Numerical simulation analysis of the influence of foundation pit excavation on the surrounding buildings of an office building

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Abstract. Based on the study of reconnaissance and extension engineering geological investigation data of an office building, combined with indoor geotechnical test results and parameter inversion calculation, the reasonable basic geophysical and mechanical parameters are obtained. The numerical simulation software MIDAS/GTS was used to simulate the four dangerous sections which affect the surrounding buildings. The influence of excavation of foundation pit on surrounding buildings was predicted by numerical simulation and analysis of construction site and combining with practice. Through the simulation of the construction steps of the foundation pit excavation, the calculation results were reasonable in theory, and had the main engineering significance for the foundation pit excavation.

Keywords: Foundation pit excavation; numerical simulation; MIDAS/GTS; stability evaluation

1. Introduction
Foundation pit excavation was a systematic and complicated project. The changes of surrounding buildings caused by foundation pit excavation would cause great losses if not properly handled. Taking an office building in Beijing as an example, this paper evaluated the stability of the design and construction of the foundation pit by numerical simulation and construction monitoring results in each construction stage, which provided a theoretical and practical basis for the smooth progress of the project and provided a certain reference value for similar projects in the future. Valuable data and experience were provided for foundation pit engineering in this area. The expansion and rebuilding project had a certain impact on the surrounding buildings. The excavation and support of the foundation pit were numerically simulated and analyzed, and the displacement of the foundation pit in the section of the surrounding buildings was detected, and the stability changes of the surrounding buildings were analyzed in real time.
2. Engineering survey and technical solutions

2.1. Project summary
The office building had 6-7 floors above ground and 4 floors in the basement. The ground elevation of the site was 43.50 m, the base elevation was -18.47 m, and the base depth was 17.17 m; The underground was a frame structure, and the ground was a steel structure. The total land area was 20,000 m², the total construction area was 82,300 m², the ground was 33,700 m², and the underground was 48,600 m². The underground of the building was "L" type, with a maximum length of 167 m in the east-west direction and a maximum width of 129 m in the north-south direction. The base elevation was -18.47 m. The current average ground elevation was -1.37 m and the foundation pit depth was 17.17 m.

![Fig.1 General plan of foundation pit engineering](image)

2.2. Support scheme
The pile-anchor support structure form was an ideal support system for deep foundation pit engineering, considering economic and safety reliability. The anchor spray support was used in the engineering. The impact of foundation pit excavation on surrounding buildings was considered. Therefore, the distance between the building and the foundation pit, the load of the house and the size of the house were considered. The foundation pit support structure was shown in Fig.2.

![Fig.2 Foundation pit support structure](image)

3. Calculation parameters and model selection
After BP neural network training for parameter inversion, combined with laboratory test results, this study was divided into 7 layers according to lithology and engineering property indicators, and the housing materials, foundations, slope protection piles, etc. were rationally simplified, the basics of each material. The physical and mechanical characteristics were shown in Table 1.
### Table 1 Material basic physical and mechanical parameters

| Layer | Soil type          | Severe(KN/m³) | C(KPa) | φ(°) | elastic modulus (MPa) | ratio |
|-------|--------------------|---------------|--------|------|------------------------|-------|
| 1     | Room waste residue | 16.5          | 10     | 10   | 14                     | 0.35  |
| 2     | Clayey silt        | 19.3          | 20     | 22   | 20                     | 0.32  |
| 3     | Sandy soil         | 20.5          | 10     | 25   | 23.6                   | 0.30  |
| 4     | Round gravel       | 21            | 0      | 40   | 29                     | 0.30  |
| 5     | Silty clay         | 20.2          | 35     | 15   | 34                     | 0.30  |
| 6     | Round pebble       | 21.5          | 10     | 30   | 35                     | 0.28  |
| 7     | The underlying     | 21            | 30     | 35   | 41                     | 0.28  |
| 8     | The wall           | 22            | 200    | 40   | 44                     | 0.25  |
| 9     | Reinforced concrete| 25            | 1000   | 45   | 20000                  | 0.22  |
| 10    | Slope protection pile | 25       | 600    | 45   | 10000                  | 0.22  |
| 11    | foundations        | 24            | 100    | 45   | 44                     | 0.25  |

The finite element method was used to simulate the foundation pit excavation using MIDAS/GTS software, and the influence of foundation pit construction on surrounding buildings was studied to conduct comprehensive analysis and evaluation. The Mohr-Coulomb constitutive model was used for all geotechnical bodies in the calculation process. The left and right sides of the model were unidirectional displacement boundary conditions in the X direction, and the bottom was fixed. Under the initial conditions, considering the self-weight stress and house load, the house load was applied according to the uniform load. The basic physical and mechanical parameters of the line load 2 kN/m rock and soil were selected according to the calculation results. In the calculation process, according to the basic construction sequence of the anchor spray support, the construction simulation of the entire foundation pit project was carried out through the MIDAS/GTS custom construction stage command, which was divided into the following steps: (1) Initial state; (2) Displacement clearing; (3) Slope protection pile construction; (4) First layer excavation; (5) Second layer excavation; (6) Third layer excavation; (7) Fourth layer excavation; (8) Fifth layer excavation. During the excavation of the second to fourth layers, anchors and prestressing were applied.

### 4. Simulation results

#### 4.1. Analysis results of section A

The A section was the smallest section of the distance between the 1# floor and the foundation pit. In order to reduce the influence of the boundary effect on the calculation results, the model range was selected to be 144 m (length) \(\times\) 42 m (height). After analyzing the engineering geological materials, the soil layer was reasonably simplified, and the model has a total of 24,872 two-dimensional units.

![Fig.3 X-direction final displacement nephogram](image1)

![Fig.4 Y-direction final displacement nephogram](image2)

In Fig.3 and Fig.4, as the construction progresses, the soil on both sides of the foundation pit tended to slide toward the foundation pit. The side wall of the foundation pit was displaced in the X direction from -10 m to -20 m, and the maximum value was 6.9 cm. However, under the action of the anchor
spray support structure, the displacement of the side wall of the foundation pit was small, and the anchor spray support had a significant effect on the stability of the side wall of the foundation pit. A local bulge occurred at the bottom of the foundation pit with a maximum displacement of 17 cm. The house remained basically stable under the influence of foundation pit excavation, but local inclination occurred during the whole construction process, and the value was small. In order to study the degree of inclination of the house under the influence of foundation pit excavation, test points were set especially at the six corners of the house to monitor the deformation of the house in each construction step. The building survey points were shown in Fig.5.

![Fig.5 Layout of building survey points](image)

The displacement in the XY direction of the six measuring points shown in the diagram was monitored in each construction step. The numerical changes were shown in Fig.6. From the displacement monitoring, the displacement of the measuring points of the house increases continuously. During the excavation of the fifth floor, the displacement change rate of the measuring points was larger. After the construction, the maximum displacement was 2.5 cm, and the changing trend of the six measuring points was basically the same, indicating that the overall changes of the house were basically the same. When the third floor was excavated, the change rate of the measured points was different. The maximum inclination value was 0.0003, which was less than the maximum inclination value of 0.002 in the code for design of building foundation (GB 50007-2002). It showed that the excavation of foundation pit had little influence on the house and could meet the requirements of the code.

4.2. Analysis results of section B

The B section was the least distance between the 2# building and the foundation pit and the dangerous section. In order to reduce the influence of the boundary effect on the calculation results, the model range was 225m (long) × 62m (high).

![Fig.7 X-direction final displacement nephogram](image)

![Fig 8 Y-direction final displacement nephogram](image)

Fig.7 showed that the soil on both sides of the foundation pit tends to slide towards the foundation pit with the construction going on. Under the action of the anchor-shotcrete supporting structure, the displacement of the side wall of the foundation pit was smaller, and the anchor-shotcrete supporting had obvious effect on the stability of the side wall of the foundation pit. The side wall of foundation pit moved larger in X direction from -10 m to -20 m, and the maximum value was 9.4 cm. Compared with the right side wall of the foundation pit, the displacement and the radius of dangerous sliding surface of the left side wall of the foundation pit were larger under the load of the house and the house. In Fig.8, a
local uplift occurred at the bottom of the foundation pit, and the maximum displacement was even more than 20 cm. Within this range, the displacement of the rock and soil body changed little and could maintain stability. The layout of measuring points was shown in Fig.9.

As shown in Fig.10, with the excavation proceeding, the displacement of the measuring points of the house increased continuously. During the excavation of the third floor, the displacement change rate of the measuring points was larger. The maximum displacement after the construction was 5.5 cm, and the changing trend of the four measuring points was basically the same, indicating that the overall change of the house was basically the same. When the third floor was excavated, the change rate of measuring points was different, and the change value of displacement was large. The maximum displacement change value reached 7.5 cm. The maximum inclination value was 0.0025, which was less than the high compressibility soil of the masonry load-bearing structure in the design code of the foundation of the building foundation (GB 50007-2002). The maximum inclination value of the local inclination was 0.003. Due to the small distance between the building and the foundation pit, the excavation of the foundation pit had a great influence on the house. During the construction process, appropriate displacement monitoring should be given and the building should be properly supported.

4.3. Analysis results of section C

The C section was the smallest and more dangerous section of the 3# building and the foundation pit. In order to reduce the influence of boundary effect on calculation results, the model range was 150 m (long) × 50 m (high).

Fig.11 showed that with the construction, the soil on both sides of the foundation pit had a tendency to slide toward the foundation pit. Under the action of the anchor-shotcrete supporting structure, the displacement of the side wall of the foundation pit was smaller, and the anchor-shotcrete supporting played an obvious role in the stability of the side wall of the foundation pit. The side wall of foundation pit moved larger in X direction from -10 m to -20 m, and the maximum value was 9.1 cm. Compared with the right side wall of the foundation pit, the displacement and the radius of dangerous sliding surface of the left side wall of the foundation pit were larger under the load of the house and the house. From the Fig.12, there was a local uplift at the bottom of the foundation pit, and the maximum displacement even reached 20 cm. Within this range, the displacement of rock and soil body changed
little and could maintain stability. But in the whole construction process, it was easy to have larger settlement and uneven local inclination. The layout of measuring points is shown in Fig.13.

![Fig.13 Layout of building survey points](image)

![Fig.14 Displacement change of building survey points](image)

The displacement of the four measuring points shown in the diagram was monitored during each construction step, and the numerical changes were shown in Fig.14. From the displacement monitoring, the displacement of the measuring points of the house increased continuously. During the excavation of the third and fourth floors, the displacement change rate of the measuring points was larger. After the construction, the maximum displacement was 4.3 cm, and the changing trend of the four measuring points was basically the same, indicating that the overall change of the house was basically the same. When the third floor was excavated, the change rate of measuring points was different, and the change value of displacement was large. The maximum displacement change value reached 4.5 cm. The maximum inclination value was 0.0016, which was less than the maximum inclination value 0.002 of masonry bearing structure in the Code for Design of Building Foundation (GB 50007-2002).

4.4. Analysis results of section D

The D section was the smallest and more dangerous section of the 4# building and the foundation pit. In order to reduce the influence of the boundary effect on the calculation results, but because the longitudinal distance of the four sections was large, the most appropriate simplification was to select the model range of 255 m (length) × 62 m (height).

![Fig. 15 X-direction final displacement nephogram](image)

![Fig. 16 Y-direction final displacement nephogram](image)

Fig.15 showed that the soil on both sides of the foundation pit tended to slide towards the foundation pit with the construction. Under the action of the anchor-shotcrete supporting structure, the displacement of the side wall of the foundation pit was smaller, and the anchor-shotcrete supporting had obvious effect on the stability of the side wall of the foundation pit. The side wall of foundation pit moved larger in X direction from -10 m to -20 m, and the maximum value was 6.3 cm. Compared with the right side wall of the foundation pit, the displacement and the radius of dangerous sliding surface of the left side wall of the foundation pit were larger under the load of the house and the house. In Fig.16, a local uplift occurred at the bottom of the foundation pit, and the maximum displacement was nearly 26 cm. In this range, the displacement of rock and soil changed little, and it could maintain stability. But in the whole construction process, it was very easy to occur local tilt due to large settlement and uneven. The layout of measuring points is shown in Fig.17.
Fig.17 Layout of building survey points  

Fig.18 Displacement change of building survey points

From the displacement monitoring, the displacement of the measuring points of the house increased continuously. During the excavation of the third and fourth floors, the displacement change rate of the measuring points was larger. After the construction, the maximum displacement was 6.5 cm, and the changing trend of the four measuring points was basically the same, indicating that the overall change of the house was basically the same. When the third floor was excavated, the change rate of measuring points was different, and the change value of displacement was larger. The maximum displacement change value reached 6.2 cm. The maximum inclination value was 0.0026, which was less than the high compressibility soil of the masonry load-bearing structure in the design code of the foundation of the building foundation (GB 50007-2002). The maximum inclination value of the local inclination was 0.003. Due to the small distance between the building and the foundation pit, the excavation of the foundation pit had a great impact on the house. The appropriate displacement monitoring should be given in the construction process, and the building should be properly supported.

5. Conclusion

(1) Through the study of the engineering geological investigation data, combined with the indoor geotechnical test results and parameter inversion calculation, the reasonable geophysical and mechanical basic parameters were obtained, which provided a basis for further study of stress and displacement deformation caused by foundation pit excavation.

(2) The two-dimensional numerical simulation of four dangerous sections affecting surrounding buildings was carried out by using the numerical calculation software MIDAS/GTS. Through the simulation of the construction steps of foundation pit excavation, the calculation results were reasonable in theory, and had the main engineering significance for the foundation pit excavation, and provided a reference for the site monitoring point type and location determination.

(3) Through the analysis of the calculation results of the four sections, the excavation of the foundation pit had limited influence on the surrounding buildings, especially the buildings of sections A and C could maintain good overall and local stability. During the construction process of the buildings around sections B and D, the displacement variation and local inclination were slightly larger, but meet the requirements of the code.

(4) According to the numerical simulation of MIDAS/GTS, the influence of foundation pit excavation on the four sections was limited, but the local displacement varied greatly during the construction. The necessary monitoring and reasonable temporary support should be carried out for the surrounding buildings, especially the 2 # building.

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