Analysis of Excavation with Numerical Simulation and Monitoring Data Has Effect on Surface Subsidence  
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Keywords: Foundation pit excavation, Ground surface settlement, Numerical simulation, Field monitoring.

Abstract. Excavations cause the settlement of surrounding soil and have other adverse effects on surrounding buildings, traffic, underground facilities and so on. In this paper, a three-dimensional model is established by finite element software Midas/GTS based on the top-down excavation of underground works in Hefei New Traffic Building. The analysis of the effect of the excavation of foundation pit have on surface subsidence based on numerical simulation and field monitoring data. Summarized the general law of surface subsidence about the top-down excavation, and the whole trend is spoon-shaped which will provide reference for future similar projects in Hefei.

Introduction

With the rapid urban change, the rapid expansion of population and the scarcity of land resources, so underground space has been continuously developed and used, the foundation pit engineering project is also larger and deeper. Deep foundation pit engineering often appears in the bustling downtown, the surrounding surface environment is complex, there are a large number of adjacent buildings, traffic roads, complex pipelines and underground facilities or structures. Therefore, limitation of the deformation of foundation pit excavation is more and more stringent, not only to the foundation pit deformation and stress analysis, but also on surrounding the surface subsidence and deformation of buildings, underground facilities, etc were analyzed.[1-10]

In this paper, under the background of underground engineering of Hefei New Traffic Building, the influence of top-down excavation on the vertical settlement of ground surface is discussed through field monitoring and Midas/GTS numerical simulation, which is of guiding significance for future similar foundation pit construction in Hefei.

Project Overview

Hefei New Traffic Building, located at the southeast corner of Metro Line 1 and 2 Big East Gate Station. There are a large number of complex pipelines and important roads, foundation pit east and south adjacent to a large number of office buildings and residential buildings, and west, north close to the envelope structure of the subway station. The building which the excavation is carried out by the top-down method underground structure have five layers, vertical structure is AM pile of a column and a pile, surrounding building envelope use a thickness of 1m and depth of about 35.3m to the diaphragm wall panel trench. The depth of the bottom of the standard section structure is 26.3m, the total foundation pit area is 8468m². There are many troubles such as deep pit, formation difference, high water level, project miscellaneous, near the building, tight schedule and other problems.
Finite Element Numerical Simulation

Relative Parameters

Soil related parameters are taken from the site geological survey report. See Table 1 for details.

<table>
<thead>
<tr>
<th>Soil related parameters</th>
<th>Parameters</th>
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<tbody>
<tr>
<td>Miscellaneous Fill</td>
<td>3.0</td>
</tr>
<tr>
<td>Silty Clay</td>
<td>6.1</td>
</tr>
<tr>
<td>Silt</td>
<td>6.9</td>
</tr>
<tr>
<td>Silty-fine Sand</td>
<td>4.9</td>
</tr>
<tr>
<td>Strongly Weathered Muddy Sandstone</td>
<td>5.0</td>
</tr>
<tr>
<td>Moderately Weathered Muddy Sandstone</td>
<td>54.1</td>
</tr>
</tbody>
</table>

The supporting structure are using concrete pouring, which the main building within the column pile adopt C60 concrete, the rest of the support structure used C40 concrete. See Table 2 for details.

<table>
<thead>
<tr>
<th>Designation</th>
<th>Parameters</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Elastic Modulus [MPa]</td>
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<tr>
<td>C40</td>
<td>32500</td>
</tr>
<tr>
<td>C60</td>
<td>36000</td>
</tr>
</tbody>
</table>

Establishment of Model

The excavation depth of foundation pit is 24.8m. According to the engineering experience and relevant data, the 3D model dimensions chose length 230m, width 190m, height 80m. The soil mass adopts the Mohr-Coulomb criterion, and the supporting structure adopts the elastic model, top surface of the model takes the free surface and the bottom surface restrains the directions of X, Y and Z, other faces are joined by the normal constraint, then join the vertical constraint after the pile foundation is completed, the whole model is added with self-weight load, and join the uniform load after the each layer horizontal structure is completed. Specific three-dimensional model shown in Figure 1 and Figure 2.

Figure 1. Three-dimensional overall calculation model diagram.  
Figure 2. Supporting structure diagram.
Numerical Simulation Process

Process one: Construction of the diaphragm wall panel trench and engineering pile.

Process two: Construction of the roof and roof beam of the first basement, while the construction load applied.

Process three: Excavation of negative a layer of soil to -5.4m, construction of the roof and stringer of the second basement, while the construction load applied.

Process four: Excavation of negative two layers of soil to -10.7m, construction of the roof and stringer of the third basement, while the construction load is applied.

Process five: Excavation of negative three layers of soil to -16.0m, construction of the roof and stringer of the fourth basement, while the construction load is applied.

Process six: Excavation of negative four layers of soil to -19.9m, construction of the roof and stringer of the fifth basement, while the construction load is applied.

Process seven: Excavation of negative five layers of soil to -24.8m, construction of the bottom plate of the fifth basement.

Numerical Simulation Results and Analysis

Selection of the main five unloading and loading processes in the construction sequence, and the curve of surface subsidence is shown in Figure 3. From the Figure 3 can be seen:

During the five unloading-loading process of the numerical simulation, the peak value of the surface settlement calculated by the simulation is located at about 10m at the edge of the foundation pit. At each condition, with the increase of the distance between the soil and the edge of the foundation pit, the surface subsidence curves are similar, the overall trend is similar to the spoon-shaped. This phenomenon occurs because of the friction between the diaphragm wall panel trench and soil, so that produce vertical constraints to the soil at the edge of the foundation pit.

After completed Process three, because the negative a layer of soil excavation is shallow, the vertical deformation of the surrounding surface is small, the maximum value is 1.92mm. With the excavation progress, spoon-shaped change trend is more obvious. The disturbance degree of surrounding soil began to increase, and the maximum soil sedimentation value increased obviously, which was 5.39mm, 8.58mm and 10.93mm. When the fifth unloading-loading is completed, the surface settlement value of the peak about 13.74mm.

Field Monitoring Analysis

Figure 4 is the curve of Surface Subsidence of field, monitoring data from the beginning of the foundation pit construction in December 2014 to the completion of the excavation of the negative five-layer soil in January 2016. From the Figure 4 can be seen:
Although the amount of surface subsidence caused by excavation in different months is different, the curves of surface subsidence are similar. Subsidence increased to the peak first and then gradually decreased to the flat, and the whole trend is similar to the spoon-shaped. It is can be know that excavation effects on the surrounding buildings, roads, underground facilities have relationship with the distance from the foundation pit. The measured maximum ground settlement is about 8-10m from the foundation pit.

With the passage of time, the excavation depth of the soil is increasing and surface subsidence also increases. The maximum sedimentation value increased from 1.96mm to 3.53mm at the beginning and reached a peak of 16.65mm when the excavation of the negative five-layer soil was completed. During the whole monitoring process, the surface subsidence is less than the warning value of 30mm and the surrounding surface deformation caused by the project is considered to be in controllable range.

Comparison Between Numerical Calculation and Field Monitoring

By comparing Figure 3 and Figure 4 we can know: Throughout the excavation process, the numerical calculation is in accordance with the curve of field monitoring and the whole trend is spoon-shaped. The surface subsidence peak of numerical simulation is located at about 10m from the foundation pit, which is close to the measured 8-10m. The maximum value of surface subsidence of the numerical calculation is 13.74mm, which is less than the maximum value of the field monitoring of 16.65mm. The difference between the two is about 3mm, there are a lot of factors result 3mm around the error.

On one hand, the model is too idealistic in the numerical simulation, which is quite different from the heterogeneous distribution of soil and the complexity of the construction environment in the natural condition. The soil-water interaction and the load of the surrounding buildings are not taken into account in the finite element calculation.

On the other hand, due to the completion of process seven, negative five floor construction is completed. With the completion of the internal structure, the structural stiffness of the foundation pit increases and bear the earth pressure behind the wall could be more effectively, so that the pit surface subsidence correspondingly reduced.

Conclusion

With the unceasing unloading of soil, the surface subsidence increases gradually, peak value of settlement is 16.65mm less than the warning value of 30mm. From the edge of the foundation pit, the variation of soil subsidence shows a first increase and then decrease to the trend of stability, and the whole trend is similar to the spoon-shaped. The maximum surface subsidence point in this project is about 8 ~ 10m away from the foundation pit, 0.3 ~ 0.4 times of the excavation depth.

From the settlement curve is not difficult to see that the surface subsidence caused by top-down excavation method is smaller. Although slightly different from the measured results, the numerical simulation by MIDAS/GTS can reflect the surface subsidence law, so the numerical simulation can roughly estimate the surface subsidence caused by the next excavation of foundation pit.
Acknowledgments

This project supported by Anhui Provincial Science and Technology Research Project Funding through grant No.1501041133, and Anhui Provincial Universities Natural Science Research Project No. KJ2015A046.

References


