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# Sliding surface searching method for slopes containing a potential weak structural surface

Aijun Yao [a,*], Zhizhou Tian [a], Yongjun Jin [b]

[a] *Key Laboratory of Urban Security and Disaster Engineering, Ministry of Education, Beijing University of Technology, Beijing 100124, China*
[b] *North China Power Engineering Co., Ltd., China Power Engineering Consulting Group, Beijing 100120, China*

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A B S T R A C T

Weak structural surface is one of the key factors controlling the stability of slopes. The stability of rock slopes is in general concerned with set of discontinuities. However, in soft rocks, failure can occur along surfaces approaching to a circular failure surface. To better understand the position of potential sliding surface, a new method called simplex-finite stochastic tracking method is proposed. This method basically divides sliding surface into two parts: one is described by smooth curve obtained by random searching, the other one is polyline formed by the weak structural surface. Single or multiple sliding surfaces can be considered, and consequently several types of combined sliding surfaces can be simulated. The paper will adopt the arc-polyline to simulate potential sliding surface and analyze the searching process of sliding surface. Accordingly, software for slope stability analysis using this method was developed and applied in real cases. The results show that, using simplex-finite stochastic tracking method, it is possible to locate the position of a potential sliding surface in the slope.
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## 1. Introduction

Slope stability analysis is a very important issue for geotechnical engineers, and it has attracted extensive attention across the world (Lu et al., 2002; Wyllie and Mah, 2004). The stability of rock slopes is in general concerned with set of discontinuities. However, in soft rocks failure can occur along surfaces approaching to a circular failure surface. Basically slope stability analysis should be conducted in two steps. The first one is to find out the position of the slope potential sliding surface, and the second is to analyze the slope stability in these surfaces. Limit equilibrium methods are very common method and widely applied to slope stability analysis with various slope shapes and engineering geological conditions (Ni, 2004; Shi and Luan, 2013). However, numerical analysis methods are nowadays used predominantly in rock slopes to safety analysis even without pre-defining slide planes. For soft rocks, the key issue is how to search the position of potential sliding surfaces. Once position of sliding surface is determined, satisfactory results can be obtained (Zhao, 2006).

Many studies have been conducted on the sliding surface searching technology since the 1970s (Fang et al., 2007; Yao and Xue, 2008). Regarding searching technology various kinds of searching methods were developed, including variation method, pattern searching algorithm, mathematical programming approach, dynamic programming method, random searching algorithm, artificial intelligence method, etc. These methods make it possible to search a single sliding surface, and fruitful achievements are obtained. When weak structural planes or surfaces are present in the slope, a potential sliding surface usually consists of two parts: one is expressed by smooth curve obtained by random searching, and the other one can be a polyline formed by weak structural planes (Yin et al., 2007; Guo et al., 2013). In this way, the above-mentioned methods are not suitable for searching the potential sliding surface, and a new method called simplex-finite stochastic tracking method is employed in the context. Engineering practice shows that the proposed method permits to solve the problem effectively.

## 2. Characteristics of slope containing weak structural plane

Weak structural planes or surfaces refer to the geological structure that controls the geometry and the position of slope (Li et al., 1996; Wang et al., 2006; Ren et al., 2008). It plays a crucial role in the stability evaluation of slopes (Zhang et al., 2001, 2012). In

* Corresponding author. Tel.: +86 13683269395.
*E-mail address:* yaj@bjut.edu.cn (A. Yao).
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practical projects, for the geometry of the model is usually adopted a straight line or a polyline to simulate the weak structural surface. A weak structural surface has the following characteristics:

(1) The origins of weak structural surfaces are very complex (Qian et al., 2006; Du, 2013). Some weak structural surfaces are formed in the digenesis stage as shown in Fig. 1a. Some are formed under the action of tectonic stress, such as the existence of discontinuities or faults within the rock slope, as shown in Fig. 1b and c. Others are formed under the action of external forces (weathering, unloading, groundwater, blasting, etc.), just like cracks and mudded intercalation, as shown in Fig. 1d.
(2) The shear strength of a weak structural surface is significantly low, induced by the presence of a certain amount of filling materials in the weak surface (Xie et al., 2006).
(3) As the strength of weak surface is significantly low, once the slope fails, it will slip along the potential sliding surface easily (Zhu et al., 2010).

## 3. Method for searching potential sliding surface

The basic principle of simplex-finite stochastic tracking method is to search and to optimize a potential sliding surface within the specified bound. In general, sliding body slips along the weak structural surface when the weak structural surface is observed in the toe or top of the slope. This paper focuses on the searching process of the slope containing prefixed weak structural plane by means of a simplex-finite stochastic tracking method. The combined sliding surface consists of two parts: circular sliding surface and fold-line plane (Liu et al., 1998). Its objective function can be defined as

$$F_S' = \min F(y) = \min F[CombinSlip(x)] \tag{1}$$

where $y = CombinSlip(x)$ is the expression of the combined sliding surface.

### 3.1. Mathematical model

The slope discretization model is shown in Fig. 2, where $y = Slope(x)$ is the formula of the expression of slope lines. It was considered that the slope is divided into six data nodes, i.e. $[N_i, i = 1, 2, \ldots, 6]$. Each data node is described by the two-dimensional coordinates, $(x_i, y_i)$. In addition, each node data must satisfy the following conditions: $x_{i+1} > x_i$ and $y_{i+1} \geq y_i$. The $y = Wstrs(x)$ shown in Fig. 2 is the expression of weak structural plane data, which are divided into three data nodes, $[A, B, C]$, and each node data must satisfy the following condition: $x_C > x_B > x_A$. In fact, the number of slope lines data and surface are determined by site-specific investigation.

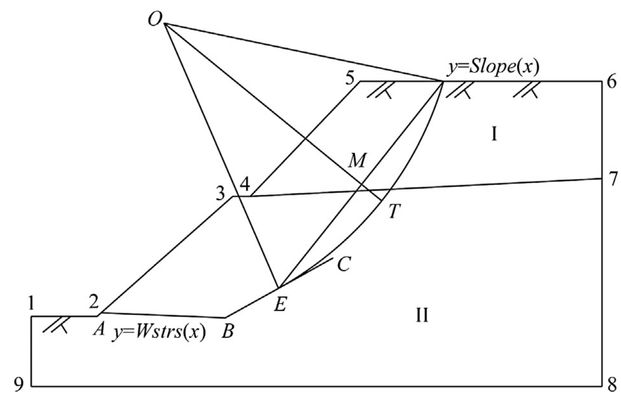


**Fig. 2.** The discretization model of slope.

The ground model can be discretized as shown in Fig. 2 for two strata: stratum I is divided into four nodes $[N_5, N_4, N_7, N_6]$, and stratum II is divided into six nodes $[N_3, N_2, N_1, N_9, N_8, N_7]$.

### 3.2. Searching process of potential sliding surface

If a weak plane exists in slope, the sliding basically slips along the potential sliding surface, so the end point $E$ of the circular sliding surface would be located in the weak structural plane, as shown in Fig. 2.

The first step is to identify the starting point $S$ of the circular sliding surface, as shown in Fig. 3. $x_S \in (x_7, x_8)$ and its expression is shown as

$$\left.\begin{aligned} x_S &= x_7 + R_1(x_8 - x_7) \\ y_S &= \frac{y_8 - y_7}{x_8 - x_7}(x_S - x_7) + y_7 \end{aligned}\right\} \tag{2}$$

where $R_1$ is a uniformly distributed random number, and $R_1 \in (0, 1)$.

The second step is to identify the searching scope of the end point $E$ in the circular sliding surface, as shown in Fig. 3. Its expression is

$$\left.\begin{aligned} x_E &= x_A + R_2(x_C - x_A) \\ y_E &= Wstrs(x_E) \end{aligned}\right\} \tag{3}$$

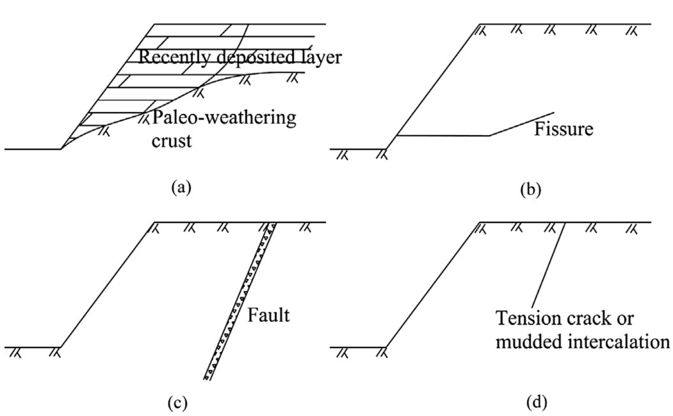


**Fig. 1.** The sketch of potential sliding surface.

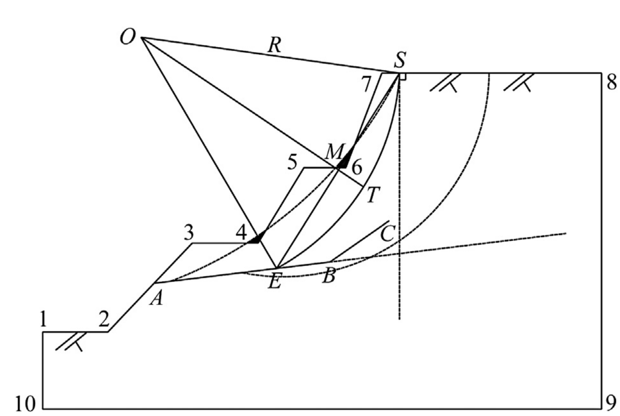


**Fig. 3.** The searching constraints diagram for potential sliding surface.

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