Study on the Influence of Soil Parameters Change on the Stability of Foundation Pit

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Abstract: Combining with engineering examples, the influence of grouting on the stability of foundation pit is analyzed by comparing the parameters before and after grouting. The numerical analysis software FLAC is used to simulate the original foundation pit without grouting. The relationship between the maximum horizontal displacement and cohesion, friction angle and elastic modulus is explored. The fitting formulas of the influence of elastic modulus, friction angle and cohesion on displacement are put forward. Enclosure design provides basic data.

1. Engineering Parameters and Design
The soil layer of a foundation pit is homogeneous sandy soil, without considering the influence of water. Foundation pit excavation depth, ground overload is \( q=17 \text{kPa} \), the average weight of soil is \( \gamma=18.2 \text{kN/m}^3 \), undisturbed soil \( c=7 \text{kPa} \), the density of mechanical parameters of soil after grouting is selected according to the increase of 5\%, \( c', \phi' \) selected by increasing 40\% and 41\% respectively, and so \( c=9.81 \text{kPa}, \phi=25.66^\circ, \gamma'=19.11 \text{kN/m}^3 \). The basic design parameters of soil nailing wall are as follows: the slope of retaining wall is vertical, and the horizontal and vertical spacing of five soil nails are \( S_h \times S_v = 1.25 \text{m} \times 1.8 \text{m} \), the downward inclination angle of the borehole is \( \theta = 15^\circ \). A total of 8 dump nails were set up from the ground to the ground. Its parameters are grade II hot-rolled deformed steel bars of \( \varphi_23 \), three rows of length \( L = 10000 \text{mm} \), \( L = 9000 \text{mm} \) three rows, \( L = 8000 \text{mm} \) in two rows. Reinforcement of soil nailing wall surface design according to structural requirements, surface reinforcement is \( \varphi_6 @ 200 \text{mm} \times 200 \text{mm} \), the thickness of shotcrete is 100mm, and the end of soil nail is made into thread end, which is connected with the surface layer by nut, wedge washer and square steel cushion plate.

2. Design Check of Soil Nailing Wall
1) Checking calculation of local stability of soil nails
Satisfactory formula for pull-out stability of single soil nail

\[
F_{s,d} N = 1.1 \pi d^2 f_{yk} / 4
\]

\[
N = \frac{1}{\cos \theta} (p + p_a) S_v S_h
\]

Taking the engineering parameters into account, it can be obtained that \( N = 142.93 \text{KN} \), \( F_{s,d} = 1.00 \), Less than 1.2-1.4 before grouting. It can be concluded that the safety requirements of soil nails are not
satisfied when they are subjected to the maximum tension under the action of self-weight and uniformly distributed load on the ground. After grouting, N=112.5KN, \( F_{s,d}=1.28 \), greater than 1.2-1.4, it can be seen that the soil nail after grouting meets the safety requirements when it bears the maximum tension under the action of self-weight and surface uniform load.

2) External stability checking

(1) Checking calculation of stability against horizontal slip

Rankine Active Earth Pressure \( E_a \) with Horizontal Action Approximating the Earth Pressure on the Back of Wall. The width of the wall is equal to the horizontal projection length \( L \cos \alpha \) of the bottom soil nail. Then the anti-smoothing safety factor \( H = \frac{\tau}{\gamma H \tan \phi + c} \), After calculation, before grouting \( H = 2.81 \), after grouting \( H' = 3.40 \). It can be seen that the anti-smoothness and stability of soil nailing wall before and after grouting can meet the requirements, but it is safer after grouting.

(2) Checking calculation of anti-overturning stability

Overturning stability of soil nailing wall should meet the requirement of formula

\[
\frac{M_a}{E_b H L \cos \theta} \geq 1.3
\]

Calculated \( H_a = 4.71 \), \( H'_a = 5.32 \). It can be seen that the anti-overturning stability of soil nailing wall before and after grouting can meet the requirements, but it is safer after grouting.

(3) Internal stability checking

The internal stability safety factor \( F_s \) is calculated by formula

\[
F_s = \sum \left( (W_i + Q_i) \cos \alpha_i \cdot \tan \phi_i + \left( R_i / S_{ik} \right) \sin \beta_i \cdot \tan \beta_i + C_i \left( \Delta_i / \cos \alpha_i \right) + \left( R_i / S_{ik} \right) \cos \beta_i \right)
\]

The position of the critical failure surface as the design basis should be determined by trial calculation. The corresponding stability safety factor is the smallest among all possible failure surfaces, not less than 1.3. Through calculation and analysis, \( F_s = 0.63 \) before grouting and 1.35 after grouting. It can be seen that grouting can change the internal stability of foundation pit from unsafe to safe.

3. Modeling

In order to further explore the relationship between the maximum horizontal displacement and cohesion, friction angle and elastic modulus, a numerical analysis software FLAC was used to simulate the original foundation pit without grouting. In this simulation, a two-dimensional calculation model was adopted. According to the theory of plastic large deformation, the failure criterion was Mohr-Coulomb criterion. The parameters of the prototype model are shown in Table 1, and the coefficient of static earth pressure is 0.45. The excavation process is divided into eight steps: 1.25m height; soil nailing support. The parameters of soil nailing wall panels are shown in Table 2 and the parameters of soil nailing are shown in Table 3.

| Prototype | Lateral Earth Pressure (KN/m) | Ground Overloading (kPa) | Critical Depth (m) |
|-----------|-------------------------------|--------------------------|---------------------|
|           | 383.55                        | 17                       | 1                   |

| Project | Thickness (m) | Concrete grade | A steel bar | Elastic modulus E (Mpa) | Poisson ratio |
|---------|---------------|----------------|-------------|------------------------|--------------|
| Soil nail panel | 0.1           | C20            | 6@200       | 3.0e10                 | 0.3          |
Table 3 Factors of Bolt

| Soil Nail Layer | Elevation | Dip Angle (°) | Aperture | Horizontal Spacing | Design Length | Soil Nail Main Reinforcement |
|----------------|-----------|---------------|----------|--------------------|---------------|-----------------------------|
| 1              | -1.25     | 15            | 110      | 1000               | 10000         | 1                           |
| 2              | -2.5      | 15            | 110      | 1000               | 10000         | 1                           |
| 3              | -3.75     | 15            | 110      | 1000               | 10000         | 1                           |
| 4              | -5        | 15            | 110      | 1000               | 9000          | 1                           |
| 5              | -6.25     | 15            | 110      | 1000               | 9000          | 1                           |
| 6              | -7.5      | 15            | 110      | 1000               | 9000          | 1                           |
| 7              | -8.75     | 15            | 110      | 1000               | 8000          | 1                           |
| 8              | -10       | 15            | 110      | 1000               | 8000          | 1                           |

The computational range is 50m * 25m and 70 * 46 meshes are divided. Soil nailing is simulated by cable element, soil nailing wall panel is simulated by lining element, the interface between structure and soil is treated by contact element, and soil is treated by non-linear elastic-plastic model. Its failure criterion is Mohr-Coulomb criterion. When initial constraints are set, it is assumed that there are horizontal hinged bars on both sides of the calculation domain, hinged supports at the bottom and free boundaries at the top with known loads. The stress field is gravity stress field, and the overload on the surface is 17 KPa.

4. Horizontal Deformation of Foundation Pit

With the deepening of excavation depth, the horizontal displacement of the retaining structure increases gradually. According to the deformation nephogram of the deformation supporting structure, the maximum horizontal displacement of the retaining structure is 1.865 cm, 3.454 cm, 6.388 cm, 12.81 cm, 19.23 cm, 28.53 cm, 38.06 cm and 47.58 cm. According to the code requirements, the horizontal deformation of foundation pit should be controlled within 0.01H, that is, the limit value of horizontal deformation of this project should be 10 cm. Comparing with the above results, it can be concluded that the deformation of foundation pit can not meet the requirements when excavation reaches the fourth step.

With the deepening of excavation depth, the safety factors of foundation pit excavation from the first step to the eighth step are 2.46, 1.5, 0.75, 0.77, 0.69, 0.62, 0.63 and 0.6, respectively. It can be seen that the safety factors of foundation pit excavation from the first step to the eighth step are lower than 1.2-1.4.

5. Effect of Soil Layer Parameters on Deformation

The influence of soil parameters on the maximum displacement of foundation pit is shown in Fig. 1, Fig. 2 and Fig. 3.
Fig1. The alternation of the X-displacement due to the changing of elastic ratio of soil

Fig2. The alternation of the X-displacement due to the changing of friction of soil

Fig3. The alternation of the X-displacement due to the changing of cohesion of soil

From Fig. 1, Fig. 2 and Fig. 3, it can be seen that the maximum horizontal displacement of the foundation pit wall decreases with the increase of cohesion, friction angle and elastic modulus. The former two have less contribution to the decrease of the maximum horizontal displacement, while the elastic modulus has more significant influence on the maximum horizontal displacement of the foundation pit wall. The grouting technology will improve the elastic modulus, cohesion and friction angle of soil in varying degrees, which can reduce the deformation of the slope of foundation pit and
increase the stability of foundation pit.

The fitting formulas can be obtained from the curves in the figure as follows:

1. The fitting formulas for the influence of elastic modulus on displacement are as follows:
   \[ Y = 66.72681 - 3.37599 X + 0.06674 X^2 - 4.37055E-4 X^3 \]

2. The fitting formula of the influence of friction angle on displacement is as follows:
   \[ y = A1 \times \exp(x/t1) + y0 \]
   Where:
   \[ y0 = 46.18269, \]
   \[ A1 = 32.96059, \]
   \[ t1 = -5.8649. \]

3. The fitting formula of cohesion effect on displacement is as follows:
   \[ Y = 59.23 + 0.21888 X - 0.26603 X^2 \]

From the fitting formula, it can be seen that elastic modulus has the greatest influence on displacement, followed by friction angle, and cohesion has the least influence on displacement.

6. Conclusion

1) Combining with engineering examples, it is clarified that grouting can stabilize unstable soil, make soil layer which can not adopt soil nailing support technology possible after modification.

2) The numerical simulation shows that the maximum horizontal displacement of the foundation pit wall decreases with the increase of cohesion, friction angle and elastic modulus. The former two have less effect on the decrease of the maximum horizontal displacement, while the elastic modulus has more significant effect on the maximum horizontal displacement of the foundation pit wall.

3) It is pointed out that grouting will increase the elastic modulus, cohesion and friction angle of soil in varying degrees, so as to reduce the deformation of foundation pit slope and increase the stability of foundation pit.

4) The fitting formulas of elastic modulus, friction angle and cohesion on displacement are put forward. The fitting formulas show that elastic modulus has the greatest influence on displacement, followed by friction angle, and cohesion has the least influence on displacement.

Acknowledgments

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