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SLOPE STABILITY ANALYZES WITH FISSURED MATERIAL

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ABSTRACT

Many developments in geotechnical engineering research about applications, theoretical, practice, to assessment slope stability, all these improvements to understanding phenomena in realty. Many cases make slope stability instable, one of these cases is fissured material. The present work deals with the slope stability analysis, by using the technique of shear strength reduction, we investigate the effect of the fissure plane, for the material with the fissures included. For this purpose, we analyse the slope by varying the angles of orientation of plane, between 0 to 75 for α_1, and α_2, to determinate the factor of safety, against a potential failure mechanism, and deducing the critical failure shape. The results show that the stability of slope is mainly dependent on angles of orientation of plane, the variation of the angles, affects in the shape of the sliding surface and on the safety factor clearly.

KEYWORDS: Fissures Included; Slope Stability; Shear Strength Reduction

INTRODUCTION

There is tons of research articles about slope stability, it is an important problem in the soil mechanics research, there are more and more side slope problems and slope engineering problems every day along with the increase in human activity. Geotechnical literature reports, there are numerous cases well documented about instability slopes, due to man-made or natural cases, one of these natural cases is fissured material. Many soils and particularly clays are weakened by joints and fissures, which may have an important influence on the engineering properties of the soils. Investigations by Skempton et al. [1], and Skempton [2], indicate that the development of a fissure can result in softening of surrounding overconsolidated clay. The softening corresponds to an increase in water content caused by soil dilation under the imposed shear stress. Softening reduces the effective stress cohesion component of the Mohr-Coulomb shear strength parameters but does not cause orientation of clay particles or reduction in friction angle Skempton [3]. Consequently, Skempton [2], suggests that the shear strength available in a fissure corresponds to the fully softened condition. Skempton [3], concluded that the fully softened shear strength is numerically equal to the drained peak strength of a normally consolidated specimen. Many techniques and methods exist to evaluation the stability of slopes, as Limit Equilibrium Method [4], widely used by researchers and engineers, the most common limit equilibrium techniques are the methods of slices [5]. In addition, numerical methods have been extensively used in the past several decades due to advances in computing power such as continuum methods [6], Finite Difference Method [7], Finite Element Method [6]. For discontinued methods, one quotes the Discontinuous Deformation Analysis [8], Discrete Element Method [8]. The basic purpose of slope stability analysis, is determining a factor of safety against a potential failure mechanism and then deducing the failure shape.

This study focuses on the modeling slope stability with fissure plane material by fissured Mohr-Coulomb. The present work deals with the slope stability analysis, by the technique of shear strength reduction coupled to the finite element method, that to investigate the effects of the fissure plane, for the material with the fissures included. For this purpose, we analyse the slope by varying the angles of orientation of plane, between 0 to 75 for α_1, α_2, to determinate the factor of safety, against a potential failure mechanism, and deducing the critical failure shape, then we compare between the factors of safety and shapes of the slip surfaces.

METHODS

Many techniques and methods to analyse slope stability have been developed. The limit equilibrium methods most often used by researchers and engineers. The application of FEM in geotechnical analysis has become increasingly common, as computer performance has improved. In this section, we will give three methods briefly. We start by Limit Equilibrium Method, then Finite Element Method, finally, Limit Analysis Method.

Limit Equilibrium Method

For slope stability analysis, the (LEM) is widely used by researchers and engineers conducting slope stability analysis, because these are traditional and well established. The most common limit equilibrium techniques are methods of slices, such as the ordinary method of slices Fellenius [9], and the Bishop simplified, Spencer, and Morgenstern-Price methods. In these methods, many differences among them about the slip surface or assumptions in force. We will give an example based on the shapes of slip surface assumed, the LEMs can be grouped in tow: the first group is methods of analysis which use circular slip surfaces include: Fellenius [9]; and Bishop [10]. The second is methods of analysis which employ non-circular slip surfaces include: Morgenstern and Price [11]; Spencer [12]; and Sarma [13]; Janbu [14], and others. The slice methods have some common features and Zhu et al [15], have summarized them as follows:

- The surface of the sliding body is divided into a finite number of slices, this slices are usually vertical cut.
- The strength of the slip surface is mobilized to the same degree to bring the sliding body into a limit state. It means there is only a single factor of safety which is applied throughout the whole failure mass.
- The safety factor is calculated from force and/or moment equilibrium equations.

The definition of the Factor of Safety (FS) is the same for all these methods, it is commonly used to quantify the safety level of a slope [16], is defined as follows:

$$FS = \frac{\text{Shear strength of soil}}{\text{Shear stress } required \text{ for equilibrium}}$$

The various slice methods of limit equilibrium analysis have been well surveyed and summarized in many studies such as Abramson [17]; Duncan, [4].

Finite Element Method

Among the continuum methods, the Finite Element Method (FEM) is largely used to analysis the solid and structural mechanics [18–21]. The numerical methods, and in particular the finite element method (FEM), has developed rapidly and become increasingly popular for the slope stability analysis. Literature analysis of slope stability using FEM, based on the technique of shear strength reduction was reviewed by Duncan [4], and Griffiths and Lane [22], and by L, et al [23]. Generally, there are two approaches using the finite element method to analyse slope stability Rabie [24]. One approach is to increase the load of gravity and the second approach is to reduce the strength characteristics. The second approach is adopted in this study using the finite element software. Generally, two major tasks coupled in the slope stability analysis: the computation of the factor of safety and the location of the critical slip surface. The definition of the factor of safety is not unique [25, 26].The technique of strength reduction (SRM) is typically applied to calculate the factor of safety by progressively reducing or increasing the shear strength of the material to bring the slope to a state of limiting equilibrium [27]. The technique is also adopted in several well-known commercial geotechnical finite element programs.

Mohr–Coulomb Failure Criterion

The Mohr-Coulomb criterion is the most common failure criterion encountered in geotechnical engineering. Many geotechnical methods and programs require use of this strength model. The Mohr-Coulomb criterion describes a linear relationship between normal and shear stresses (or maximum and minimum principal stresses) at failure. The Mohr-Coulomb failure criterion can be written as the equation for the line that represents the failure envelope given by:

$$\tau = c + \sigma_n \tan\varphi$$

Where τ is shear stress; σ_n is normal stress; c is the cohesive strength, and φ is the internal friction angle. The failure criterion can be expressed in terms of the relationship between the principal stresses. From the geometry of the Mohr circle. The Mohr-Coulomb criterion for triaxial data is given by the following equation:

$$\sigma_1 = \frac{2c\ \cos\varphi}{1-\sin\varphi} + \frac{1+\sin\varphi}{1-\sin\varphi}\sigma_3$$

FISSURES

The strength of materials with regular fissure patterns may be accounted for by using a combination of the usual Mohr-Coulomb failure criterion supplemented with additional constraints on the normal and shear stresses on the fissure planes Davis 1980 [28]; Zheng et al. 1997 [29]. Here, we can define these two fissure planes such that the strength is limited by:

$$F(\sigma) \leq 0$$

$$|\tau_1| + \sigma_1 \tan\varphi_1 - c_1 \leq 0, \qquad \sigma_1 \leq K_{t1}$$

$$|\tau_2| + \sigma_2 \tan\varphi_2 - c_2 \leq 0, \qquad \sigma_2 \leq K_{t2}$$

Where F is the usual Mohr-Coulomb yield function, and (σ_1, σ_2) are the normal stresses and (τ_1, τ_2) are the shear stresses on the fissure planes (α_1, α_2). Here, up to two fissure planes (not necessarily mutually orthogonal). In addition c_i, Cohesion on Plane i [kPa]; φ_iFriction angle on Plane i, [◦]; α_i, Orientation of Plane, [◦]; and k_{ti}, Tensile strength of Plane, [kPa].

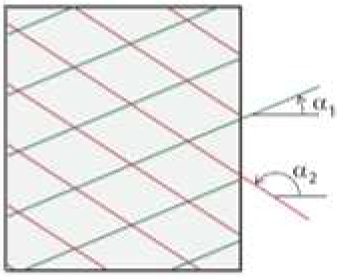


Figure 1: Layer of Soil in Fissured Material with Definition of Angle α_1 and α_2

Where i = 1, 2 and the angles α_i are as shown in Figure 1. Note: setting k_{ti} = Infinity implies that the constraint $\sigma_i \leq k_{ti}$ is ignored.

SHEAR STRENGTH REDUCTION

An important task in evaluation of soil slope stability is measuring or estimating the strengths of the slopes [30]. As we said previously, the strength reduction method (SRM) has been used to compute the factor of safety, and to trace the failure slip surface of a slopes, it is also called Phi-c reduction. In recent years, there have been various developments in this technique to evaluate the soil slope stability [31]. This method was used in 1975 by Zienkiewicz et al. [32], and has since been applied by Naylor [33], Donald and Giam [34], Matsui and San [35], Ugai [36], Song [37], and others. The main advantages of the SRM are as follows:

- The critical failure surface is found automatically from the application of the gravity loads and/or the reduction of shear strength;
- It requires no assumption on the inter-slice shear force distribution; and it is applicable to many complex conditions and can give information such as stresses, movements, and pore pressures.

Shear Strength Reduction by Mohr–Coulomb Failure Criterion

The Mohr Coulomb failure criterion, is the most used in the programs of FEM and FDM, for slope stability analysis, the SRM decrease gradually the strength parameters (c, φ) of the slope until instability occurs. The safety factor by SRM is the ratio between actual strength parameters and critical strength parameters, the corresponding formula is:

$$FS = \frac{c}{c_r} = \frac{\tan \varphi}{\tan \varphi_r}$$

FS: Safety of factor; c: Initial cohesive strength; φ: initial internal friction angle; c_r: reduced cohesive strength; and φ_r: reduced internal friction angle.

NUMERICAL EXAMPLE

This study concerns the stability of a slope of fissured Mohr-Coulomb material, we use the plane strain model to analyse slope stability, Figure 2, shown geometry of our slope, the material properties are ($E = 30$; $\vartheta = 0.25$; $\gamma = 21$ KPa; C = 20 kPa, φ = 22°). The slope contains two sets of angle of the failure plane (α_1,α_2), an angle of α = 45°, as shown in Figure 2. The fissure plane has Mohr-Coulomb parameters c = 0, and φ = 22°, we will change the angles, but by the one, we start by α_1 with blue color, then α_2, with red color, like illustrated in Figure 2. Slope has a single layer, 10 m high and 26 m long, see below.

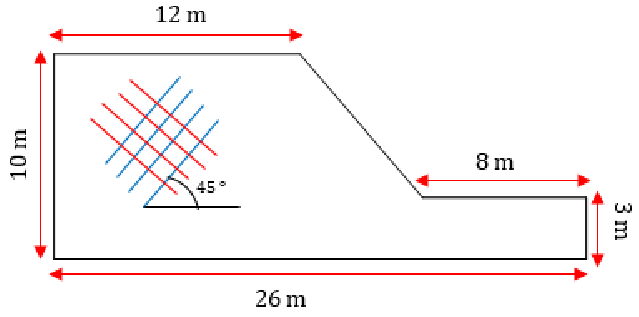


Figure 2: Slope Geometry

RESULTS AND DISCUSSIONS

In this problem, we have examined the effect of the orientation angle of failure plane on the stability of a slope according to the change in angles of failure plane (α_1,α_2). Firstly, in Figure 3 and 4, we present failure surface of our slope without fissure plane (intact).

(a) **(b)**

Figure 3: Failure Surfaces

Figure 3, shows the mesh of failure surface (a) and shear strains (b) analyzed by technique of shear strength reduction coupled by finite element method. The safety factors, if the slope is Fs = 1.465, we notice that slope is almost stable.

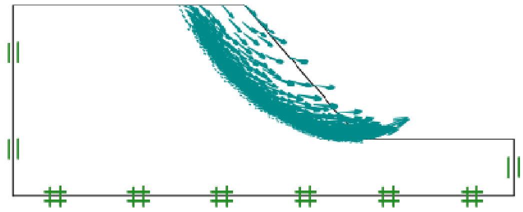


Figure 4: Area of Displacement

Figure 4, presents the area of displacement increments of our slope without fissure plane (intact). We notice that the sliding surfaces in, Figure 3 and 4 are circular and pass through toe of slope.

Now, we vary the angle of the failure plane and calculate factors of safety by shear strength reduction, the following figure 5, shows graphically the results of various calculations obtained for to change in angles of failure plane α_1.

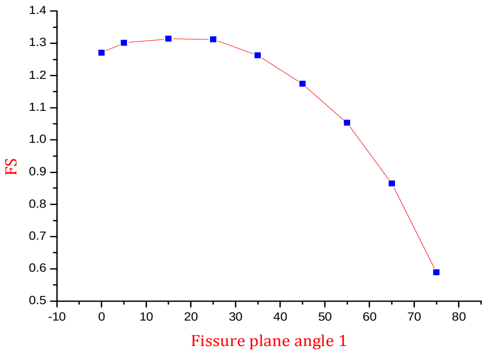
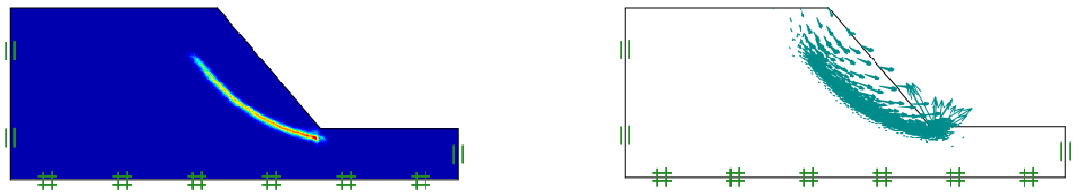


Figure 5: Safety factor of angle α_1

We found through the changes of angle α_1 in the interval (0°, 75°), that the angles of failure plane α_1 plays a significant role in the behavior of the slope, in addition all safety factors with effect of angles of failure plane α_1 are small compared the safety factor without angles of failure plane. As we see in Figure 5, this graph divided into two parts, the first part from $\alpha_1 = (0°$ to 15°), in this part the safety factor increasing with low values, the second part from α_1 =(25 to 75) we observed in this part the safety factors decreasing. We chose two angles $\alpha_1 = 25°$ and α_1 =55° to present the results of the sliding surfaces. The safety factor of $\alpha_1 = 25°$ is FS=1.312, the slope is instable.

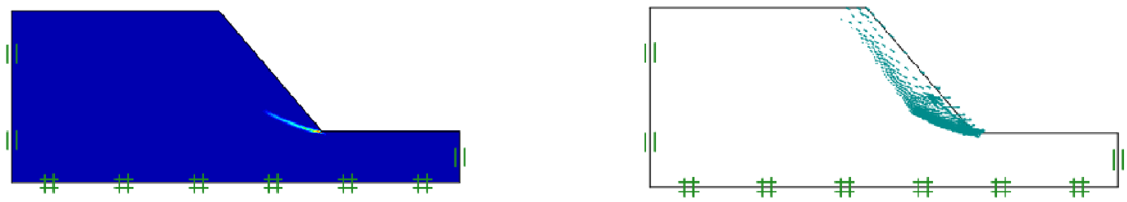


(a) **(b)**

Figure 6: Shear Strains and Area Displacement by $\alpha_1 = 25°$

Figure 6, present the shear strains (a), and the area of displacement increments (b), with fissure plane $\alpha_1 = 25°$, there is difference between these surfaces Figure (a) and (b) and the surfaces on the Figures 3 and 4, which present simulation of slope without fissure plane (intact), that is confirmed the effects of presence angles of failure plane, on the sliding surface.

Now we present the results of the sliding surfaces of α_1 =55°, the safety factor of this example is FS=1.053, the safety factor is indicated that the slope is instable, and small compared when $\alpha_1 = 25°$



(a) **(b)**

Figure 7: Shear Strains and Area Displacement by $\alpha_1 = 55°$

In Figure 7 (a), we have the shear strains, and the area of displacement increments (b), with fissure plane $\alpha_1 = 55°$. we see a change in the sliding surface shape, there is difference between these surfaces Figure 7 (a), (b), and the surfaces on the Figures 3 and 4, which present simulation of slope without fissure plane (intact), also we have difference in surfaces when $\alpha_1 = 25^\circ$. That is confirmed the effects of presence angles of failure plane, on the sliding surface.

Finally, we change the angle of the failure plane and calculate factors of safety by shear strength reduction, the following figure 8, shows graphically the results of various calculations obtained for to change in angles of failure plane α_2.

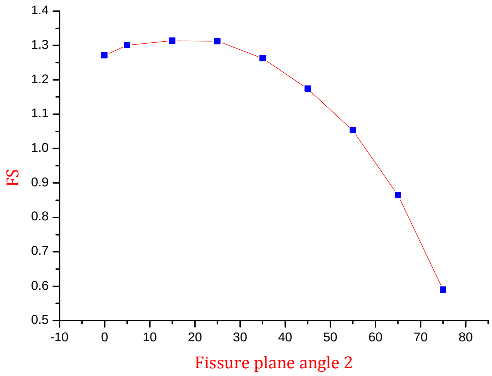
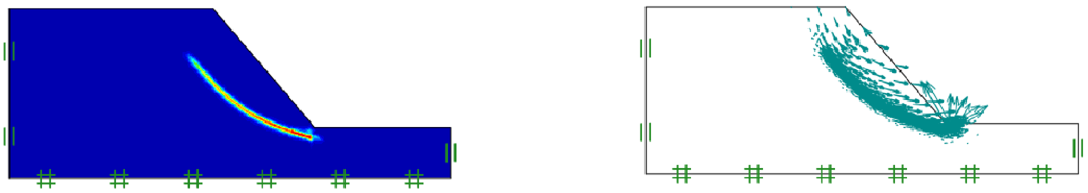


Figure 8: Safety Factor of Angle α_2

Here also we used different angles for α_2, through the changes of this angle, in the interval (0°, 75°), we have same remarks with angle α_1, all safety factors with effect of angles of failure plane α_2 are small compared the safety factor without angles of failure plane. As we see in Figure 8, this graph divided into two parts, the first part from α_2 = (0° to 15°), in this part the safety factor increasing with low values, the second part from α_3 =(25 to 75) we observed in this part the safety factors decreasing. We found, the angles of failure plane α_2 shows an important character in the behavior of the slope.

Figures 9 and, 10 shows results through different angles, α_2 = 25° and α_2 =55° to present the effects of failure plane in sliding surfaces. Figure 9, illustrate the sliding surfaces by α_1 = 25°. The safety factor is FS=1.312, the slope is instable.



(a) (b)

Figure 9: Shear Strains and Area Displacement by $\alpha_2 = 25^\circ$.

Figure 6 (a), illustrate the shear strains and, Figure 6 (b), shows the area of displacement increments, by fissure plane $\alpha_2 = 25^\circ$. There is difference between surfaces of Figure 6, and the surfaces on the Figures 3 and 4, which present simulation of slope without fissure plane (intact). There is no difference between the surfaces of sliding Figure 6 and 9, also we have safety factors FS=1.321, when $\alpha_1 = \alpha_2 = 25^\circ$.

By technique of shear strength reduction withe presence of failure plane in our slope, figure 10 shows the results of the sliding surfaces of α_2 =55°, the safety factor of this example is FS=1.053, the safety factor is indicated that the slope is instable, and small compared when $\alpha_2 = 25°$.

(a) (b)

Figure 10: Shear Strains and Area Displacement by $\alpha_2 = 55°$

We illustrate the shear strains of our slope in Figure 10 (a), and the area of displacement increments figure 10 (b). in these figures we see a change in the sliding surface shape, there is difference between surfaces Figure 10 (a), (b), and the surfaces on the Figures 3 and 4, which present simulation of slope without fissure plane (intact), also we have difference in surfaces when $\alpha_2 = 25°$. However, there are no variance between the surfaces of sliding Figure 7 and 10, also we have safety factors FS=1.053, when $\alpha_1 = \alpha_2 = 55°$. All these points confirmed the effects of presence angles of failure plane, on the sliding surface.

CONCLUSIONS

In this study, we determined the sliding surfaces and the safety factors for slope, with technique of shear strength reduction by finite element method, in order to verify the effect of the change in angles of fissure plane (α_1,α_2), in interval (0° to 75°). After 19 simulations and comparison between these results. We found firstly, the presence of fissures plane decreases in the stability, also the orientation of fissure plane angles plays a significant role in the behavior of the slope instability negatively and directly, furthermore the failure slip surfaces effects by presence of fissures plane. This paper has allowed us to appreciate the risk of instability of the slope depending on the orientation of fissure plane angles. Finally we must take this problem in consideration with precision, in our analyzes instability of slopes with other characteristics, as can be sources of instability slopes.

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