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Stability Study of Rock Slopes

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Keywords

Rock masses, dip, instability, plane failure, safety factor, wedge failure.

Abstract

In contrast to soft land movements, rock instabilities appear to be very diverse due to the wide range of rigidities of rock materials and the variety of slopes affecting the massifs. In the rock masses, the discontinuities constitute the weak zones of the massif; they are the ones which essentially determine the behavior of the rock masses. In addition, discontinuities that favor the failure of the rock mass are added a potential factor which is the infiltration of water. An analytical study of the stability of the rock mass is carried out using the mechanisms of structural failure "plane, wedge and toppling". The Rock stability - Geostructural Analysis software was used to analyze the standard rock slope studied analytically. An interpretation of the results obtained is completed to better target the major parameters responsible for the instability of the rock masses.

1. Introduction

The evaluation of the instability of rock masses depends on the analysis methods implemented to evaluate the mechanical behavior of the assemblage of boulders. For this purpose, we chose to use the limit equilibrium method by exploiting the rock masses failure criteria most used by researchers such as, the Mohr Coulomb criterion and the Hoek Brown criterion [1]. In this work we carried out an analytical study on a typical profile of the rock versant, by using two failure mechanisms, plane and wedge failure [2]. While varying the dip, the cohesion and the position of the water level in order to discern the major parameters affecting the stability of the rock slope [3]. We also performed an analysis using the Rock Stabiity-GeoStructural analysis “Bentley” software using the same standard

2. Analytically analysis of rock slope stability

In rock masses, a structural failure occurs on one or more failure surfaces defined by the pre-existing discontinuities in the rock mass [4]. Stability analysis is carried out on the rock slope which the characteristics are shown in table 1 where (φ) angle of friction, (θ) the dip of the failure plane, (α) the angle of dip of the slope face, H the height of the slope, (γ) the density of the rock and c the cohesion. Analytical analysis is carried out using both Planar and Wedge failures.

Table 1. The characteristics of rock slope

γ [kN/m^3]	φ [°]	α [°]	θ [°]	c [kN/m^2]	H [m]
26	20	60	35/40/45	50/75/ 100	20

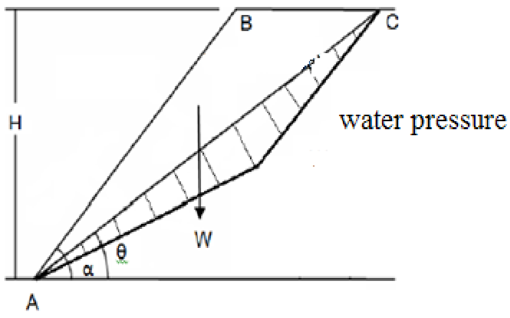
2.1. Planar failure

Planar failures are governed by a single discontinuity surface dipping out of a slope face. Planar failures are those in which movement occurs by sliding on a single discrete surface that approximates a plane on which the action of water is often exerted. Stability must be evaluated by a limit-equilibrium analysis [5]. The safety factor (Fs) is estimated with and without tension crack present in upper slope (Fig. 1a and 1b)

The factor of safety, Fs, is expressed according to Equation 1:

$$F_s = \frac{CA+(w\cos\theta - U - V\sin\theta)\tan\varphi}{w\sin\theta + V\cos\theta} \quad (1)$$

According to the parametric study carried out by varying the failure angle (θ) and the water level taken equal to (2/3H) in both cases: without and with tension crack (Fig. 2 and 3)



a)

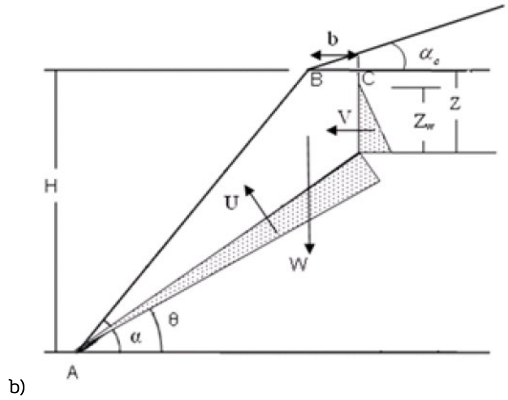


Figure. 1. Plane failure: a) without tension crack b) without tension crack

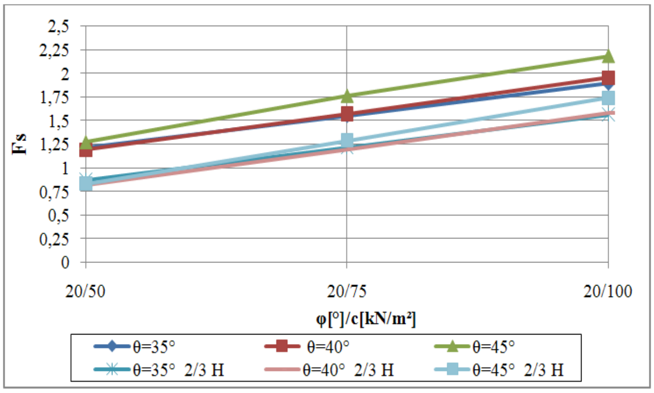


Figure. 3. Comparison of Fs depending on the failure angles and the water level in a plane failure (without tension crack)

After the figures 3 and 4, we could deduce the following results:

The safety coefficients are minimum when the dip θ= 35 ° and when the tension crack is filled with water (ZW = Z).

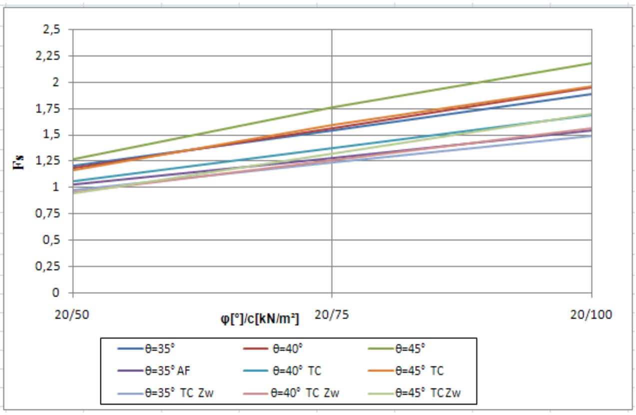


Figure.4. Comparison of Fs depending on the failure angles and the water level in a plane failure (with tension crack Zw=Z)

We can note that the safety factors decrease with the reduction in the cohesion existing between the discontinuities.

2.2. Wedge failure

Wedge failures result when rock masses slide along two intersecting discontinuities both of which dip out of the cut slope at an oblique angle to the cut face, forming a wedge-shaped block (Fig. 5) [6]. The safety factor is given by Equation 2.

$$F_s = \frac{3}{\gamma_r H}(C_A X + C_B Y) + \left(A - \frac{\gamma_w}{2\gamma_r} X\right) \tan \emptyset_A + \left(B - \frac{\gamma_w}{2\gamma_r} Y\right) \tan \emptyset_B \quad (2)$$

Where cA and cB are the cohesive strengths, and φA and φB are the angles of friction respectively on planes A and B,(γr =26kN/m3) is the unit weight of the rock and (H=40m) is the total height of the wedge.

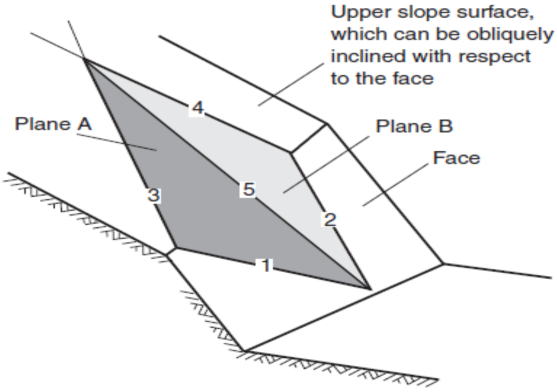


Figure. 5. Pictorial view of wedge showing the numbering of intersection lines and planes.

The safety factors are shown in Table 2 obtained by varying the cohesion of the planes A and B.

Table 2. Safety factors for wedge failure analysis

φA [°]	φB [°]	cA [kPa]	cB [kPa]	Fs
20	20	50	50	1.44
20	20	75	75	1.95
20	20	100	100	2.45

3. Analytically analysis of rock slope stability

3.1 Failure plane analysis

The standard profile of the rock slope studied analytically was analyzed by means of the “Rock Stability” software integrated into the “GeoStructual Analysis” software.

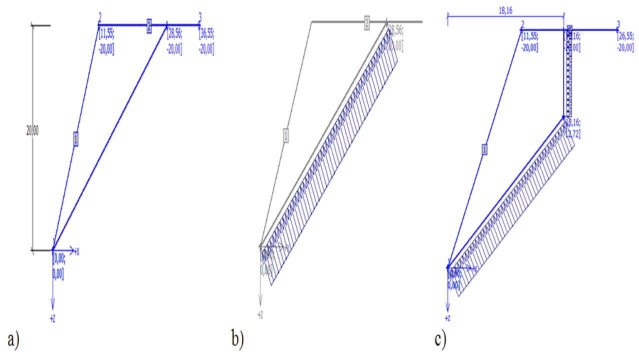


Figure. 6. Analysis of the stability of the rock slope in plane failure

a) without water b) with water c) with tension crack and water

In both cases: with and without tension crack by varying the level water and cohesion. The results of the analysis are shown in Figure 6.

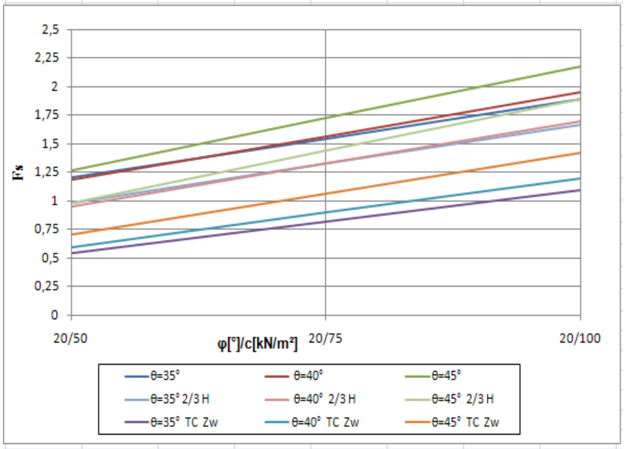


Figure. 7. Comparison of Fs according to the failure angles and the water level in a plane failure (with tension crack)

3.2 Failure wedge analysis

In this analysis, we used the same geometric and geotechnical characteristics used in the analytical study [7]. We considered a variation on the position of the tension crack (L = 5 and 10 m) and of the water level (0; 1/2H; 2/3H) .

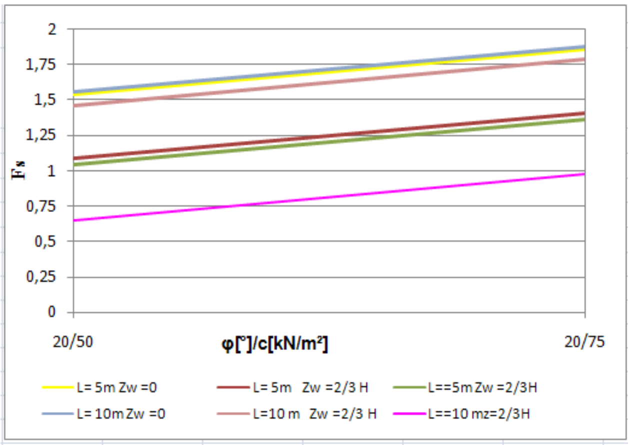


Figure. 8. Results of safety factors for wedge failure

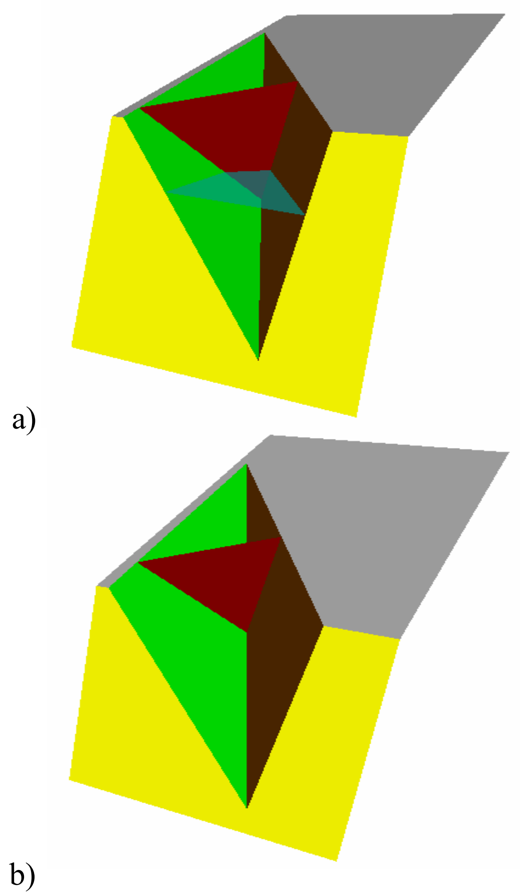


Figure.9. Wedge failure with tension crack obtained from Rock Stability software
a) With water b) With without water

4. Conclusions

From the analytical study carried out using the two failure models: plane and wedge failure. We were able to achieve the following results: Safety factors decrease considerably when it forms a tension crack the upper face of the slope with increasing water level in it. The decrease in the cohesion between the joints of the rock masses has an unfavorable effect on the stability of the rock versant, it should be noted that this cohesion is due to the presence of filling materials between the joints. Slope failures in rock masses are governed by joints that develop across surface form by one or several sets of joints. The variation of the dip shows that a rock masses loses its stability when there is a very specific dip in relation to the resistance parameter "the friction angle and the cohesion"

Declaration of Conflict of Interests

The author(s) declare(s) that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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