Analysis of Mechanical Characteristics of Foundation Pit Excavation of Super High-rise Building in Strong Weathered Sandstone Area

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Abstract. The foundation pit excavation of the natural foundation of the super high-rise building in the strong weathered sandstone area of Lanzhou is the first foundation excavation project of Gansu Province. Excavation method and soil condition affect the excavation of foundation pits to different extents. In order to obtain the excavation method of foundation pit excavation in the area, based on the local soil conditions, the ABAQUS finite element software was used to establish the 3D numerical simulation of foundation pit excavation, and the stress and deformation curves during foundation excavation were drawn. The simulation results were compared with the specifications to obtain a feasible scheme for foundation pit excavation. Then a typical soil layer was selected for excavation, and the effects of elastic modulus and cohesion on the deformation of the foundation pit during excavation were studied, the model damage cloud diagram during the foundation pit excavation process is obtained. By comparing the deformation of a certain path in the model and drawing the curve, the influence of elastic modulus and cohesion force on the excavation deformation of the foundation pit is obtained. At the same time, this article can also provide reference for similar projects in the future.

1. Introduction
With the continuous development of science and technology, the development and utilization of underground space, the excavation of foundation pits has gradually turned into a deep foundation pit. The deformation of the surrounding soil caused by the foundation pit construction is more serious, and the mechanical characteristics of the excavation process of the foundation pit are analyzed by using the indoor experiment with poor repeatability and high cost. It is more important to use numerical simulation research.

Hu Haiying[1] et al. used the three-dimensional finite element program Midas/GTS to analyze the influence of foundation pit excavation on the subway tunnel. The results show that the foundation pit is not necessarily unloading during the excavation, and sometimes the tunnel confining pressure is increased. This is related to the excavation depth of the foundation pit and the positional relationship between the tunnel and the foundation pit. It is also related to the construction method of the foundation pit support structure. It should be combined with the specific mechanical transmission path to determine
whether it is unloading or loading. Liu Jiguo and Zeng Yawu [2] used FLAC3D software to simulate the excavation and support of the deep foundation pit of the Yangtze River cross-river tunnel in the Yangtze River, and calculated the surface subsidence, the basement uplift and the horizontal displacement of the soil behind the wall in different excavation stages, they provide reference for engineering design and construction. Cui Honghuan [3] et al. used ABAQUS to simulate the whole process of deep foundation pit excavation of a high-rise building, and discussed the factors affecting the deformation and stability of the foundation pit, and proposed some methods to control the deformation of the supporting structure and maintain the stability of the foundation pit. Qin Huilai [4] et al. verified the feasibility of ABAQUS numerical simulation to analyze and calculate the deformation problem of foundation pit excavation. Wang Guowen [5] used FLAC 3D finite difference software to analyze the effects of friction angle and cohesion on the horizontal and vertical displacement of the top of deep foundation pit. When the friction angle and cohesion of the soil gradually become larger, the horizontal displacement of each side of the foundation pit is lower than that of the original soil, and the calculation result shows a downward trend. After reaching a certain value, as the internal friction angle and cohesion continue to increase, the horizontal and vertical displacement of each side of the foundation pit gradually rises. Mo Shixiong [6] et al. used Tongji Shuguang three-dimensional finite element analysis software to calculate the deformation of the foundation pit and compare it with the measured value. It is concluded that the deep foundation pit changes linearly with the change of the internal friction angle and the ground settlement during the excavation process, and the fitting regression relationship is given. Jia Di [7] et al. have studied three methods for obtaining the elastic modulus of soil in numerical analysis using survey report data: (1) direct estimate, conversion from compression modulus to secant modulus; (2) estimation of elastic modulus by undrained shear strength, plasticity index and overconsolidation ratio; (3) converting the elastic modulus using the cone tip resistance of static penetration. Zhang Peiwen [8] et al. satisfied the hyperbolic relationship according to the elastic modulus and Poisson's ratio of soil, and gave the basic principle of elastic modulus and Poisson's ratio reduction. The analysis of the example shows that adjusting the Poisson's ratio has an effect on the solution of the safety factor, but the influence of the elastic modulus is generally small.

Therefore, based on the above research, this paper takes the foundation pit excavation of a super high-rise building in the strong weathered sandstone area of Gansu Province as the background, and uses ABAQUS software to carry out three-dimensional numerical simulation, which is a feasible design for engineering construction, and through the study of typical soil layer parameters, the effects of elastic modulus and cohesion on the excavation deformation of foundation pit are analyzed.

2. Project Overview
The project is located in Chengguan District of Lanzhou City. The project covers an area of 14511.1 m². It is a comprehensive architectural project integrating large-scale urban complexes with large-scale commercial, Grade A office, luxury apartments, resettlement houses and supporting kindergartens. It will become a new city landmark in Lanzhou.

2.1. Formation condition
According to engineering geological survey and on-site drilling, the site is relatively simple, from top to bottom: ① mixed soil, ② silt, ③ pebble, ④ 1 strong weathered sandstone, ④ 2 middle weathered sandstone.
2.2. Numerical test overview and mechanical parameters
The model selects a 60m×60m×60m cube body, the excavation depth of the foundation pit is 10m, and the underground continuous wall is set at the same time. The wall height is 20m. The specific excavation is shown in Fig. 1. The ground connecting wall is 20m high and 1m wide, and the C30 concrete is poured. The elastic modulus is \(3.0 \times 10^7\) KPa, the Poisson's ratio is 0.19, and the density is \(2.4 \times 10^2\) kg/m\(^3\). The geotechnical parameter material table is shown in Table 1.

| Stratum                  | depth(m) | severe strength | Elastic Modulus | Poisson's ratio |
|--------------------------|----------|-----------------|-----------------|-----------------|
| mixed soil               | 0.0 ~ 3.0| 16.0            | 4.0 \times 10^5| 0.38            |
| silt                     | 3.0 ~ 8.0| 18.0            | 8.0 \times 10^4| 0.37            |
| pebble                   | 8.0 ~ 12.4| 20.0           | 4.0 \times 10^4| 0.36            |
| 1 strong weathered sandstone | 12.4 ~ 35.0 | 23.0 | 5.0 \times 10^5 | 0.35            |
| 2 middle weathered sandstone | 35.0 ~ 64.6 | 24.0 | 8.0 \times 10^5 | 0.35            |

3. Numerical simulation implementation process

3.1. Modeling process
All A three-dimensional model was created in the ABAQUS according to the size above, as shown in Fig. 2 and 5. Because the geotechnical layer in this area is simple and the soil quality is good, the Mohr Coulomb theory is adopted in the simulation. The depth of layered excavation is: 3m, 5m, 2m. The design conditions of the working conditions in the simulation process are shown in Table 2.
3.2. Simulation result

3.2.1. Deformation of soil during excavation. Deformation is an important factor in the excavation of foundation pits. The calculation results show that the maximum stress of the model is 1.429×103Kpa, and the maximum deformation of the soil is 21.6mm, when the foundation pit is excavated to the bottom, as shown in Fig.3. Select a typical path to make a horizontal displacement and settlement curve, as shown in Fig. 4. The path of the horizontal displacement curve is the sidewall of the foundation pit, and the selection path of the settlement curve is the bottom of the foundation pit, as shown in Fig. 5. The maximum level of the side wall is 15.45 mm and the maximum settlement is 9.27 mm.

3.2.2. Deformation of the ground wall during excavation. Since the grounding wall is installed in the foundation pit excavation, the stress and displacement of the grounding wall are analyzed. The calculation results show that the ground-connected wall has been subjected to tension during the excavation process. The maximum stress value is 12.83KN, the maximum deformation value is 21.21mm, and the stress and deformation cloud diagrams are shown in Fig. 6 and Fig. 7.
3.3. Summary
According to the “Safety Technical Specification for Construction of Deep Foundation Pit Construction JGJ311-2013”, the deformation control of the side wall and the ground of the foundation pit shall be carried out according to the design requirements. When there is no specific requirement, it shall be deformed according to the safety level of the foundation pit. Restricted control: The foundation pit with safety level is first grade, the maximum deformation limit of horizontal displacement of the side wall of the foundation pit is 30mm or $3\%H$ (H is the excavation depth of the foundation pit); the maximum settlement of the sidewall of the foundation pit is $1\%H$. Through calculation, the displacement deformation meets the requirements of the specification.

4. Effect of simulation parameters on deformation
Since the above simulation results meet the requirements of the specification, the influence of the parameters on the deformation is used in the first layer of the above model, and the elastic modulus and cohesion are increased to obtain the settlement results.

4.1. Influence of elastic modulus on settlement of foundation pit
On the basis of the original elastic modulus, the simulation study was carried out by 1 time, 2 times and 3 times respectively. The original maximum deformation value of the model was 14.53 mm. The maximum deformation values of the elastic modulus increased by 1, 2, and 3 times were 14.53 mm, 14.53 mm, and 14.53 mm. The maximum value is only the same value, but the direction is opposite. When the elastic modulus is doubled, it is settled like the original model. However, when the height is increased by 2 times and 3 times, the bottom surface of the foundation pit is in a bulging state. The settlement deformation cloud diagram of the bottom surface of the foundation pit is shown in Fig. 8. The deformation path is obtained by selecting the same path on the bottom surface of the foundation pit, as shown in Fig. 9.

![Figure 8. Settlement damage of the bottom](image)

![Figure 9. Deformation curve](image)

![Figure 10. Deformation curve](image)
4.2. Influence of cohesion on settlement of foundation pit

On the basis of the original cohesion, the simulation was carried out by 0.5 times, 1 time and 2 times respectively. The original maximum deformation value of the model was 14.53 mm. The maximum deformation values of the cohesive force increased by 0.5 times, 1 time, and 2 times were 14.53 mm, 14.53 mm, and 14.53 mm, respectively, all of which belonged to settlement, and there was no bulging phenomenon, and there is no change in the maximum settlement. Moreover, the contrast curve of sedimentation shows that the change of cohesion has no effect on the settlement. The settlement deformation damage cloud diagram is shown in Fig. 8. Similarly, select the same path on the ground of the foundation pit to obtain the deformation curve, as shown in Fig. 10.

4.3. Summary

In the above numerical simulation, it can be seen from Fig. 9 that as the elastic modulus increases by 1, 2, and 3 times, the deformation curve is mainly divided into two parts, when the modulus of elasticity is doubled, it is consistent with the original model, but when it is increased by 2 times and 3 times, the direction is opposite. So, there should be a boundary point in the region where a certain elastic modulus is the direction of vertical displacement. As can be seen from Fig. 10, as the cohesive force is increased by 0.5 times, 1 time, and 2 times, the sedimentation curve does not change.

It can be seen that in the excavation of the foundation pit in the area, the elastic modulus has a certain influence on the settlement, but the cohesion is not.

5. Conclusion

(1) It is feasible to use layered excavation and grounding in the foundation excavation of the natural foundation of super high-rise buildings in the strong weathered sandstone area of Lanzhou City.

(2) In the simulation of foundation pit excavation, with the calculation and analysis of various working conditions, the maximum displacement deformation value is continuously increasing. The maximum displacement of the foundation pit excavation is 21.6mm; The maximum deformation in the horizontal direction is 16.29mm, the maximum deformation occurs in the sidewall of the foundation pit; The vertical displacement of the sidewall of the foundation pit is 9.27 mm. Meet the "Safety Technical Specifications for Construction of Deep Foundation Pit Construction JGJ311-2013".

(3) In this simulation, as the elastic modulus increases, the settlement value does not change and the direction changes during the excavation process. As the cohesion increased, the settling did not change. From the deformation and failure cloud diagram and deformation curve, the elastic modulus has a certain influence on the settlement deformation in the foundation pit excavation.

(4) The above conclusions are based on numerical simulation results, assuming the homogeneity and isotropic characteristics of the soil, which provides a certain theoretical guiding significance for practical engineering, but its accuracy requires actual excavation for further verification and further optimization and calculation.

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