Evaluation on Slope Stability of Unsaturated Expansive Soil based on Strength Reduction Theory

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Abstract: In view of the difficulties existing in the analysis methods of unsaturated expansive soil slope, a feasible calculation method based on Lu Zhaojun's unsaturated strength theory and strength reduction finite element theory is proposed in this paper. Firstly, based on Lu Zhaojun's developing the strength of the unsaturated expansive soil strength reduction method, secondly, using FORTRAN programming realized based on Lu Zhaojun's strength of unsaturated expansive soil strength reduction calculation program, finally, through the calculation of unsaturated expansive soil slope stability, respectively discusses three kinds of calculation method of difference, and the calculated results were compared. The results show that the strength reduction method based on Lu Zhaojun's unsaturated expansive soil strength is consistent with the numerical calculation results of the other two strength reduction methods, providing an effective method to analyze the slope stability of unsaturated expansive soil.

Keywords: Unsaturated soil; Matric suction; Strength of unsaturated expansive soil; Strength reduction finite element method (srfem); Evaluation of slope stability

1. Introduction

Expansive soil has remarkable expansibility, crack and over consolidation, which leads to its poor engineering properties, making the instability of expansive soil slope become one of the world's difficult problems. Therefore, it is of great theoretical and practical significance to study and solve the stability problem of expansive soil slope. There are two main methods for calculating the instability of unsaturated soil slopes: the limit equilibrium method of traditional methods and the new strength reduction finite element method. Compared with the traditional limit equilibrium method, the strength reduction finite element method has some advantages in slope stability analysis.

The shear strength formulas of unsaturated soils include the strength of unsaturated soils based on single effective stress and the strength of unsaturated soils based on double stress variables. Because the strength of unsaturated soils with single effective stress and the strength of unsaturated soils with double stress variables are difficult to test and determine the parameters, Lu Zhaojun and others put forward the third theoretical formula of shear strength of unsaturated soils. Although the formula of strength of unsaturated soils is used to measure the expansive force and determine the relative parameters. It is simple, but its application in expansive soil slope engineering needs further study.

Therefore, this paper develops a strength reduction calculation program based on the strength of unsaturated expansive soil of Lu Zhaojun, and verifies the strength reduction calculation method based on the strength of unsaturated expansive soil of Lu Zhaojun through an example, in order to provide an effective method for analyzing the stability of unsaturated expansive soil slope.

2. The Principle of Establishing Strength Reduction Finite Element Method based on Lu Zhaojun's Theory

In 1995, Lu Zhaojun et al. proposed the third theoretical formula for shear strength of unsaturated soils:

$$\tau_{\mathrm{f}} = c' + (\sigma - u_{\mathrm{a}})\tan\varphi' + mp_s \tan\varphi' \quad (1)$$

In the formula: τ_{f} is the ultimate shear strength of unsaturated soils; c' is effective cohesion; σ is normal stress; u_{a} is pore pressure; φ' is the effective internal friction angle; p_s is expansion force of unsaturated soil measured by immersion under volume-invariant conditions; m is the effective coefficient of expansive force.

The theoretical formula for shear strength of unsaturated soils proposed by Lu Zhaojun is deformed into:

$$\tau_{\mathrm{f}} = c' + \left[(\sigma - u_{\mathrm{a}}) + mp_s\right]\tan\varphi' \quad (2)$$

Lu Zhaojun et al. Found that the expansive force can be expressed as a power function of water content ω by sorting out and regression analysis of test data of soil and calcareous soil in Guangxi:

$$p_s = a\omega^{\lambda} \tag{3}$$

In the formula: a and λ are parameters determined by the properties of soils.

For formula (3), the common logarithm is taken at the same time on both sides:

$$\lg p_s = \lg a + \lambda \lg \omega \tag{4}$$

Expansion force p_s can be described by power function of water content ω. Therefore, after the parameters a and λ of a certain kind of soil have been measured in the laboratory, the expansive force in practical engineering can be predicted by water content.

Based on the strength reduction finite element program of Lu Zhaojun unsaturated expansive soil, the displacement increment isoline between adjacent reduction coefficients is used to describe the internal characteristics of the slope. The closest point of the isometric displacement increment isoline is the location of the potential sliding surface, which is the maximum gradient of displacement increment.

3. Stability Analysis of Expansive Soil Slope

3.1. Project survey

Based on the strength reduction finite element program of Lu Zhaojun unsaturated expansive soil and the strength reduction finite element program of other two kinds of strength, the stability of expansive soil slope of an expressway in Ankang is calculated and analyzed. The numerical model is shown in Fig.1. The groundwater level is 3 m below the surface.

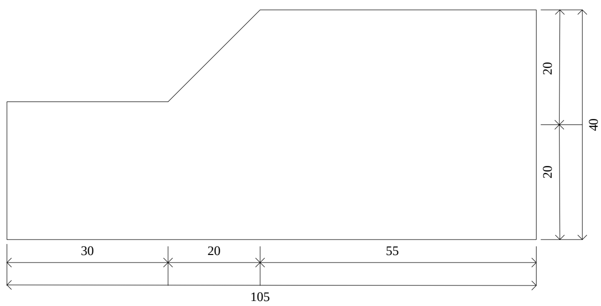


Figure 1. Schematic diagram of slope dimension(m)

3.2. Calculating parameters

The stability of expansive soil slope of an expressway in Ankang is calculated and analyzed.

The effective stress formula for shear strength of unsaturated soils proposed by Bishop et al. is as follows:

$$\tau_f = c' + (\sigma - u_a)\tan\varphi' + \chi(u_a - u_\omega)\tan\varphi' \tag{5}$$

In the formula: u_ω is pore water pressure; χ depends on the saturation, soil type, dry-wet cycle and stress path of loading and suction.

The effective stress formula for shear strength of unsaturated soils with Fredlund double stress variable is as follows:

$$\tau_f = c' + (\sigma - u_a)\tan\varphi' + (u_a - u_\omega)\tan\varphi_b \tag{6}$$

In the formula: $\tan\varphi_b$ is the internal friction coefficient of suction $(u_a - u_\omega)$.

The theoretical formula of shear strength of unsaturated soils proposed by Lu Zhaojun is as follows:

$$\tau_f = c' + (\sigma - u_a)\tan\varphi' + mp_s\tan\varphi' \tag{7}$$

The typical physical and mechanical indexes of expansive soil along an expressway in Ankang are as follows:

$$\begin{aligned} &\gamma = 19.64kN/m^3, \\ &E = 19Mpa, v = 0.3, \\ &c' = 32kPa, \varphi' = 17°, \\ &\varphi'_b = 12°, x = 0.6954, \\ &m = 1.424, A = 8.31429\times 109, \\ &\lambda = 5.4292 \end{aligned} \tag{8}$$

3.3. Computing scheme

Calculating working conditions 1-1. Considering the influence of matrix suction and the non-uniform distribution of matrix suction, the strength reduction finite element program based on Bishop single-value effective stress formula was used to analyze.

Calculating working conditions 1-2. Considering the influence of matrix suction and the non-uniform distribution of matrix suction, the strength reduction finite element program based on Fredlund's two-stress variable formula was used to analyze the matrix suction.

Calculating working conditions 1-3. Considering the effect of suction equivalent expansive force, the maximum expansive force exists and the suction equivalent expansive force is non-uniformly distributed. The strength reduction finite element program based on Lu Zhaojun's unsaturated soil strength formula is used for analysis.

Calculating working condition 2. When the matrix suction is lost, the conventional strength reduction finite element program is used for analysis.

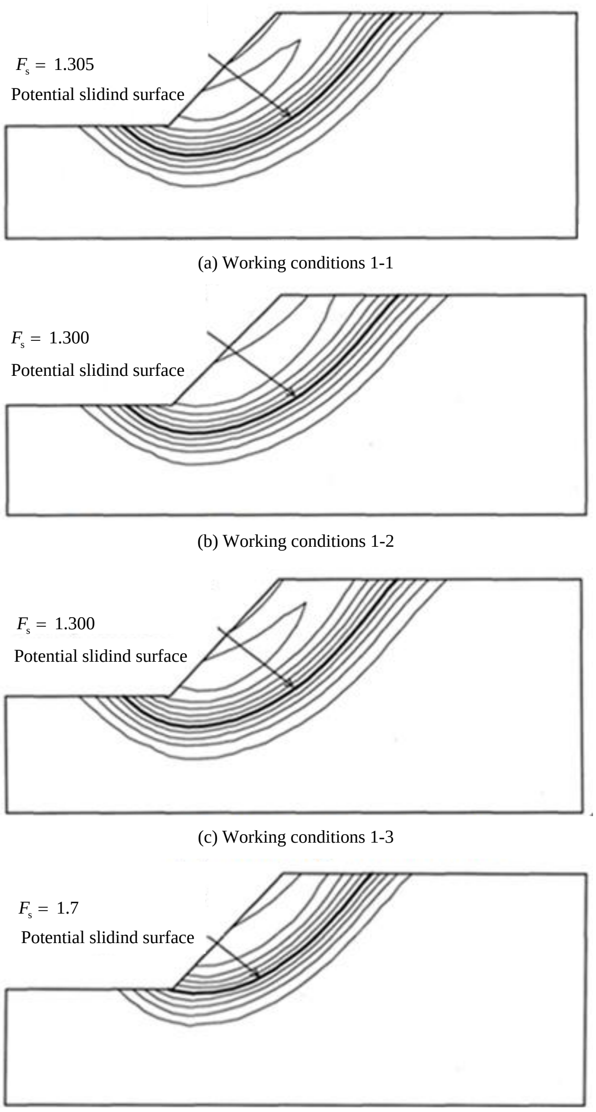
3.4. Calculation and analysis of working conditions

Considering the non-uniform distribution of matric suction, the strength reduction finite element program based on Bishop single-value effective stress formula is used to calculate the slope safety factor $Fs = 1.305$, as shown in Fig. 2(a).

Considering the non-uniform distribution of matric suction, the strength reduction finite element program based on Fredlund's two-stress variable formula is used to analyze the working condition 1-2, and the slope safety factor $F = 1.300$ is calculated, as shown in Fig. 2 (b).

Considering the non-uniform distribution of the maximum expansive force, the strength reduction finite element program based on Luzhaojun's unsaturated soil strength theory formula is used to calculate the slope safety factor $Fs = 1.300$, as shown in Fig. 2 (c).

In the case of loss of matrix suction, the conventional strength reduction finite element program is used to analyze the calculation condition 2, and the slope safety factor $Fs = 1.17$ is calculated, as shown in Fig.2 (d).



(d) Working conditions 2

Figure 2. Contour of displacement increment

Comparing the numerical results of three kinds of unsaturated soil strength reduction finite element methods, the calculation conditions of three kinds of unsaturated soil strength reduction finite element methods are the same, the safety factors of calculation conditions 1-1, 1-2 and 1-3 are basically the same, and the position of potential sliding surface is also consistent. It shows that the strength reduction finite element program based on the strength of Lu Zhaojun unsaturated soil is developed. Successfully achieved the expected engineering effect.

4. Conclusion

According to Lu Zhaojun's theoretical formula of shear strength of unsaturated soils, the strength parameters of unsaturated expansive soils are not changed in the effective stress space, which determines the strength failure surface of unsaturated expansive soils in the effective stress space. By using the product of expansive force and expansive force parameters, the shear strength of unsaturated expansive soils is superimposed on the original effective stress state, forming a new one. Considering the effective stress state of expansive force, the non-uniformity of strength of unsaturated soil is solved.

The stability of unsaturated expansive soil slope is analyzed by strength reduction finite element method based on the strength of Lu Zhaojun unsaturated expansive soil and strength reduction finite element method based on the strength of other two kinds of strength. When the calculation conditions of the slope are the same, the stability analysis results tend to be consistent, that is, based on the strength of Lu Zhaojun unsaturated expansive soil. The strength reduction finite element method can provide an effective method for unsaturated expansive soil slope engineering.

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