

Research on the reasonable pile spacing of micro pile composite soil nailing

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Abstract. Through the numerical simulation software FLAC3D, study on the synergetic effect of micro pile composite soil nailing will be studied. By adjusting the micro pile spacing and analysing the displacement field and stress field of soil, we can find that supporting effect of the soil nail hasn't work yet when the micro pile spacing is 2D. The soil arching between piles has been formed in the pile spacing 4D ~ 6D. The composite effect of micro pile and soil nailing will be the best and the soil arch behind piles will be firstly formed in 6D, the horizontal saddle soil arch will be formed between the nails. The nail head coincidence pressure area and micro pile pressure area are overlapping to maintain stability in the soil between piles. When the micro pile spacing is 9D, the arch behind piles will be failure, the soil flows around, but the saddle arch between the nails into circular arch, the supporting effect of the soil nailing is enhanced. When the micro pile spacing is 12D, the arch of the nails becomes smaller, sliding surface appears primitively. Based on the conclusions above, it is suggested that the micro pile spacing between 2D ~ 6D is suitable for the micro pile and soil nailing composite support. The conclusion can provide theoretical basis for the design and construction of micro pile composite soil nailing.

1. Introduction

The micro pile composite soil nailing support has the advantages of well-adapted, better ability of deformation control, better economy, and it is widely used in the area of soil foundation pit engineering.

Compared with the engineering practice, the research on the synergistic effect of micro pile composite soil nailing is lagging behind. Most of the researches concentrate on the resistance. Many scholars have proved that soil arching effect is existed and most of them are horizontal arching effect by three dimensional numerical modeling and model test. But the research on the composite supporting effect of the micro pile and soil nailing is very few. When I compile the *Technical code for composite soil nailing wall in Retaining and protection of excavation GB50497-2012*, the mechanism study of the micro pile composite soil nailing support is immature after many researches. There is a big difference in engineering design: one idea is that the weakening of steel pipe pile or steel pipe pile is not considered when foundation pit designing, in accordance with the design of soil nailing wall, the strength and stability to meet the basic requirements of the situation, to further control the deformation



by steel pipe pile. Another idea is that considering the force of the steel pipe pile when it was designed, the stability of foundation pit is guaranteed by soil nailing and shear resistance of micro pile.

The micro pile spacing has an effect on the soil nailing. Wang Zhao believed that the soil on the sliding surface and the micro steel pipe pile could not achieve shear strength limit state at the same time. With the high strength of micro steel pipe pile, the limit resistance of the foundation pit is controlled by extruding strength of the surrounding soil rather than shearing resistance of the pile. So when we make a research about the composite support limited equilibrium method, we can't easily make assumptions that the components of it on the sliding surface arrived the limit state at the same time, we should consider various types of failure pattern

This article will make a research on the synergistic effect in the single-row micro pile composite soil nailing during the excavation by the numerical modeling and try exploring the composite mechanism in them.

2. Model establishment.

The depth of foundation pit is 7 meters, the length of the micro pile is 12 meters, three rows of the soil nailing. The specific parameters are shown in Table 1~3. The soil is uniform cohesive soil, the normal stiffness of the contact surface $k_n=1e8\text{KN/m}$; shear stiffness $k_s=k_n$; the diameter of micro pile 200mm, adopt isotropic solid elements, the elastic modulus of volume is $11e6\text{Pa}$, the elastic shear modulus is $8e6\text{ Pa}$. The soil nailing is simulated by cable element, cement paste bond force is 800kpa , grout friction angle is 25° ; unit length paste stiffness is $7e6$. The spacing between micro pile and soil nailing is shown in Table 2. The model is shown in the Fig 1.

Table 1. Soil parameters

	elastic modulus of volume /pa	Elastic shear modulus /pa	Poisson ratio	internal frictional angle	Cohesion /kpa	density Kg/m3
clay	18.33e6	3.93e6	0.3	11	30	1890

Table 2. The spaces of the micro piles and soil nails

Miniature pile spacing	2D	4D	6D	9D	12D
Soil nailing horizontal spacing	0.4m	0.8m	1.2m	1.8m	2.4m

Table 3. Parameters of soil nails

soil nail	vertical distance /m	Length /m	elasticity modulus E /pa	strength of extension f/pa
1st	2.0	8.0	200e9	1e10
2nd	2.0	10.0		
3th	2.0	8.0		

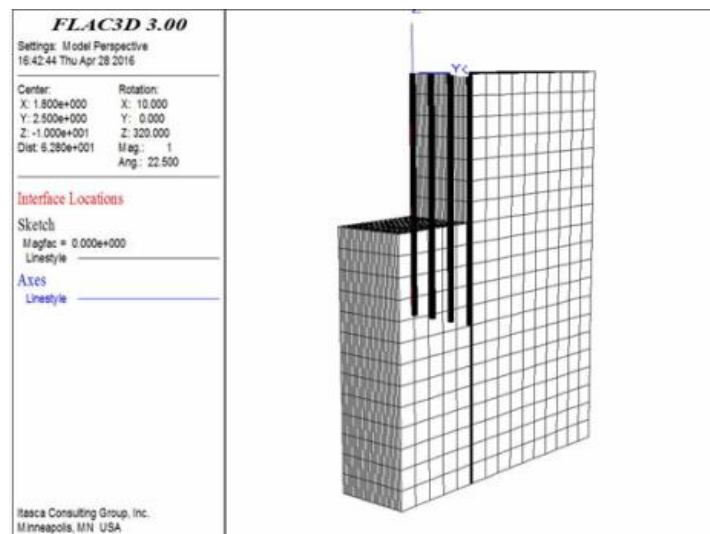


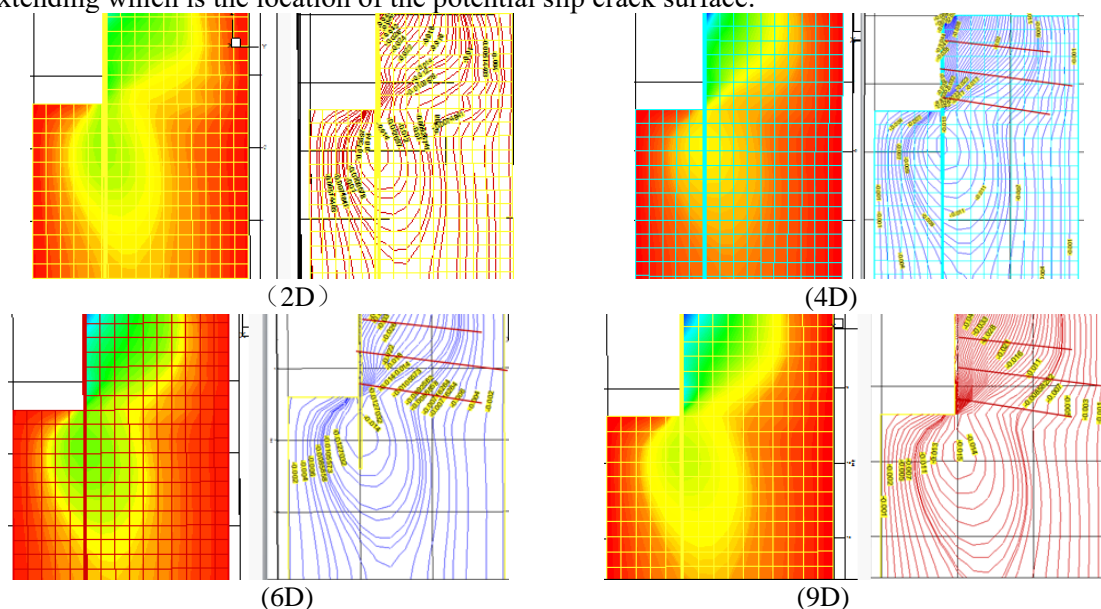
Fig.1 Numerical model

3. The displacement analyse between different spacing of micro pile composite soil nailing.

When spacing of micro pile is 2D, the scope of displacement influence becomes lesser. As same as cantilever pile model, the horizontal displacement is the main displacement, and the total deformation of the foundation pit is smaller.

When the spacing between the micro piles is 4D, the displacement gradient of the slope becomes larger. It is shown that the displacement and displacement gradient of the slope increases with the increase of the spacing between the piles.

When spacing of micro pile is 6D, the displacement of toe and top of slope become biggest, the force of soil nailing becomes manifest. And the area of the displacement gradient behind the slope soil is extending which is the location of the potential slip crack surface.



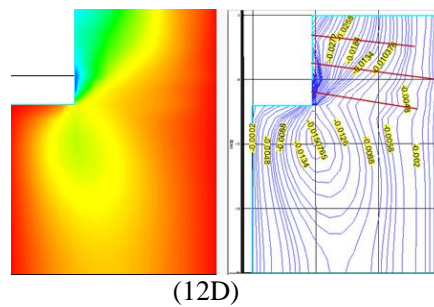


Fig.2 Horizontal displacement contour map and micro pile spacing contour map 2D、4D、6D、9D、12D
(left: Contour map of horizontal displacement right: Contour map)

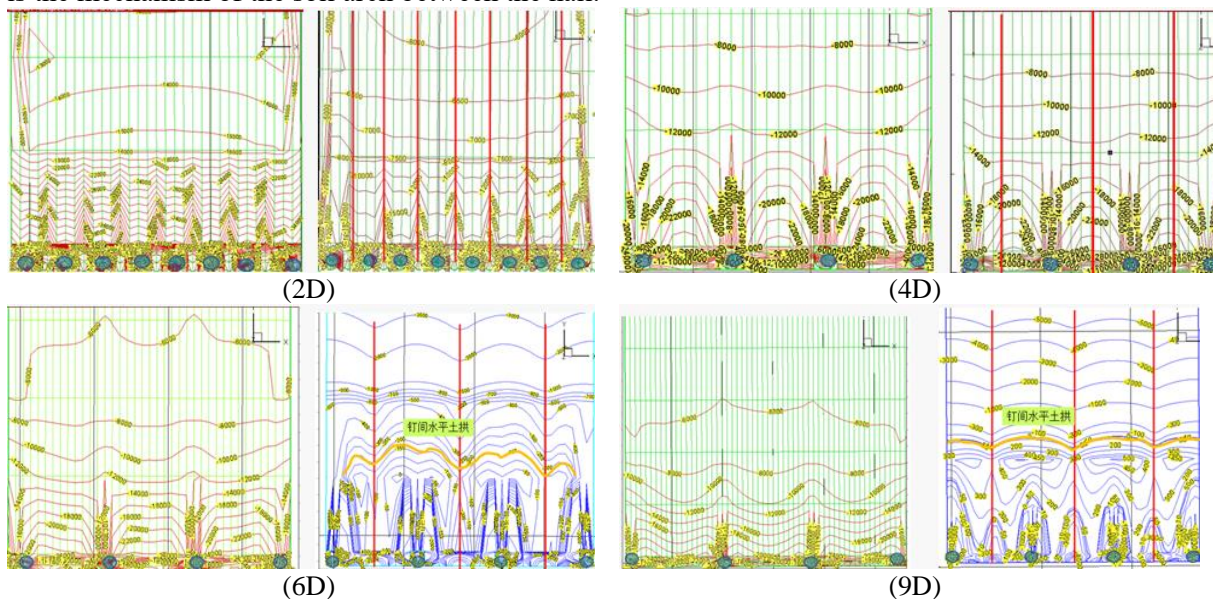
When spacing of micro pile is 9D, soil nailing supporting effect is enhanced, and displacement gradient becomes uniformity range the slope of potential sliding surface. But the displacement gradient of slope toe is biggest, the force of soil nailing becomes manifest. There is also an area of the displacement gradient behind the slope soil, and it is the potential sliding surface formation position.

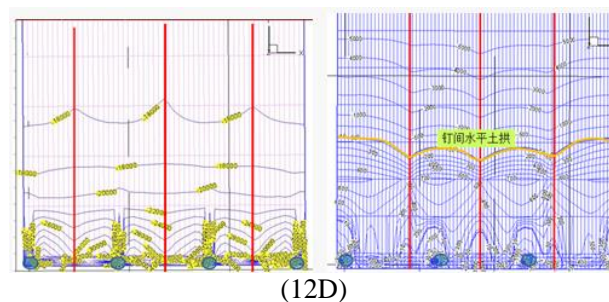
When spacing of micro pile is 12D, the displacement gradient of toe becomes stronger, the back displacement gradient becomes homogeneous and the slip surface begins to form.

4. Analysis of soil arch between piles.

When micro pile is supporting, the soil between piles couldn't slide because of the soil arch effect, which makes the principal stress among pile soil produce deflection. It will form a successive principal stress arch effect, which transmits the soil pressure behind the arch to the both sides of the pile and the stabilized soil around. Supporting pile as the foot arch plays a role in supporting. The stress behind micro pile is delivered by the interaction from soil to piles, from soil to soil. When the soil between piles produce micro deformation or stress releasing, many unload arches among the soil behind the piles appears because of the frictional resistance. The larger the deformation is, the more obvious unload arch effect is. When the deformation reaches limit, the effect of the soil arch between piles reaches limit equilibrium state.

With the increase of the space of pile, stress concentrates on soil nails, support role of soil nailing will be strengthened. But the role of micro-piles is subdued. Besides what the regular scholars calls "nail on the soil arch" in the nail, there will also be conditions of forming a horizontal arch of the nail. This soil arch changes the distribution of stress field and displacement field. Soil nailing wall has the effect of reducing the horizontal stress outside the foundation pit. This mechanism of stress reduction is the mechanism of the soil arch between the nail.





(12D)

Fig.3 The large principal stress contour map of the micro pile spacing is 2D、4D、6D、9D、12D

(Left: Single micro pile Right: Composite support of micro pile and soil nail)

The soil itself has certain strength. There are frictional resistance and friction between soil particles. When the soil is subjected to external loads, the stress state of the soil have change. It will result in the soil between the piles or the tacks will move, while the post-pile soil or soil nail position of the soil displacement is small. Because the shear strength of the soil has the tendency to keep the original position of the moving soil, the shear strength of soil particles in two different displacements of soils inevitably prevents the formation of such relative displacement. It will result in the transfer of force and the pressure of the moving part of the soil particles is reduced. But pressure of the fixed part soil particles has increased. This phenomenon called “arch effect” that the pressure of the moving soil is transferred to the adjacent fixed soil. For the strength theory, the soil arch effect is one phenomenon that stress transfer is achieved by exerting the shear strength of itself.

When spacing of micro pile is 2D, there isn't obvious difference between the displacement of piles and it of the micro pile displacement. The distribution of stress among soil outside the foundation pit is as same as stress among the simple micro pile support, that is to say, the micro pile support plays an important role rather than the soil nails.

When spacing of micro pile is 4D, the soil arch effect between piles becomes obvious and the arch is located on the side of the micro pile. It forms friction soil arch, which makes soil nailing force, head start in arch internal stress concentrated area, the soil nailing supporting role begins to emerge.

In the micro pile support, the arch foot lies in the pile position and it is called the arch behind pile which is the end bearing arch. The friction arch couldn't work means that free zone will be formed between pile soil. The displacement of soil between piles makes the soil nailing effect start to appear in the micro pile composite support. There is tension in the soil nailing, counterforce on head position, showing the concentration of compressive stress, anti-slide pile anti force acting on the pile soil after the formation of soil pressure in the diffusion zone and head pressure zone connected at the slope soil when free zone of slope and soil has not been formed, but the soil nail makes the stress back. The saddle shaped soil arch appears after the start of nails.

In the absence of soil nailing, there will be failure state in the micro pile arch. But in the composite support, nail head pressure area and micro pile pressure area is no longer continuous. Soil between the pile instability flows, and the horizontal arch of the nail is transformed into the arc arch. When the pile spacing is 12D, all of the failure of soil arch, the soil arch between the nails moved forward, and the plastic sliding zone appeared.

5. Summary

Through the above research, we can draw the following conclusions:

(1) When the pile spacing is 2D, the support function of the micro pile is the main, and the support effect of the soil nailing has not been played. The soil arch between piles has not been formed.

(2) When the pile spacing is 4D ~ 6D, the friction soil between pile soil arches were first formed. When the 6D pile, the end pile after pile play a role, in the level of the horizontal saddle arch between the arches have formed, the nail head pressure area and micro pile area overlapped remained stable under the action of soil between piles. It shows that the micro pile and soil nailing the best synergistic effect of composite.

(3) When the pile spacing is $9D$, the end pile after pile is failure, and the soil nails flow around the soil, but the saddle arch between the soil nails is transformed into an arc arch, and the supporting effect of the soil nail is enhanced.

(4) When the spacing between the piles is $12D$, the height of the arch between the nails becomes smaller, and the slip surface of the slope soil is formed.

(5) According to the above research conclusion, it is suggested that the spacing of the micro pile spacing between the micro pile and soil nailing composite support is between $2D$ and $6D$.

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