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Numerical Analysis of the Influence of Foundation Pit Excavation on Surrounding Buildings and Underground Pipelines

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Abstract

The excavation of foundation pit will lead to the settlement of surrounding soil, which will lead to the deformation of surrounding buildings and underground pipelines. Based on the Qingdao parking berth and Haier Road Yinchuan Road regional transportation infrastructure construction project, this paper uses MIDAS GTS/NX numerical simulation software to model the actual project and carry out numerical simulation calculation, aiming at the distance between the building and the edge of the foundation pit. The size of the pipe material and the size of the pipe are analyzed and studied. The results show that the farther the building is from the edge of the foundation pit, the smaller the deformation is and the safer it is. The size of the pipeline deformation is proportional to the elastic modulus, and as the size increases, the displacement variation gradually becomes smaller.

Keywords

Foundation Pit Excavation; Numerical Simulation; Buildings; Underground Pipeline.

1. Introduction

In recent years, with the rapid development of China 's economy, the number of urban motor vehicles has grown rapidly. The rapid growth of the number of urban motor vehicles has led to the difficulty of driving and parking in hot spots. In order to alleviate the parking problem in hot spots, the development and construction of underground parking lot is urgent. The development of underground parking lot involves the excavation of foundation pit, and the excavation of foundation pit must have a certain impact on the surrounding buildings. In the process of foundation pit excavation construction, it is not only necessary to ensure the safety of the foundation pit, but also to ensure the safety of the surrounding buildings. Otherwise, it will affect the life and work of nearby residents, and even life safety. Therefore, it is necessary to control the adverse effects of foundation pit excavation on adjacent buildings. With the help of Flac3D software, Xue et al. [1]discussed and analyzed the failure mode of foundation pit under the limit state and the influence of excavation on adjacent buildings; Zhang Yao et al [2]combined with finite element simulation, studied the influence of foundation pit construction on the settlement and horizontal displacement of piers; Chen Yuansheng et al. [3]used Midas GTS to simulate the deformation of foundation pit retaining structure and adjacent buildings in the whole process of construction. The results show that the settlement of buildings mainly occurs in the excavation stage; Wang Lin et al. [4]simulated by finite element analysis software, and obtained the conclusion that the foundation pit construction has little influence on the building force, but has a great influence on the building deformation; Yang Qingguang et al. [5]used Flac3 D to establish a three-dimensional model to study the influence of foundation pit on the stability of underground pipelines crossing the pit wall at different angles; Xu Hongzeng et al. [6]established a three-dimensional numerical model to simulate and study the displacement changes of adjacent pipelines

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along the length direction caused by the excavation of narrow municipal pipe gallery foundation pit under different envelope structures.

The above research has certain reference significance, but due to the different geological conditions in different regions, the foundation pit engineering is regional, and targeted research should be carried out for different foundation pits.

2. Project Overview

This project is a transportation infrastructure construction project for Qingdao parking berth and Yinchuan Road area of Haier Road. The project is located in the underground area of the green space in the interchange area of Haier Road and Yinchuan Road in Laoshan District of Qingdao City. The underground garage of this design is divided into four plots: A, B, C and D. The garage of plot C selected in this simulation is the first underground floor. The foundation pit is only 6m away from the A building of Darong Center (34F), and the power pipeline on the west side of the foundation pit is only 2.6m according to the outer edge of the foundation pit. Considering that the deformation and settlement of surrounding buildings and pipelines caused by foundation pit excavation should be strictly controlled, the safety level of the whole foundation pit project is the first level. The size of the foundation pit is 64 × 134m, and the depth of the foundation pit is about 8.5m. Combined with the surrounding drilling information, the foundation pit is mainly located in the quaternary soil layer. The support adopts the pile-anchor system, the long pile type, the support pile adopts the Φ1m @1.5m bored pile, and the horizontal spacing of the anchor cable is 1.5m. The groundwater treatment measures adopt Φ1m @0.75m high pressure jet grouting pile.

The object of this study is the power pipeline with a section size of 1500 × 1700mm, which is 2.6m from the outer line of the foundation pit, and the building A (34F) of Darong Center, which is 6m from the outer line of the foundation pit. According to the field geological survey report and the local specific construction experience, the physical and mechanical parameters of the rock and soil can be obtained as shown in Table 1:

Table 1. Physical and mechanical parameters of soil

Soil layer number	Name of Soil layer	Average layer thickness **d** (m)	Volumetric weight **γ** (KN/m^3)	Angle of internal friction **Φ** (°)	Force of cohesion **C** (kPa)	Elastic modulus **E** (MPa)	Poisson ratio **μ**
1	Plain fill	4	18.7	15	12	2	0.34
2	Silty clay	6	19.9	14.2	28.8	6	0.32
3	Strongly weathered granite	4	23	45	0.2	45000	0.24
4	Moderately weathered granite	3	25.5	55	0.2	47000	0.22
5	Light weathered granite	13	26.3	65	0.2	74000	0.2

3. Establish a Numerical Model

In order to study the influence of foundation pit excavation on surrounding buildings and underground pipelines, it is necessary to establish a numerical model including support system, soil around foundation pit and buildings. The constitutive model of rock and soil mass is the core of numerical simulation of geotechnical engineering, and it is the key factor that affects whether the simulation results are in line with the actual engineering situation [7,8].

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In this study, Midas GTS finite element analysis software was used for simulation. The basic assumptions of the calculation are as follows:

(1) The modified Mohr-Coulomb model is used in each stratum and the soil around the foundation pit excavation. The combination of nonlinear elastic model and elastic-plastic model [4] can effectively simulate the foundation pit project accurately;

(2) The types of pipelines and buildings around the foundation pit are isotropic-elastic materials;

(3) Because the displacement changes of buildings, pipelines and soil layers are consistent, and the high-pressure jet grouting pile water stop measures are set up, the process of defining the construction stage group is simplified, without considering the influencing factors of groundwater.

The soil adopts the modified Mohr-Coulomb model. In addition to the parameters already given in Table 1, there are also parameters such as E_{50}^{ref} (secant stiffness of triaxial compression test), E_{oed}^{ref} (tangent stiffness of one-dimensional compression test), E_{ur}^{ref} (unloading and reloading modulus). The model reference experience E_{50}^{ref} is equal to the deformation modulus, the value of E_{oed}^{ref} is the same as that of E_{50}^{ref}, and the value of E_{ur}^{ref} is 4 times of E_{50}^{ref}.

The calculation model is established. Considering that the influence range of foundation pit excavation is 2 ~ 4 times of the excavation depth and the surrounding environment, the model size is set to 220 × 220 × 45 m. In order to facilitate the calculation of the boundary conditions, the automatic constraints built in the software are selected, and the self-weight is applied to restore the actual situation. The superstructure of the building only considers the stiffness effect, so the load of the superstructure is converted into the concentrated force of the single column load. Create a three-dimensional finite element model as shown in Figure 1:

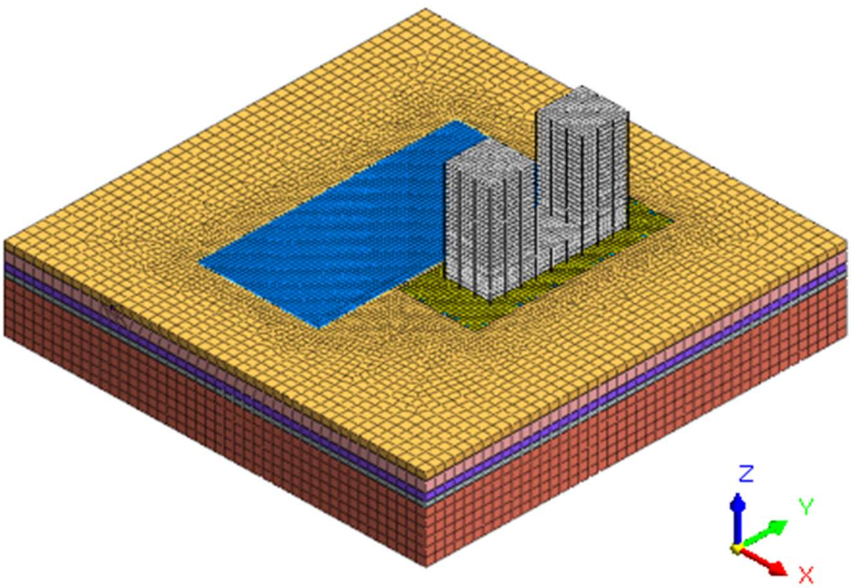

Figure 1. Three-dimensional finite element model

4. Numerical simulation analysis

Due to the complex construction conditions and external natural conditions, it is difficult for numerical simulation to reflect the actual construction conditions, so the simulation results are different from the actual measurement results.

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4.1 Analysis of simulation results

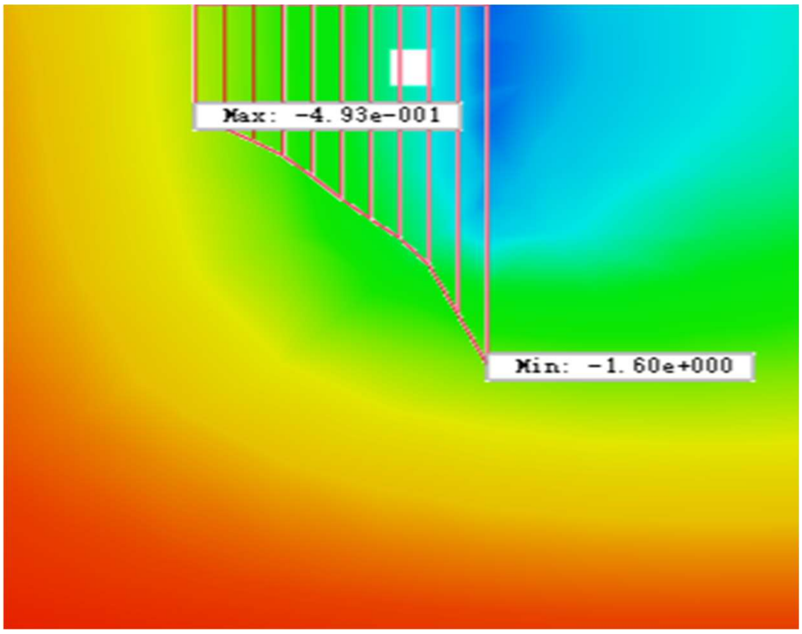

Figure 2. Simulation cloud map of surface subsidence

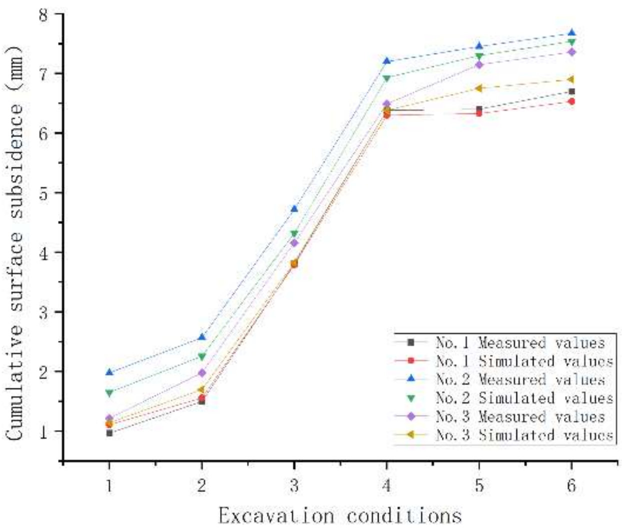

Figure 3. Comparison curve of surface subsidence measurement and simulation

As shown in Figure 2, the surface settlement curve after excavation is basically the same as that of the foundation pit without internal support in the foundation pit support structure proposed by Ou [9], and the surrounding surface settlement is ' triangle ' mode. It can be seen from Figure 3 that the numerical simulation results of each excavation condition are basically consistent with the field monitoring values, and the change rate of surface settlement gradually decreases in the later stage of foundation pit excavation. The simulated maximum value of surface settlement is 7.67 mm, and the actual monitoring value is 7.33 mm. The difference between the simulation results and the actual results is 0.34 mm, indicating that the numerical simulation results are ideal. The model can be used as a reference to analyze the influence of foundation pit excavation on surrounding structures.

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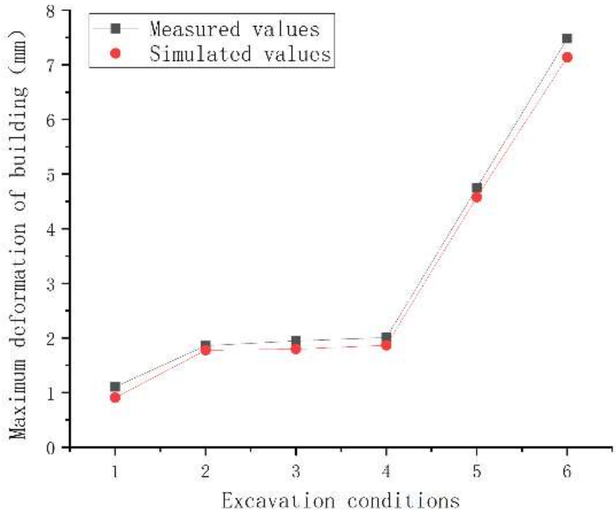

Figure 4. The relationship between the maximum deformation of adjacent buildings and excavation conditions

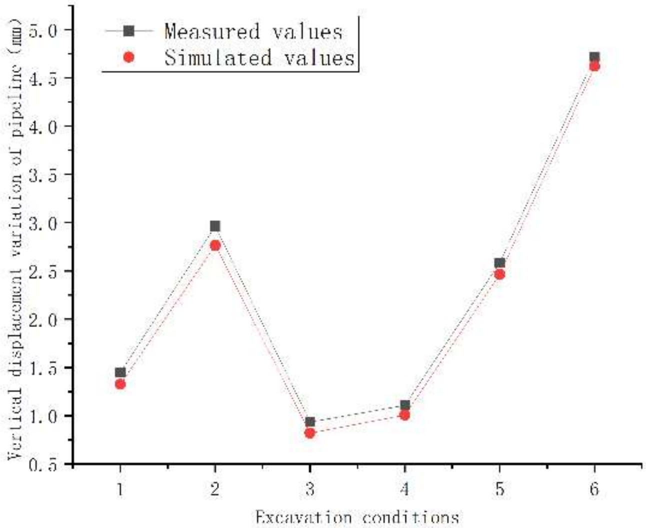

Figure 5. Comparison between the vertical displacement of the pipeline and the measured one

It can be seen from Figure 4 that under working condition 1, the maximum deformation value of the building is about 1.11 mm. When working conditions 2 and 3, the maximum influence changes of the building are 1.86 mm and 1.95 mm respectively. After the soil excavation starts from working condition 4, the change rate of the building increases obviously, and the maximum deformation value is 7.14 mm. It can be seen from Figure 5 that the vertical displacement of the pipeline gradually increases with the gradual construction of the foundation pit. It can be seen from the above that with the increase of excavation depth, the deformation of buildings and pipelines adjacent to the foundation pit will become larger and larger.

In view of the deformation difference caused by the excavation of the foundation pit to the buildings and different pipelines located at different distances near the foundation pit, further detailed analysis is needed.

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4.2 Analysis of the Influence of Buildings at Different Distances from the Foundation Pit

In order to analyze the influence of excavation on buildings with different distances adjacent to the foundation pit, it is assumed that the width of the building in the model is 8m, and the nearest distance between the three buildings and the foundation pit is 6m, 14m and 22m.After simulation calculation, the results are extracted and the following graphics are drawn.

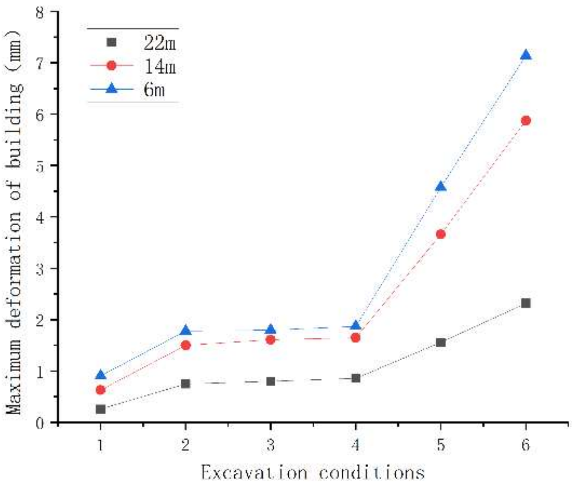

Figure 6. Maximum deformation of buildings at different distances

Observing the maximum deformation curve of the building at different distances in Fig.6, it can be seen that the maximum deformation of the building is closely related to the distance from the foundation pit. The farther the distance is, the smaller the deformation is, the safer it is, and vice versa. Therefore, the protection and monitoring of buildings should be strengthened around the foundation pit construction.

4.3 Analysis of Deformation Factors of Foundation Pit Adjacent Pipeline

There are many factors affecting the deformation of underground pipelines, such as the distance from the foundation pit, the size of the foundation pit, the material of the pipeline, the size of the pipeline, the buried depth of the pipeline and so on. This study is based on the actual project, so the material of the pipeline and the size of the pipeline are selected for analysis.

4.3.1 Pipe Material

In order to explore the influence of different materials on the pipeline itself during the excavation of the foundation pit, the original concrete material of the pipeline is replaced by steel and PVC. The material parameters of the pipeline are shown in Table 2, and the remaining parameters of the pipeline are unchanged according to the original engineering parameters. The numerical simulation shows that the vertical displacement comparison curve of the pipeline is shown in Figure 7:

Table 2. Pipeline material parameters

Material code	Pipeline material	Volumetric Weight (KN/m³)	Elastic modulus (Mpa)	Poisson ratio
1	Concrete	86	300	0.3
2	Steel	79	2000	0.3
3	PVC	15	23	0.35

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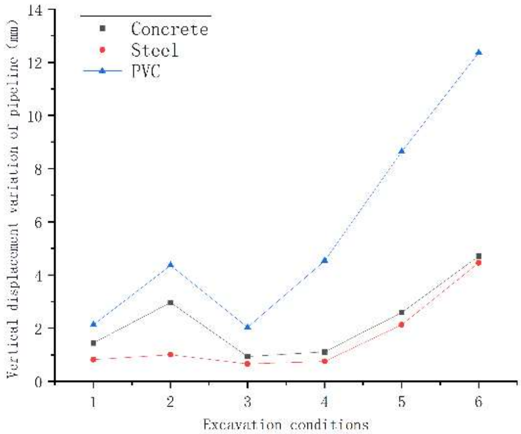

Figure 7. Displacement changes of pipelines with different materials

From Figure 7, it can be seen that among the pipes of three different materials, the displacement change of PVC pipe is the largest, and that of steel pipe is the smallest. Observing the material parameters in Table 2, it can be concluded that the deformation of the pipe is closely related to the elastic modulus of the material, and its ability to resist external deformation is proportional to the elastic modulus.

4.3.2 Pipe Size

According to the above, the greater the stiffness of the material, the stronger the ability to resist deformation. Pipe size is also an important factor affecting its deformation. This section studies the influence of foundation pit excavation on pipelines of different sizes. Except for the size of the pipeline, the other parameters are the same as the actual situation.

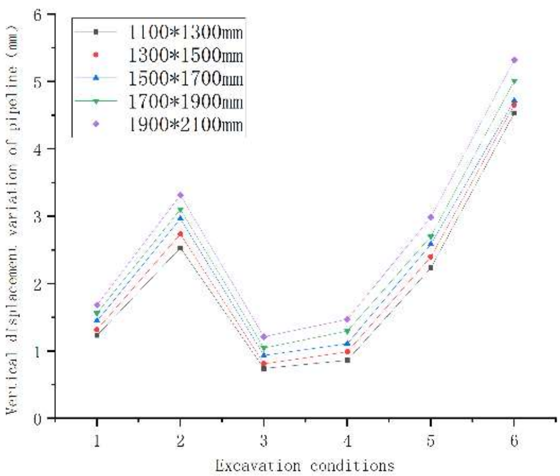

Figure 8. Displacement changes of pipelines with different sizes

Through the analysis of Figure 8, it can be seen that the displacement variation of the concrete pipe gradually decreases with the increase of the size. It can be seen that the pipeline has stronger resistance to deformation with the increase of the size. Combined with Figure 7, it can be concluded that the variation of concrete pipes and steel pipes during foundation pit excavation is similar. Considering the project cost, it is obvious that concrete pipes are more economical.

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5. Conclusion

(1) In the process of foundation pit excavation, the maximum deformation of the building is closely related to the distance from the foundation pit. The farther the distance is, the smaller the deformation is and the safer it is. The protection and monitoring of buildings should be strengthened around the foundation pit construction;

(2) The deformation of the pipeline is closely related to the elastic modulus of the material, and its ability to resist external deformation is proportional to the elastic modulus. With the increase of the size, the displacement variation gradually decreases, so the pipeline with the increase of the size, the stronger the resistance to deformation;

(3) The geological conditions are regional. Based on the actual engineering analysis of Laoshan District in Qingdao, this paper has certain limitations and can provide reference for similar projects in Qingdao;

(4) There are many factors affecting the excavation of the foundation pit. This paper only selects the buildings with different distances from the foundation pit, three different materials and five different sizes of pipelines for analysis, and fails to analyze and study all the influencing factors one by one. In the future research, it needs to continue to supplement and improve.

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