ISSN 2616-5767 Vol.5, Issue 2: 13-23, DOI: 10.25236/AJETS.2022.050204

Simulation Research of Foundation Excavation Retaining and Protecting Optimization Based on Midas Structural Analysis Technology

Guanting She[a], Yingrun Chen[b,*], Shijian Xu[c], Tao Zhang[d], Yuyang Liang[e]

Hefei University of Technology, Hefei, 230000, China
[a]1393900945@qq.com, [b]2764667759@qq.com, [c]2582959436@qq.com, [d]2580668657@qq.com, [e]1015828911@qq.com

Abstract: *With the rapid development of our society in recent years, the supply of urban land has become increasingly insufficient. In order to ensure the supply of urban land, the stability requirements for foundation pit retaining and protecting projects have also been increasing. At present, retaining and protecting for foundation pit has been widely used as a relatively new type of support. However, the research in this area is relatively few and theoretically insufficient, and there is a lack of relevant research on the design and construction of retaining and protecting for foundation pit schemes. Therefore, based on the research object of foundation pit engineering in City A, this paper conducted a comprehensive and in-depth study on the scheme design and maintenance of foundation pit engineering by introducing the method of finite element strength reduction to fully understand the current deep foundation pit engineering retaining and protecting in City A support system, and specify the general situation and development loopholes of the current supporting system. On this basis, the rationalization framework and safety consideration scheme are proposed for the deep foundation pit supporting scheme design, and the support design calculation of the deep foundation pit supporting structure is carried out by using Midas structural analysis technical design software, which is compared with the actual detection data to further verify the feasibility of the scheme.*

Keywords: *Foundation pit retaining and protecting; Midas structural analysis; Deep foundation pit excavation technology*

1. Introduction

In recent years, with the rapid development of China's economy, urban construction projects are gradually improving construction, high-rise building projects are becoming the core of the infrastructure. Deep foundation pit excavation technology has gradually become a key technology in the process of high-rise building foundation excavation, and the demand for rational application of underground space is also gradually reflected[1]. Deep foundation pit engineering retaining and protecting system design has always been an important research topic in the field of soil mechanics foundation, but also one of the difficult problems in the geotechnical field because of the high technical requirements of geotechnical test and field exploration test. In the traditional engineering field, the accuracy of foundation pit warning is usually studied to improve the design level of deep foundation pit engineering retaining and protecting, but this scheme is limited by the complexity of deep foundation pit[2]. With the increasing application of underground space in China, the existing technology level can no longer meet the needs of engineering projects.

Therefore, the finite element method is mainly used for the overall modeling of the earthwork within the excavation range of the foundation pit currently, and each physical quantity is interconnected to obtain the integral characteristic equation of the foundation pit. Finally, the Midas structural technical analysis software is used to model and solve the foundation pit's stability problem.

Based on the research object of foundation pit engineering in A city, this paper conducted a comprehensive and in-depth study on the scheme design and maintenance of foundation pit engineering by introducing the method of finite element strength reduction to fully understand the current deep foundation pit engineering retaining and protecting in City A support system, and specify the general situation and development loopholes of the current supporting system. On this basis, the rationalization framework and safety consideration scheme are proposed for the deep foundation pit retaining and

ISSN 2616-5767 Vol.5, Issue 2: 13-23, DOI: 10.25236/AJETS.2022.050204

protecting scheme design, and the support design calculation of the deep foundation pit supporting structure is carried out by using Midas structural analysis technical design software, which is compared with the actual detection data to further verify the feasibility of the scheme.

2. Project Overview and Analysis

2.1 Project Overview

The proposed site of the project is located in City A. This model is the simulation analysis of the construction stage of the excavation and retaining and protecting the process of the foundation pit. The excavation part of the foundation pit is 57.6m long, 33.3m wide, and 31m deep. According to the excavation scope of the foundation pit, the influence range of the model is determined as follows: X direction 195m, Y direction 158m, Z direction 100m. The main analysis content of this model is the ground settlement, the uplift of the pit bottom, the stress and deformation of the supporting structure, etc., during foundation pit excavation.

The foundation pit site has a complex structure in this project area. The east side is close to high-rise buildings with highly complex foundation situations. The north side is close to the urban main trunk roads, overpasses, and other traffic arteries, and there are corresponding cable power supply channels and underground water supply networks around. The excavation depth of this foundation pit is large, which is a typical deep foundation pit.

2.2 Geological General Situation

The tectonic situation and location of this area belong to grade III tectonic area, which has dual structural characteristics, and its structure is as follows.

From top to bottom, the stratum of the site is composed of pile-soil, silty clay, gravel pebble, and pebble, and its main physical and mechanical parameters are as follows:

Soil layer number	Soil layer	Bottom elevation(m)	Layer thickness(m)	Elasticity modulus(Kn/m^3)	Volumetric weight(Kn/m^3)	Poisson's ratio	Saturated unit weight(Kn/m^3)	C(kPa)	J(°)
1	pile soil	-2	2	54600	17.8	0.331	18.8	11	14.1
2	silty clay	-10	8	110180	19.5	0.294	20.5	12	10.5
3	gravel pebble	-26	16	337370	21.1	0.262	21.1	0	50
4	pebble	-	-	487840	21.4	0.259	21.4	0	48

The type of fold structure in this area is the west to east fold, with the main short-axis anticline, and the axial trace is distributed in the east to west direction and nearly northwest direction. The area contains two groups of brittle fracture structures distributed from southwest to northeast. Faults generally dip to the east with a steep dip angle, and some faults are translational faults, which are often accompanied by ring faults.

2.3 Design Overview

The retaining and protecting structure of the foundation pit is usually constructed together by a vertical retaining structure and horizontal bracing system to form a complete ring beam supporting system. The ring beam support system includes ring beam, support beam, side beam, column, etc. The side beam is composed of beams and columns fixed in row piles and diaphragm walls [3]. The side beam bears water and soil pressure through its enclosure structure and transfers the pressure to the support beam. When the support beam is too long, its stability will be affected by the above, so it is necessary to fix and design the support points of each part of the column, and the lower end of the column will also be inserted into the engineering pile for fixing.

Based on the above situation, the design scheme of the foundation pit is as follows: the construction system of the whole project is constructed by smooth practice method, and a diaphragm wall supports

ISSN 2616-5767 Vol.5, Issue 2: 13-23, DOI: 10.25236/AJETS.2022.050204

the enclosure structure, and double ring reinforced concrete structure to construct the system. The supporting column is perfused in the form of a borehole and anchor steel lattice column. The diameter of the ring beam is supported by the angle brace in the inner corner, and the trusses connect the ring beam and the angle brace structure in the middle part. This ring beam design support system has the characteristics of large excavation space, convenient earthwork excavation and transportation, and a clear ring beam layout.

The "wall-brace-anchor" composite support system is adopted[4]. The diaphragm wall depth is 45m, and the inner support adopts full bracing, which is arranged at -2m, -10m, -18m, and -26m, respectively, in the vertical direction. The bolt is arranged at 0.5m on each excavation surface, and no anchor rod is applied on the east side of the foundation pit. The excavation of the foundation pit is completed five times.

Section data and parameters of each retaining and protecting member are as follows:

	Type	Element type	Constitutive model	γ (Kn/m^3)	E(Kpa)	section
Diaphragm wall	falt	plate	Elastic	25	28000000	Thickness:1.0m
Bolt	Rectilinear	Implantable truss	Elastic	78.5	200000000	Circular diameter:0.025m
Concrete bracing	Rectilinear	Truss	Elastic	25	28000000	Rectangle:1.4*1.0 m
Circuit purlin	Rectilinear	Beam	Elastic	25	28000000	Rectangle:1.5*1.0 m

3. Numerical Simulation Analysis of Foundation Pit Based on MIDAS-GTS Finite Element Method

MIDAS GTS software is mainly applied in geotechnical finite element analysis. The analysis focuses on the uncertainty of the material itself and the real physical state of rock and soil in the construction stage[5], therefore it requires the user to provide the corresponding boundary conditions for the real construction scene simulation. Thus the static analysis, seepage analysis, consolidation and construction stage analysis and so on can be performed. The analysis program section mainly includes basic constitutive and custom constitutive models, including three-dimensional plane modeling, terrain generation, tunnel modeling, bolt modeling, etc., and has 3d dynamic simulation analysis.

3.1 The Boundary Conditions of Model Establishment

Three models construct boundary conditions: the constitutive model, truss element, and plate element. The specific design process is as follows.

3.1.1 Constitutive Model

Mohr-Coulomb criterion of rock failure is used to establish elastic-plastic constitutive relation in the constitutive model. The envelope equation of its line is as follows:

$$|\tau| = c + \delta \tan\varphi \tag{1}$$

Where: c 、 $\varphi =$ strength parameter of the material,

$c =$ cohesion

$\varphi =$ angle of internal friction

The boundary equation of the model can be obtained by principal stress relation as follows:

$$\delta_1 \frac{(1-\sin\varphi)}{2c\cos\varphi} + \delta_2 \frac{(1+\sin\varphi)}{2c\cos\varphi} = 1 \tag{2}$$

ISSN 2616-5767 Vol.5, Issue 2: 13-23, DOI: 10.25236/AJETS.2022.050204

Where δ_1 and δ_2 are the principal stresses, and their distributions satisfy the principal stress relationship.

The above equation is expressed by stress invariants J_1, J_2 and θ_0 as follows:

$$\begin{aligned} f\left(J_1, J_2, \theta_0\right) &= -\frac{1}{3} I_1 \sin\varphi + \sqrt{J_2}\left(\cos\theta + \frac{1}{\sqrt{3}}\sin\theta\sin\varphi\right) - c\cos\varphi \\ &= \sqrt{J_2}\,\frac{\frac{1}{3} I_1 \sin\varphi + c\cos\varphi}{\left(\frac{1}{\sqrt{3}}\sin\theta\sin\varphi + c\cos\theta\right)} \\ &= 0 \end{aligned} \tag{3}$$

3.1.2 Truss Element

A truss element is a kind of three-dimensional linear element under unidirectional tension and compression. Its transmission structure is usually dominated by axial pressure or tension and is composed of two nodes. This paper uses this element to simulate the mechanical characteristics of rock and soil bolts. The finite element equation of axial deformation is as follows:

$$\prod = \int_0^1 \mu^T B^T D B \mu dx = \int_{-1}^1 \mu^T B^T D B \mu J^{-1} d\xi \tag{4}$$

Where $\mu =$ axial displacement, $x =$ axial position.

3.1.3 Plate Element

The plate element is composed of 3, 4, 6, and 8 nodes in the same plane to form the corresponding discrete Kirchhoff element based on the thick plate theory. The formula of element bending stress is as follows:

$$\underline{\delta_b} = \begin{Bmatrix} \delta_x \\ \delta_y \\ \delta_z \end{Bmatrix} = zD\underline{k} = z\frac{E}{1-v^2}\begin{Bmatrix} 1 & v & 0 \\ v & 1 & 0 \\ 0 & 0 & (1-v)/2 \end{Bmatrix}\underline{k} \tag{5}$$

Where, $z =$ the z -direction displacement of the neutral plane, $\underline{k}$ =the curvature vector.

3.2 Modeling Parameters

In this paper, according to the excavation situation of the site foundation pit, the foundation pit model is established through the following steps:

(1) Establish the relevant geometric curve of the foundation pit, entity segmentation, entity structure model of the extension unit, and automatic mesh division, define the network solid soil model through the above process, and complete the three-dimensional construction process of the foundation pit model, as shown in Figure 1.

(2) Draw free multi-section lines and anchoring sections of anchor cables. The four-story anchor cable truss element is simulated and built through Midas anchor building assistant.

(3) Conduct diaphragm wall simulation for the plate attributes of the west side unit of the grid in the process of foundation pit excavation.

(4) Boundary conditions are defined according to boundary condition equation, load conditions and construction stage are defined and divided, three-dimensional numerical analysis and calculation of foundation pit are carried out in detail, and the process is automatically completed by Midas system.

ISSN 2616-5767 Vol.5, Issue 2: 13-23, DOI: 10.25236/AJETS.2022.050204

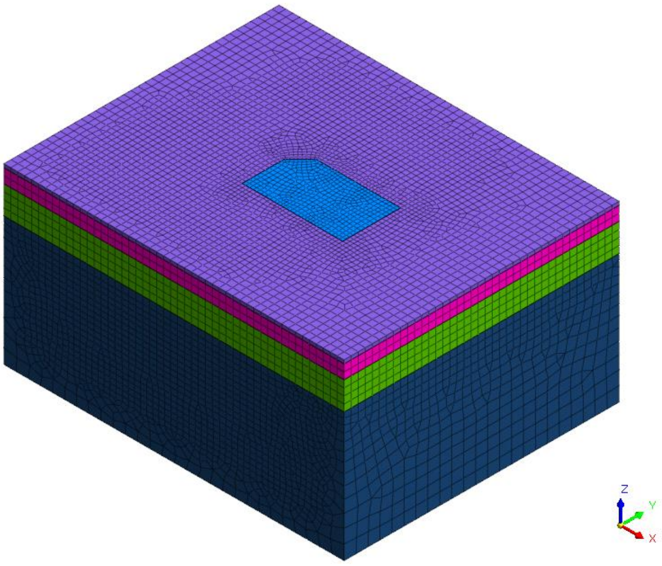

Figure 1 Overall model situation

3.3 Modeling Parameters

The following steps are usually performed during numerical analysis:

(1) The influence of groundwater seepage on the physical structure of the foundation pit should be considered in the process of foundation pit modeling.

(2) In order to satisfy the boundary equation condition, the fully plastic constitutive relation of the plastic model of the elastic structure is defined by the Mohr-Coulomb criterion of rock failure.

(3) The basic conditions of foundation pit support are simulated by tensile members, and the prestressed anchor cable in the retaining and protecting process is mainly stimulated. The structural analysis process of the truss element is shown in Figure 2.

(4) The diaphragm wall in the retaining pile is simulated through the structural transformation of the plate element to realize the conversion process between pile and plate.

(5) Quadrilateral element is used to fill solid soil unit of foundation pit, as shown in Figure 4.

(6) Set boundary conditions and automatic ground support at the same time, and set gravity direction as vertical downward Z-axis form.

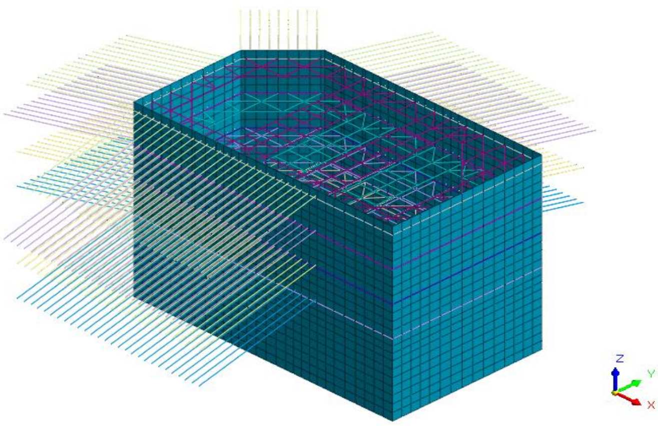

Figure 2 Foundation pit support

ISSN 2616-5767 Vol.5, Issue 2: 13-23, DOI: 10.25236/AJETS.2022.050204

4. Midas-GTS Calculation Results

In MIDAS-GTS finite element analysis, displacement changes in xoy plane after foundation pit excavation and overall displacement changes of foundation pit are presented by stress change diagram, and the specific process is as follows[6].

4.1 Vertical Displacement of Soil

The vertical displacement changes of soil mass are shown by the displacement changes in the z-axis direction after foundation pit excavation, including one-dimensional stress changes of foundation pit retaining prestress, one-dimensional stress changes of anchor cable, and the overall two-dimensional stress-strain diagram of retaining pile after foundation pit excavation, as shown in Figures 3-7 below.

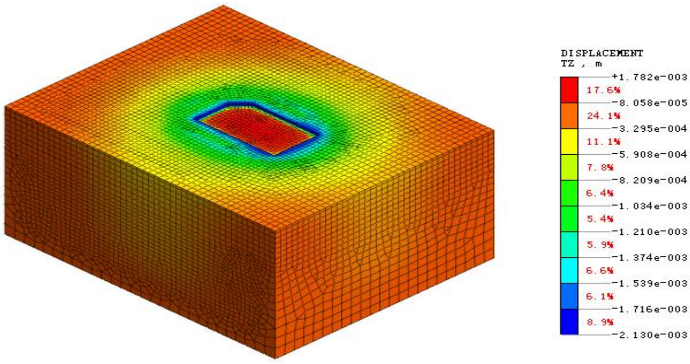

Figure 3 Vertical displacement of soil Ⅰ after excavation

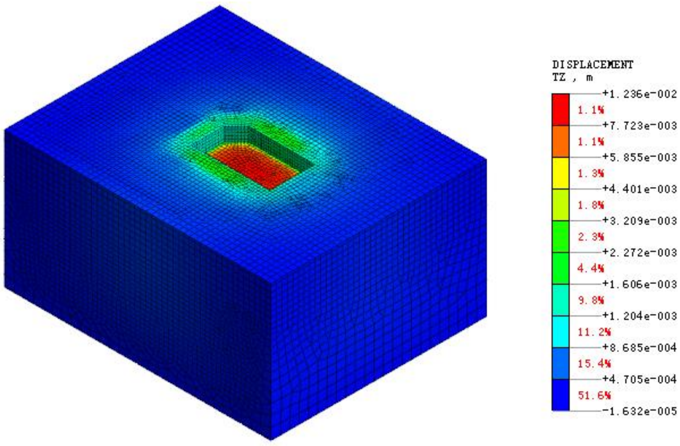

Figure 4 Vertical displacement of soil Ⅱ after excavation

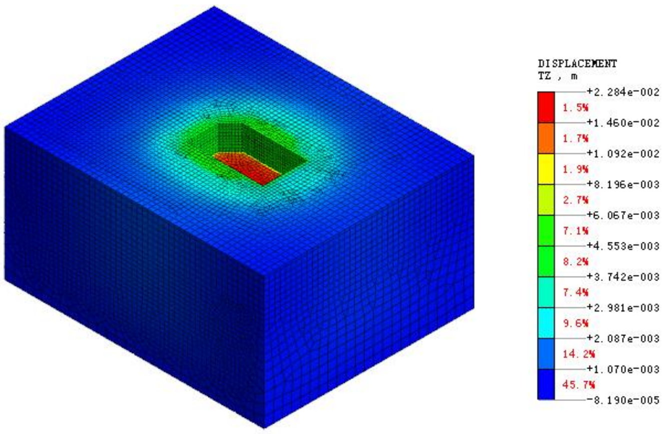

Figure 5 Vertical displacement of soil Ⅲ after excavation

ISSN 2616-5767 Vol.5, Issue 2: 13-23, DOI: 10.25236/AJETS.2022.050204

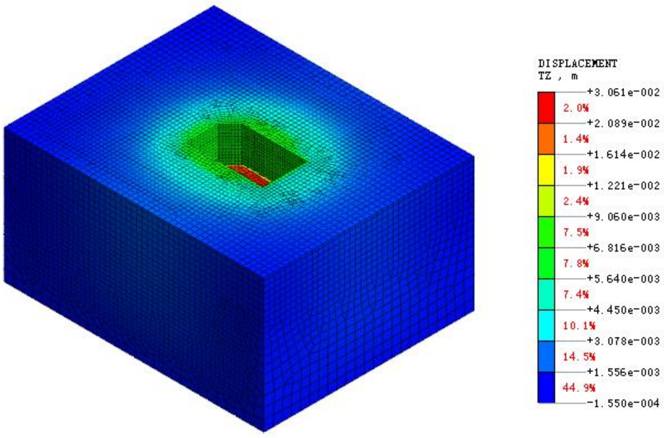

Figure 6 Vertical displacement of soil IV after excavation

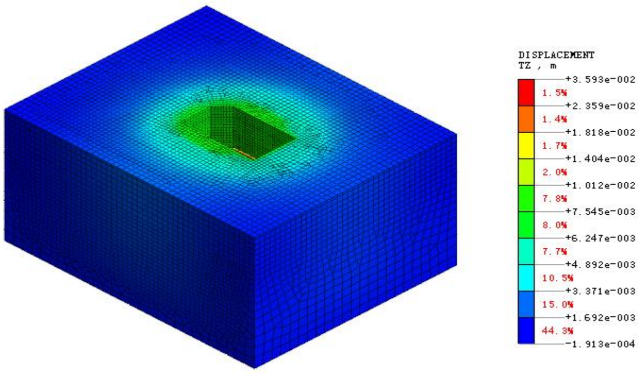

Figure 7 Vertical displacement of soilVafter excavation

The retaining and protecting structure plays a certain control role on the soil displacement because of the large foundation pit edge stiffness. At the same time, the friction between soil and pile limits the deformation of soil, so the maximum surface settlement occurs at a certain distance from excavation. The bottom of the foundation pit uplifts and deforms due to excavation unloading

4.2 Horizontal Displacement of Diaphragm Wall

The two-dimensional stress of horizontal displacement of diaphragm wall in xoy plane represents its horizontal displacement, including two-dimensional shear isoline of underground diaphragm wall, two-dimensional bending moment isoline of underground diaphragm wall, two-dimensional strain isoline, etc., which is reflected by horizontal displacement of five diaphragm wall, as shown in Figures 8-12.

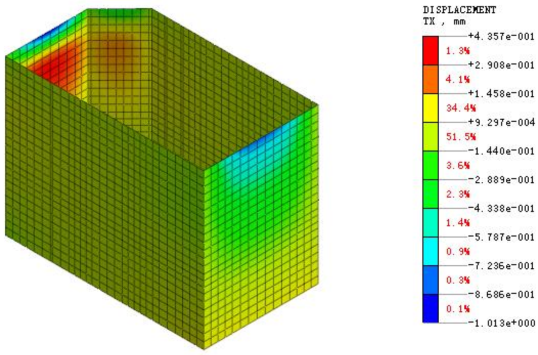

Figure 8 Horizontal displacement of diaphragm wall I after excavation

ISSN 2616-5767 Vol.5, Issue 2: 13-23, DOI: 10.25236/AJETS.2022.050204

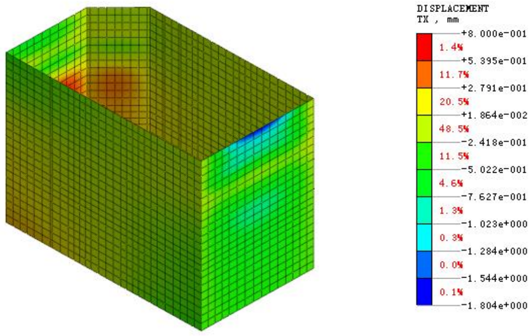

Figure 9 Horizontal displacement of diaphragm wall II after excavation

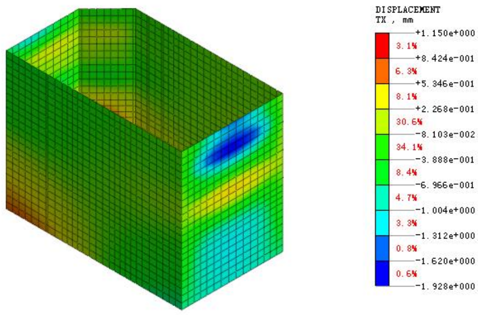

Figure 10 Horizontal displacement of diaphragm wall III after excavation

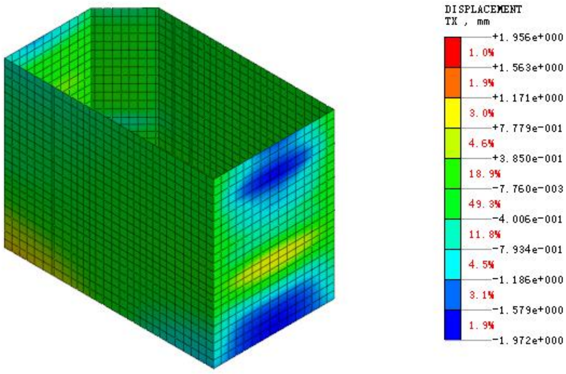

Figure 11 Horizontal displacement of diaphragm wall IV after excavation

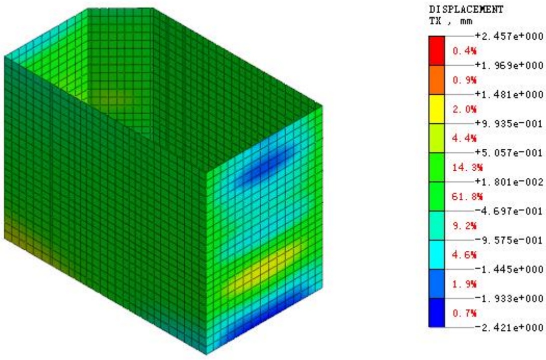

Figure 12 Horizontal displacement of diaphragm wallVafter excavation

As can be seen from the simulation results in the Figure, the lateral movement of the underground diaphragm wall is also the key content of foundation pit excavation. With the foundation pit excavation, the lateral movement gradually increases, and the final lateral movement is controlled within 3mm, which is within the standard and safety range.

ISSN 2616-5767 Vol.5, Issue 2: 13-23, DOI: 10.25236/AJETS.2022.050204

4.3 Axial Force of Internal Support

The internal support axial force is excavated in five stages, as shown in Figures 13-16 below.

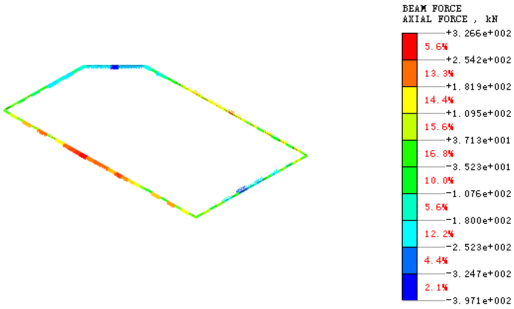

Figure 13 Axial force of internal support II after excavation

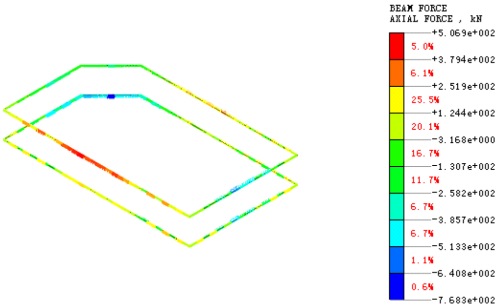

Figure 14 Axial force of internal support III after excavation

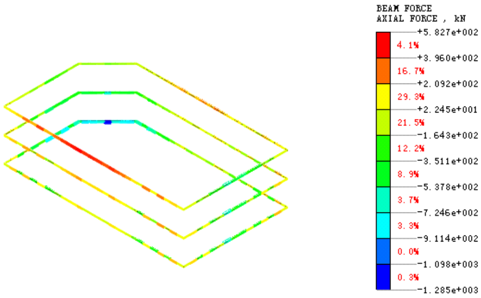

Figure 15 Axial force of internal support IV after excavation

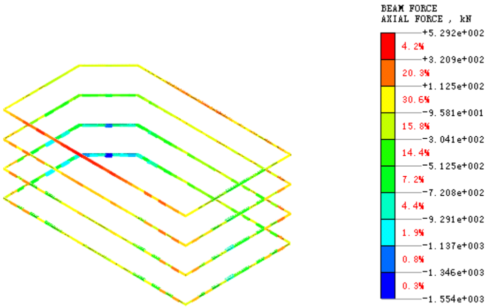

Figure 16 Axial force of internal support V after excavation

The axial diagram of the inner support is shown above. It can be seen that, with the progress of excavation, the stress is redistributed, the axial force of the inner support is increasing, and the force on the corner brace is larger, which is consistent with the actual situation. Therefore, the corner brace should take corresponding reinforcement measures in the construction process to avoid danger.

ISSN 2616-5767 Vol.5, Issue 2: 13-23, DOI: 10.25236/AJETS.2022.050204

4.4 Bolt Axial Force

The bearing capacity of the bolt is as follows:

$$P = N_u + Q = \pi D L_e \tau_z + q\,\mathrm{A} \quad (6)$$

Where, D - the diameter of soil borehole, which is divided into D_1 and D_2;

Q- Resistance to soil pressure;

τ_s - shear strength of soil around the anchorage section;

Le-effective length of zinc solid segment;

P -ultimate bearing capacity design value of bolt;

A- Earth pressure area;

Q - Earth pressure per unit area;

N_N - Axial tensile capacity of the bolt;

Its Midas analysis is shown in Figures 17-21 below, which is subdivided into five bolts.

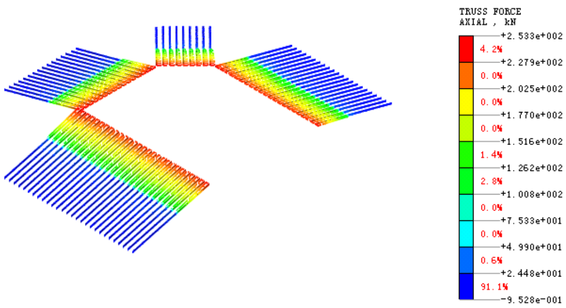

Figure 17 Bolt axial force I after excavation

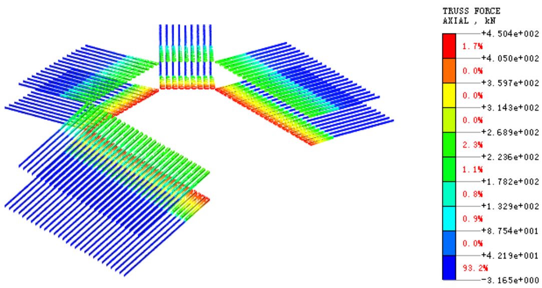

Figure 18 Bolt axial force II after excavation

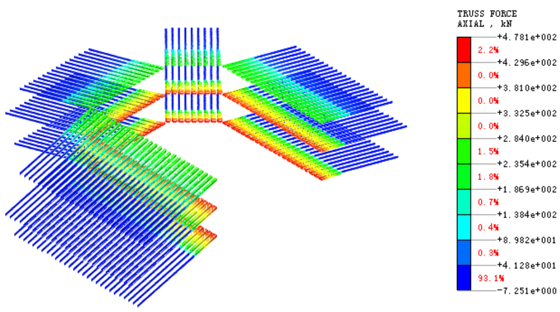

Figure 19 Bolt axial force III after excavation

ISSN 2616-5767 Vol.5, Issue 2: 13-23, DOI: 10.25236/AJETS.2022.050204

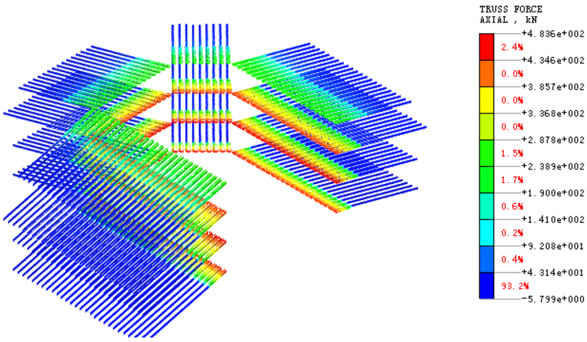

Figure 20 Bolt axial force IV after excavation

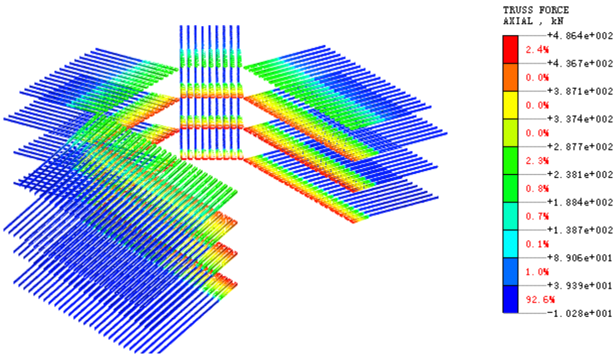

Figure 21 Bolt axial force V after excavation

5. Conclusion

Based on the premise background of complex foundation pit retaining and protecting in the process of foundation construction, this paper conducts an optimization simulation analysis on the overall support condition. This paper conducted a comprehensive and in-depth study on the scheme design and maintenance of foundation pit engineering by introducing the method of finite element strength reduction to fully understand the current deep foundation pit engineering retaining and protecting in City A support system, and specify the general situation and development loopholes of the current supporting system. On this basis, the rationalization framework and safety consideration scheme are proposed for the deep foundation pit supporting scheme design, and the support design calculation of the deep foundation pit supporting structure is carried out by using Midas structural analysis technical design software, which is compared with the actual detection data to further verify the feasibility of the scheme. Therefore, the finite element method is mainly used for the overall modeling of the earthwork within the excavation range of the foundation pit currently, and each physical quantity is interconnected to obtain the integral characteristic equation of the foundation pit. Finally, the Midas structural technical analysis software is used to model and solve the foundation pit's stability problem to make the physical process of engineering application clear.

References

[1] Hong Sheng. Numerical Simulation and Deformation Analysis of Foundation Pit Enclosure Based on Midas GTS [J]. Building Construction, 2018, 40(4):4.
[2] He Ming. Numerical Simulation of Foundation Pit Support Based on Midas GTS NX Software [J]. Engineering Technology Research, 2017(10):2.
[3] Wang Chao, Ding Haitao. Numerical Simulation Analysis of Pile-anchor Support for Deep Foundation Pit Based on MIDAS [J]. Sichuan Building Materials, 2019, 45(1):2.
[4] Zhu Yifei. Research on Optimization Technology of Deep Foundation Pit Retaining and Protecting based on Spatial Effect Theory [D]. East China Jiaotong University, 2014.
[5] Yang Guanghua. Practical Calculation Method and Application of Deep Foundation Pit Retaining and Protecting structure [J]. Geological Publishing House, 2004.
[6] Lin Mengjie, Liu Mengliang. Practical Calculation Method and Application of Deep Foundation pit Retaining and Protecting Structure [J]. Building Technology, 2014(7):3.