The Comparison and Analysis between Numerical Simulation and Monitor Data of Deep Foundation Pit Excavation Deformation

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Abstract. Taking a large-scale deep foundation pit project in Guangzhou financial city as the research background, the construction process of the foundation pit is analyzed by the finite element software Midas GTS-NX. The simulated results are compared with the monitoring data, and the surface settlement deformation of the foundation pit and the horizontal displacement of supporting piles are compared and analyzed. Although the comparison results are different, the overall change trend is the same and the data are similar, and within the range of engineering deviation, the results show that the numerical simulation can provide reference for foundation pit deformation monitoring scheme design and construction scheme design.

Keywords. Foundation pit, finite element, numerical simulation, settlement deformation, horizontal displacement.

1. Introduction
With the development of urban construction at home and abroad, the number and height of high-rise buildings are increasing. The depth of the foundation is also increasing due to the structural requirements, a large number of deep foundation pit projects are produced as a result. During the process of the foundation pit construction, the changes in the initial stress field of the soil will cause displacement and deformation of the bottom rock and soil body and the retaining structure, and there are many factors that affect stress and strain. If the stability of the excavation process is not guaranteed, accidents will be inevitable [1-5]. Therefore, through the numerical simulation analysis by finite element software, the mechanical model is established according to the actual condition of foundation pit, and the simulation data and the monitoring results are compared and analyzed. It is concluded that the theoretical data are close to the measured results trend, which can provide a reference for the design and monitoring of the foundation pit deformation [6].

2. Project Overview and Geological Condition
2.1. Project Overview
The area of Guangzhou International Finance City covers Huangpu Avenue in the north, Pearl River in the south, Chebei Road in the east, and Keyun Road in the west, covering an area of about 1.32 square kilometers. The monitoring scope of the foundation pit is the financial square city, the planned Chunrong Road in the west, the planned Lurong Road in the east, the Huacheng Avenue in the north, and the Linjiang Avenue in the south (will be relocated). The total circumference of the pit is about...
2,000 m, and the area is about 220,000 m². Because the large-scale of the foundation pit and there are many plot of land need traded and the time sequence of each plot is uncertain, beyond that the service life is more than 2 years and there is uncertainty, the construction period of the project is long (from January 2018 to now). Therefore, only the excavated land is simulated, the perimeter of the excavated foundation pit is 320m, the length and width is both 80m, and the depth is 9 m.

2.2. Geological Condition
According to the geotechnical engineering investigation report of this foundation pit, the upper Quaternary overlying soil layer is mainly composed of miscellaneous (plain) fill of artificial accumulation, silty clay (or clay) of alluvial layer, silt (muddy soil), silty clay of fine sand, medium coarse sand layer and residual layer, etc.: the underlying bedrock is mainly argillaceous siltstone, mudstone, conglomerate, gravel-bearing coarse sandstone.

3. Finite Element Numerical Simulation

3.1. Material Properties of Foundation Pit
In this paper, the parameters of foundation pit numerical simulation mainly include soil material parameters, retaining structure parameters and structural material parameters. The retaining structure includes the underground continuous wall as a 2D slab unit, the ring beam, the inner support and the foundation pit pillar pile are all 1D beam unit, and the anchor rod is a 1D implantable truss unit. Comprehensively considering the engineering geological exploration report and the construction experience parameters of the area where the project is located, the main parameters used in the numerical simulation are shown in tables 1-3:

| Soil       | Miscellaneous Fill | Silt          | Silty Clay   |
|------------|--------------------|---------------|--------------|
| Thickness (m) | 4                  | 12            | 20           |
| Poisson Ratio | 0.32               | 0.30          | 0.32         |
| Unit Weight (kN/m³) | 18.9               | 18.8          | 19.9         |
| Saturated Unit Weight (kN/m³) | 19.9               | 19.8          | 20.9         |
| Cohesive Force (KPa) | 18.8               | 12.9          | 30.6         |
| Frictional Angle | 10.7               | 27.2          | 4.3          |
| $E_{50}$ (MPa) | 28.8               | 54.0          | 73.8         |
| $E_{90}$ (MPa) | 24.0               | 45.0          | 61.5         |
| $E_{ur}$ (MPa) | 86.4               | 162.0         | 221.4        |

| Structure Name                  | Element Type | Sectional Dimension |
|--------------------------------|--------------|---------------------|
| Underground Diaphragm Wall      | 2D Plate Element | B=1                |
| Ring Beam                      | 1D Beam Element | H=0.8, B=1         |
| Inner Support                   | 1D Beam Element | H=0.8, B=1         |
| Anchor Rod                      | 1D Embedded Truss Element | D=0.025 |
| Foundation Pit Pillar Pile      | 1D Beam Element | D=0.9              |
Table 3. Structural Material Parameters.

| Material Name   | Elasticity Modulus (GPa) | Poisson Ratio | Unit Weight (kN/m³) |
|-----------------|--------------------------|---------------|---------------------|
| C35 Concrete    | 31.5                     | 0.2           | 23.5                |
| Anchor Rod      | 200                      | 0.3           | 76.98               |

3.2. Numerical Calculation Model

In this paper, the excavation depth of the simulated foundation pit is 9 m, length and width is both 80 m. In terms of engineering experience, the impact range is 3 to 5 times the plane size of the foundation pit and the excavation depth of the foundation pit, so the whole size of this model is 360 m×360 m×36 m. We input the material properties of the foundation pit in the material properties box, then establish the geometry according to the determined size, the next is divide the soil and foundation pit and automatically print the column line of the foundation pit to ensure the coupling between the pile and soil nodes, and select the automatic connection and Boolean operation to ensure that shared surfaces are generated between various entities. Then to divide the three-dimensional grid, first divide the foundation pit, the grid size is 5, using the hybrid grid generator, generate 2435 nodes and 4827 elements; the following is the division of three-layer soil, the grid size is 12.5, using the hybrid grid generator. 7158 nodes and 12413 elements are generated. After the three-dimensional meshing is completed, the generated mesh group is sorted out and modify the mesh attributes again (figures 1-4). Make the structural element of the model, use the geometry to extract the underground diaphragm wall to ensure the coupling between the plate element and the solid element node; The ring beam is analyzed, the inner support is divided into one-dimensional grid, and the anchor is set by using the anchor modeling assistant. The boundary conditions are imposed, the RZ direction constraints are imposed on the foundation pit columns, the boundary constraints are applied around the model, and the initial water head and dewatering head are set. Set the static load and only consider the dead weight of the model. The following picture shows the completed foundation pit model and the grid diagram of the retaining structure and the model after the load is applied.

![Figure 1. Model axonometric view.](image1)

![Figure 2. The soil axonometric view of foundation pit excavates part.](image2)

![Figure 3. Retaining structure Model view.](image3)

![Figure 4. Applying boundary conditions and static load models.](image4)
3.3. Set up Construction Phases
Midas GTS-NX simulates different construction stages of foundation pit by activation and passivation. This article divides the construction simulation of foundation pit excavation process into the following eight construction stages:

Construction stage 1: The name of the stage is the initial seepage analysis, and the type of the stage is steady state without considering the time factor and no construction. Activate the corresponding units: soil 1 under the foundation pit, soil 2 under the foundation pit, excavation 1, excavation 2-1, excavation 2-2, miscellaneous fill, silt, silty clay, initial water head.

Construction stage 2: The name of the stage is the initial stress analysis, and the type of the stage is stress. The displacement will be cleared to zero without considering the original settlement displacement of the foundation. Active boundary condition and static load: boundary constraint, dead weight;

Construction stage 3: The stage name is underground continuous wall and foundation pit column pile, and the stage type is stress, applied underground continuous wall and foundation pit column. Activate the corresponding unit and boundary conditions: underground diaphragm wall, foundation pit column pile, foundation pit column pile constraint;

Construction stage 4: The stage name is excavation 1 and support 1, the stage type is stress, the first layer of soil is excavated, and the ring beam 1 and the internal support 1 are applied. Activate the corresponding units: ring beam 1, inner support 1. Passivate the corresponding unit: excavate soil 1;

Construction stage 5: The stage name is excavation 2 and support 2, the stage type is stress, the second layer of soil is excavated, and the ring beam 2 and the inner support 2 are applied. Activate the corresponding units: ring beam 2, inner support 2. Passivating the corresponding units: excavating soil 2-1, excavating soil 2-2;

Construction stage 6: The stage name is foundation pit precipitation, and the type of stage is steady state, without considering the time factor. Activate boundary conditions: precipitation head;

Construction stage 7: The name of the stage is stable precipitation, and the type of stage is stress;

Construction stage 8: The stage name is excavation 3 and support 3, the stage type is stress, the third layer of soil is excavated, the ring beam 2 and the anchor rod are applied. Activate corresponding units and boundary conditions: ring beam 2, anchor rod, anchor rod prestress.

The above is the setting of the construction stage group. After the construction stage is defined, the entire excavation process of the foundation pit can be calculated and analyzed, that is, the analysis of the working conditions.

3.4. Simulated Construction Scheme
In the numerical simulation of the excavation process of the foundation pit project, the construction plan is divided into five steps: the first step is to set the underground continuous wall and the foundation pit pile; the second step is to excavate to 3 m, and set the first inner support and ring beam. The third step is excavated to 6m, set the second inner support and ring beam; the fourth step is excavated to 9.8 m; the fifth step is excavated to 9m, set the third ring beam and anchor.

4. Comparative Analysis of Simulated and Monitored Data of Foundation Pit
Numerical simulation is the simulation of the construction, engineering geology and surrounding environment of foundation pit engineering, but the actual foundation pit engineering is complex and changeable, so it is impossible for numerical simulation to simulate all the cases of actual foundation pit engineering. The actual deformation monitoring value of foundation pit is an important index to reflect the actual deformation of foundation pit. However, this does not mean that numerical simulation analysis is not useful in foundation pit deformation monitoring, it can simulate the deformation trend of foundation pit in advance before construction, and provide guidance for the next step of construction. In this paper, the relationship between the results of numerical simulation analysis of foundation pit excavation construction and the actual deformation monitoring value of foundation pit excavation construction is compared and studied, and the surface settlement
deformation of foundation pit and the horizontal displacement of supporting piles are compared and analyzed.

4.1. Comparative Analysis of Simulated and Monitored Surface Settlement Values

Ground settlement data are extracted from the vertical displacement cloud image of the foundation pit obtained from the numerical simulation software after the excavation is completed. Case 1 (excavate to the depth of 3 m, the first inner support and ring beam), Case 2 (excavate to the depth of 6 m, set the second inner support and ring beam), working condition three (excavate to the depth of 9 m, set the third ring beam and anchor). And compared with the actual monitoring data after the excavation is completed, figure 5 is drawn as follows:

![Figure 5](image)

**Figure 5.** Comparison diagram of monitored and simulated settlement data.

Because the buildings and loads around the foundation pit are not taken into account in the modeling, and the construction environment is complex, the predicted value of the foundation pit model is less than the actual monitoring value, and the actual settlement fluctuates greatly. It can be seen from figure 5 that the deformation trends of the two are generally similar, and the deformation trend shows a "pipe-like" distribution, in which the actual monitoring maximum cumulative settlement is 17.68 mm, the maximum cumulative settlement predicted by the model is 15.78 mm, the absolute error is 1.9 mm, and the relative error is 12.04%. There is a certain deviation. The maximum cumulative settlement is less than the alarm value of 40mm, and the surface settlement around the foundation pit is in a safe range [8].

4.2. Comparative Analysis of the Measured and Simulated Data of the Horizontal Displacement of the Foundation Pit Pillar

Extract the data from the horizontal displacement cloud diagram of the retaining structure after the excavation of the foundation pit obtained from the numerical simulation software. Take the horizontal displacement of a foundation pit pillar pile as an example, compare the finite element simulation value and the actual monitoring value:
Figure 6. Monitored and simulated result of horizontal displacement of foundation pit pillar.

It can be seen from figure 6 that the deformation of the horizontal displacement of the retaining pile is small at both ends and large in the middle. The model simulates a maximum horizontal displacement of 3.45 mm, and the actual monitored maximum horizontal displacement is 4.96 mm, which does not exceed the warning value. Because the model does not consider the surrounding buildings and loads of the foundation pit, the simulated value of the model is less than the actual monitoring value, but the deformation of each part simulated by the model is still close to the actual deformation trend, so the horizontal displacement deformation simulated by the model has reference value [9-10].

5. Conclusion

The finite element software Midas GTS-NX was used to simulate the excavation process, and the following conclusions were drawn:

(1) When the model simulates the surface settlement around the foundation pit, the surface settlement around the foundation pit increases continuously with the excavation, and with the increase of the distance from the foundation pit, the surface settlement increases at first and then decreases. The deformation trend under various working conditions shows a "pipe-like" distribution, and the maximum settlement point is about 15m from the edge of the foundation pit. When the model simulates the horizontal displacement deformation of the retaining structure, the horizontal displacement deformation of the foundation pit column pile and the underground diaphragm wall increases with the progress of excavation. The underground diaphragm wall shows the trend of inward depression on both sides of the wall, and the displacement of the edge of the wall is small, which is consistent with the changing trend of its horizontal stress [11]. The horizontal displacement deformation of foundation pit column pile shows a trend of small at both ends and large in the middle.

(2) Taking the horizontal displacement of a column pile in a foundation pit as an example, it is found that although there are differences between the numerical simulation value and the actual monitoring value, the overall change trend is the same and the numerical value is similar, within the range of engineering deviation. the results show that the numerical simulation can provide reference for the design of foundation pit deformation monitoring scheme.

(3) The excavation process of foundation pit is divided into eight construction stages to carry out construction simulation. By comparing the prediction results of foundation pit deformation obtained by finite element analysis and the actual monitoring results in the process of foundation pit excavation, it is found that the predicted deformation trend of each structure of foundation pit is basically consistent with the deformation trend obtained by actual deformation monitoring. Therefore, the numerical modeling can be carried out according to the actual project before the foundation pit excavation construction, which can simulate the construction location which is not detected or not
easy to detect, predict the stress and deformation, analyze the simulation results, report the problems in
time, and take remedial measures in advance. Optimize the construction plan and improve the safety
and economy of the project.

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