Supporting Effect of Soil Nailing to Foundation Pit with Positive Angle

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ABSTRACT
Foundation pit with positive angle will deform significantly during excavation. This is caused by two free faces at the positive angle. Soil nailing is an economic and simple support. A FLAC-3D model of foundation pit with positive angle was established in this paper. Based on this model, the supporting effect of soil nailing to foundation pit with positive angle was analyzed by comparing its horizontal displacement to that of foundation pit without support. The foundation pit with soil nailing was excavated in stepwise manner. The optimum soil nail spacing, diameter and length were proposed. Results demonstrated that soil nailing can reduce horizontal displacement at the positive angle effectively. Shorter soil nail spacing, but longer and bigger soil nails will bring better supporting effect. However, this may not always be taken for granted; it has been established that there are optimum soil nail spacing, diameter and length.

KEYWORDS: Foundation pit with positive angle, soil nailing, support, FLAC-3D, soil nail spacing, diameter, length

INTRODUCTION
Positive angle often occurs in foundation pit due to the diversified plane shapes of buildings. Two free faces at the positive angle increase difficulties in controlling deformation of foundation pit. Many researchers have studied positive angle in foundation pit. Wu Zhimin et al (2007) explored effect of positive angle and negative angle during layer-based excavation of foundation pit. They discovered that displacement at negative angle decreases to a certain extent, while displacement at the positive angle increases significantly. Wang Hongde et al (2014) analyzed deformation of deep soil-rock foundation pit with positive angle through finite element analysis, confirming the significant effect of positive angle and negative angle in deep foundation pit. Soil nailing is a slope support characteristic of easy construction and low cost. It is widely used in practical engineering. Some scholars have studied applications of soil nailing in positive angle of foundation pit. Pan Hong et al (2008) studied spatial effect and deformation at corners of composite soil nailing wall. They reported that the maximum horizontal displacement of composite soil nailing wall is at the positive angle surface close to the positive angle. Wang Haixu et al (2011) introduced in concept of redundancy design theory and reinforced the middle...
beam at the positive angle of foundation pit with soil nailing. They also analyzed redundancy and concluded that such middle beam reinforcement can effectively control displacement at dangerous positions, shift redundant load, and increase channels for load transfer. In other words, middle beam reinforcement at the positive angle of foundation pit with soil nailing can increase redundancy of the supporting system. All of these researches disclose the adverse effect of positive angle on control of foundation pit deformation and provide important guidance to application of soil nailing.

However, previous researches on supporting effect of soil nailing to foundation pit with positive angle are mainly based on theoretical derivations. In this paper, a FLAC-3D model of foundation pit with positive angle and soil nailing was established to analyze supporting effect of soil nailing to foundation pit with positive angle. The optimum soil nailing parameters were proposed.

**FOUNDATION PIT MODEL**

The plane size of studying foundation pit is shown in Figure 1. It is 8m deep. Considering the reach of foundation pit deformation on the plane, the model size was set 80m*95m*16m (Figure 2).

![Figure 1: Plan and size of the foundation pit studied](image-url)
The soil mass in the model uses clay and is simulated by Mohr-Coulomb model. Parameters of soil mass and soil nailing are listed in Table 1.

**Table 1: Parameters of soil mass and soil nailing**

<table>
<thead>
<tr>
<th>The soil</th>
<th>Soil nailing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>2000 kg/m³</td>
</tr>
<tr>
<td>Cohesion</td>
<td>30kPa</td>
</tr>
<tr>
<td>Friction angle</td>
<td>25°</td>
</tr>
<tr>
<td>Deformation modulus</td>
<td>36MPa</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSION

(1) Figure 3 is the cloud chart of deformation of foundation pit without supporting.

![FLAC3D 3.00](image)

**Figure 3**: Cloud chart of deformation of foundation pit without supporting

Horizontal displacements at the positive angle along the depth of foundation pit without supporting are listed in Table 2.

<table>
<thead>
<tr>
<th>depth (m)</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>X displacement (mm)</td>
<td>12</td>
<td>12.8</td>
<td>14</td>
<td>14</td>
<td>14.8</td>
<td>15.6</td>
<td>17</td>
<td>18</td>
<td>8.2</td>
</tr>
<tr>
<td>Y displacement (mm)</td>
<td>9.8</td>
<td>9.2</td>
<td>9.8</td>
<td>10.2</td>
<td>10.8</td>
<td>11.4</td>
<td>12.4</td>
<td>13</td>
<td>3.2</td>
</tr>
<tr>
<td>XY displacement (mm)</td>
<td>15.5</td>
<td>15.7</td>
<td>17.1</td>
<td>17.3</td>
<td>18.3</td>
<td>19.3</td>
<td>21.0</td>
<td>22.2</td>
<td>8.8</td>
</tr>
</tbody>
</table>

In Figure 3, the horizontal displacement at the positive angle of foundation pit is significantly larger than that at other places. It increases as the foundation pit deepens. Since the X-oriented free face at the positive angle is twice longer than the Y-oriented free face, X-oriented displacement is larger than the Y-oriented displacement.

(2) Soil nailing program

In this paper, the vertical soil nail spacing was determined 2m and the foundation pit was excavated in five steps.

Step 1: Balance ground stress on the initial soil mass. No support is used.
Step 2: Excavate to 2m deep and eliminate all units within 0~2m depth of the foundation pit. Hammer the first row of soil nails into the positive angle.

Step 3: Excavate to 4m deep and eliminate all units within 2~4m depth of the foundation pit. Hammer the second row of soil nails into the positive angle.

Step 4: Excavate to 6m deep and eliminate all units within 4~6m depth of the foundation pit. Hammer the third row of soil nails into the positive angle.

Step 5: Excavate to 8m deep and eliminate all units within 6~8m depth of the foundation pit. Hammer the fourth row of soil nails into the positive angle.

(3) The variation of horizontal displacement at the positive angle against depth is shown in Figure 4. Soil nailing parameters are: diameter: 100mm; length: 8m; horizontal soil nail spacing: 1.0 m, 1.2 m, 1.4 m, 1.6m, 1.8m and 2.0m.

Figure 4: Effect of soil nail spacing on horizontal displacements at the positive angle

Figure 4 shows that soil nailing can reduce horizontal displacement at positive angle of foundation pit. Given fixed vertical soil nail spacing, the horizontal displacement at positive angle is proportional to the horizontal soil nail spacing. However, the horizontal displace at positive angle reduces slightly after the horizontal soil nail spacing shortens to 1.2m, but increases significantly after the horizontal soil nail spacing widens to 1.6m.

(4) Impact of soil nail diameter (70mm, 80mm, 100mm, 120mm, 140mm and 160mm) on the supporting effect is analyzed under 2m vertical soil nail spacing, 1.4m horizontal soil nail spacing and 8m length of soil nails (Figure 5). The foundation pit is excavated in same way.
Figure 5: Effect of soil nail diameter on horizontal displacements at the positive angle

It can be seen from Figure 5 that the horizontal displacement at positive angle is inversely proportional to soil nail diameter. Bigger soil nail has larger contact area with surrounding soil mass and higher tensile strength, thus supporting the soil mass better. However, such supporting effect strengthens slightly after soil nail diameter increased to 140mm and decreased to 80mm.

Impact of soil nail length (5 m, 7 m, 9 m and 11m) on the supporting effect is analyzed under 2m vertical soil nail spacing, 1.4m horizontal soil nail spacing and 100mm diameter of soil nails (Figure 6). The foundation pit is excavated in same way.
It can be seen from Figure 6 that the horizontal displacement at positive angle is inversely proportional to soil nail length. However, there’s a reasonable variation range of soil nail length. Under 2 m ×1.4 m soil nailing spacing and 100 mm soil nail diameter, the reasonable length of soil nail is 7m~9m, that is, 0.85H~1.13H (H is depth of foundation pit).

CONCLUSIONS

In foundation pit with positive angle, the horizontal displacement at positive angle is larger than other places, which can be reduced by soil nailing effectively. Shorter soil nail spacing, but longer and bigger soil nails will bring better supporting effect. However, there are optimum soil nail spacing, diameter and length. For the positive angle in the studying foundation pit, the optimum soil nail spacing, diameter and length are 1.2~1.6m, 80mm~140mm and 0.85H~1.13H (H is depth of foundation pit), respectively. This can provide reference for similar engineering projects.

REFERENCES


