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International
Journal
Of Modern Engineering Research (IJMER)

Safety Margin of Slope Stability Using Common Deterministic Methods

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Abstract: *The objective of this research was to develop a model for deterministic slope stability analysis. The study was performed through different methods of analysis and compared with Bishop simplified method, the variation of each input parameter ranged using traditional behavior equations to produce a distribution of the factor of safety verses the variables. A sensitivity analysis is then applied to the output factor of safety with each variable to select the slope design parameters with acceptable effect on factor of safety. To demonstrate the application of the deterministic methods developed during this paper, the methodology was applied to case study to present the effect of each variable on factor of safety, the study of slope failure was assumed to be circular slip surface .*

Keywords: *Safety factor, Sensitivity analysis, Slope stability.*

I. Introduction

The slope stability problems is difficult to accurately modeled because of variety of factors. one of main problem is that the exact behavior of slopes cannot be exactly predicted. Hence, engineers resort to a factor of safety approach to reduce risk of slope failure. the approach of deterministic methods present systematic way to treat uncertainties of variables, especially slope stability. The stability of a slope has a considerable effect on the surrounding area of the slope, because very often, human lives are in danger or significant material damage results if a slope fails. Thus the slope stability analysis is one of the most important areas of practical use in soil engineering.[10].

in this paper study a model of embankment dam using different methods of analysis in deterministic behavior. many variables affecting the safety factor value ,these variable are tabled in this paper as ranged values with mean value for each variable to include the effect of variation of variables in sensitivity analysis.

the safety factor is computed for mean value of each variable to make comparison study between different methods of analysis with Bishop method.

II. Slope Failure Modes

The analytical prediction of the slope failure in a given system requires the location of the slip surface, the determination of acting forces, and the prediction of the available reactive forces on it which acting along the slip surface and the working shear is the sum of the shearing stresses produced by causes (dead load, water, etc.) along the same surface. The stability analysis is largely a trial-and-error process, accomplished by numerical or graphical methods. Because of the cyclic (repetitive) nature, the calculations and the graphical constructions are well suited to computer programming, which reduces the involved labor considerably.[3,6,7] . Classification of gravity induced movements was introduced by Varnes that was based on two variables; type of material and type of movement. The main difference between this classification and the submarine classification, derived by Varnes, is that the material is totally saturated in water, so there is no degree of wetness. Some geologists argue that there is no concrete classification scheme for submarine slides because there is not just one type involved in one event; i.e. sliding results in a turbidity flow as acceleration of the debris increases, they can be summarized as follows:-

Falls occur when rock, mud or sand sized particles break free from the top of a steep or nearly vertical slope and pummels to a lower position. Multiple events in one location accumulate to form talus deposits at the base of the slope.

Slides which the most frequent type of wasting that moves a mass with translational motion down the contour due to failure of its base.

Flows occur when bodies of sediment or rock fragments are set into motion down a slope at a slow rate sometimes experiencing turbulence. There are several types of flows that are dependant on the size of the particle and the type of motion within the flow. Turbidity flows are events in which denser water forces sand-size and smaller debris to flow turbulently down the slope. Also; slope of failures may be classified according to the type of the failure surface as shown in fig.1 to:

1. Straight lines (particularly so in granular media).
2. Approximate to arcs of circles.
3. Approximate to logarithmic spirals.
4. Combination of straight lines, arcs of circles, and/or
5. Logarithmic spirals.

These types of the slope failure may differ as the material type, and the degree of complexity is function in the variety of the variables in the failure zone. Slopes often appear to fail on circular slip surfaces and it is often reasonable to analyze slope stability using circular slip surfaces. However, there are also many instances when this is not the case. Non-circular slip surfaces may be more critical than circular slip surfaces when:

1-There is a weak layer present in the foundation. The weak layer could be soft clay or liquefiable sand.

2-There is a heavily over consolidated, stiff fissured-clay or clay-shale foundation for an embankment.

3- A dam's core is sloping and is significantly weaker than its shell.[4,9,10]

Slope failure may also take the shape of the following when firm layer existed under the slope:

1. The base failure figure (2.a) in cohesive soils is preceded by the formation of tension cracks above the upper edge of the slope, followed by a shear failure along a slip surface.

2. The slope failure figure (2.b) in cohesive soils is again preceded by the Formation of tension cracks at the top, followed by a critical shear failure along slip surface that intersects certain point of slope.

3. The toe failure Figure (2.c) in soils of $\varphi > 0$ forming steep slopes is a Shear failure along a slip surface that intersects the toe of the slope.

Although this group classification is a convenient descriptive approach, sometimes the actual failures occur in a less distinct form as a combination of two modes. [1, 2, 8]

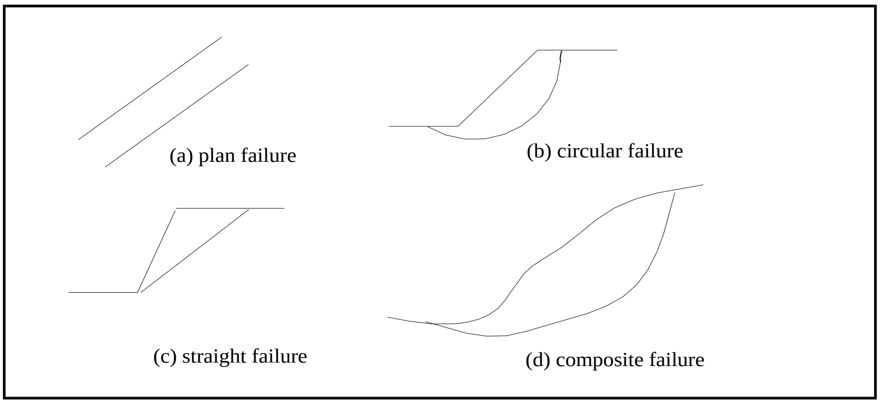


Fig.1 General types of the slope failure.

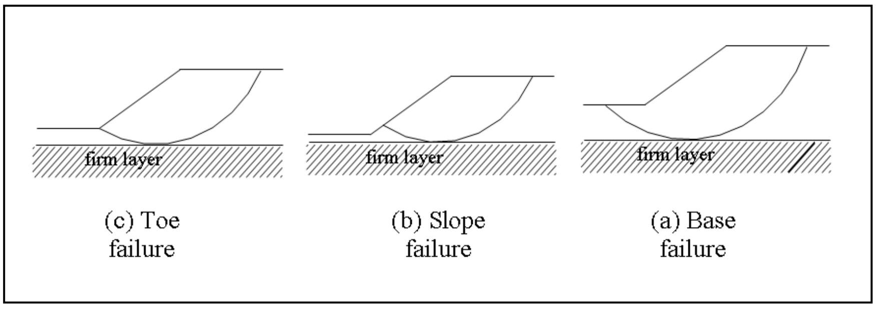


Fig.2 Types of failure of slope contain firm layer. (8)

III. Analysis Of Failure And Safety Factor

At any surface of slope failure safety factor can be found from the following equation:

$$F_s = \frac{\text{forces opposing slip (ultimate shear)}}{\text{forces causing slip (working shear)}} \qquad (1)$$

Where the ultimate shear is the sum of the critical shearing stresses as the next equation

$$\tau = c + \sigma \tan\varphi \qquad (2)$$

many methods studied the slip surface considering certain number of slices to determine the critical safety factors such as :

1. Karl Edward Peterson method (1915).
2. Bishop's Simplified Method - popular - use for circular failure (1950).
3. Janbu's Simplifies Method - popular - use for noncircular failures.
4. Lowe and Karafiath's Method.
5. Corps of Engineer's Method (1982).
6. Spencer's Method - use for rigorous analysis (1973).
7. Bishop's Rigorous Method.
8. Jambu's Generalized Method.
9. Sarma's Method.
10. Morgenstern - Price Method (1965).

All involve the principle of limit equilibrium of tangential and normal forces on the slip surface as shown in Fig.3

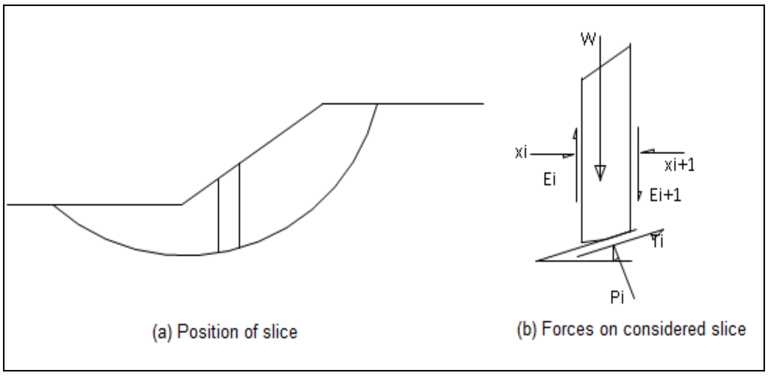


Fig.3 forces on slice from slip surface

IV. Simulation Results

Case study is used to compute the safety factor, the dimensions of studied earth dam is as shown in Fig.4

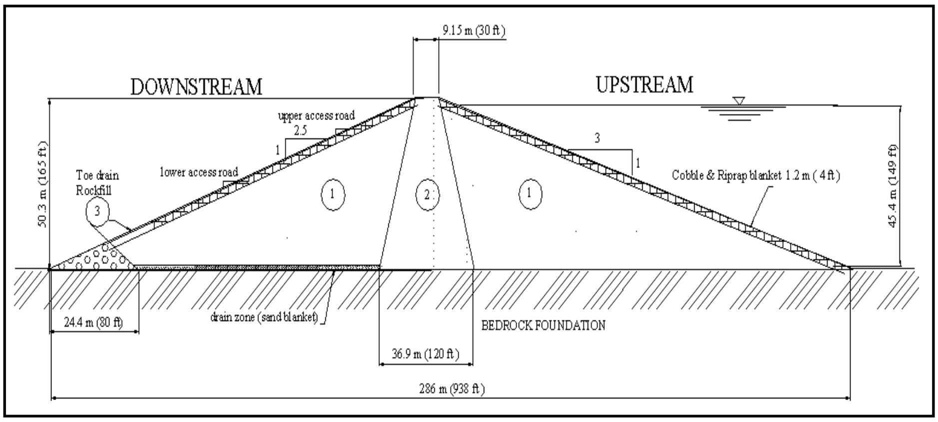


Fig.4 Earth dam considered as case of study (Miramar earth dam)

Input variables for this case of study used with mean values of detailed in table .1 below

Table.1 input variables for case study

	variable	Unit	Mean value
Zone 1		kN/m^3	18.2
	C	kN/m^2	30
	Φ	degree	30.6
Zone 2	Γ	kN/m^3	15.8
	C	kN/m^2	37.2
	Φ	degree	15
	Γ	kN/m^3	18
Zone 3	Φ	degree	25
General variables	γ_w	kN/m^3	9.81
	H	m	50.3
	$h_{capillary}$	m	0
	h_{water}	m	0
	X1	m	29.5
	Y1	m	38.3
	R	m	68.3
	S	dimensionles s	2.5

where

C:Cohesion
H: height of dam above underlying stiff layer
h:height of dam in upstream side
$h_{capillary}$: Capillary rise of water .
h_{water}: water height in upstream side.
R: raduis of the failed surface.
S: slope of upstream side
X1:horizontal distance of center of failure to toe
Y1: vertical distance of center of failure to toe
γ: unit weight
φ: internal friction angle

During the process of the analysis the factor of safety is estimated to the method accepted for solving the problem, the value of the factor of safety in some cases does not converge to certain value with some methods such as Bishop method. thus in such a case we should treat the slope with other method of analysis. Bishop simplified method has some what degree of convergence to the exact solution for the reason that it considered the equations of equilibrium in the force and moment and at the same time omit one of the interslice forces which some what has no great effect to the factor of safety. evaluation and the results as shown in Table. 2

Table (2) The Values of factor of safety with each method.

Method of analysis	Factor of safety F_s	Deviation to Bishop method %
Peterson	1.984	-3.9
Solution of Upper bound	2.449	18.6
Solution of lower bound	2.324	12.5
Bishop simplified	2.065	-
Spencer	2.082	0.8
Morgenstern	1.940	-6.1

the safety factor varies according to value of each variable , Fig.5 through Fig.10 shows these variations

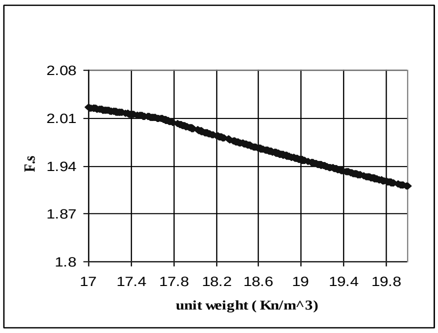


Fig. 5 variation of Fs with γ

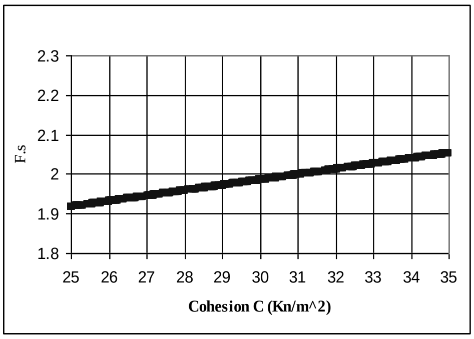


Fig. 6 variation of Fs with C

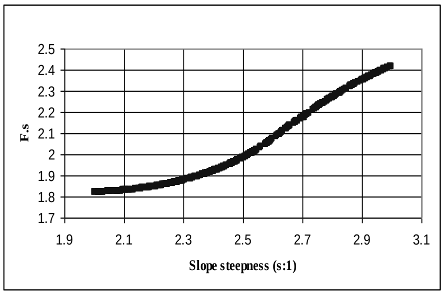


Fig.7 variation of factor of safety with S

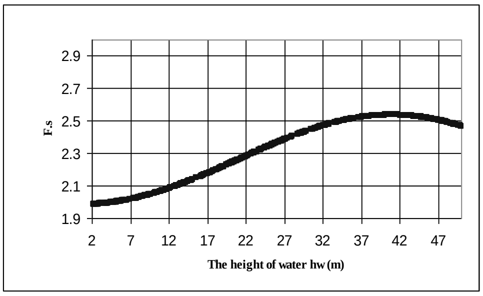
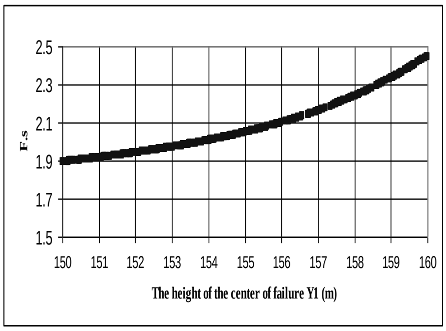


Fig.8 variation of Fs with hw



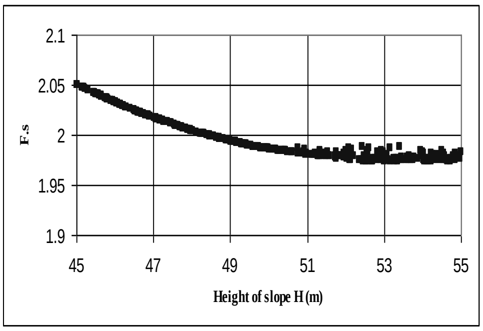
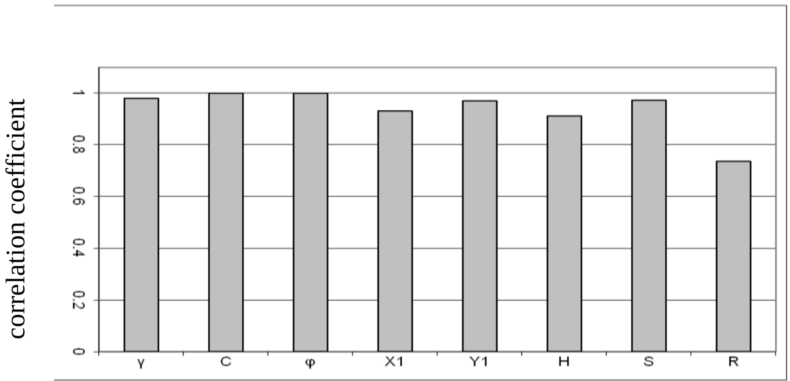


Fig.9 variation of Fs with H

Fig.10 variation of Fs with y1

Sensitivity analysis is then applied using correlation coefficient to present the more effective parameters to the factor of safety lead to results shown in Fig.11



input variables

Fig.11 sensitivity analysis of the input variables with correlation coefficient

V. CONCLUSION

The paper presented herein developed a computer program using different methods of slope stability analysis. Deterministic model for slope analysis were implemented into the SLOPE/SCF program including complete range of traditional slope analysis methods. To demonstrate the capabilities of this methodology, a case study was adopted using circular analysis methods. From the stability analysis of a slope with a circular failure surface and factor of safety for uncorrelated input parameters the following points are concluded.

The sensitivity analysis conducted using a correlation and standard error analysis indicated that the cohesion, internal friction angle, and unit weight were the most critical inputs when analyzing the slope for a circular failure surface. The sensitivity analysis confirms the expected significance of each input parameter.

The mean factor of safety from this analysis was 2.141.This was deviated from the midpoint factor of safety from the modified Bishop's method of slices (2.065) by about 3.7 %. The methods of analysis have same pattern for the variables with percent of variation between them (3 to 20%).

For this model and with comparing the results of the factor of safety from different methods, Morgenstern method appears to have a lower bound of the solution for the factor of safety. The upper bound of solution is the friction circle method, and the Bishop simplified method has a value near to the mean value estimated by the methods.

Acknowledgement

Author is thankful to prof. Fathi lais, Dr. hassan Elmezwighi , Dr. Amer Boshalla university of Benghazi for thier helping. Special thanks for my wife for endeavor supporting.

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