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A study on the method of stability calculation of soil nailing expansive soil slope

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Abstract. In order to analyze the stability and optimize the project of soil nailing engineering for expansive soil slope, the calculation formulas for unsaturated soils strength, soil nailing surface bond strength, and nail withdraw strength was deduced based on the Mohr-Coulomb strength formula and national regulations. The sliding resistance of the soil nailing was taken into consideration based upon the Bishop slice method; Calculating models on soil nailing expansive soil slope stability analysis was designed; The influence of fissure, rain infiltration, and soil nailing on the expansive soil slope stability were also taken into account. Based on engineering example, fixed slope soil parameter and according soil nailing parameter, the influential factors were analyzed by changing soil nails inclination, installation position, and length. As it was demonstrated by engineering example, the methods and corresponding calculating procedure were reasonable for stability analysis and design optimization for soil nailing expansive soil slope. It is of certain engineering application value.

1. Introduction

Expansive soil, a kind of unsaturated soils with notable swelling-shrinkage, is distributed mainly over 20 provinces in China. It may lead to slope instability in engineering construction and the swelling-shrinkage may cause great lose in road, building, and hydraulic engineering construction.With the development of economic construction, civil engineering construction scale became larger and larger; mega construction projects like splendid long bridges, tall buildings, and urban subways, etc. emerged massively. As a result, there is a rapid increase in the need of the expansive soil slope nailing construction. It is of great need to ensure safety for expansive soil slope project to reduce engineering accidents. It is arduous and urgent task to optimize the nailing engineering for expansive soil slope, which is also the major issue in the study of expansive slope. Slope instability, the main accident in construction, is harmful and complex. Hence, the study on failure mechanism of the expansive soil, analysis of soil nailing stability for expansive soil slope, and optimization of the design is of urgent need at present.

2.Stability of the expansive soil slope

Expansive soil features swelling-shrinkage and low permeability. It is multifractured and porous because of high contractility and low permeability. Low permeability leads to contractive nonuniformity vertically and causes cracks. As illustrated in Figure 1, soil with low permeability contracts freely vertically and is confined horizontally. Horizontal shrinkage and deformation lead to lateral tensile stress against vertical plane with a tensile strength of σ_a and lateral tensile stress of σ_x.

If the shrinkage is moderate, the lateral tensile stress on the vertical plane will be weaker than lateral anti-tensile stress($\sigma_a + \sigma_x$) on the lateral plane, the adjoining unit will not be torn apart and shrinkage will only occur vertically. In all, it may cause subsidence. If the shrinkage is notable, it will cause greater lateral tensile stress than ($\sigma_a + \sigma_x$) against vertical plane and cracks will occur. The release of stress can cause cracks bigger. For instance, the excavation at foundation pit, road and railway cutting can cause the lack of lateral support and decease of σ_x, fracture will be easily developed accordingly.

Figure 1. Cracking of expansive soil

The research about stability of expansive soil slope mainly focuses on the influence of cracks and rainfall permeation on the slope.

The influences of crack on slope stability are as followings: (1) Soil strength reduces due to cracks. Scholars conducted experiment under dry-wet cycle and found that soil strength reduces with the development of crack and slope instability will be caused[1]. (2) Slope can be classified into cracked and uncracked one. Research showed that with the development of cracks, the soil anti-shear strength is weakened in the overlying soil, while the anti-shear strength is strong in sole without cracks[2]. Slip surface will appear at the shallow area and cannot reach the bottom with strong intensity. (3) Rain ponding in the crack may form penetration and seeping force increases sliding torque which actually greatly influences the slope stability[3]. (4) Under certain condition and with the passage of time, crack depth is the basic cause for slope instability.

Engineering practice shows that rainfall is the main cause for expansive soil slope instability. It increases water content in soil, which raises saturation level and reduces shear strength. Continuous rainfall results in the rise of groundwater level and appearance of water in the relative aquifuge, which may lead to slope instability and even landslide. Based upon previous researches, reasons for slope instability can be summarized as: (1) rainfall penetration leads to the increase of water content and the decrease of soil cohesion, internal friction angle, and soil matric suction, which finally causes the weakness of soil shear strength[4]. (2) rainfall penetrates along with the crack to deep soil and the crack will be expanded under the water pressure, which leads to slope instability. (3) rainfall results in seepage strength, which also leads to slope instability[5].

3. Workability and Stress Characteristics of Soil Nailing Support

Expansive soil slope support, a traditional course in geotechnical engineering, is a complex subject. Supporting systems mainly include row pile support, bolting support, and soil nailing support. Soil nailing support was used for slope support and geotechnical reinforcement in 1980s in China. It was widely used because of its low cost, short time limit, and high adaptability. It brought obvious social and economic effectiveness. Soil nailing support for slope differs from other forms of slope support construction and is constructed layer by layer. It will change the position of the potential slide plane and stability has to be checked during construction. The expansive soil slope excavation may cause sudden change in soil stress field and strain field, which leads to abrupt change in soil body, soil nailing support, and slope stability. The paper, therefore, intends to study the stability and optimization of design of soil nailing support for expansive soil slope.

The study of soil nailing support now mainly focuses on two aspects:

(1) Working mechanism of soil nailing support is studied through field experiment, model test indoors and outdoors, and data analysis.

Yu Xiao-jin, based upon the study on slope excavation engineering stability, put forward the parameter for cohesion and rupture angle. Regression formula was given for soil and soil nailing support through experimental data fitting, which was used for predicting the safety of soil nailing support[6]. Huo Ruo-lan built numerical analysis model for soil nailing support in pit excavation. Interfacial element unit was used to analogy deformation of soil nailing interface. It was confirmed to be reliable through data analysis and engineering practice[7]. Zhang Qing-shan analyzed the monitoring data of field deformation in support construction and studied the law of horizontal displacement and sedimentation. His study indicated that construction procedure, supporting layout and surrounding condition were the main factors for deformation in pit engineering support[8]. Xiao Xi-ze built experimental model of soil nailing support for pit engineering and it showed soil nailing dip angle had marked impact on deformation and stability for side wall[9].

The above researches provide important theoretical basis for analysis, design, and construction of soil nailing support, extends the applied field, and indicates the significance of soil nailing support.

(2) Based on value analysis, the paper tends to study the design technique for soil nailing support.

Tu Bing-xiong used sheer lag theory to build computer model for soil nailing internal force transfer and analyzed the transferring law of internal force. Through theoretical analysis and careful calculation, the model was useful for the design of soil nailing support and analysis of internal force[10]. Ding Min set up optimized model for soil nailing support, selected the acceptable range for parameter after analyzing parameter sensitivity, and improved the genetic algorithm by using adaptive dynamic technique and non-standard genetic operator. The research showed that improved genetic algorithm made it more rational for soil nailing support[11].

To sum up, lots of achievements have made about the study on soil nailing support for slope at home and abroad, but little research has done on soil nailing support for expansive soil slope. This paper, hence, intends to study stability and optimized design for soil nailing support at expansive soil slope so to provide the theoretical basis and optimized parameter for soil nailing expansive soil slope.

4. Analytical model for soil nailing expansive soil slope stability

4.1 Parameter calculation for unsaturated soil

Computer model is set to test the influence of cracks and rainfall permeation on stability at the expansive soil slope. When exterior load is not taken into account and pore pressure at normal constant, matric suction is related with moisture content. Citation[12] formula for unsaturated soil effective stress parameters is as following:

$$\sigma' = (\sigma - u_a) + S_r(u_a - u_w) \tag{1}$$

σ stands for total stress, u_a for pore air pressure, u_w for pore water pressure, ($u_a - u_w$) for matric suction, ($\sigma - u_a$) for net normal stress, and S_r for saturation level. When, $S_r = 0$ $\sigma' =$ ($\sigma - u_a$) accords with effective stress in Fredlund's two accelerating stresses; when $S_r = 1$, $\sigma' =$ ($\sigma - u_w$) is the effective stress in Terzaghi saturated soil.

Combine Mohr-Coulomb strength formula:

$$\tau_f = c' + \sigma' \tan\phi' \tag{2}$$

With formula (1) and (2), calculation formula for unsaturated soil strength is drawn as:

$$\tau_f = c' + [(\sigma - u_a) + S_r(u_a - u_w)]\tan\phi' = [c' + S_r(u_a - u_w)\tan\phi'] + (\sigma - u_a)\tan\phi' = c_u + (\sigma - u_a)\tan\phi' \tag{3}$$

In the formula, c' stands for effective cohesion of saturated soil, ϕ' for effective internal fiction angle of saturated soil, τ_f for shear stress at damaged plane, c_u for cohesion of unsaturated soil.

Use formula (3), soil strength can be calculated according to the saturated soil strength and soil-water characteristic curve. Process to calculate unsaturated soil strength and stability can be simplified.

4.2 Nailing-soil plane calculation parameter

Bonding strength and stability for soil nailing at expansive soil slope were analyzed and Mohr-Coulomb strength formula was formed as:

$$\tau = c' + \gamma h \tan\phi' \tag{4}$$

In the formula, γ for weight, and h for depth.

4.3 Soil nailing force calculation parameter

At present the national standard soil nailing calculation is mainly in document. Active earth pressure distributes triangularly and single soil nailing stress is calculated according the formula:

$$T_{jk} = \zeta e_{ajk} S_{xj} S_{zj} / \cos\alpha_j \tag{5}$$

In the formula, ζ is for loading reduction factor, e_{ajk} for horizontal load in pit foundation S_{xj} and S_{zj} for horizontal and vertical interval respectively, and α_j is for the angle between j pillar and horizontal plane.

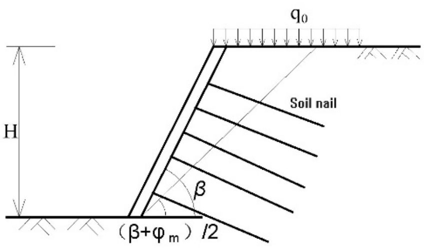

Figure 2. Sketch diagram of soil nail force calculation

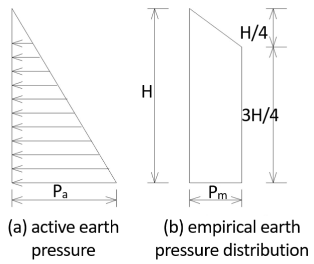

Figure 3. Soil nail force along the depth distribution slip surface

$$\zeta = \tan\frac{\beta - \varphi_m}{2} \cdot \left[\frac{1}{\tan(\beta + \varphi_m)/2} - \frac{1}{\tan\beta}\right] \cdot \tan^{-2}(45^\circ - \varphi_m/2) \tag{6}$$

β stands for angle between soil nailing plane and horizontal plane, φ_m for internal friction angle average value in different soil planes, and $(\beta + \varphi_m)/2$ is the angle between sliding surface and horizontal surface.

In engineering practice, soil nail is distributed with small one on top and at bottom, big one in the middle. This is due to constructing time and sequence. Therefore during the construction soil nailing stress calculation, construction process should be taken into consideration. According to document[13], the paper uses simplified calculation and figure 3 for soil nail distribution, supposing total soil nail stress equals to Rankine earth pressure resultant.

$$\frac{1}{2} P_m \cdot \frac{1}{4} H + P_m \cdot \frac{3}{4} H = \frac{1}{2} P_a H \tag{7}$$

$$\text{and} \quad P_m = \frac{4}{7} P_a \tag{8}$$

P_a stands for Rankine's earth pressure strength in pit foundation, the formula is as:

$$P_a = \gamma H k_a - 2c\sqrt{k_a} \tag{9}$$

In formula (7), total active earth pressure strength should be calculated layer by layer when soil stratifies. If soil nail load reduction factor is ζ , soil nail stress formula would be:

$$T_{jk} = \zeta P_{mj} S_{xj} S_{zj} / \cos(\alpha_j) \tag{10}$$

P_{mj} is the P_m value at j soil nail.

4.4 Safety coefficient calculation

Figure 4 is the calculating formula for soil nail expansive slope stability. Based upon Bishop analytical method and consideration of soil nail anti-slide effect, the paper put forward safety coefficient calculation formula:

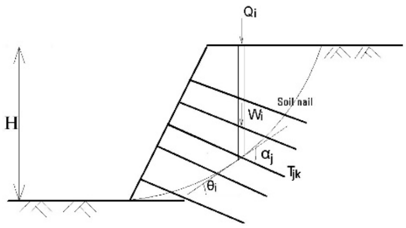

Figure 4. Stability analysis calculation diagram

$$Fs = \sum[c_u l_i + (W_i + Q_i)\cos\theta_i \tan\phi' + (T_{jk}/S_{xj})\sin\alpha_j \tan\phi' + (T_{jk}/S_{xj})\cdot\cos\alpha_j] \Big/ \sum(W_i + Q_i)\sin\theta_i$$

(11)

In the formula, c_u is for unsaturated soil cohesion, ϕ' for effective angle of internal friction, l_i for length of slip soil surface, W_i is self-weight of soil i, Q_i for surface load of soil i, θ_i for included angle between bottom and horizontal plane, T_{jk} for soil nail stress, S_{xj} for horizontal spacing with soil nail j, and α_j for included angle between soil nail j and slip surface.

The paper, basing upon the above mentioned formulas and figure 11, used Visual Fortran language to write program for calculating stability for soil nail expansive slope.

5. Strength reduction FEM to verify the stability analysis model of the soil nailing expansive soil slope in the text

In order to verify the stability analysis method and calculation program of the soil nailing expansion slope in the text, the strength reduction finite element method is used for analysis and verification.

5.1 Model boundary

Use the two-dimensional FEM to calculate the boundary: the dimensions of the left and right boundaries are determined according to the geological conditions and the excavation depth (H) of the slope. Based on the engineering experience, the boundary between the slope top and the slope site, ie the excavation surface, is taken at (2~3)H, the lower boundary is taken below the bottom of the excavation (0.5~1)H. Model boundary conditions: Sliding constraints ($u_x = 0$, u_y free) are applied to the boundary of the geometric model, and a completely fixed constraint is applied to the bottom.

5.2 Simulation of soil, soil nail and interface unit

The soil unit is simulated with a 15-node triangular element, and the numerical integration uses 12 Gauss points. The soil nails are simulated by geogrid units, and each geogrid unit is defined by 5 nodes. The nail-soil interface unit is defined by 5 sets of nodes. The interface element stiffness matrix is derived from Newton Cotes integration.

5.3 Construction process simulation

In the initial model finite element mesh, the information of each component unit is established, the soil is all activated, the structural unit and the load are frozen, and the soil of the excavation part is frozen according to the construction process. The soil nail is activated, and the activation setting is activated. So is the concrete surface layer.

According to the design requirements, the quasi-excavation soil is divided into several layers, and each layer of soil is excavated to calculate the equivalent joint force of the soil unit, and the equivalent joint forces of the same magnitude and opposite direction are taken as the joint load to perform a nonlinear analysis. The soil nailing construction loads the corresponding soil nailing unit into the total stiffness matrix, and the slope body layer construction replaces the original soil parameters with the corresponding surface material parameters. Each layer of finite element mesh corresponding to its geometry and support state is used, and the newly formed total stiffness matrix and total load array are used for each stage of load calculation.

5.4 Strength reduction finite element method

In the strength reduction method, the soil strength index is adjusted until the slope reaches critical damage, and the reduction factor is the safety factor. For the calculation parameters of the nail-soil interface in the soil nailed expansive soil slope, the interface strength is also reduced in the same way, and the soil nail strength is not affected. The reduced soil strength parameters c'_f and ϕ'_f are:

$$c'_f = \frac{c'}{Fs}, \quad \phi'_f = \arctan(\frac{\tan\phi'}{Fs}) \tag{12}$$

Fs is the reduction factor. c'_f, ϕ'_f ,is the effective cohesion and internal friction angle of the soil after reduction.

In this text, the strength reduction finite element method is used to analyze the instability criterion of soil nailing expansion soil slope. It is mainly from two aspects: the plastic zone penetration of the slope and the sudden displacement of the slope top as the finite element calculation instability criterion. In each case, the corresponding minimum safety factor is the safety factor of soil nailing expansion slope stability.

6.Engineering study

In a section of the semi-filled and semi-excavated highway slope in Huoshan County of Lu'an City, the soil is expansive soil, and the section is shown in Figure 5. The road is built away from the river bay. The slope is expansive soil. The development of surface fissures is more fully regarded as fissure zone. The lower fissures are seldom regarded as non-fracture zones. The soil is used as a consolidation soil for undrained direct shear test as shown in the parameter table 1. The upper excavated slope material is pulverized and mixed with sand and gravel as the subgrade retaining wall filler. The construction is carried out in the dry season, the water level is relatively low, so the slope is basically not affected by water. The water level may rise to the rainy season under heavy rainfall conditions. The upper part of the slope has an adverse effect on the stability of the slope. After the completion of the construction, the roadbed began to tilt toward the river bay in the first rainy season. After the heavy rainfall, the slope stability decreased. To ensure the stability of the slope, soil nail reinforcement measures were taken against the retaining wall of the embankment and below.

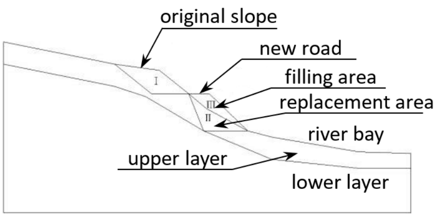

Figure 5. Section of the highway slope

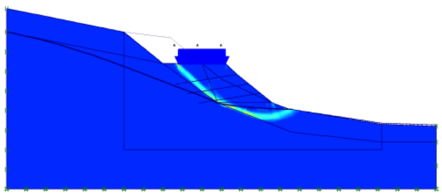

Figure 6. Rainfall water level uplift of slope potential

Table 1. Soil parameter table

name	Soil parameter				
	c /kPa	φ/(°)	γ /KN/m^3	E /MPa	ν
upper layer	19.5	13	19	20	0.35
Lower level	30	20	19	20	0.35
filler	19.5	18	21	22	0.35

6.1 Stability analysis of the construction process considering the dry season and rainy season

The original slope should be excavated and filled. Firstly, the I Area in Figure 5 is excavated for natural grading; the II Area is replaced, and the III Area is backfilled. After the construction of the above three areas is completed then having the construction of the pavement. For the convenience of analysis and calculation, the road load is set to the line load direction down to 10KN/m/m.

In order to verify the rationality of the stability analysis program of the expansive soil slope in the text, the FEM is used for analysis. The effects of groundwater seepage on the stability of expansive soil slopes during the dry season and rainy season are considered separately. The calculation results of the safety factor are shown in Table 2. The potential slip surface change of the slope of the rainfall water level is shown in Figure 6.

Table 2. Safety factor of expansive soil slope under dry season and rainy season

	Method in the text F_s	Strength reduction of finite element method F_s
dry season	1.51	1.53
Rainy season	1.465	1.487

It can be seen from Table 2 that the calculation results of the safety factor of the method and the strength reduction finite element method are similar in the following two cases, which fully demonstrates that the method and program analysis and calculation of the stability of the expansive soil slope are reasonable and feasible.

Figure 6 the change of the potential slip surface of the slope of the rising water level indicates that the expansive soil in the upper slope of the water level rises near the saturated water, the effective stress in the slope decreases, and the effective shear strength decreases. The safety factor calculation result drops from 1.51 to 1.465.

6.2 Stability analysis of soil nailed expansive soil slope

Since the construction section is an expansive soil slope, in order to ensure the safety and reliability of the project, three rows of soil nails are set according to the construction plan, and the surface layer is made of steel mesh concrete, and the connection between the soil nail and the surface layer is firm. Three rows of soil nails were set at 1.2m below the road surface, that is, the slope of the III Area. The vertical spacing and horizontal spacing of the soil nails were both 1.2m. The basic parameters of soil nails are as follows $EA = 5.275\times10^{3} KN/m$. The axial stiffness and the maximum tensile force design value is $F_p = 150KN/m$ and 100mm for soil nails, 25mm for steel bars, 8m for soil nails. The vertical spacing of soil nails is 1.2m, and the horizontal spacing of soil nails is 1.2m. The soil nail is inclined to the horizontal direction with 10°.

The soil nail grouting material has a strength grade of 42.5 cement, a water-cement ratio of 0.5-0.6, using pressure grouting, a shotcrete surface layer, the concrete mix ratio is determined by experiments, the maximum aggregate particle size is not more than 12mm, the water-cement ratio not more than 0.45, the order of shotcrete should be from bottom to top. The distance between the nozzle and the surface to be sprayed is controlled within the range of 0.6m to 1.2m, and the direction of the jet is directed perpendicularly to the spray surface.

In this stage, the safety factor of soil nailing expansion slope is calculated by using the method of FEM in consideration of rainfall infiltration conditions. The calculation results of safety factor are shown in Table 3. The calculation results of the maximum axial force of soil nails under stability analysis are shown in Table 4. The change of potential slip surface of slope after three-row soil nail reinforcement is shown in Figure 7.

Table 3. Safety factor of expansive soil slope under soil nailing

	Method in the text F_s	Strength reduction of finite element method F_s
Set a row of soil nails	1.612	1.649

Set two rows of soil nails	1.653	1.691
Set three rows of soil nails	1.655	1.694

Table 4. Maximum axial force of soil nails under stability analysis

	Method in the text/(KN/m)	Strength reduction of finite element method/(KN/m)
Set a row of soil nails	110.23	115.15
Set two rows of soil nails	64.56	68.10
Set three rows of soil nails	62.37	67.99

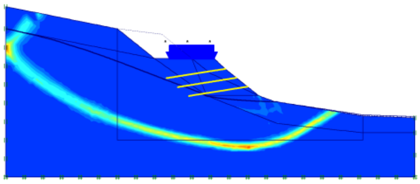

Figure 7. Potential slip surface of expansive soil slope under soil nail support

It can be seen from Table 3 that after the expansive soil slope is reinforced with soil nails, the safety factor is increased to 1.6 or more, and the slope stability is obviously improved. The safety factor has been stabilized after the three rows of soil nails are set. Figure 7 shows that after the three rows of soil nails are set, the potential slip surface of the slope penetrates deep into the soil, which changes the failure mechanism of the slope, and the stability of the road slope is improved to meet the safety design requirements. It can be seen from Table 4 that the maximum axial force of each soil removal nail meets the design requirements, and the maximum axial force of the soil nail tends to be stable when the two rows and three rows are set. From the stability analysis, the above soil nail support scheme is reasonable. The calculation results of the two methods in Table 3 and Table 4 are similar. Therefore, the method proposed in the paper can be applied to engineering practice.

6.3 Soil nail support optimization design

Under the condition of ensuring the soil parameters of the road slope, soil nail reinforcement measures and related parameters, the influence of changing soil nail inclination, soil nail setting position and soil nail length on the stability of expansive soil road slope is analyzed. Therefore, it provides a reference for optimizing the design of soil nail support for expansive soil slope. The stability analysis uses the method in the text and the corresponding calculation program.

(1) Influence of soil nail inclination

The length of the three rows of soil nails is 8m, and the calculation result of the safety factor of the soil nail inclination angle is shown in Figure 8. It can be seen from the figure that the safety factor α increases with the increase of three stages. When the value of α is changed by the inclination angle $5^\circ \sim 10^\circ$, the safety factor increases with the inclination angle. The small basic tends to be stable; when it is $10^\circ \sim 15^\circ$, the safety factor decreases with the increase of the inclination angle; when it is $15^\circ \sim 35^\circ$, the safety factor decreases with the increase of the inclination angle and the change amount is significantly higher than the previous stage.

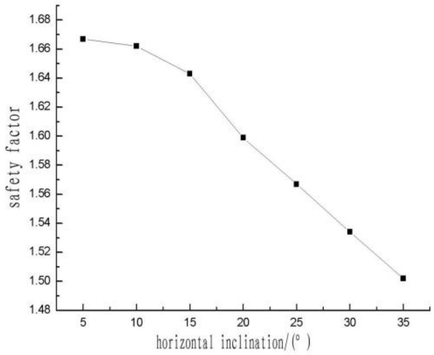

Figure 8. Effect of soil nail inclination on safety factor

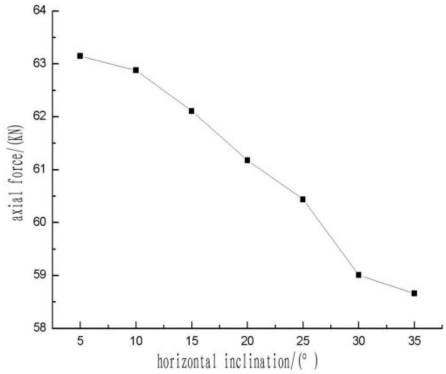

Figure 9. Effect of soil nail inclination angle on maximum axial force of three rows of soil nails

The calculation results of the maximum axial force of the soil nails inclination angle α $5^\circ \sim 35^\circ$ from the change period of the three nails are shown in Figure 9. It can be seen from the figure that the maximum axial force of the soil nails with growing α is divided into four stages. When α is $5^\circ \sim 10^\circ$, the maximum axial force of the soil nails increases with the inclination angle. The small amount basically stabilizes; when it is $10^\circ \sim 25^\circ$, the maximum axial force of the soil nail gradually decreases; when it is $25^\circ \sim 30^\circ$, the maximum axial force of the soil nail decreases rapidly; when it is $30^\circ \sim 35^\circ$, the maximum axial force of the soil nail increases with the inclination angle. Large changes are basically stable.

From the above calculation results and engineering practice, the soil nails are used to reinforce the expansive soil slope, and the soil nail inclination angle is better in the range of $10^\circ \sim 15^\circ$, and the soil nails fully play the role to improve the overall stability of the slope.

(2) Influence of soil nail setting position

The main consideration is the influence of the horizontal spacing of soil nails on the soil nailing force and the stability of soil-slope-supported expansive soil road slopes, which are taken as 0.6m, 0.8m, 1.0m, 1.2m, 1.4m, 1.6m and 1.8m. The results are shown in Figure 10. It can be seen from Figure 10 that when S_x is small, the increase of Fs is faster, the maximum value of Fs is reached when $S_x = 1.4$ m, and Fs is gradually decreased when S_x is large. It can be seen from Figure 11 that the soil nailing force increases rapidly when S_x is small, the soil nailing force increases slowly when S_x is large, and the soil nailing force tends to be stable when $S_x = 1.8$ m.

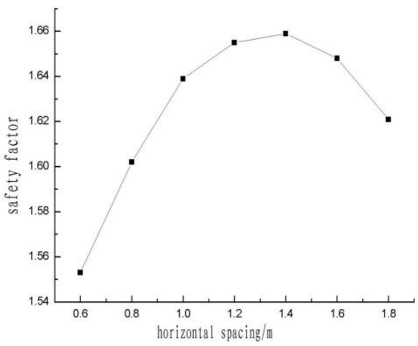

Figure 10. Effect of the position of the soil nail on the safety factor

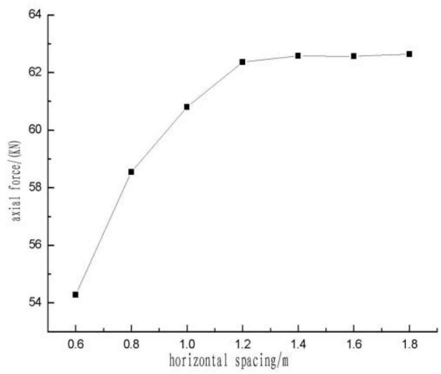

Figure 11. Effect of the position of soil nails on the maximum axial force of three rows of soil nails

It can be seen from the above calculation results that when soil nails are used to reinforce the expansive soil slope and the nails work together and the soil nails are densely set, the load generated on the slope during construction excavation is jointly undertaken by the soil nails, which can effectively restrain the soil deformation and improve the overall stability of the slope.

(3) Influence of soil nail length

The total length of the three rows of the soil nails remains unchanged. As shown in Table 5, the soil nail length layout of the four working conditions is considered. The stability analysis of the soil nailed slopes of the soil nails is carried out by the method.

Table 5. Layout of soil nail length under different working conditions

	Soil nail length/m			
	Working condition 1/The same length	Working condition 2/Upper short, middle and lower length	Working condition 3 /Middle part length	Working condition 4/ Upper length, middle and lower short
Row 1	8	6.5	7	10
Row2	8	7.5	10	7.5
Row 3	8	10	7	6.5

The safety factors of the above four working conditions are 1.655, 1.69, 1.642, 1.631. The safety factor of working condition 4 is relatively low, and the safety factor of working condition 2 is relatively high. The reason is that the anti-slip torque generated by working condition 2 is greater than other working conditions. The anti-sliding moment generated, the ratio of the corresponding anti-slip torque to the sliding moment, that is, the greater the safety factor. Therefore, under the condition that the total length of the soil nail design is constant, working condition 2 (upper short, middle and lower part long) is the best design.

7. Conclusion

Based upon Mohr-Coulomb strength formula, saturated soil strength formula and cohesion strength for nail-soil interface are drawn out respectively. Soil nail stress calculation formula is arrived at according to national regulations and soil nail load reduction. As a result, calculation for unsaturated soil strength, nail-soil interface cohesion, and their stabilities is simplified. Soil nail stress is also taken into consideration during construction.Based upon construction case, road slope soil parameter, soil nail supporting and relevant parameter remain the same. According methods and computer program mentioned in the paper are used to change the soil nail angle, position, and length so as to analyze the influence on expansive soil slope stability. Then reference to optimized design for soil nail expansive soil slope is provided.

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