Determining Important Grade of Environmental Risk Factors at Slopes

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Abstract— *Both, natural and man-made slopes formed for various purposes may cause numerous permanent problems in engineering applications. Therefore, it is important to know composition and mechanical behavior of soil environment leading to geotechnical problems on slope surfaces. The risk analyzes of natural and artificial slopes, realized detailed, can lead to reliable results. Based on those results, it is possible to produce optimal technical solutions with respect to an acceptable risk level. The researches on these subjects give new opportunities to improve the existing knowledge by reviewing them. The main aim of this study is objectively to evaluate the parameters caused slope stability problems. In this regard, the parameters of slope angle, internal friction angle and cohesion of soil, and groundwater level, which are main risk factors for a slope, and should contribute to raise awareness about this issue, were investigated.*

Keywords— Factor of safety, risk factors, slope stability.

I. INTRODUCTION

Surfaces that are oriented horizontally at a certain angle are defined as slopes. If angle of earth surface is great enough, soil moves downward due to gravity. Thus, slope loses its stability and this event caused an environmental risk situation. In order to assess the environmental risk of slopes, it is necessary to know the safety factor of natural slopes, on which are frequently encountered in the natural ear surface, excavation slopes and slopes compacted as controlled against landslide. The all factors affecting displacements need to be considered for a slope, which the environmental risk ratio (slope safety) will be determined. The safety of soil structure is often defined by a parameter called the safety factor (the environmental risk factor). This parameter can be described as the ratio of strength of soil to the load applied to it. Since this is a mathematical term, which represents the stability of the structure examined, this ratio varies based on the shear strength and stresses examined in the slope stability. A number of safety factor (environmental risk factor) definitions are available in engineering literature. The safety factor is a ratio of resistive forces along the sea surface to the shear forces; of the existing shear strength of soil along the potential shear surface to the mean shear stresses; and is a factor that the shear strength parameters decrease to maintain slope at limit equilibrium condition along a specific shear surface. For complete stability of a soil depending on these descriptions mentioned above, the safety factor F is defined as:

SF=available shear strength/shear stress required for equilibrium

It is stated that the minimum value of the safety factor given as a basic formula above should be 1.0 on a sliding surface not only for fail but also for stable condition. In following years, lots of studies on both analyzes of slope and their movement characteristics were conducted (Bishop [1]; Spencer [2]; Spencer [3]; Maksimovic [4]; Ching and Fredlund [5]; Fredlund [6]; Brinkgreve and Bakker [7]; Duncan [8]; Griffiths and Lane [9]; Cheng [10]; Hammah and diğ. [11]; Cheng and Lansivaara [12]). The main objective of many studies in the literature on slopes is to obtain economical and safe solutions to avoid an environmental risk (an adequate safety factor value) in ground structure, excavations and fills. The slope-based environmental risk studies on this subject cover a detailed investigation of the environment, material on the environment and economical parameters. In recent years, slope stability analysis has gained importance due to rapid population growth, increase of motorways based on technological development, dams, and deep and large excavation.

The finite element method was developed for stress analysis of aircraft bodies in 1956 and has later been started to use in solution of engineering problems in the following years. This method has been developed rapidly over the years, and used in many engineering applications. Numerical analyzes are effective mathematical methods used to solve complex engineering problems. The finite element method the most commonly utilized among the numerical analysis methods is one of the mathematical methods. In this method, the engineering problems can be solved by dividing the continuous environment into various geometric subspaces called the finite element. The finite element method is a numerical analysis technique widely used in many engineering applications both for research and in design (Köksal, [13]).Since the stress analysis in soil mass is approximation in conventional slope stability analysis, calculation has some difficulties for different loading conditions and geometries. The finite element method has increasingly been used in slope stability analysis with the spread of computer use in engineering as well as in all areas. The advantage of finite element approach over the other conventional limit equilibrium methods is that there is no need for an assumption for the location and shape of slide (shear) surface, and properties and orientations of the slices. The finite element method as with two or three dimensions can be applied to all types of failure mechanism in complex slope geometries and conditions of various soil boundary and loading. It is possible to obtain the knowledge of material structure behavior in close to present conditions, and of accurately stress and replacements in soil. Moreover, the method can be used easily in long and short stability analyzes, and in conditions of slope reinforcement by materials such as geotextile or soil nail, and availability of ground water.

II. MATERIAL AND METHOD

In this study, numerical analysis by using finite element method (Plaxis 2D) [14]were carried out in order to investigate the effect of parameters of cohesion, internal friction angle, slope angle and groundwater level on the slope failure mechanism in sloped areas. Therefore, two-dimensional analyses using finite element method were performed by considering plane strain state. The finite element model used in analyzes is presented in Figure 1.

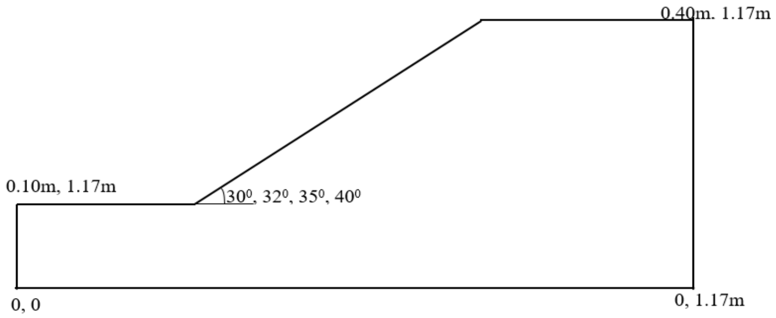

FIGURE 1. THE MODEL OF FINITE ELEMENT USED IN THE ANALYZES

In this context, MC (Mohr-Coulomb) soil model, which can model elasto-full (complete) plastic soil behavior and is widely available in the literature, was selected. MC model contains five different parameters of elasticity modulus (E), Poisson ratio (v), cohesion (c), internal friction angle (ϕ) and dilation angle (ψ). In addition, advanced parameters such as Eincrement and cincrement are also included in the model. The analyzes were carried out by choosing the most fine mesh selected from the five different mesh types in Plaxis 2D software.

III. FINDINGS AND DISCUSSION

In the study, the results of analyzes using the finite element method to determine the effect of the parameters such as slope angle, internal friction angle and cohesion of soil, and groundwater level on the safety factor (environmental risk factor) of a slope are presented below.

3.1 Influence of Slope Angle

Analyzes performed by the finite element method were also conducted to investigate the effect of slope angle change on the safety factor of a slope. Internal friction angle (ϕ=350), unite weight (γ=17.2 kN/m^3), cohesion (c=0.01 kN/m^2), elasticity modulus (E=24000 kN/m^2), poisson ratio (v=0.20) as constant parameters, and slope angle (β) values ranging from 300 to 400 as variable parameter were selected in the calculations. The determined results of the safety factors (environmental risk factors) vs. the slope angle values are seen in Figure 2 and Table 1.

TABLE 1
THE VALUES OF THE SAFETY FACTORS

Slope Angle, β	Safety Factor
Model 1. β=30°	1.270
Model 2. β=32°	1.192
Model 3. β=35°	1.022
Model 4. β=40°	0.914

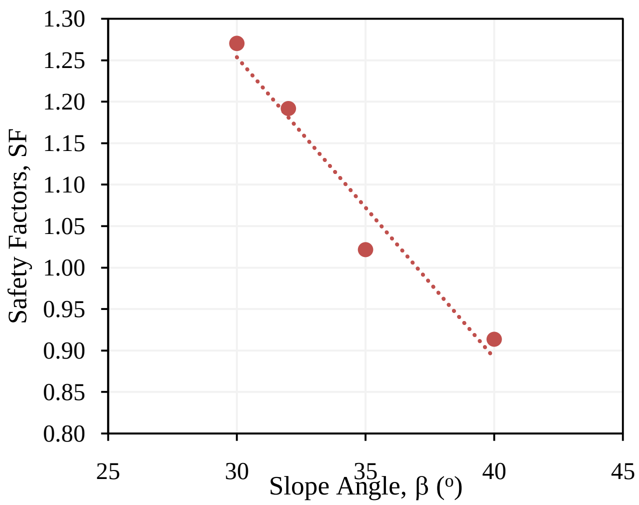

FIGURE 2. THE VALUES OF THE SAFETY FACTORS FOR SLOPE ANGLE

As a result, it was determined that the safety against landslide (failure) decreases due to the increase of slope angle, and obtained a strong (R=0.98) relationship between the slope angle and the safety factor. The data from the analyzes by the finite element method indicate that an increase in slope angle of 100 causes an decreases in the safety factor as per 28%, and thus it has been emphasized analytically that the slope angle change is very important parameter in terms of the slope stability.

3.2 Influence of Internal Friction Angle

Analyzes based on the finite element method were also carried out in order to evaluate the effect of internal friction angle change on the safety factor of a slope. The soil model parameters used in the analyzes were selected as constant values of slope angle ($\beta=30^0$), unite weight ($\gamma=17.2$ kN/m^3), cohesion (c=0.01 kN/m^2), elasticity modulus (E=ranging from 22000 to 28000 kN/m^2), poisson ratio (v=0.20), and as the variable parameter of internal friction angle (ϕ) values ranging from 30^0 to 43^0. The results obtained from these analyzes are seen in Figure 3 and Table 2.

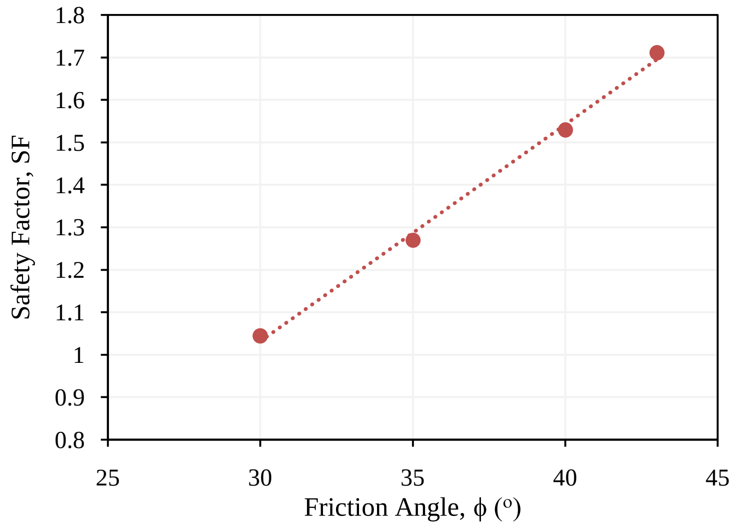

FIGURE 3. THE VALUES OF THE SAFETY FACTORS FOR FRICTION ANGLE

TABLE 2
THE VALUES OF THE SAFETY FACTORS FOR FRICTION ANGLE

Friction Angle, ϕ	Elasticity modulus	Safety Factor
Model 1. ϕ=30°	22000 kN/m^2	1.044
Model 2. ϕ=35°	24000 kN/m^2	1.270
Model 3. ϕ=40°	26000 kN/m^2	1.529
Model 4. ϕ=43°	28000 kN/m^2	1.711

The results from the analyzes by the finite element method indicate that the increase of internal friction angle increases the safety against sliding (failure) of slope, and the relationship between the internal friction angle and the safety factor has a strong (R=0.99) correlation coefficient. It was also found that an increase in internal friction angle of 43^0 at a constant slope angle leads an increase in the safety factor as per 39%. On the other hand, the degree of importance of internal friction angle for slope stability analyzes was revealed as well.

3.3 Influence of Cohesion

Analyzes made using the finite element method were conducted to assess the effect of cohesion change on the safety factor of a slope, as well. Internal friction angle (Φ=10), slope angle ($\beta=32^0$), unite weight (γ=17.2 kN/m^3), elasticity modulus (E=24000 kN/m^2), poisson ratio (v=0.20) as constant parameters, and cohesion values ranging from 0.500 to 1.500 kN/m^2 as variable parameter were selected in the calculations. The determined safety factor (environmental risk factor) values depending on cohesion values of a soil are shown in Figure 4 and Table 3.

TABLE 3
THE VALUES OF THE SAFETY FACTORS FOR COHESION

Finite Element Method, c (kN/m^2)	Safety Factor
c=0.500	0.624
c=0.625	0.764
c=0.750	0.901
c=0.780	0.932
c=0.820	0.976
c=0.850	1.006
c=0.875	1.036
c=1.000	1.173
c=1.125	1.312
c=1.250	1.720
c=1.500	2.200

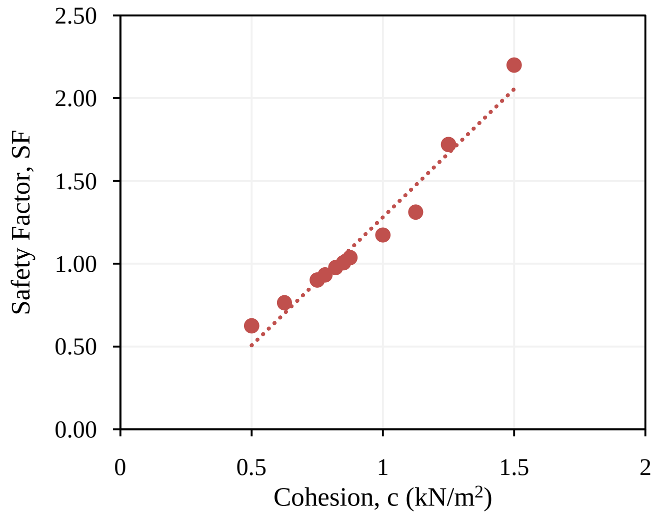

FIGURE 4. THE VALUES OF THE SAFETY FACTORS FOR COHESION

As a result of the analyzes, it was exhibited that the safety factor increases depending on increasing of cohesion of soil, and was acquired a strong (R=0.98) relationship between the cohesion and the safety factor. The data from the analyzes by the finite element method point out that an increase in cohesion value of 1 kN/m^2 leads an enhancement in the safety factor as per 72%. Moreover, it was revealed from the analyzes that how cohesion of soil forming slope affected stability of slope.

3.4 Influence of Groundwater Level

Analyzes performed by the finite element method were also conducted to investigate the effect of groundwater level change on the safety factor of a slope. Internal friction angle (ϕ=10), slope angle ($\beta=32^0$), and unite weight (γ=17.2kN/m^3), cohesion (c=0.85kN/m^2), elasticity modulus (E=24000 kN/m^2), poisson ratio (v=0.20) as constant parameters, and groundwater level values ranging from 0 to 0.45 m as variable parameter were selected in the calculations. The determined results of the safety factors (environmental risk factors) vs. the groundwater level values are seen in Figure 5 and Table 4.

TABLE 4
THE VALUES OF THE SAFETY FACTORS FOR WATER GROUND LEVEL

Water Ground Level (m)	Safety Factor
0	1.006
0.05	1.002
0.10	1.000
0.15	1.000
0.20	1.044
0.25	1.134
0.30	1.275
0.35	1.492
0.40	1.822
0.45	2.312

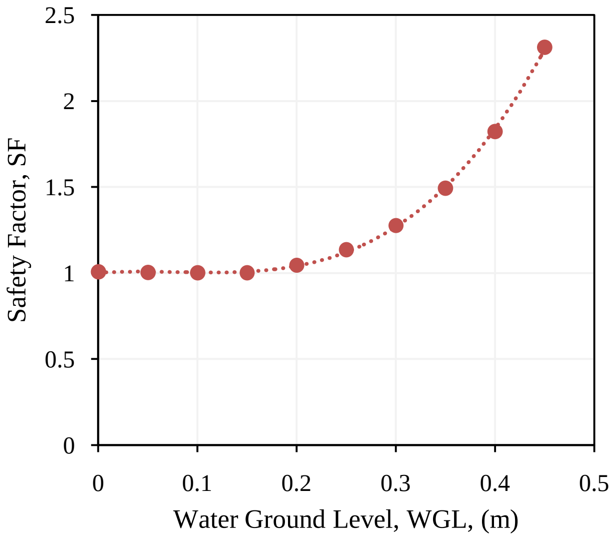

FIGURE 4. THE VALUES OF THE SAFETY FACTORS FOR WATER GROUND LEVEL

There is an asymptotic negative relationship with a strong correlation coefficient between the groundwater level and the safety factor according to the analyzes. While a significant change in safety factor does not occur at depth of the groundwater level from 0 to 0.2m, the deepening of groundwater level from 0.2m leads to an increase in the safety factor at much larger values.

IV. CONCLUSION

Series of numerical analysis by using finite element method (Plaxis 2D) [14] were performed to investigate the effect of a change of cohesion, internal friction angle, slope angle and groundwater level on the safety factor of slope failures. From the data and assessments presented in this paper the following conclusions can be drawn:

Based on increasing of slope angle, the safety of slope against landslide (failure of slope) decreases. An increasing in the slope angle of range from 30 to 400 leads to an average 28% reduction in the safety factor.

It was determined that the safety of slope against to failure decreases depending on the increment of the internal friction angle. An increase of the internal friction angle ranging from 30^0 to 43^0 causes an increment in the safety factor as per 39%.

The enhancement of cohesion value of soil forming a slope causes significantly the safety of slope against to failure. An increase of the cohesion ranging from 0.500 to 1.500 kN/m2 leads to an increment in the safety factor as per 72%.

In case of lowering groundwater level from top of the slope, there is no significant change in safety factors up to a certain depth (0.20 m from the top of slope), and distinct changes in safety factor occur from 0.2 meter by deepening the ground water level. The relationship between the safety factor and the groundwater level has an asymptotic with strong correlation coefficient.

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