Three-dimensional computer simulation of soil nailing support in deep foundation pit

Chang Zhi Zhu[1,2]*, Quan Chen Gao[1]

[1] *School of Mechanics & Civil Engineering, China University of Mining & Technology, Beijing 100083, China*

[2] *School of Urban and Rural Construction, Agricultural University of Hebei, Baoding 071001, China*

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Abstract

The computer application program that is applied based on the finite difference method. By taking the soil nailing support structure in Shijiazhuang city as an example, the three-dimensional computer numerical model of deep foundation pit is set up; the horizontal displacement and the ground settlement of the deep foundation pit are simulated in the process of excavation and support. The simulation result is consistent with the test result. The results show that the deformation behaviour of the deep foundation pit can be analysed by using three-dimensional computer simulation technology in actual project. The method overcomes the deficiency of theoretical analysis method and offers effective guidance for design and construction of foundation pit excavation and support.

Keywords: Three-dimensional computer simulation, Soil nailing support, Deep foundation pit

1 Introduction

Because of its economy, stability and flexibility, the method of soil nailing was widely applied to the foundation pit support [1, 2]. In the process of the design of soil nailing supporting structure, the design method adopted was combination theoretical analysis with experience of practical engineering, but there are a number of assumed conditions in the process of theoretical analysis, the interaction mechanism is very complicated [3, 4] between the supporting structure and soil, these will cause a lot of parameter values that cannot be calculated exactly, which may affect the foundation pit itself and safety of surrounding buildings.

In recent years, with the rapid development of computer simulation technology, many researchers are using this technology in the field of engineering design or scientific research. Thus in order to overcome the deficiency of pure theoretical analysis in the soil nailing structure design, the method of computer simulation technology was introduced in the analysis of the soil nailing structure, the interaction mechanism was simulated by the computer program, and analyse the deformation behaviour in the process of the deep foundation pit excavation and support.

In this paper, taking the soil nailing support structure in Shijiazhuang city as an example, based on finite difference program, the process of the deep foundation pit excavation and soil nailing support was simulated by the numerical analysis model, analyse the law of the horizontal displacement and the ground settlement, the numerical simulation and measured result can be used to analyse the deformation behaviour, the result can be used to offer effective guidance for design and construction of foundation pit excavation and support.

2 Engineering situation

The foundation pit of a high-rise building was in Shijiazhuang, the depth was 13 m, the total construction area was 62585.46 m^2, there was a 3-story office building on the top of the foundation pit east. The length of building was about 50 m, the width was 13 m. The distance from the axis of the exterior wall to the edge of foundation pit was about 2 m. Plane arrangement chart of the site was shown in Figure 1.

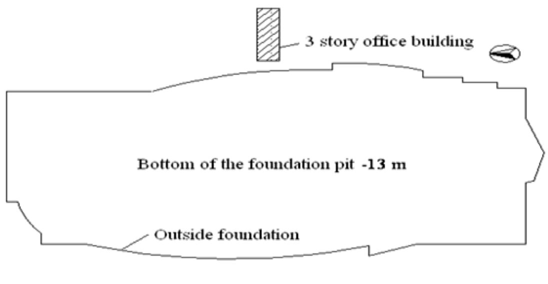

FIGURE 1 Plane arrangement chart of the site

The soil physical and mechanical properties were shown in Table 1. The slope of pit was 90°, soil nails was used in the process of the excavation of foundation pit, the soil nails was eight rows in number, the diameter of hole was 100 mm, and the angle with the horizontal plane was 15°. The horizontal and vertical distance was 1.0 m, the steel's diameter was 22 mm, and the length of the soil nailing was shown in Figure 2.

* ***Corresponding author*** e-mail: 13930854216@139.com

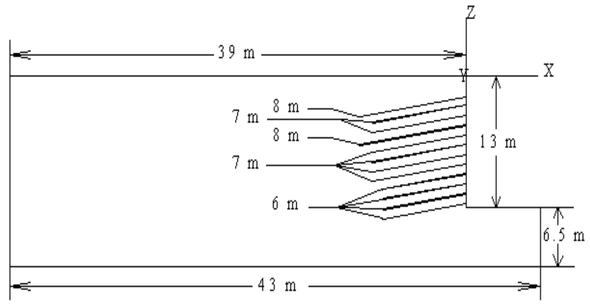

FIGURE 2 The profile of foundation pit support design

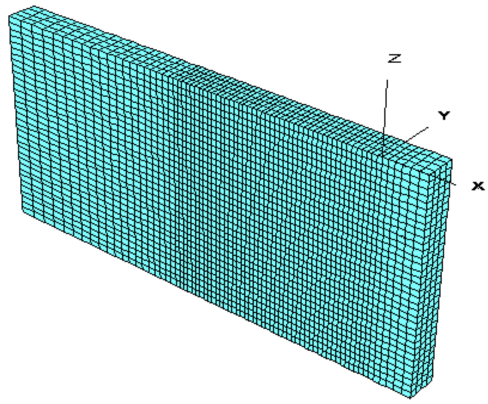

FIGURE 3 Model diagram

3 Calculation model

3.1 THE GEOMETRY MODEL OF FOUNDATION PIT

According to engineering experience, when the soil nails were arranged in the soil at a certain distance along the horizontal and vertical directions, the most dangerous parts of the pit was generally not near the corner, but in of the central part [5, 6] of the long side of the foundation pit. So 3 m wide range soil of the central part of the long side of the foundation pit was simulated by establishing the numerical model, the model geometry was determined by trial calculation, and the specific dimensions were shown in Figure 2. The numerical model was shown in Figure 3. In order to meet accuracy requirements, the regional units were small in the range of soil nail reinforcement regional, and it was a total of 9588 regional units.

3.2 BOUNDARY CONDITIONS OF MODEL

The boundary conditions of the numerical model were these: The bottom surface of the foundation pit was fixed, the displacement of horizontal and vertical direction was restricted; the top surface and air face after excavating were free; the horizontal displacements of other side surfaces were restricted, and vertical displacements were free.

3.3 VALUES OF MATERIAL PARAMETER IN MODEL

The physical and mechanical parameters of the soil were shown in Table 1. Soil nails were stimulated by cable element, and the parameters were shown in Table 2.

TABLE 1 The soil physical and mechanical properties

Soil No.	Soil name	Thickness (m)	γ(kN·m^{-3})	c(kPa)	φ(°)	K(MPa)	G(MPa)	μ
1	fill	0.80	16.0	15.0	10.0	36.25	27.18	0.4
2	silty clay	2.60	19.2	20.0	17.6	8.02	3.70	0.3
3	loess-like silt	1.40	19.6	9.6	23.4	6.75	4.05	0.25
4	silty clay	3.20	19.2	22.0	22.8	10.14	4.68	0.3
5	fine sand	1.20	18.0	0.0	28.0	50.56	30.33	0.25
6	medium sand	6.10	18.0	0.0	33.0	50.33	35	0.25
7	fine sand	3.2	18.6	0.0	36	54.3	36	0.24
8	silty clay	2.20	19.4	25.0	21.8	12.14	5.23	0.29
9	coarse sand	1.2	19.6	0.0	26.0	54.2	35.7	0.23
10	silty clay	8.20	19.9	20.0	20.0	12.03	5.55	0.3

TABLE 2 The calculation parameter values of soil nails

Elastic modulus of steel bar (kPa)	Tensile strength of steel bar (MPa)	Density of steel bar (kg·m^{-3})	Mortar stiffness (kPa)	Mortar cohesion (kPa)	Mortar friction angle (°)	Cross sectional area of soil nailing (m^2)
2.0e8	335	7800	185.1	5.4e5	25	2.011e-4

3.4 NUMERICAL SIMULATION

In the numerical analysis model, the constitutive model of the soil was non-linear elastic-plastic, the failure criteria was Mohr-Coulomb criteria [7], It can reflect the characteristics of the soil well [8], due to the deformation of soil under the action of soil nails and the tension of soil nail were closely related with the construction process [9], so the process of numerical simulation was accordance with the actual construction process rigorously, concrete steps are as follows:

1) The model was calculated on the condition of gravity stress, and the initial stress state of soil was obtained.
2) Initialize the displacement, velocity, boundary conditions, and apply external load, calculate the stress.

3) Simulated excavation, after the first step excavation, the balance calculation was done, and then soil nails were driven into the soil, calculating again, until the calculation precision to meet the requirements for the next step, and so on, until the end of excavation and support process.

4 Numerical results and analysis

Figure 4 to Figure 7 were the change curve of horizontal displacement with the depth of the excavation of the excavation surface and the positions away from the excavation surface were 3 m, 6 m, and 9 m, respectively. From the figures, we can see, with increasing of excavation depth, the lateral restraint of slope was gradually lifted, on the action of gravity stress and external loads, the horizontal displacement of the soil increased with the number of excavation steps increased at the same location of slope. After every step of the excavation is completed, of the horizontal displacement of the slope soil decreased with the soil depth increased. By comparing Figure 4 to Figure 7, the horizontal displacement of the slope that was at the same the depth of soil decreased with the distance from the excavation surface increased.

Figure 8 was the change curve of the settlement of the top of slope with the change of the number of excavation steps. Moreover, it shows that in the early stage of excavation, as stress redistribution of the soil caused by the excavation, there was a certain amount of resilience. Therefore, it showed a range of rising of the excavation surface. With the excavation depth increases, the settlement of the slope soil increased on the action of gravity stress and external loads. The settlement of excavation surface was the largest, and it decreased with the distance from the excavation surface increased.

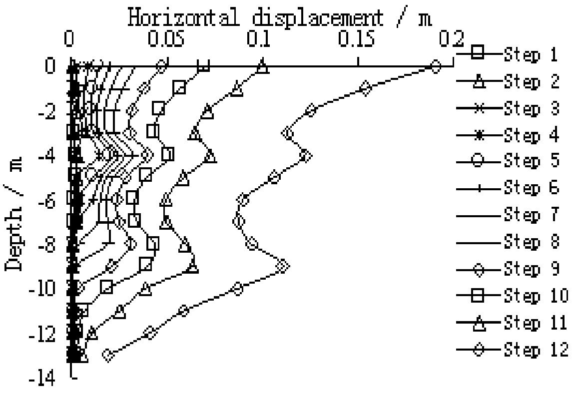

FIGURE 4 The change curve of horizontal displacement with the depth of the excavation surface.

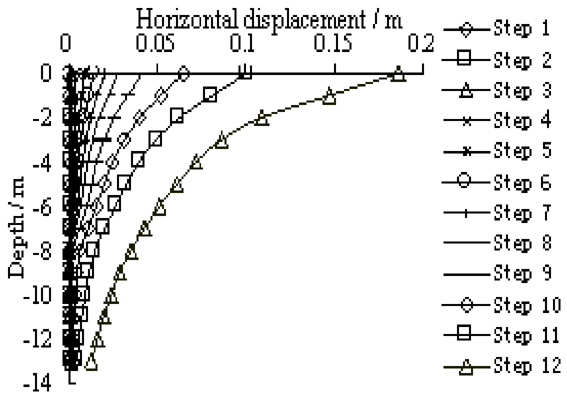

FIGURE 5 The change curve of horizontal displacement with the depth of the excavation that the position away from the excavation surface was 3 m

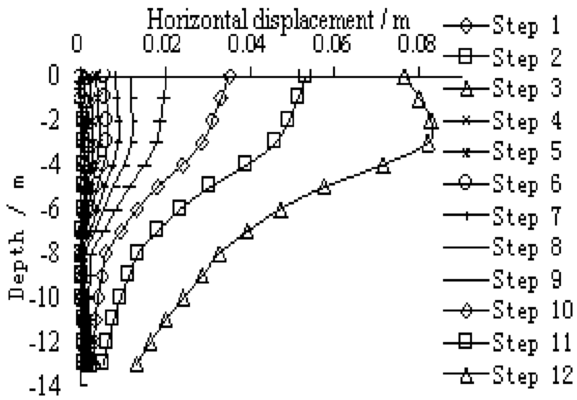

FIGURE 6 The change curve of horizontal displacement with the depth of the excavation that the position away from the excavation surface was 6 m

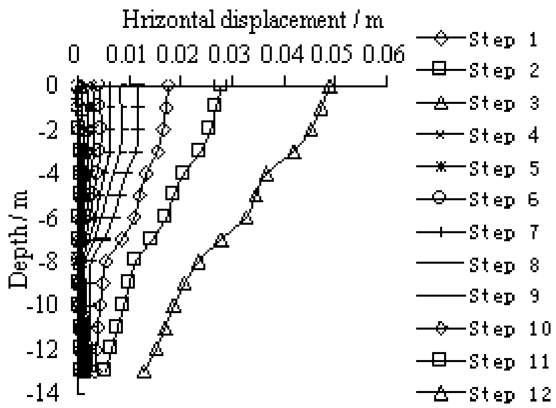

FIGURE 7 The change curve of horizontal displacement with the depth of the excavation that the position away from the excavation surface was 9 m

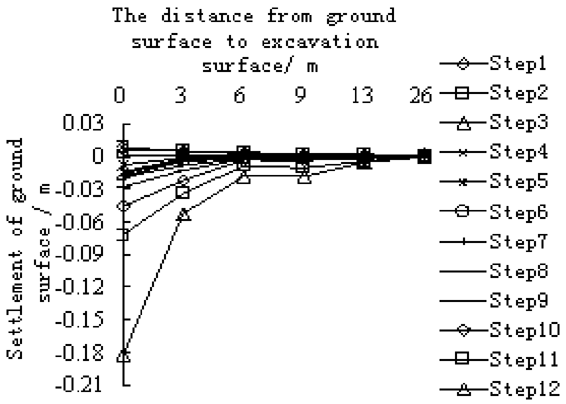

FIGURE 8 The change curve of the settlement of the top of slope with the change of the number of excavation steps

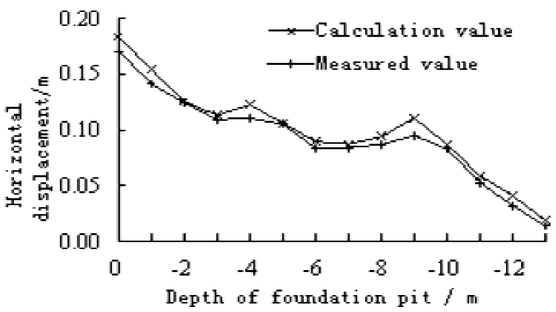

FIGURE 9 The comparison curve of the displacement of calculation value and measured value of excavation surface

Figure 8 shows that the settlement of the top of the slope of position that the distance from the excavation surface was 9 m increased, and this phenomenon was more obvious when the excavation for the tenth and eleventh step by step. The reason was that there was a building on the top of the excavation surface of the slope, and on the action of the load of building, the settlement of the surface increased.

Figure 9 is the change curve of the simulated values and the measured values of horizontal displacement with the depth of the foundation pit after the excavation completed, the simulation result was consistent with the test results. Whether calculated or measured horizontal displacement were large at the depth 9 m, Mainly because the soil were fine sand or medium sand, this type of the soil conditions were not conducive soil nailing to play the role of supporting structure, so that the horizontal displacement is too large.

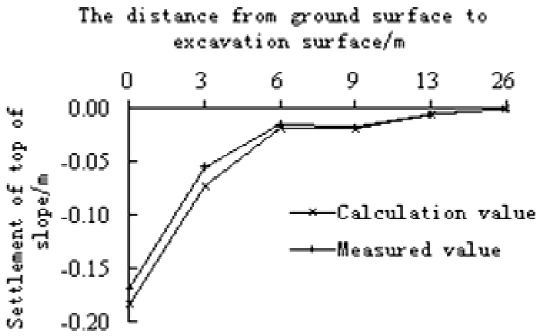

FIGURE 10 The comparison curve of displacement calculation value and measured value of ground surface

Figure 10 is the related curve of the simulated values and the measured values of the settlement of the top of the slope with the distance away from the excavation surface of the foundation pit after the excavation completed. It shows that the simulation results were consistent with the measured ones. The final calculation value of settlement is 0.183 m, and the measured one is 0.168 m, the relative error is only 8.2%.

5 Conclusions

The following conclusions can be drawn from the study:

1. Based on practical engineering, a numerical analysis model was established by the finite difference program, and the process of the deep excavation and support was simulated by computer, the horizontal displacement of the slope and settlement of the top of the slope are obtained, the results shows that there not only has the same regularity but also good agreement between calculated and measured values.
2. The fine difference program can be used to the simulation of the excavation and support of deep foundation pit, and it will provide the basis for the design and construction of practice project.

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Authors

Changzhi Zhu, born in April, 1980, Zunhua county, Hebei province, China

Current position, grades: Work in urban and rural construction institute, Agricultural University of Hebei, and doctoral candidate in geotechnical engineering, China University of Mining & Technology
University studies: Urban and rural construction institute (Faculty of civil engineering, 1999), Master of engineering degree in structural engineering, agricultural university of Hebei, Baoding, China, 2003; Doctoral candidate in geotechnical engineering, China University of Mining & Technology, (2012-)
Scientific interest: Computer simulation of geotechnical engineering
Publications: Published 7 papers
Experience: Member of Chinese Sub-Society for Soft Rock Engineering & Deep Disaster Control, (2004-)

Quanchen Gao, born in November, 1957, Wanrong county, Shanxi province, China

Current position, grades: Professor of China University of Mining & Technology
University studies: School of Mechanics & Civil Engineering (Faculty of underground engineering, 1977); Master of engineering degree in mine construction engineering, China University of Mining & Technology, Beijing, 1984; Doctor of engineering degree in mine construction engineering, China University of Mining & Technology, Beijing, 1988
Scientific interest: Deep foundation pit support engineering
Publications: more than 20 papers
Experience: Vice Chairman of Blasting Professional Committee of China Coal Society (2006-); Director of China Society of Engineering Blasting (2003-)