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# The Location of Critical Reliability Slip Surface in Soil Slope Stability Analysis

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**Abstract**

This study aims to find the difference between the slip surface having minimum factor of safety(called critical slip surface in deterministic analysis of slopes) and the slip surface having minimum reliability index(called critical reliability slip surface). The performance function used in reliability analysis was formulated by unbalanced thrust force method and the value of reliability index regarding given potential slip surface was obtained by Rosenbleuth method. The harmony search algorithm was adopted to alter the potential slip surface in order to locate the critical reliability slip surface. One complicated soil slope was analyzed and the results have shown that the critical slip surface is considerably different from critical reliability slip surface for multi-layer slopes and the reliability index of critical slip surface is larger than that of critical reliability slip surface.



*Keywords*: Slope stability analysis; limit equilibrium method; Reliability index; Rosenbleuth method; Harmony search algorithm

## 1. Introduction

The slope stability is usually performed by limit equilibrium method [1-3] because of its simplicity and extensive engineering experience. This method is usually named deterministic method because the property variables such as soil strength, soil density, and pore water pressure and so on are represented by single values. Traditionally, deterministic methods are used for the safety evaluation of soil slopes and the factor of safety is considered as an index of stability. Representing these variables by single values implies that the values are predicted with certainty, which the case is seldom. Slope stability problems are characterized by many uncertainties, and deterministic methods are unable to handle the uncertainties in

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the analysis, while the reliability analysis based on probability theory has been proven to be an alternative approach to the deterministic method.

The Monte-Carlo method is usually used to estimate the reliability index of given slip surface of soil slope, However this method is rarely adopted in the location of critical reliability slip surface due to its huge calculation time [4-7]. Besides Monte-Carlo method, First-Order Second-Moment (FOSM) method can also give the value of reliability index for given slip surface. In FOSM, in order to calculate the reliability index the partial derivative of performance function is needed. Because the performance function in slope stability analysis is usually implicit, the partial derivatives of performance function are complex and difficult to be obtained. However, The Rosenbleuth method [8-9] yields the reliability index for given slip surface by several samples at points following with prescribed rules, so it will be used in this study to locate the critical reliability slip surface.

## 2. Simulating Potential Slip Surface

To find the critical reliability slip surface, the first step is to simulate the slip surface using mathematical procedure. The present study adopted the procedure provided by Cheng [10] which is easy to conduct. In a word, the slip surface is simulated mathematically by vector $\boldsymbol{V}=[x_1,x_{n+1},y_2,...,y_n]$, where $x_1$ and $x_{n+1}$ are the $x$-coordinates of exit and entrance points on the slip surface respectively and the rest variables are the $y$-coordinates of points on the slip surface except the exit and entrance points. The second step to find the critical reliability slip surface is to calculate the reliability index for given slip surface. The performance function $G$ is formulated by Equation (1).

$$G=F_s-1 \tag{1}$$

Where the factor of safety $F_s$ is calculated by using the unbalanced thrust method [11].The third step to find the critical reliability slip surface is to alter the potential slip surface according to the reliability index, the following harmony search algorithm is adopted this study.

## 3. Harmony Search algorithm

The harmony search algorithm[12-13]was original developed by Dr. Geem based on the musical process of searching for a perfect state of harmony. The HS algorithm does not require initial values for the decision variables. Furthermore, instead of a gradient search, the HS algorithm uses a stochastic random search that is based on the harmony memory considering rate $H$ and the pitch adjusting rate $P$ so that derivative of function is unnecessary during the analysis. Harmony search algorithm is a population based search method. A harmony memory HM containing harmonies is used to generate a new harmony which is probably better than the optimum in the current harmony memory. In this study, the harmony is analogous to the slip surface. Consider $\mathrm{HM}=\{h_1 \quad h_2 \quad ,..., \quad h_M\}$, in which $h_i=(x_{i1},x_{im},y_{i2}...,y_{in})$ represents one slip surface. The generation of a new harmony $h_{M+1}$is of importance to harmony search algorithm which will be described as follows:

Taking the second element $x_m$ in $V$ for example, its lower and upper bound were $x_l$ and $x_u$ respectively. A random number $r$ in the range of 0 to 1 was generated, if $r \le H$ , $x_{M+1,m}$was randomly chosen from HM, i e., $x_{M+1,m} \in \{x_{1m},..., x_{Mm}\}$ then $P$ was utilized to adjust $x_{M+1,m}$, thereby $x_{M+1,m}$ was obtained; if $r > H$ , $x_{M+1,m}$was randomly generated from its lower and upper bound, the abovementioned procedure was applied to other elements in $V$ thereby obtaining a new harmony $h_{M+1}$.

The iterative steps of harmony search algorithm are as follows:

Step1: initialize the algorithm parameters: $H$, $P$, $M$ and randomly generate $M$ harmonies (slip surfaces);

Step 2: generate a new harmony (as described above) and evaluate it, i.e calculate the factor of safety using unbalanced thrust force method;

Step 3: update the HM; i e., if the new harmony $h_{M+1}$is better than the worst harmony in the HM in terms of factor of safety, the worst harmony was replaced with the new harmony, thus one iteration was finished.

Step 4: repeat steps 2 and 3 until the number of iterations reaches the maximum allowed value $T_{\max}$.

The values of parameters *H, P, M* are 0.95, 0.1, and 50. The value of $T_{\max}$ is 1000.

## 4. Case Studies

The focused example is a case considered by reference [4] and the geotechnical parameters are listed in Table 1. The cross section of the example is shown in Fig.1.

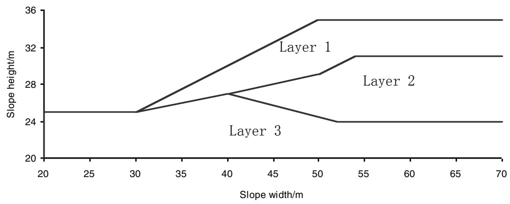


Fig. 1. Cross section of example slope.

Table 1. Geotechnical parameters for example

| Layer | $\gamma$ (kN/m$^3$) | $c$ (kPa) | | $\Phi$ (º) | |
|---|---|---|---|---|---|
| | | $\mu_c$ | $\sigma_c$ | $\mu_\phi$ | $\sigma_\phi$ |
| 1 | 19.5 | 0.0 | 0 | 38.0 | 5.31 |
| 2 | 19.5 | 5.3 | 0.6 | 23.0 | 2.56 |
| 3 | 19.5 | 7.2 | 0.1 | 20.0 | 2.56 |

In Table.1, $\gamma$ is the unit weight of soil layer, $c$ is the cohesion of soil layer and $\Phi$ is the internal friction angle of soil layer. $\mu_c$ and $\sigma_c$ are the mean value and standard deviation value of $c$ parameter respectively, similarly,$\mu_\Phi$ and $\sigma_\Phi$ are the mean value and standard deviation value of $\Phi$ parameter respectively. In order to compare the slip surface with minimum factor of safety and that with minimum reliability index, the deterministic analysis and reliability analysis were performed using the same harmony search algorithm with identical parameters such as *H*, *P*, *M* and$T_{\max}$. The comparison of critical slip surface and critical reliability slip surface was shown in Fig.2.It was clearly noticed that the whole of critical reliability slip surface located in the layer 1, while the critical slip surface was made up of parts across three layers. The reliability index of critical reliability slip surface is 1.96.

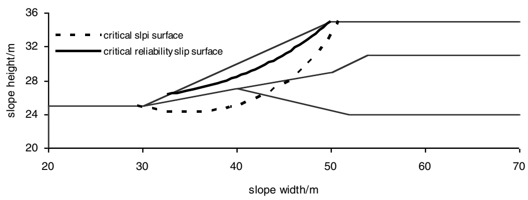


Fig. 2. The comparison of critical slip surface and critical reliability slip surface

## 5. Conclusion

In this study, the unbalanced thrust force method was used to generate the performance function and Rosenbleuth method was adopted to calculate the reliability index for given slip surface, the critical slip surface and critical reliability slip surface were compared and results have shown that there are considerable difference between critical slip surface and critical reliability slip surface.

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## References

[1] Bishop A W.The use of the slip circle in the stability analysis of slopes[J].Geotechnique,1955,5(1):7-17.

[2] Morgenstern N R, Price V E.The analysis of the stability of general slip surfaces [ J]. Geotechnique, 1965, 15(1): 79-93.

[3] Sarma S K.Stability analusis of embankments and slopes[J].Geotechnique,1973,23(3):423-433.

[4]CHEN Zu-yu. Stability analysis of soil slopes: theories ,methods and programs[M].Beijing：water power press ,2003. (in Chinese)

[5] Christian J. T., Ladd C. C., Baecher G. B. Reliability applied to slope stability analysis[J].Journal of Geotechnical Enggineering, 1994,120(12):2180-2207.

[6] XU Jiang,YANG Geng-she,LIU Hui.Evaluation of permafrost slope with Monte Carlo simulation method[J]. Chinese Journal of Underground Space and Engineering,2007,3(8):1433-1437. (in Chinese)

[7] YUAN Jing, ZHANG Xiu-li. Slope's reliability analysis based on Monte-Carlo method [J].Journal of Liaoning Technical University, 2005,24(Suppl.)10-13. (in Chinese)

[8] Chowdhury R N. Recent developments in landslide studies: probabilistic methods, state of the art report[C]//4th International symposium on Landslides, Toronto.1984(1):209-228.

[9] Li K S. Some common mistakes in probabilistic analysis of slopes[C]//6th International symposium on landslides, Christchurch.1992:475-480.

[10] Cheng Y.M. Location of Critical Failure Surface and some Further Studies on Slope Stability Analysis[J]. Computers and Geotechnics. 2003,30(3):255-267.

[11] SHI Wei-min,ZHENG Ying-ren,TANG Bo-ming,et al. Accuracy and application range of imbalance thrust force method for slope stability analysis[J].Chinese Journal of Geotechnical Engineering,2004,26(3)：313-317. (in Chinese)

[12] Geem Z W, Kim J H,Loganathan G V.: Harmony search[J].Simulation. 2001, 76(2)：60-68.

[13]Geem Z W .Optimal cost design of water distribution networks using harmony search[J] .Engineeering optimization. 2006,38(3):259-280.