Study on the Supporting Features of Composite Soil Nailing Wall

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Abstract. This paper was based on a deep foundation pit support project in Beijing. FLAC³D software was used to simulate the excavation and support process of the foundation pit in detail according to design parameters and geological conditions. The experiment data of the horizontal and vertical displacements of walls, the axial forces of soil nailing and prestressed anchor cables during excavation and support process of the foundation pit provided a technical reference for the site construction and ensured the safety of the whole project.

Keywords. composite soil nailing wall, deep foundation pit, numerical simulation, displacement.

1. Introduction

With the rapid development of infrastructure construction and real estate in China, a large amount of high-rise and super high-rise buildings are built for more space from high sky to deep underground. Therefore, the excavation depth and scale of foundation pit engineering [1-6] are increasing, with a more difficult excavation and support demand. Soil nailing wall has been acknowledged as a very practical foundation pit and slope support technology after pile, wall, brace and anchor [7]. The biggest difference between prestressed anchor cable composite soil nailing wall and traditional soil nailing wall is that the former one is active supporting, while the latter one is passive supporting. Under the same working circumstance, the safety level of the prestressed anchor cable composite soil nailing is higher than that of the pure soil nailing. Hence, as a new supporting technology of deep foundation pit, prestressed anchor cable composite soil nailing wall has unique advantages obviously [8-9].

2. Overview

2.1. Geology Overview

The proposed project site is located in Dongbeiwang, Haidian District, which is in the northwest of Beijing and located in the middle and upper reaches of Yongding River Alluvial Plain. The site was an open space with relatively flat terrain, and natural ground elevation of 47.01-47.62 m. The soil layer mainly includes: fill, silty clay, sandy clay, fine sand, round gravel and fine medium sand.

2.2. Hydrogeology Overview

There is a layer of ground water (phreatic water) explored within the depth of 30 m under the site. The buried depth of the still water level is 19.02-19.51 m and the water level elevation is 27.83-28.36 m. The aquifer of it is mainly composed of pebble layer and fine sand layer. The supply source is atmospheric precipitation infiltration and lateral flow.
2.3. Supporting Design Scheme
The safety level of the foundation pit support of the project is Level II; composite soil nailing wall was used in the foundation pit supporting, which is divided into two sections (See figure 1 for details).

![Figure 1. The layout plan of the foundation pit supporting.](image)

As seen from figure 1, the excavation depth of the west foundation pit is with a small number of 11.46 m; and the excavation depth of the east side with a large number of 12.96 m. Taking the different excavation depths as boundary, the support part is divided into two bisects. The bisect 1-1 is on the west side of the shallower excavation depth, and the bisect 2-2 is on the east side of the deeper excavation depth.

3. Analysis of Excavation Data

3.1. Establishment of Excavation Model
A soil model was established as shown in figure 2 based on the physical-mechanical parameters shown in the investigation report and the soil model size set before.

![Figure 2. The model of soil.](image)

The established soil model consists of 45510 nodes and 40880 units as shown in figure 2. The colorful part from top to bottom on the left side is the stratified excavation part. The first excavation
depth is 2.0 m, the second to the seventh excavation is each of 1.5 m, and the eighth is 1.76 m to the bottom of the trench. The designed elevation of the foundation slab is -12.96 m, but 12.76 m was excavated in the model. This was mainly due to the situation that there should be a reservation of 0.2 m from the bottom of the trench when the excavation of large face excavation of foundation pit was completed. This soil layer reservation was to be removed manually before the foundation slab made. Usually the time period is uncertain, and the thickness of the reservation is not that large. So this part of soil was not included in the excavation. In the above figures, the blue part is the soil inside and behind the wall. The red part is the soil at the bottom of the trench, and the green part is the soil below the wall.

3.2. Excavation and Supporting Engineering Simulation
Four or five soil nails or prestressed anchor cables (five in odd row and four in even row) were set in each layer, which were completely in quincunx shape. The specific excavation and supporting conditions of each layer are shown in figure 3.

![Figure 3](image-url)

Figure 3. Excavation and supporting map.
As shown in figure 3, after the excavation of the soil model completed, the distance between the foot of the soil nailing wall and the left edge of the model is 33 m while the distance between the top of the soil nailing wall and the edge of the model is 40 m.

4. Simulation Results and Analysis

4.1. Analysis of Horizontal Displacement of the Slope Top

It can be seen from figure 4 that (1) the excavation of foundation pit and the construction of soil nailing are the root causes of the horizontal displacement of wall. In the process of excavation, the soil cannot achieve self-stability at all. But according to the displacement nephogram in figure 4, there was no plastic failure for the soil. This was due to the soil nails and the layer of sprayed concrete with fine aggregate concrete, which both played good supporting roles limiting the occurrence of excessive displacement of wall; (2) In the whole process of constructing the composite soil nailing wall, the maximum horizontal displacement was changing constantly, but just in the 2/3 of the excavation depth. At the same time, the trend of large displacement near the excavation surface was more obvious as the excavation continued.
It can be seen from figure 5 that soil nail and anchor cable have an obvious restraint effect on horizontal displacement of wall, but the effect of anchor cable is more obvious. And in figure 5, the line of horizontal displacement of wall is not smooth, where there were all with soil nails or prestressed anchor cables in these positions.

4.2. Analysis of Vertical Displacement of the Slope Top
From figure 6, we can see that (1) from the first step to the seventh step of the excavation, the vertical displacement of soil with soil nails and prestressed anchor cables is not obvious, which shows that soil nail and prestressed anchor cable can limit the vertical displacement and protect the original structure of soil well, which makes the soil stay in a very stable state; (2) From the above figures 4.9h and 4.9i, it can be seen that the area with the largest vertical displacement is gradually extended from the top of
the wall, but rapidly reduced in the position the prestressed anchor cable located. It shows that the effect of the prestressed anchor cable to limit the soil displacement is very obvious.
4.3. Analysis of Axial Force of Soil Nail and Prestressed Anchor Cable

It can be seen from figure 7 that: (1) the axial force of prestressed anchor cable is obviously greater than that of other soil nails. This is mainly because of the 40 kN prestressing force on the anchor cable, and the longer and bigger diameter of the anchor cable compared with the soil nail with a corresponding larger tensile strength; (2) The axial force value of each layer of soil nail changes with the development of excavation of foundation pit. And the soil nails newly set are often with a very small axial force value in the initial period of time. The reason is that the newly set soil nail is close to the bottom of the pit, and the share load for it is relatively small, but then increases rapidly with the excavation depth. For example, the axial force value of the soil nail in the second layer is very small before the third step of excavation. But after the third step, its axial force increases rapidly and exceeds the first row of soil nails; (3) The axial force of soil nail is basically distributed as big in the middle, and small at both ends in the length direction. The axial force of the free section of the anchor cable is the same, but the anchoring section gradually reduces from the surface layer. On the other hand, the maximum value of axial force of soil nail is constantly changing in the whole construction process.
5. Conclusions
This paper was based on a deep foundation pit support project in Beijing. FLAC3D software was used to simulate the excavation and support process of the foundation pit in detail according to design parameters and geological conditions. The horizontal and vertical displacements of walls, the axial forces of soil nailing and prestressed anchor cables during excavation and support process of the foundation pit in the whole excavation and support process are studied. The following conclusions are drawn:

1) The excavation of foundation pit and the construction of soil nails are the main reasons for breaking the original balance of soil and causing the horizontal displacement of wall. And the step-by-step excavation and support has led to the wall displacement and obviously increasing in a stepped form.

2) The effect of soil nail and prestressed anchor cable on limiting the horizontal displacement of the wall is obvious, and the more obvious effect is the prestressed anchor cable on the displacement of the surrounding soil. Therefore, the horizontal displacement of the wall does not increase linearly.

Figure 7. Axial force under the every circumstance.
along with the depth direction of the foundation pit. Besides, the deformation control effect of prestressed anchor cable is much greater than that of soil nail, and the horizontal displacement of wall near prestressed anchor cable is significantly smaller than that of surrounding soil.

(3) The axial force of soil nails in each row is large in the middle and small at both ends, and the maximum point of axial force of soil nails in each layer is not uniform. It is not the midpoint of soil nails, but is constantly changing. When the excavation depth is not large and the wall is in a stable state, the existence of prestressed anchor cable can lead to the compression state of the upper part close to the end of soil nail.

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