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Numerical Simulation for Determination of Sliding Type and Stability Factor of Safety in Finite Slopes with Limit Equilibrium Method

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ABSTRACT: In this study, the effect of soil material parameters including soil specific weight (γ), cohesion (C) and angle of internal friction (∅) and geometric parameters of slope including angle with the horizontal (β) and slope height (H) on factor of safety (Fs) are investigated. Slope factor of safety is considered in two scenarios: (i) slope with dry condition and (ii) slope with steady-state saturated condition that comprises water level drawdown circumstances. In addition, the type of slip circle investigated. For this purpose, the limit of equilibrium method (LEM) is implemented. Results indicated that, decreasing of water level and omitting the hydrostatic pressure on the slope, would result in safety factor decrement such a way that with drawdown of 5.5 m water level, the factor of safety decreases about 41.42 % and also the type of slip circle is changed. Comparison of the plane and circular failure surfaces showed that plane failure method has good results for near-vertical slopes only. Determination of clip type showed that for $\beta<60^{o}$ each of the three types of slip (toe circle, midpoint circle and slope circle) occur, but for $\beta>60^{o}$ only toe circle can happen. Application of the LEM in Bishop's method resulted the values of R2 and RMSE equal to 0.93 and 0.121, respectively that the error of this method is 1.3% respect to other methods, which can be neglected in comparison with the complex and accurate methods.

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1. INTRODUCTION

Slopes failure is a natural phenomenon that occurs in many countries around the world. Due to the construction of roads and residential buildings on the slopes in different parts of the world, preservation stability of these slopes is considered necessary. In general, the cause of the failure of the soil slope is mainly due to increase in the shear stress force at the surface of failure. The factor of safety represents the stability of a soil mass against potential failures [1]. Different factors affect the stability of slopes. These parameters include soil cohesion, soil friction angle, existing stresses and water surface level [2]. The main objective of this research is to investigate the effect of soil material parameters including soil specific weight (γ), cohesion (c), angle of internal friction (∅) and geometric parameters of slope including angle with the horizontal (β) and slope hight (H) on factor of safety (Fs) and presenting the relations to calculate the direct factor of safety. In this study, a complete dry and drainage mode was considered and then the impact of the water surface draws down on the homogeneous slope is considered. In order to achieve this goal SLOPE/W software (which is a sub-program of Geo-Studio, version 2012) is used. In order to predict of factor of safety of dry and saturated condition, different models by runs of SLOPE/W was made and the factor of safety of slopes was investigated.

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2. METHODOLOGY

In SLOPE/W software, unlike other subgroup of Geo-Studio, 2012, the finite element method is not used and includes a set of graphical and limit equilibrium methods for analyzing slope stability [3]. In general, various procedures of stability analysis may be classified into two groups: (i) mass procedure, and (ii) method of slices. In case (i) the mass of the soil above the surface of sliding is taken as a unit. Although, this is not the case in most natural slope. This procedure is useful when the soil that forms the slope

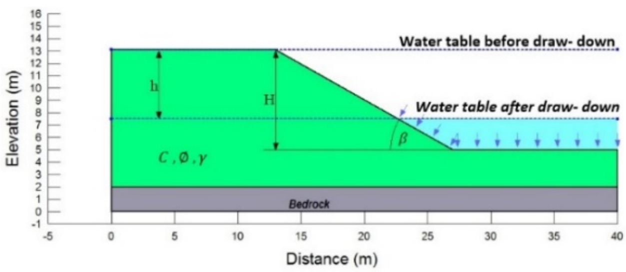

Fig. 1. A schematic representation of the simulated model and the studied parameters.

Table 1. The range of parameters studied in the numerical model of this study.

Unit weight (γ) (kN/m^3)	Cohesion (C) (kN/m^2)	Angle of friction ($\emptyset$) (deg.)	Angle of slope (β) (deg.)	Water level draw down (m)
15	15	14	30	0
17	20	18	45	3
21	25	22	60	5.5
25	30	-	75	8

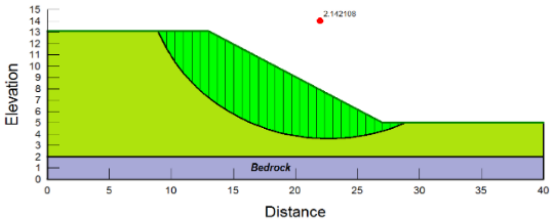

Fig. 2-A. The factor of safety and the type of slip circle for the state

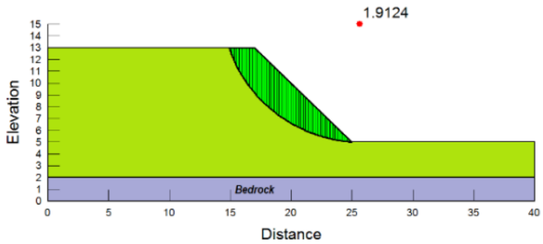

Fig. 2-B. The factor of safety and the type of slip circle for the state

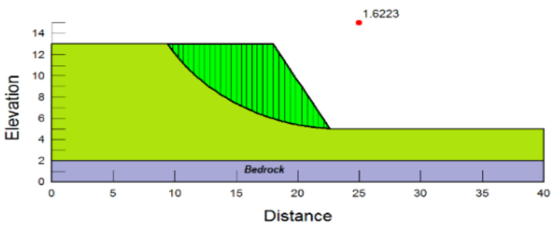

Fig. 2-C. The factor of safety and the type of slip circle for the state

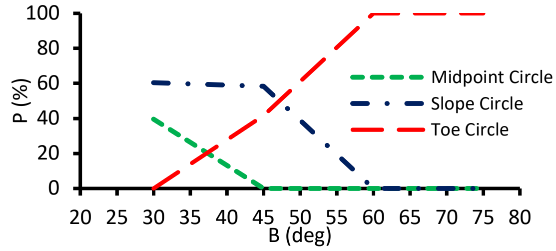

Fig. 3. The boundaries of the potential slip circle slope relative to the slope angle.

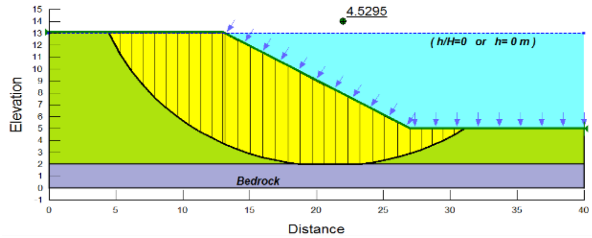

Fig. 4-A. Slip circle type changes without water surface draw down,

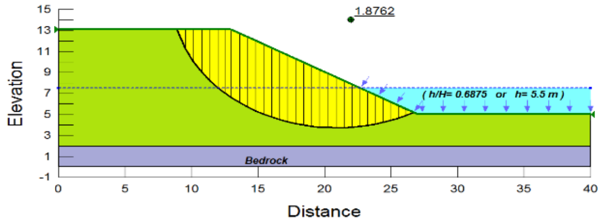

Fig. 4-B. Slip circle type changes with water surface draw down:

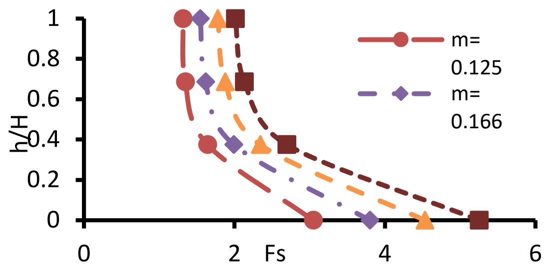

Fig. 5. Changes factor of safety (F_s) against relative water level loss (*h/H*) for the state ()

is assumed homogeneous. In case (ii) the soil above the surface of sliding is divided into a number of vertical parallel slices and the stability of each slice is calculated separately. This is a popular technique in which the non-homogeneity of the soils and pore water pressure can be taken into consideration [2]. Fig. 1 shows the schematic representation of the simulated model and the studied parameters.

3. RESULTS AND DISCUSSION

Based on Fig. 2, the change in the geometric shape of the slope causes a relative change in the resistant and destructive forces and various degrees of stability factor of safety have arisen. The factor of safety has decreased with increasing slope angle, β.

Fig. 3 shows the boundaries of each of mode of failure circle relative to the slope angle. Vertical axis is the occurrence percentage of each slip circle. For all angles less than 60 degree (β>60°), each of the three types of failure circles (toe, slope or midpoint circle) can be occurred, for angle less than 45 degrees (β<45°), there will only be two mode of failure circle: midpoint circle and toe circle. For angles larger than 60 degrees (β>60°), the mode of failure circle for all conditions is toe circle.

In Fig. 4 (A and B) the change in the water level, the slope is fully flooded and full immersion is achieved with a drown ward 5.5 m water level. Factor of safety due to the removal of load due to the weight of water on the slope, which is in the direction of stability before the drop of the water level was reduced by 41.42 %. In addition, the slip surface has changed from touch-midpoint circle to slope circle.

Fig. 5 shows that when the value of (h/H) approaches the toe of slope (h/H=1), the factor of safety decreases by decreasing the stability number. Therefore, factor of safety decreases during draw-down of the water level (pore water pressure does not dissipate), but with increase of stability number it will be in more stable condition.

In order to estimate the stability factor of safety with each Morgenstern-price [4], Junbu [5], Bishop [6] and Ordinary [7] methods, linear regression equations were also extracted by using SPSS [8]. An analytical method has also been proposed by Culmann [9] to determine the factor of safety, in which the failure surface is created on a sliding plane along the slope. In other words, the slip surface is linear and not circular for simplicity in two-dimensional mode.

4. CONCLUSIONS

Culmann's method offers good results for steep slopes and near the vertical but does not yield acceptable results for mild slopes. Equation instead of Michalowski's method charts in the state of dry soil condition to determine factor of safety, F_s, was provided that remove interpolation method. Comparison between numerical results and the presented methods by other researchers were carried out and good agreement was observed.

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