following conclusions:

1) With the foundation pit adjacent to the building, with the excavation of the North foundation, the horizontal displacement and settlement of the building foundation are all rising, and close to 3 times. The horizontal displacement of the pile top of the North foundation pit decreases instantaneously when the South foundation pit is excavated, but the settlement deformation of the building is very small.

2) When the foundation pit is excavated to 1/3 of the total depth, it has a great disturbance to the surrounding soil layer, and the deformation rate of the foundation settlement of the building is the largest, which should be the key monitoring period of the project.

3) With the excavation of the north foundation pit, the differential settlement of the building foundation presents an upward trend, and the settlement far away from the north foundation pit is relatively large, but with the excavation of the south foundation pit, the differential settlement of the building foundation decreases.

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