Research Article

Analytical Analysis of Infinite Heterogeneous Slope Stability considering Suction Influence

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Soil heterogeneity in an infinite unsaturated slope increases the difficulty of analysing its stability. A common method of modelling the spatial variability in the slope stability analysis is to use random fields together with Monte Carlo simulation, but this requires an impressive amount of computational efforts. To reduce the computing time, this paper develops an analytical approach to study the stability of infinite heterogeneous unsaturated slopes. The analytical method provides a newly time-efficient way of analysing such kinds of slopes. It has been used to investigate the stability of four different kinds of unsaturated soil slopes. Meanwhile, the influences of the correlation between the strength parameters and the autocorrelation length of the strength parameters are investigated. The analysed results show that the suction has influences on the distribution of the FOS for both homogeneous slopes and heterogeneous slopes. In addition, the correlation coefficient between the strength parameters and the autocorrelation length of the strength parameters affects the mean and standard deviation of FOS for homogeneous slopes and the probability of failure for heterogeneous slopes.

1. Introduction

Slopes are commonly seen structures in engineering, such as large open-pit mines [1, 2] and hydropower engineering [3, 4]. The slope stability is of great concern to those projects. For the shallow failure occurrence in soil slopes, the slope is often deemed as an infinite slope. The stability of the infinite slope is usually evaluated by the limit equilibrium method [5–7] or finite element method [8, 9]. Traditional way of characterising the stability is in terms of a factor of safety (FOS) [10].

However, natural soils are heterogeneous [11, 12]. It is the prerequisite for an accurate analysis to incorporate soil heterogeneity in the slope stability analysis [13, 14]. Since the 1970s, probabilistic analysis of slope stability has been developed and gradually replaced the traditional single FOS method [15–17]. Several probabilistic methods have been developed and applied since then [18, 19], such as first-order second moment (FOSM) method, first-order reliability method (FORM), point estimate method (PEM), and Monte Carlo method (MCM). The simple method, e.g., FOSM, FORM, and PEM, only accounts for the distribution of soil properties, i.e., the mean and standard deviation. The advanced method, i.e., MCM, together with the random field theory can account for the spatial variability of soil properties. However, the MCM requires loads of computational efforts as it needs to generate multiple realisations of random field of soil parameters.

To overcome the disadvantage of MCM, Cai et al. [20] developed an analytical method which can account for both the distribution and the spatial correlation of soil properties. This analytical method saves a lot of time compared to the time-consuming MCM. However, the method developed by Cai et al. [20] is limited to dry slope, in which it assumes there is no water flow in the slope. They do not take the influence of suction into consideration. In reality, the effect of suction on slope stability has been confirmed to be significant [21–26]. Therefore, in this paper, the authors extend the analytical method to investigate the influence of suction on the probabilistic analysis of unsaturated slope stability.

The paper is organised as follows. First, the analytical method which includes the effect of suction is developed. Then, the method is validated with a previous research paper. After that, the method is applied to conduct the
probabilistic analysis of infinite unsaturated slopes. Four different types of soil slopes have been taken as examples. These four different types of soil generally represent a wide range of soils so that it assures the suction variation is representative.

2. Analytical Formulation of Slope Stability

An infinite slope example is investigated. The slope geometry is shown in Figure 1. The slope angle is $\theta$, $H$ and $L$ are the depths of the infinite slope and the ground water table, respectively.

2.1. Deterministic Analysis of Infinite Unsaturated Slope Stability

2.1.1. Hydraulic Behavior of Unsaturated Soil

The matric suction of point A (Figure 1) in the hydrostatic state at depth $H$ is [27, 28]

$$ \psi = \gamma_w (L - H) \cos^2 \alpha_{\text{inf}}, $$

where $\psi$ is suction and $\gamma_w$ is the unit weight of water. The suction decreases linearly with the increase of the depth.

The soil water retention behavior can be modelled by Fredlund and Xing [29]:

$$ \theta_w = \frac{1 - \ln \left(1 + (\psi/\psi_r) \right)}{\ln \left(1 + (10^{\theta_r}/\psi_r) \right)} \frac{\theta_r}{\ln \left(1 + (\psi/\psi_r) \right)} $$

where $\theta_r$ is the volumetric water content, $\psi_r$ is the residual suction, $a_f$ is the suction value at the inflection point and is related to the air entry value of the soil, $n_f$ is the slope of the water retention curve at the inflection point, and $m_f$ is the fitting parameter related to the residual volumetric water content.

2.1.2. FOS of Infinite Unsaturated Slope

The FOS of an infinite slope at depth $H$ which considers the influence of suction can be expressed as [28]

$$ \text{FOS} = \frac{c'}{\gamma H \sin \alpha_{\text{inf}} \cos \alpha_{\text{inf}}} + \frac{\tan \phi'}{\tan \alpha_{\text{inf}}} + \frac{c(\psi)}{\gamma H \sin \alpha_{\text{inf}} \cos \alpha_{\text{inf}}}, $$

where $c'$ is the effective cohesion, $\phi'$ is the effective friction angle, and $\gamma$ is the total unit weight of the soil. $c(\psi)$ is the suction-induced apparent cohesion and can be modelled by Fredlund et al. [30]:

$$ c(\psi) = \psi \Theta_r \tan \phi', $$

$$ \Theta_r = \frac{\psi}{\theta_w}, $$

where $\Theta_r$ is the dimensionless water content and $k$ is the fitting parameter.

2.2. Analytical Formulation Used for Probabilistic Slope Stability Analysis

2.2.1. Homogeneous Slopes

For homogeneous slopes, strength parameters $c'$ and $\phi'$ are assumed to be normally distributed, whereas the spatial variability of strength parameters is not included, which means the parameters are uniform across the whole domain.

Since both $c'$ and $\phi'$ are assumed to follow normal distribution and Equation (3) is a linear equation, so the distribution of the FOS is also normal. In addition, it can be seen from Equation (3) that the FOS decreases with the increase of depth. The minimum value of FOS is corresponding to the maximum depth of the infinite slope, i.e., $H$. The mean and standard deviation of FOS at depth $H$ is derived based on Equations (3)–(5) as

$$ \mu_{\text{FOS}} = \frac{\mu_{\psi}}{\gamma H \sin \alpha_{\text{inf}} \cos \alpha_{\text{inf}}} \tan \phi' + \frac{\mu_{\tan \phi'}}{\tan \alpha_{\text{inf}}} + \frac{\gamma H (L - H) \cos^2 \alpha_{\text{inf}} \Theta_r \mu_{\tan \phi'}}{\gamma H \sin \alpha_{\text{inf}} \cos \alpha_{\text{inf}}}, $$

$$ \sigma^2_{\text{FOS}} = \frac{\sigma^2_{\psi}}{(\gamma H \sin \alpha_{\text{inf}} \cos \alpha_{\text{inf}})^2} + \frac{\gamma H (L - H) \Theta_r}{\gamma H \tan \alpha_{\text{inf}}} \mu_{\tan \phi'}^2 + \frac{2 \gamma H (L - H) \Theta_r}{\gamma H^2 \sin^2 \alpha_{\text{inf}}} \sigma^2_{\tan \phi'} \rho_{c' \tan \phi'}^2 \sigma_{\tan \phi'}^2, $$

where $\mu_{\text{FOS}}$ and $\sigma_{\text{FOS}}$ are the mean and standard deviation of the FOS. $\mu_{\psi}$ and $\sigma_{\psi}$ are the mean and standard deviation of the effective cohesion, and $\mu_{\tan \phi'}$ and $\sigma_{\tan \phi'}$ are the mean and standard deviation of $\tan \phi'$. $\rho_{c' \tan \phi'}$ is the correlation coefficient between the effective cohesion and friction angle.
As long as the mean and standard deviation of the FOS are calculated, the normal distribution is determined. Therefore, the probability of failure can be calculated as

\[ p_f = p(\text{FOS} < 1) = \Phi\left(\frac{1 - \mu_{\text{FOS}}}{\sigma_{\text{FOS}}}\right), \]  

(8)

where \( \Phi(\cdot) \) is the cumulative standard normal function.

### 2.2.2. Heterogeneous Slopes

In infinite heterogeneous slopes, the spatial variability of the strength parameters is considered, which means the strength parameters vary with depth. The slope could fail at any depth from the top \( z = 0 \) to the base \( z = H \). The corresponding FOS at any depth \( z_j \) is denoted as \( \text{FOS}_i \). Thus, the probability of failure of an infinite heterogeneous slope can be written as follows:

\[ p_f = 1 - P[\text{FOS}_1 \geq 1, \text{FOS}_2 \geq 1, \ldots, \text{FOS}_N \geq 1]. \]  

(9)

To be precise, the number of slip surfaces, i.e., \( i \) in the above equation, should be infinite. In practice, in order to solve Equation (9), a large but finite number of slip surfaces \( N \) have been approximated. Then, the probability of failure is approximated as [20]

\[ p_f = 1 - P[\text{FOS}_1 \geq 1, \text{FOS}_2 \geq 1, \ldots, \text{FOS}_N \geq 1]. \]  

(10)

The mean of FOS at different depths \( z \) (\( 0 \leq z \leq H \)) is

\[ \mu_{\text{FOS}} = \frac{\mu_{\text{FOS}}}{y_z \sin \alpha_{\text{inf}} \cos \alpha_{\text{inf}}} + \frac{\gamma_{z} + \gamma_{w}(L - z)\Theta_{d}^{\text{c}}}{y_z \tan \alpha_{\text{inf}}} \mu_{\tan \phi}. \]  

(11)

The covariance of FOS at different depths is

\[ R_{\text{FOSFOS}} = \frac{R_{\text{c}'c'}}{(y_{\text{z}} \sin \alpha_{\text{inf}} \cos \alpha_{\text{inf}})^2 z_{zj}} + R_{\tan \phi' \tan \phi} \left[ \frac{y_{\text{z}} + \gamma_{w}(L - z)\Theta_{d}^{\text{c}}}{y_{\text{z}} \tan \alpha_{\text{inf}}} \right] + R_{\tan \phi \tan \phi'} \left[ \frac{y_{\text{z}} + \gamma_{w}(L - z)\Theta_{d}^{\text{c}}}{y_{\text{z}} \tan \alpha_{\text{inf}}} \right] \]  

(12)

where \( \mu_{\text{FOS}} \) is the \( N \times 1 \) mean vector of FOS, \( R_{\text{FOSFOS}} \), and \( R_{\tan \phi \tan \phi'} \) are the \( N \times N \) auto-covariance matrices for FOS, \( \tan \phi' \) and \( \tan \phi \). \( R_{\tan \phi \tan \phi'} \) is the \( N \times N \) cross-covariance matrix between \( \tan \phi \) and \( \tan \phi' \).

The auto-covariance matrices \( R_{\text{c}'c'} \) and \( R_{\tan \phi \tan \phi'} \) can be calculated based on Li et al. [31]

\[ R_{\text{c}'c'} = \sigma_{\text{c}'c'} C_{\text{c}'c'}, \]  

(13)

and the deviation of the cohesion of each slip surface. \( \sigma_{\text{c}} \) is the standard deviation of the cohesion of the \( i \)th slip surface. \( \rho(\tau_{ij}) \) is the correlation between \( \tau_{ij} \) and \( \tau_{ji} \), where \( \tau_{ij} \) is the distance of the two slip surfaces \( i \) and \( j \) in the \( y \) direction. An exponential function is employed in this paper to calculate the correlation.

\[ \rho(\tau) = \exp \left( -\frac{2\tau}{\lambda} \right), \]  

(15)

where \( \lambda \) is the correlation length, over which the soil parameters are correlated.

The cross-covariance matrices \( R_{\tan \phi \tan \phi'} \) can be calculated as [32]

\[ R_{\tan \phi \tan \phi'} = \sigma_{\tan \phi} C_{\tan \phi \tan \phi'}, \]  

(16)

where \( \sigma_{\tan \phi} \) and \( \sigma_{\tan \phi'} \) are the \( N \times N \) diagonal matrix of the standard deviation of the cohesion and \( \tan \phi' \) of each slip surface. \( C_{\tan \phi \tan \phi'} \) is the cross-correlation matrix and can be expressed as

\[ \sigma_{\tan \phi} = \begin{bmatrix} \sigma_{\tan \phi_1} & 0 & \cdots & 0 \\ 0 & \sigma_{\tan \phi_2} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \sigma_{\tan \phi_N} \end{bmatrix}, \]  

(17)
4. Analytical Analysis of an Infinite Slope

The geometry of the example infinite slope is shown in Figure 1. The parameters used in the paper are listed in Tables 1 and 2. In order to check the suction influence for different types of soil, four types of soil with four different soil water characteristic curves (SWCCs) were selected to investigate the stability of the infinite slope. The parameters of the four SWCCs are listed in Table 2. The four SWCCs with different parameters, which are sandy soil, fine-grained soil (e.g., silt), clays, and extremely fine-grained soil, generally cover various types of soil [28].

4.1. Homogeneous Slopes. In homogeneous slopes, the cohesion and friction angle are both assumed to be constant across the depth. Equations (6) and (7) are used to calculate the mean and standard deviation of the FOS for the four different soil slopes. The correlation coefficient between \( c' \) and \( \tan \phi' \) is assumed to be 0.

Figure 2 shows the result of the comparison. From the figure, it can be seen that the results calculated by this paper are consistent with the results from Cai et al. [20], which proves the validity of the proposed method in this paper.

### Table 1: Parameters used for the example infinite slope.

| Parameters                   | Unit | Value |
|------------------------------|------|-------|
| Depth of ground water table \( L \) | m    | 10    |
| Unit weight of soil \( y_i \)    | kN/m³| 17    |
| Unit weight of water \( y_w \)    | kN/m³| 10    |
| Slope angle \( \alpha_{inf} \)   | °     | 30    |
| Saturated volumetric water content \( \theta_i \) | —    | 0.4   |
| Slope at inflection point \( n_f \) | —    | 2     |
| Fitting parameter \( m_f \) | —    | 1     |
| Residual volumetric water content \( \theta_r \) | —    | 0.081 |
| Mean of cohesion \( \mu_c \) | kPa  | 10    |
| Standard deviation of cohesion \( \sigma_c \) | kPa  | 3     |
| Mean of \( \tan \phi' \) \( \mu_{tan \phi'} \) | —    | 0.5774 |
| Standard deviation of \( \tan \phi' \) \( \sigma_{tan \phi'} \) | —    | 0.17322 |

be solved by using the method proposed by Genz [33].

\[
p_f = 1 - P[FOS_1 \geq 1, FOS_2 \geq 1, \ldots, FOS_N \geq 1] = 1 - \left( \frac{1}{(2\pi)^{N/2}} \right) \left[ \frac{1}{(R_{FOS})^{1/2}} \right] \times \int_{1}^{\infty} \cdots \int_{1}^{\infty} \exp\left(-\frac{1}{2}(FOS - \mu_{FOS})^2 \right) dFOS_1 \cdots dFOS_N.
\]

### Table 2: Parameters for water retention behavior.

| Soil type     | Matric suction at inflection point \( \alpha \) (kPa) | Residual suction \( \psi_r \) (kPa) | Fitting parameter \( k \) (-) |
|---------------|------------------------------------------------------|-----------------------------------|-----------------------------|
| Sandy soil    | 1                                                     | 10                                | 1                           |
| Fine-grained soil | 10                                                | 100                               | 1.8                         |
| Clays         | 100                                                   | 1000                              | 2.2                         |
| Extremely fine-grained soil | 1000                                           | 10000                             | 2.5                         |

3 kPa. The mean and standard deviation of \( \tan \phi' \) are 0.5574 and 0.17322. 200 potential slip surfaces are used to discretize the slope depth. Equation (15) is the correlation function used here. The correlation coefficient between \( c' \) and \( \tan \phi' \) is assumed to be 0.

Figure 2 shows the result of the comparison. From the figure, it can be seen that the results calculated by this paper are consistent with the results from Cai et al. [20], which proves the validity of the proposed method in this paper.

### 3. Validation of the Proposed Method

In order to check the validity of the proposed method, the calculated results are first compared with the results from Cai et al. [20]. Since in Cai et al. [20] the infinite slope is in a dry condition, the suction is not considered in this validation example. In this validation example, the following parameters are used: \( H = 5 \text{ m} \), \( \gamma = 17 \text{ kN/m}^3 \), and \( \beta = 30 \text{ s} \). Both \( \sigma_c' \) and \( \tan \phi' \) are considered to be random variables. The mean and standard deviation of \( \sigma_c' \) are 10 kPa and...
variations have opposite influence on the value of the FOS. When the cohesion and friction angle are positively correlated, the cohesion increases and the friction angle also increases; these two variations have the same influence on the value of the FOS. This causes larger variation of the FOS, i.e., the larger standard deviation of the FOS. Similarly, for the sandy soil and the fine-grained soil, the difference of \( \sigma_{FOS} \) between the cases with and without considering suction is not obvious. However, for the clays and extremely fine-grained soil, the difference becomes significant. For the extremely fine-grained soil, the increase of \( \sigma_{FOS} \) is the largest. From Figure 3, the influence of considering suction on the stability analysis of infinite slopes is found to be significant. For different types of soil, the influence is the largest for the extremely fine-grained soil.

To clearly demonstrate the effect of suction on the probability of failure of the infinite slope, the cumulative distribution functions (CDFs) under different correlation coefficients for four different soils have been shown in Figures 4 and 5. The CDF can be calculated based on the mean and standard deviation of the FOS since the FOS also follows a normal distribution. Figure 4 shows the CDFs under different correlation coefficients, which are \( \rho_c \tan \phi' = -1.0 \) for Figure 4(a), \( \rho_c \tan \phi' = -0.5 \) for Figure 4(b), \( \rho_c \tan \phi' = 0 \) for Figure 4(c), \( \rho_c \tan \phi' = 0.5 \) for Figure 4(d), and \( \rho_c \tan \phi' = 1.0 \) for Figure 4(e). From Figure 4, it can be found that with the increase of the correlation coefficient, the difference between the CDFs increases. For the sandy soil and fine-grained soil, the difference of CDF between the cases with and without considering the suction is not significant. For clays and the extremely fine-grained soil, the difference between the cases with and without considering the suction is significant. Moreover, when the correlation coefficient is 0 (Figure 4(c)), the CDFs of the sandy soil and fine-grained soil intersect with the CDF without considering suction. This intersection could affect the estimation of the probability of failure of the infinite slope. From Figures 4(c) and 4(d), when the correlation coefficient increases from 0 to 1.0, the influence on the estimation would become greater. This means that when the cohesion and friction angle of the sandy soil and the fine-grained soil become positively correlated, the stability analysis of the infinite slope without considering the suction influence could underestimate the probability of failure of the slope (\( p(FOS < 1.0) \)).

Figure 5 shows the CDFs for the four different types of soil. Figures 5(a)–5(d) represent the sandy soil, fine-grained soil, clays, and extremely fine-grained soil, respectively. It is evident that the difference of CDF between the cases with and without considering suction is not significant for the sandy soil and fine-grained soil, but for clays and the extremely fine-grained soil, the difference is significant. Additionally, it can be found from the CDFs for the sandy and fine-grained soil (Figures 5(a) and 5(b)) that the probability of failure of the slope (\( FOS < 1.0 \)) could be underestimated if suction is not considered. When the correlation coefficient increases, the underestimation could be worse. For example, in Figure 5(a), the difference between the case with \( \rho_c \tan \phi' = 1.0 \) and the case without considering suction is the largest. Furthermore, for the same type of soil, the mean of the FOS is the turning point of the CDFs considering suction. If a specific value of FOS other than 1.0 is chosen as a limit value, when the specific value is smaller than the turning point, the probability of failure increases with the increasing of the correlation coefficient. On the contrary, when the specific value is larger than the turning point, the probability of failure decreases with the increasing of the correlation coefficient.

4.2. Heterogeneous Slopes. In heterogeneous slopes, the cohesion and friction angle are both assumed to be varying with the slope depth. The values of cohesion in different depths are correlated, and so are the values of the friction angle. In addition, \( \phi' \) and \( \tan \phi' \) are cross-correlated. The autocorrelation \( \rho \) is used to describe the correlation between cohesions at different depths and can be characterised by an exponential correlation function shown in Equation (15). The autocorrelation length \( \lambda \) is related to the deposition process [34], so it is reasonable to assume that the autocorrelation lengths of the cohesion and friction angle are equal to each other [35].
The slope depth is $H = 5$ m and is equally discretized into 200 potential slip surfaces along with the slope depth and the autocorrelation length is assumed to be 0.5 m, 2.5 m, 5 m, 10 m, 50 m, and 100 m, respectively. Other parameters remain the same as the parameters used in the previous computation of the homogeneous slope. The following figures show the comparison between the case with and without considering suction for different soils.

Figure 6 shows the variation of the probability of failure of the heterogeneous slope with the change of the following correlation coefficients: (a) $r'_{c} \tan \phi' = -1.0$, (b) $r'_{c} \tan \phi' = -0.5$, (c) $r'_{c} \tan \phi' = 0$, (d) $r'_{c} \tan \phi' = 0.5$, and (e) $r'_{c} \tan \phi' = 1.0$.

The slope depth is $H = 5$ m and is equally discretized into 200 potential slip surfaces along with the slope depth and the autocorrelation length is assumed to be 0.5 m, 2.5 m, 5 m, 10 m, 50 m, and 100 m, respectively. Other parameters remain the same as the parameters used in the previous computation of the homogeneous slope. The following figures show the comparison between the case with and without considering suction for different soils.

Figure 6 shows the variation of the probability of failure of the heterogeneous slope with the change of the
autocorrelation length for different soils. Figures 6(a)–6(e) represent the case without considering the suction, the sandy soil slope, the fine-grained soil slope, the clay slope, and the extremely fine-grained soil slope, respectively. For each figure, the different colour lines denote five different correlation coefficients between the cohesion and friction angle. First, it is found that the probability of failure decreases with the increasing of the autocorrelation length. From the curve, the decrease is dramatic when the autocorrelation length is small. A large autocorrelation length indicates that the soil property is varying slowly, while a small value indicates that it is varying rapidly [36]. When the autocorrelation length is small, the values of cohesion and friction angle along with the depth change greatly. This implies that the chance of holding some small values somewhere along with the slope depth increases, which is a disadvantage for the slope stability. Thus, the probability of failure of the slope is higher when the autocorrelation length is small.

Furthermore, comparing Figures 6(a)–6(e), it can be found that the probability of failure increases with the increasing of the correlation coefficients. The reason is that when the two parameters are negatively correlated, the effect of smaller values of one parameter on the FOS would be mitigated by large values of the other parameter. When the two parameters are positively correlated, the effect of smaller values of one parameter on the FOS would be amplified by small values of the other parameter.

Figure 7 shows the variation of the probability of failure of the heterogeneous slope with the change of the autocorrelation length for different correlation coefficients between the cohesion and friction angle. It can be seen from the figure that when suction is not considered in the stability
analysis of heterogeneous slopes, the probability of failure is higher than the cases considering suction. For clays and the extremely fine-grained soil, the probability of failure of the slope is relatively lower than that of the sandy soil slope and the fine-grained soil slope. The differences of the probability of failure between the case without considering suction and the clay slope or the extremely fine-grained soil slope are larger than those between the case without considering suction and the sandy soil slope or the fine-grained soil slope. From the figure, it can be concluded that the influence of the suction on the probability of failure of the clay slope and the extremely fine-grained soil slope is greater than that on the sandy soil slope and the fine-grained soil slope.
5. Conclusions

In this paper, an analytical approach has been developed to analyse the probability of failure of infinite heterogeneous unsaturated slopes. Compared to the commonly used method of linking random fields with Monte Carlo simulation, the analytical method is time-efficient and saves lots of computing time. It provides a new way of analysing the stability of infinite heterogeneous slopes. The new approach has been validated and demonstrated in the illustrative figures.

Figure 7: Probability of failure for different correlation coefficients: (a) $\rho_{c^* \tan \phi^*} = -1.0$, (b) $\rho_{c^* \tan \phi^*} = -0.5$, (c) $\rho_{c^* \tan \phi^*} = 0$, (d) $\rho_{c^* \tan \phi^*} = 0.5$, and (e) $\rho_{c^* \tan \phi^*} = 1.0$. 

No suction
Sandy soil
Clays
Extremely fine-grained soil
Fine-grained soil
example. In this example, four different types of soil slope with different SWCCs, which generally represent a wide range of soils, have been analysed.

The results have shown that if there is no spatial correlation in the strength parameters, i.e., homogeneous slopes, the mean and standard deviation of the FOS increase due to the suction. For the four different soils, when the cohesion and friction angle are correlated, the mean and standard deviation of the FOS increase with the increasing of the correlation coefficient. The effect of suction on the FOS of the clay slope and the extremely fine-grained soil slope is larger than that of the sandy soil slope and fine-grained soil slope.

For the heterogeneous slopes, the strength parameters are spatially variable. The probability of failure of the heterogeneous slope in which the suction is considered is smaller than that of the slope without considering suction. The probability of failure for a soil slope increases with the correlation coefficient. For clays and the extremely fine-grained soil, the probability of failure of the slope is relatively lower than that of the sandy soil slope and the fine-grained soil slope. Moreover, it is found that the probability of failure decreases with the increasing of the autocorrelation length. The decrease is dramatic when the autocorrelation length is small.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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