

Numerical Analysis of the Stability of Excavation Support and its Impact on Factory Foundation

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Abstract

This paper establishes a three-dimensional detailed numerical model of foundation pit excavation using the finite element simulation software Midas GTS NX to analyze the deformation characteristics of the excavation support structure, factory cap foundation, and pile foundations under three working conditions. The study shows that during the excavation process, due to lateral soil movement, the maximum horizontal displacement of the excavation support piles is concentrated in the middle and lower parts, while the vertical displacement is influenced by the reinforcing effect of the pile foundations. The support piles closer to the piles exhibit smaller vertical displacement, while those farther from the piles exhibit larger displacement. The horizontal and vertical displacements of the cap beams and steel pipe supports show relatively symmetric distribution. In the case of pile foundations and cap foundations, the impact of the excavation on horizontal and vertical displacements is small, with the largest displacement concentrated in the upper part of the pile foundations and the middle inner part of the cap foundations. In conclusion, the impact of foundation pit excavation is minimal on the displacement of pile foundations and cap foundations due to the shallow excavation depth and good overall stability of the excavation support structure. However, the numerical simulation only considers ideal conditions, and variations during construction are not fully reflected. Therefore, construction quality must be strictly controlled during the project, especially regarding the construction quality of cement-soil mixing piles, to ensure the smooth progress of the project.

Keywords

Foundation Pit Excavation; Finite Element Numerical Simulation; Midas GTS NX; Excavation Support Structure; Pile Foundation; Cap Foundation; Construction Quality.

1. Preface

With the increasing number of construction projects, the depth of foundation pits is also becoming larger. The construction conditions are becoming more complex, leading to adverse effects on surrounding structures and posing a threat to the safety of the surrounding terrain. Several researchers have conducted studies on the impact of foundation pit excavation on surrounding structures using MIDAS GTS and other simulation tools^[0-9].

2. Three-dimensional Detailed Numerical Calculation Model of the Foundation Pit

2.1 Calculation Area and Stratigraphic Distribution

The project plans to use the finite element software Midas GTS NX to establish a three-dimensional numerical model for the construction area, simulate the construction process, and analyze the stress characteristics of the excavation support structure and its impact on the factory cap and pile foundations during construction.

According to the foundation pit support design scheme, the support piles, cap beams, steel supports, and tie beams are constructed before excavation. The base soil is pre-reinforced to a depth of 4 meters, and the factory cap and pile foundations are constructed at the designed elevation. Subsequently, the soil is excavated in a single stage.

Based on the foundation pit support layout plan and longitudinal cross-section diagram, a three-dimensional finite element numerical model is established around the foundation pit and factory pile foundations as the core area, as shown in Figure 1. The dimensions of the foundation pit are 140 meters in the X-direction and 42 meters in the Y-direction. To eliminate boundary effects, the model boundary must extend more than three times the excavation depth. In this case, the extension is 30 meters in the positive and negative X-direction and about 40 meters in the positive and negative Y-direction.

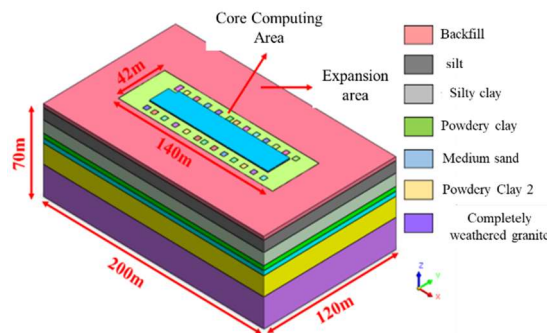


Figure 1. Geological Geometry Model in Midas GTS NX

$$E_s I_s = \frac{E_c (\omega + t) b^3}{12} \quad (1)$$

$$b = \sqrt[3]{\frac{12 E_s I_s}{E_c (\omega + t)}} = 0.515 \quad (2)$$

2.2 Grid Division of the Calculation Model

In the software, the established geometric model is divided into a grid, and the material and calculation parameters determined in Tables 2-1 and 2-2 are assigned to the calculation elements. The final calculation model includes a total of 20 grid groups, with 55,426 elements and 38,150 nodes. The three-dimensional finite element numerical grid calculation model is shown in Figures 2-3 to 2-5.:

After excluding earthquake and live loads, the most dangerous load combination is taken as 1.3 dead load + 1.5 wind load. The load applied to each cap foundation is based on the maximum load from the entire set of load combinations. The specific working conditions are as follows:

Working Condition 1: Only dead load considered, with a pressure of 991 kN, shear force of 140 kN, and bending moment of 1412 kN·m. Working Condition 2: 1.3 dead load + 1.5 wind load (left wind), with a pressure of 1115 kN, shear force of 294 kN, and bending moment of 2754 kN·m. Working

Condition 3: 1.3 dead load + 1.5 wind load (right wind), with a pressure of 1117 kN, shear force of 208 kN, and bending moment of 1903 kN·m.

3. Analysis of the Stress and Deformation Characteristics of the Excavation Support Structure

3.1 Horizontal Displacement of the Support Piles

Figures 2 show the contour plots of the horizontal displacement of the excavation support piles under three different working conditions after foundation pit excavation. After excavation, under the action of lateral soil pressure, the horizontal displacement is mainly characterized by the movement of the soil on both sides of the foundation pit towards the inside of the pit. From the figures, it can be observed that the maximum displacement occurs in the middle and lower sections of the support piles, which are located below the reinforced soil layer. Due to the asymmetry of the pile foundation arrangement, there is a noticeable difference in displacement on both sides of the foundation; the displacement of the outer support piles is larger because they are farther from the pile foundation.

Comparing the three working conditions, the maximum horizontal displacement under dead load only is 5.63553 mm, under left wind load is 5.63451 mm, and under right wind load is 5.63181 mm.

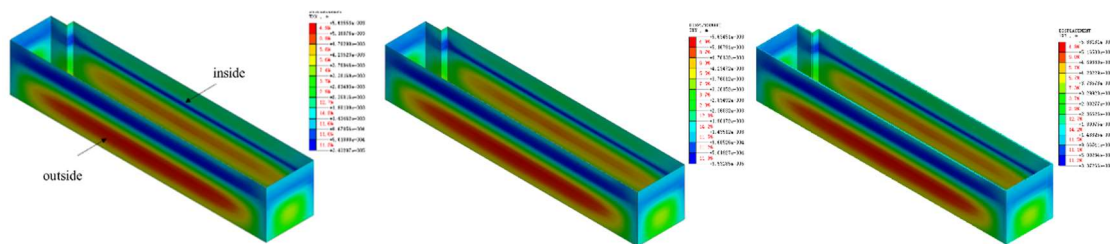


Figure 2. Horizontal Displacement of the Foundation Pit Support Piles under Working Condition 1, 2, 3

3.2 Vertical Displacement of the Support Piles

Figures 3 show the vertical displacement of the support piles after complete excavation of the foundation pit. From the figures, it can be seen that after the excavation of the pit soil, due to the unloading caused by excavation inside the pit, the soil at the pit bottom experiences some rebound heave, while the surrounding soil of the pit undergoes settlement under the combined effect of construction load and soil deformation. Comparing the degree of settlement on both sides of the pit, it is clear that the displacement of the outer support piles is more significant than that of the inner support piles. The support pile system itself is approximately a rectangular shape, and overall it is nearly symmetric, so the effects of geometry can be neglected.

Due to the proximity of the inner support piles to the cap foundation and pile foundations, the piles themselves have a reinforcing effect on the surrounding soil, leading to smaller vertical displacements around the inner foundation pit support piles. On the other hand, the outer support piles are farther from the pile foundation, resulting in larger vertical displacements.

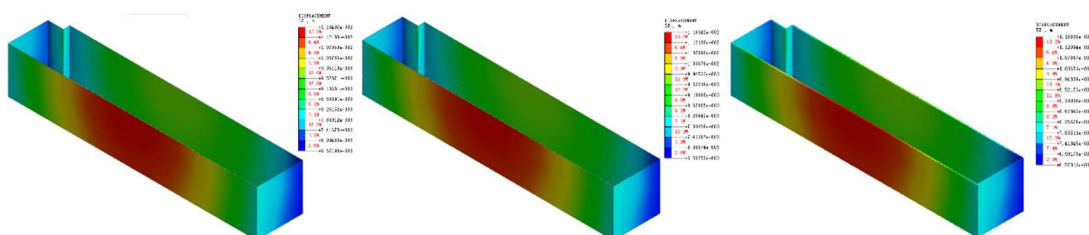


Figure 3. Vertical Displacement of the Foundation Pit Support Piles under Working Condition 1, 2, 3

Comparing the three working conditions, it can be seen that the displacement distribution pattern is essentially similar. When only considering dead load, the maximum vertical displacement is 11.6407 mm; under left wind load, the maximum vertical displacement of the support piles is 11.6342 mm; and under right wind load, the maximum vertical displacement is 11.6300 mm.

Figures 4 show the horizontal displacement of the cap beams and steel pipe supports under three different working conditions. From the figures, it can be observed that after the excavation of the foundation pit, the maximum horizontal displacement is concentrated at the "cornered" section of the cap beam. This location, being at a right angle, is often the point where the excavation support system experiences concentrated forces, and it represents a weak link in the structure. Apart from this, the horizontal displacement of the cap beams on both sides is relatively symmetrical, indicating that the pile foundation's position has a minimal effect on this displacement.

Comparing the three working conditions, the location of the maximum displacement is the same. Under the condition of dead load only, the maximum horizontal displacement is 2.20297 mm; under left wind conditions, the maximum horizontal displacement is 2.20022 mm; and under right wind conditions, the maximum horizontal displacement is 2.19896 mm. This indicates that, under the effect of the lateral steel pipe supports, the overall horizontal displacement of the cap beam is relatively small.

3.3 Vertical Displacement of the Internal Supports

Figures 4 show the vertical displacement of the cap beams and internal supports under three different working conditions. From the figures, it can be observed that after the excavation of the foundation pit, the maximum vertical displacement is concentrated in the middle section of the outer cap beam, which is consistent with the displacement distribution of the support pile system. Comparing the displacement of the cap beams on both sides, it can be seen that the vertical displacement distribution is asymmetric, maintaining consistency with the vertical displacement trend of the foundation pit.

Comparing the three working conditions, the location of the maximum vertical displacement is the same. Under the condition of dead load only, the maximum vertical displacement of the cap beam is 11.6359 mm; under left wind conditions, the maximum vertical displacement is 11.6294 mm; and under right wind conditions, the maximum vertical displacement is 11.6253 mm.

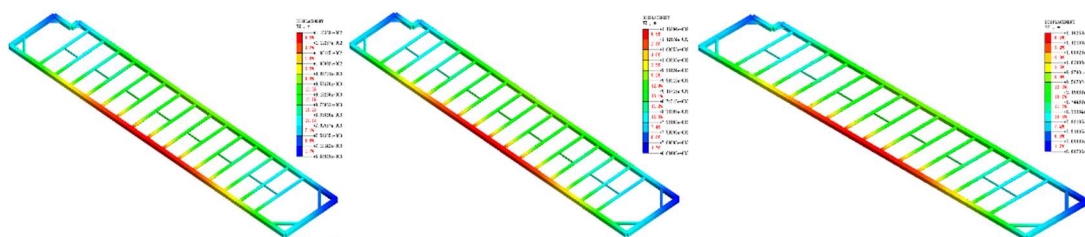


Figure 4. Vertical Displacement of the Internal Supports under Working Condition 1, 2, 3

4. Analysis of the Impact of Foundation Pit Excavation on the Factory Cap and Pile Foundations

4.1 Horizontal Displacement of the Cap Foundation and Piles

Figures 5 show the contour plots of the horizontal displacement of the cap foundation and piles after foundation pit excavation under three different working conditions. From the figures, it can be observed that after excavation, the pile foundations and cap foundation experience horizontal displacement towards the inside of the foundation pit. The maximum horizontal displacement is concentrated in the upper region of the pile foundation, which is located below the reinforced soil layer at the pit bottom. The horizontal displacement of the pile foundations on both sides is basically symmetrical.

Comparing the three working conditions, the location of the maximum displacement is the same. Under the condition of dead load only, the maximum horizontal displacement is 4.43802 mm; under left wind conditions, the maximum horizontal displacement is 4.42942 mm; and under right wind conditions, the maximum horizontal displacement is 4.43952 mm. Overall, since the foundation pit excavation depth is small and the excavation support structure is relatively stable, the horizontal displacement of the pile foundations and cap foundation under the excavation impact is not large.

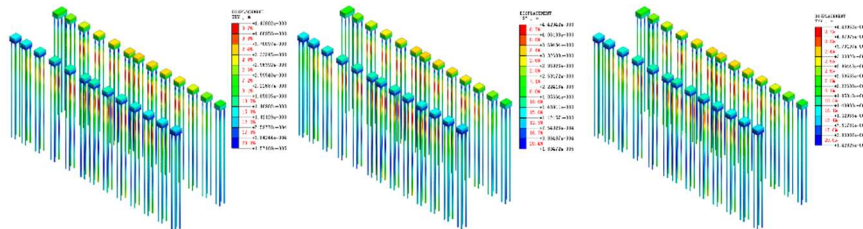


Figure 5. Horizontal Displacement of the Cap Foundation and Pile Foundations under Working Condition 1, 2, 3

4.2 Vertical Displacement of the Pile Foundations

Figures 6 show the contour plots of the vertical displacement of the cap foundation and piles after foundation pit excavation under three different working conditions. From the figures, it can be observed that after excavation, both the pile foundations and cap foundations experience vertical displacements in the positive direction. The maximum vertical displacement is concentrated at the middle cap foundation of the inner row, while the vertical displacement of the pile foundations on both sides is asymmetrical.

Comparing the three working conditions, the location of the maximum displacement is basically the same. Under the condition of dead load only, the maximum vertical displacement is 7.27598 mm; under left wind conditions, the maximum vertical displacement is 7.26303 mm; and under right wind conditions, the maximum vertical displacement is 7.27342 mm.

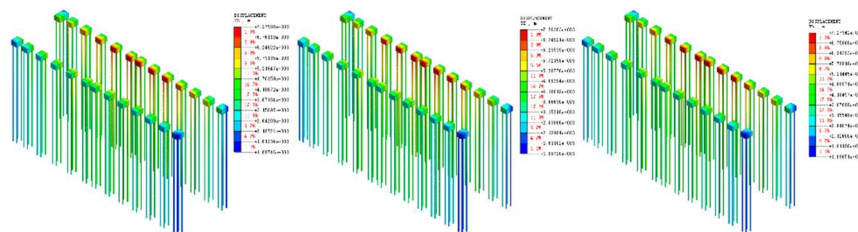


Figure 6. Vertical Displacement of the Pile Foundations under Working Condition 1, 2, 3

5. Conclusion

A three-dimensional detailed numerical model of foundation pit excavation was established using the finite element simulation software Midas GTS NX. The deformation characteristics of the excavation support structure, cap foundation, and pile foundations under three working conditions were calculated as follows:

Working Condition 1: Only dead load, pressure of 991 kN, shear force of 140 kN, and bending moment of 1412 kN·m. **Working Condition 2:** Left wind load, pressure of 1115 kN, shear force of 294 kN, and bending moment of 2754 kN·m. **Working Condition 3:** Right wind load, pressure of 1117 kN, shear force of 208 kN, and bending moment of 1903 kN·m.

The key findings are summarized as follows:

During the excavation process, lateral soil movement towards the inside of the foundation pit caused the maximum horizontal displacement to concentrate in the middle and lower sections of the excavation support piles. The vertical displacement of the support piles, due to the varying distances

between the piles on both sides, was smaller in areas closer to the pile foundation (due to the reinforcing effect of the piles) and larger in areas farther from the pile foundation.

The maximum displacement of the internal supports occurred at the cap beams, with the maximum horizontal displacement concentrated at the "cornered" section. The maximum vertical displacement of the cap beams was concentrated in the middle section of the outer part, consistent with the displacement distribution of the excavation support piles.

The maximum horizontal displacement of the cap foundation and pile foundations concentrated in the upper part of the piles. The maximum vertical displacement concentrated in the middle part of the inner cap foundation. During the excavation process, the overall displacement of the excavation support structure was small. Additionally, due to the relatively large distance between the pile foundations, cap foundation, and the foundation pit, the overall displacement of the pile foundations and cap foundation under the excavation impact was not significant.

In summary, the excavation depth of the foundation pit in this project is relatively shallow, and with the protection provided by the excavation support structure, the overall stability of the excavation support structure remains good under the three working conditions. The overall displacement of the pile foundations and cap foundations due to the excavation is not large.

Additionally, the numerical calculations represent an analysis under ideal conditions and may not fully reflect the variations during construction. Therefore, it is essential to strictly control construction quality during the project and ensure the engineering quality of the foundation pit's support measures, with particular emphasis on the construction quality of the cement-soil mixing piles, which must be carefully monitored and ensured.

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