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Analysis on the influence of heavy rainfall on slope stability

Xiaoguang Zhao, Yanjie Sun[*] and Qiuyan Feng

College of Geology & Environment, Xi' an University of Science and Technology, Xi'an, China

*Corresponding author e-mail:747720426@qq.com

Abstract. A total of 200 rainfall models were constructed with the slope ratio, rainfall intensity and rainfall duration as the variables for the stable state changes of the loess slope under rainfall conditions. Based on the Fredlund theory combined with the finite element numerical simulation software and the soil mechanics method, the changes of the volume water content and pore water pressure of the slope slope with the rain intensity and the rainfall time were analyzed, and the limit equilibrium theory was obtained. The results show that the rainfall time of the lower slope is different in different rainfall intensity. In the case of slope gradient, the corresponding stability coefficient will decrease with the increase of rain intensity. With the increase of rainfall, the contours of the volume water content and pore water pressure of the slope shoulder and slope foot are becoming more and more intensive.

1. Introduction

Northwest China's terrain complex, high terrain, the surface covered with a large number of loess. Numerous studies have shown that [1-4] the slope instability occurs mainly in the rainy season, and rainfall has become a major factor causing slope instability. The slope instability caused by rainfall is mainly caused by the rainfall infiltration, which leads to the increase of soil moisture content and pore water pressure in the slope, which leads to the decrease of the matrix suction in the slope soil until its disappearance and the decrease of the shear strength of the soil. Soil weight increases, which in turn adversely affects the stability of the slope. A large number of indoor and outdoor rainfall experiments, statistical analysis and numerical simulation are carried out for domestic and foreign scholars [5-11] on the mechanism and laws of rainfall-induced slope failure. Geo-studio software is widely used in numerical simulation of slope instability in geotechnical engineering. Different modules can be selected according to different needs for analysis. The results of the analysis are of scientific value and great value. In this paper, based on the fundamental theory of double-stress strength of Fredlund unsaturated soils, combined with Geo-studio SEEP/W module (transient saturated-unsaturated seepage finite element method) and SLOPE/W module Rainfall intensity and the effect of rainfall on slope stability are analyzed to provide theoretical guidance for prevention and treatment of loess slope instability induced by rainfall.

2. Basic principle

At present, the research results on the stability analysis of unsaturated soil slopes are mostly based on the unsaturated soil strength theory formula proposed by Bishop et al. And Fredlund et al. However, the non-saturation intensity theory proposed by Fredlund is more accurate and applied to a broader analysis. Based on the Mohr-Coulomb failure criterion, Fredlund proposed the use of the unique stress state variables of unsaturated soils to describe the strength of unsaturated soils [12], and the shear strength formula.

$$\tau_f = c' + (\sigma - u_a)\tan\varphi' + (u_a - u_w)\tan\varphi^b \quad (1)$$

Where c' is the effective cohesion; (σ-u_a) is the net normal stress; φ' is the effective internal friction angle; ua is the pore pressure; u_w is the pore water pressure; ; φ^b is the suction friction angle; (u_a-u_w) tanφ^b is the adsorption strength (the intensity provided by the substrate suction).

Based on the physical and mechanical parameters of the main loess in western China, a variety of slope models were established using rainfall intensity, rainfall duration and slope gradient as variables. The slope stability coefficient was analyzed by using Fredlund theory and Geo-studio numerical simulation software. The SEEP/W module in Geo-studio is mainly used to analyze the transient seepage analysis of unsaturated loess under rainfall conditions and simulate the changes of internal water content and pore water pressure under different rainfall intensity and rainfall. Based on the analysis results The SLOPE/W method is used to calculate the slope stability coefficient under different slopes

3. Parameter selection and model establishment

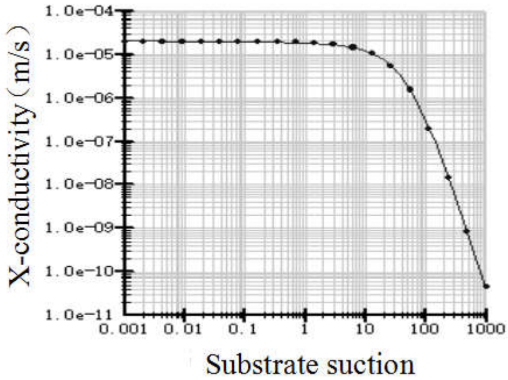
3.1. Parameter Selection

The topsoil in northern Shaanxi mainly consists of Malan loess and Lishi loess. According to the relevant literature data of loess physical and mechanical parameters in northern Shaanxi [13, 14], the physical parameters of the model are given here. According to the characteristics of loess, slope types and rainfall types in northern Shaanxi, 200 slope models were established with slope gradient, rainfall intensity and rainfall duration as variables. The slope of the model is respectively slope ratio of 1:1.25, 1:1,1:0.75,1:0.5 and slope slope of 90°. According to “rainfall level” (GB/T 28592-2012) Divided into eight grades, heavy rainfall intensity of rainfall, in a short period of time can have a huge impact on the stability of the slope, so this paper selected the rainfall within 12h as the research object, set the rainfall intensity and from small The major orders are: rainfall intensity 1, rainfall intensity 2, rainfall intensity 3 and rainfall intensity 4, the specific parameters are 3.47×10^{-7}m /s, 6.94×10^{-7}m/s, 1.62×10^{-6}m/s and 3.24×10^{-6}m /s. In order to analyze the change of slope body during rainfall, the duration of rainfall is 2.4h, 4.8h, 7.2h, 9.6h, 12h, 14.4h, 16.8h, 19.2h and 21.6 h and 24h.

Table 1. Physical mechanics parameters of loess.

Severe (kN/m^3)	Deformation modulus/MPa	Poisson's ratio	φ/ (°)	Cohesion	Permeability coefficient/ (m·s)	Porosity
20	2	0.38	25	35	2×10^{-5}	0.52

In this paper, the hydraulic parameters in the calculation process are derived from the built-in functions in the SEEP/W module. The infiltration curve is generated by the built-in Van. Genuchten model. Soil water characteristic curve and permeability coefficient function curve shown in Figure 1 and Figure 2.



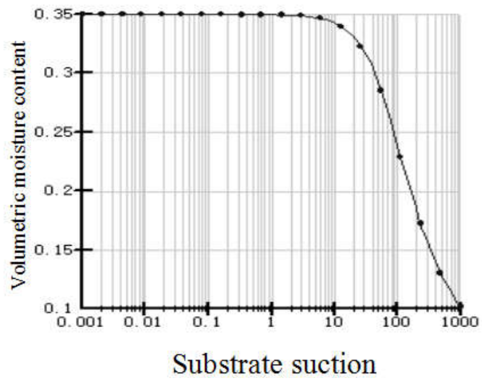


Figure 1. Curve of soil permeability coefficient. **Figure 2.** Curve of soil water characteristic function.

3.2. Model Establishment

Set the slope height of 15m, slope ratio was 1:1.25,1:1,1:0.75 and 1:0.5, the physical parameters of the model shown in Table 1. The model uses the boundary conditions (unit flow) as the rainfall intensity and sets the total flow on both sides of the slope model to zero. Since this article does not consider the effect of groundwater, the total flow at the bottom of the model is set to zero. Precipitation is viewed as acting vertically on the ground. Usually the rains range from the top of the slope to the top of the slope, but at a slope of 90°, the slope is considered as free from any rainfall. Due to the different rainfall ranges at 90° and non-90°, two major categories of rainfall models are presented in this paper.

4. Calculation results and analysis

4.1. Calculation Results

The established model is analyzed by using SEEPW module and SLOPE/W module in Geo-studio. Based on the established model, the calculation results are summarized according to the slope ratio respectively. The result is shown in Fig.4(The square in the figure represents rain intensity 1, the circular shape represents rain intensity 2, the right triangle represents rain intensity 3, and the inverted triangle represents rain intensity 4).

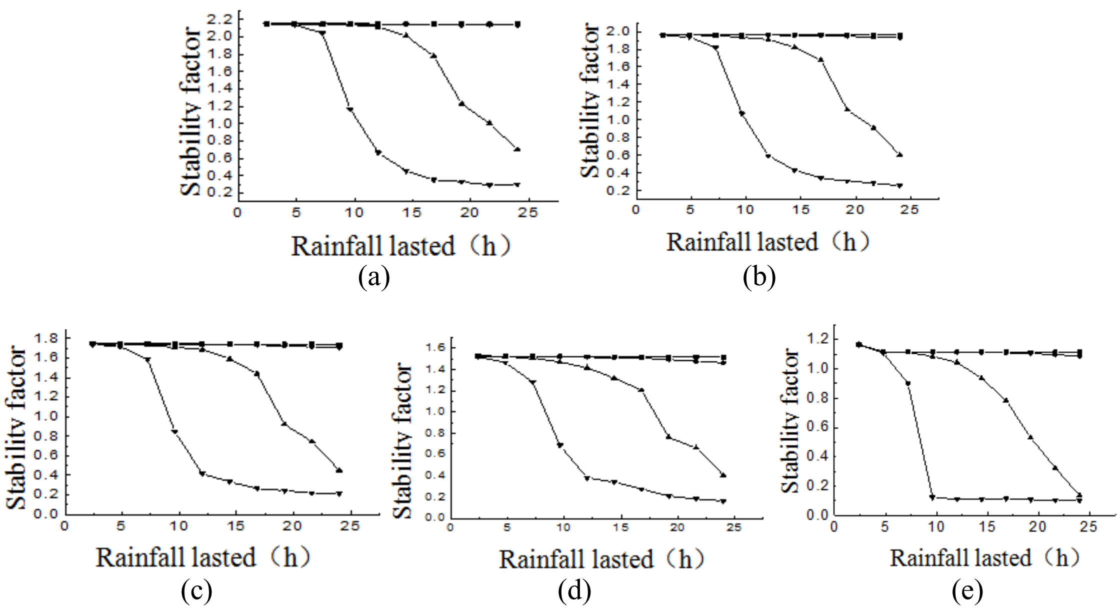


Figure 3. Variation of slope stability coefficient under different slope and rainfall conditions.

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We can find the following results under different slopes and rainfall conditions: When slope gradient is different, the corresponding stability coefficient will gradually decrease with the increase of rainfall intensity. At the same time, the order of stability coefficient of four rainfall intensities is as follows: rainfall intensity 4 <rainfall intensity 3 <Rain intensity 2 <rainfall intensity 1, but the decreasing trend of stability coefficient corresponding to rainfall intensity 1 and rainfall intensity 2 is not obvious; and the decrease of stability coefficient corresponding to rainfall intensity 3 and rainfall intensity 4 is obvious.

When the gradient of the slope is not 90 °, when the rainfall intensity is rain intensity 3 and rainfall intensity 4, the slope stability coefficient will decrease immediately when the slope instability occurs, and the reduction rate is larger. Under different slope conditions, the change tendency of slope stability coefficient with the same rain intensity is basically the same.

4.2. Result analysis

According to Figure 3, we can find the following results under different slopes and rainfall conditions: When slope gradient is different, the corresponding stability coefficient will gradually decrease with the increase of rainfall intensity. At the same time, the order of stability coefficient of four rainfall intensities is as follows: rainfall intensity 4<rainfall intensity 3<Rain intensity 2<rainfall intensity 1, but the decreasing trend of stability coefficient corresponding to rainfall intensity 1 and rainfall intensity 2 is not obvious; and the decrease of stability coefficient corresponding to rainfall intensity 3 and rainfall intensity 4 is obvious. When the gradient of the slope is not 90°, when the rainfall intensity is rain intensity 3 and rainfall intensity 4, the slope stability coefficient will decrease immediately when the slope instability occurs, and the reduction rate is larger.

In order to further analyze the influence of slope ratio on slope stability, the influencing factors of slope stability are analyzed here using the model of clay slope. As shown in Figure 7, the AC is assumed to be a sliding surface with O as the center and R as the radius. When the soil ABC is stable, it must meet the moment balance condition (the normal reaction force N on the arc is passed through the center of the circle), so the stable safety factor is shown in Eq. (2) [9].

$$K = \frac{\tau_f \widehat{AC} R}{Ga} \tag{2}$$

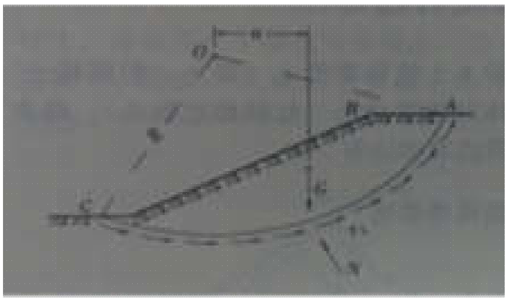

Figure 4. Overall arc sliding of homogeneous soil slope.

Figure 4 shows that the main factors affecting the slope stability are the anti-skid moment and sliding moment. Combined with equation (2), it can be seen that in the case of constant sliding torque, the magnitude of anti-slip torque determines the stability factor. In this paper, four different slope ratios are constructed under non-90 ° conditions. The smaller the slope ratio, the greater the anti-slip torque. As can be seen from Figure 6, the volumetric water content due to rainfall basically does not change with the change of slope, so we can assume that the sliding torque is constant. According to Eq. (2), we can get the difference between two different slope ratios is a constant. It shows that the trends of different slope ratios are the same in the case of non-90 °, and the ratio of the stability coefficient in the same rainfall time is a constant.

When the gradient of the slope is 90 °, the volumetric water content from the slope to the slope hardly changes. The volumetric water content and pore water pressure at the foot of the slope increase with the increase of rainfall and increase with the increase of rainfall Shear damage. Since the slopes are not directly infiltrated by rainwater, the sliding moment of the slope at 90 ° must not be the same as the sliding moment at other slopes, so it cannot be the same as the stability coefficient at other slopes.

5. Conclusion

Based on Fredlund theory and finite element numerical simulation software and soil mechanics method, the changes of volumetric water content and pore water pressure with different slope slopes within 24 hours with the changes of rainfall intensity and rainfall time were analyzed and obtained by the theory of limit equilibrium Due to the slope stability coefficient after rainfall intensity and slope change, the following conclusions are obtained:

The rainfall time when the slope reaches the instability under different rainfall intensity is different. When the gradient of the slope is not 90 °, the following conclusions are drawn: during the rainfall period of 24h, rainfall intensity 1 and rainfall intensity 2 do not cause slope instability, The stability coefficient decreases slightly with the increase of rainfall duration. When the rainfall intensity is rainfall intensity 3, the slope instability occurs when the rainfall duration is 19.2h; when the rainfall intensity is rainfall intensity 4, Rainfall lasted 9.6h instability occurred. When the slope is 90°, the slope instability occurs under rainfall.

Under the condition of different slopes, the corresponding stability coefficient will gradually decrease with the increase of rainfall intensity. At the same time, the order of stability coefficients of four rainfall intensities is as follows: rainfall intensity 4 < Rainfall intensity 3 <Rain intensity 2 <Rain intensity 1, but the decreasing trend of stability coefficient corresponding to rainfall intensity 1 and rainfall intensity 2 is not obvious. The decrease of stability coefficient corresponding to rainfall intensity 3 and rainfall intensity 4 obvious. In all the different slopes than the case (except 90°), the trend of slope stability coefficient of the same rainfall intensity is basically the same.

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