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Stability Analysis of Homogeneous Earth Slopes

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Abstract. Slope is an exposed ground surface that stands at an angle with the horizontal. Slopes are required in the construction of highway and railway embankments, earth dams, levees, canals etc., and are generally less expensive. Failure of natural slopes and man-made slopes has resulted in much death and destruction. Slope stability analysis consists of determining and comparing the shear stress developed along the potential rupture surface with the shear strength of the soil. Attention has to be paid to surface drainage, groundwater, and the shear strength of soils in assessing slope stability. For a safe slope FOS should be greater than 1. The advent of electronic computers made it possible to more readily handle the iterative procedures and the use of slope stability software has simplified the analysis to a great extent. In the present study the software SLOPE/W has been used to analyze the homogeneous slope for various cohesive strengths.

Key words: slope, analysis, factor of safety, cohesion, failure, stability.

1. Introduction

A slope is an unsupported, inclined surface of a like soil mass. Slopes can be natural or man-made. These may be above ground level as embankments or below ground level as cuttings. Earth slopes are formed for railway embankments, earth dams, canal banks, levees, and at many other locations. Instability related issues in engineered as well as natural slopes are common challenges to both researchers and professionals. Instability may result due to rainfall, increase in groundwater table and change in stress conditions. Similarly, natural slopes that have been stable for many years may suddenly fail due to changes in geometry, external forces and loss of shear strength. In addition, the long-term stability is also associated with the weathering and chemical influences that may decrease the shear strength. In such circumstances, the evaluation of slope stability conditions becomes a primary concern everywhere. When a mass of soil has an inclined surface the potential of slope to slide from higher level to lower level always exist. The sliding will occur if shear stress developed in the soil exceeds corresponding shear strength of soil. However certain practical considerations make precise stability analyses of slope difficult in practices. The engineering solutions to slope instability problems require good understanding of analytical methods, investigative tools and stabilization measures. Chowdhury [1] (1978) says, "The primary aim of slope stability analyses is to contribute to the safe and economic design of excavation, embankment and earth dams".

1.1. Importance of study

Development activities may face great challenges due to unstable grounds. Similarly, the slope failure may interrupt the established imperative services like traffic movement, drinking water supply, power production and similar infrastructures. The main motivation of stability analyses is to save human lives, reduce property damages and provide continuous services. Therefore, the most suitable and reliable stability analysis methods have great scope and thus, they are increasingly demanding. The chosen method should be able to identify the existing safety conditions and suggest for technically feasible and economically viable

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solutions. With this intension, limit equilibrium method like SLOPE/W, is adopted to study the causes of failure and to avoid the failures of slope as for as possible.

1.2. The objectives of the present study

The present study involves in analysis of stability of a homogeneous earth slopes with varying soil parameter and using different methods.

This study is limited to:

a) Calculation utilizing Slope/W software for limit equilibrium analysis.

b) Analysis for limit equilibrium based on ordinary or Fellenius method, Bishop's simplified method, Janbu simplified method, Spencer method, Sarma method, Corps of Engineers#1, Corps of Engineers#2 and General limit equilibrium.

2. Literature Review

Fellenius [2] (1936) introduced the Ordinary or Swedish method of slices. In the mid-1950s Janbu [3] (1954) and Bishop [4] (1955) developed advances in the method. The advent of electronic computers in the 1960's made it possible to more readily handle the iterative procedures inherent in the method which led to mathematically more rigorous formulations such as those developed by Morgenstern and Price [5] (1965) and by Spencer [6] (1967). One of the reasons the limit equilibrium method was adopted so readily, is that solutions could be obtained by hand-calculations. Simplifying assumption had to be adopted to obtain solutions, but the concept of numerically dividing a larger body into smaller pieces for analysis purposes was rather novel at the time.

H. Rahardjo et.al [7](2007) studied on the relative importance of soil properties, rainfall intensity, initial water table location and slope geometry in inducing instability of a homogenous soil slope under different rainfall through a series of parametric studies. B.N Sinha [8] (2008) emphasis that advanced method of slope-stability analysis for economical design of earth embankment and discusses on the concept and theory involved in different methods of slope stability analysis of earth embankment. Abdoullah Namdar et al [9] (2010) say that achievement of slope load sustainability using mixed soil technique is considered acceptable method for slope construction technology.

3. Causes of Failure of Slopes

The important factors that cause instability in slope and lead to failure are (1) Gravitational force. (2) Force due to seepage of water (3) Erosion of the surface of slope due to flowing water (4) The sudden lowering of water adjacent to the slope and (5) Forces due to earthquakes.

Different types of slope failures are rotational Failure, slope circle failure, toe circle failure, base circle failure, translational failure, compound failure, wedge failure.

3.1 Types of stability analysis

There are two different ways for carrying out the slope stability analyses. The first approach is the total stresses approach which corresponds to clayey slopes or slopes with saturated sandy soils under short term loadings with the pore pressure not dissipated. The second approach corresponds to the effective stress approach which applies to long-term stability analyses in which drained conditions prevail. For natural slopes and slopes in residual soils, they should be analyzed with the effective stress method, considering the maximum water level that can be reached under severe rainstorms. Slope stability analysis using computers is an easy task for engineers when the slope configuration and the soil parameters are known. However, the selection of the slope stability analysis method is not an easy task and effort should be made to collect the field conditions and the failure observations in order to understand the failure mechanism, which determines the slope stability method that should be used in the analysis. Therefore, the theoretical background of each slope stability method should be investigated in order to properly analyze the slope failure and assess the reliability of the analysis results.

4. GEOSTUDIO – SLOPE/W

GEO-SLOPE is a suite of application for geotechnical and geo-environmental modeling. SLOPE/W, developed by GEO-SLOPE International Canada, is used for slope stability analysis SLOPE/W. It has become one of the powerful features of this integrated approach and opens the door to all types of analysis of a much wider and more complex spectrum of the problem.

4.1 Geometry

Fig. 1 shows a homogeneous soil slope with a slope height equal to 6 m and slope angle equal to 45 °, the size of the domain considered is 20m in width and 10m in height. The following are the limit equilibrium methods used in this study: ordinary or Fellenius method, BSM, JSM, M-PM, Spencer method, Sarma method, Corps of Engineers#1, Corps of Engineers#2, and GLE.

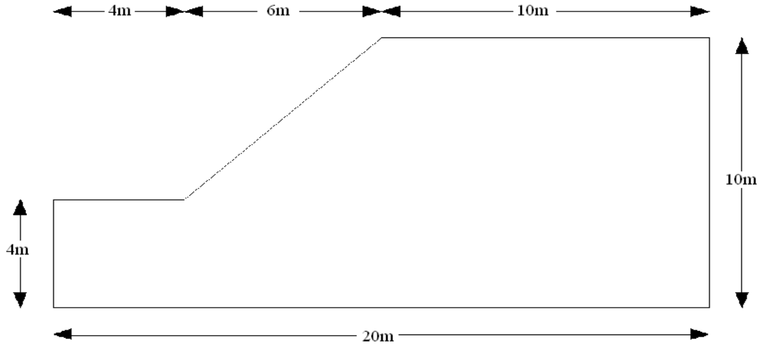

Fig. 1: Homogeneous soil slope geometry for "model"

4.2 Analysis and result

In this parametric study, the cohesive strength of the soil varies from 0, 5 and 10–20 kPa. The density and Friction angle of the soil is kept at 20kN/m^3 and 30 °respectively, in all the analysis. Fig. 2a and Fig. 2b shows CSS and FOS by M-PM (Auto Locate) and CSS and FOS by M-PM (Exit and Entry) respectively.

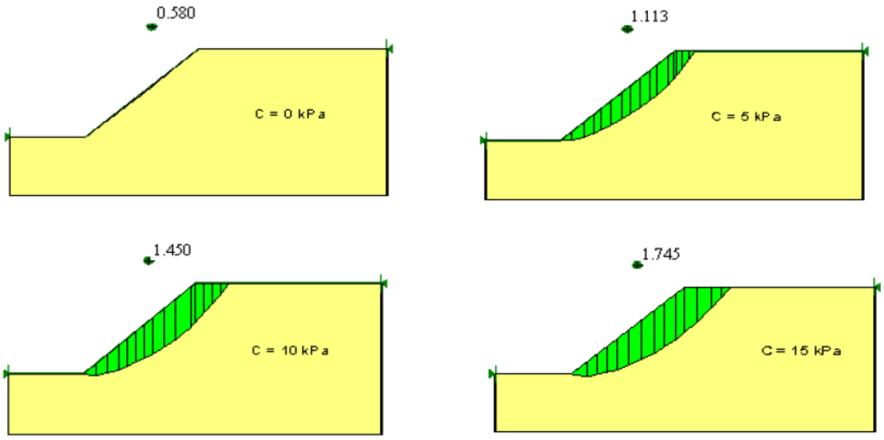

Fig. 2(a): CSS and FOS by M-PM (Auto Locate)

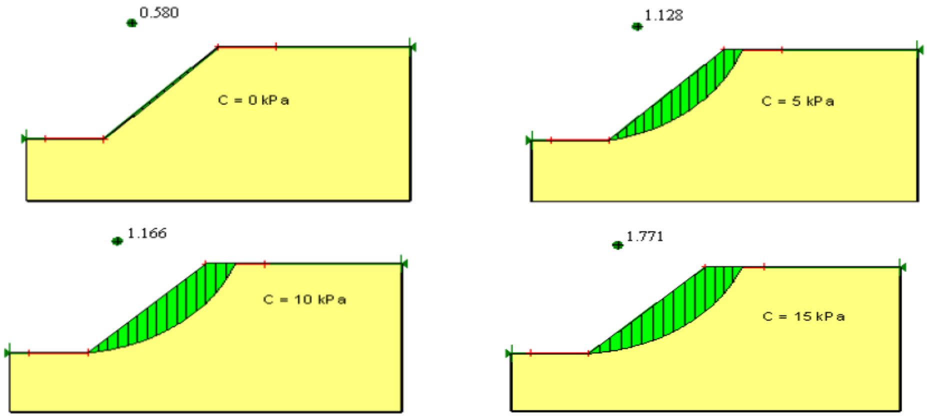

Fig. 2(b): CSS and FOS by M-PM (Exit and Entry)

Table 1 and Table 2: represents minimum factor of safety for varying cohesion (Auto Locate) and minimum factor of safety for varying cohesion (Entry and Exit) respectively.

Table 1: Minimum factor of safety for varying cohesion (Auto Locate)

No.		1	2	3	4	5
γ (kN/m^3)		20	20	20	20	20
C (kPa)		0	5	10	15	20
φ(°)		30	30	30	30	30
M-P	**Moment**	0.58	1.113	1.45	1.745	2.017
	Force	0.578	1.112	1.45	1.745	2.01
Ordinary	**Moment**	0.578	1.052	1.388	1.664	1.929
Bishops	**Moment**	0.586	1.118	1.468	1.739	1.997
Janbu	**Force**	0.578	1.068	1.38	1.658	1.912
Spencer	**Moment**	0.58	1.128	1.464	1.758	2.04
	Force	0.578	1.129	1.458	1.762	2.044
GLE	**Moment**	0.609	1.113	1.48	1.745	2.004
	Force	0.609	1.113	1.48	1.745	2.004
Corps Engineers #1	**Force**	0.58	1.136	1.485	1.796	2.091
Corps Engineers #2	**Force**	0.579	1.143	1.531	1.822	2.13
Sarma	**Moment**	0.58	1.12	1.453	1.729	1.992
	Force	0.578	1.12	1.448	1.729	1.992

Table 2: Minimum factor of safety for varying cohesion (Entry and Exit)

No		1	2	3	4	5
γ (kN/m3)		20	20	20	20	20
C (kPa)		0	5	10	15	20
φ(°)		30	30	30	30	30
M-P	**Moment**	0.508	1.128	1.466	1.771	2.058
	Force	0.578	1.128	1.462	1.769	2.056
Ordinary	**Moment**	0.578	1.076	1.408	1.71	2
Bishops	**Moment**	0.588	1.135	1.472	1.776	2.063
Janbu	**Force**	0.578	1.06	1.363	1.688	1.989
Spencer	**Moment**	0.58	1.129	1.466	1.772	2.059
	Force	0.58	1.129	1.468	1.774	2.062
GLE	**Moment**	0.626	1.128	1.465	1.771	2.058
	Force	0.626	1.128	1.465	1.771	2.058
Corps Engineers #1	**Force**	0.578	1.139	1.493	1.813	2.131
Corps Engineers #2	**Force**	0.578	1.148	1.516	1.844	2.16
Sarma	**Moment**	0.58	1.126	1.462	1.767	2.054
	Force	0.578	1.125	1.461	1.767	2.056

5 Conclusion

From the parametric study, we can see that when the cohesion increases, gradually the Factor of safety also increases. When the cohesion is less than 3kPa, the factor of safety will be less than 1. FOS for design

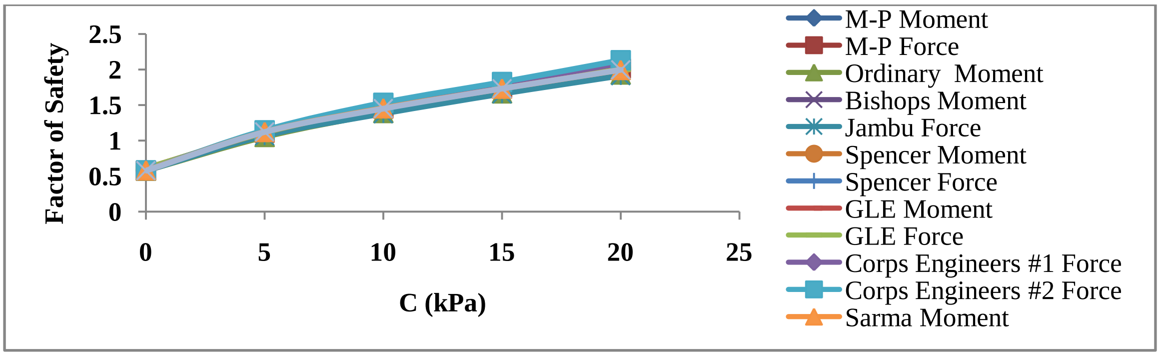

Fig. 3: Varying Cohesion v/s FOS (Auto locate)

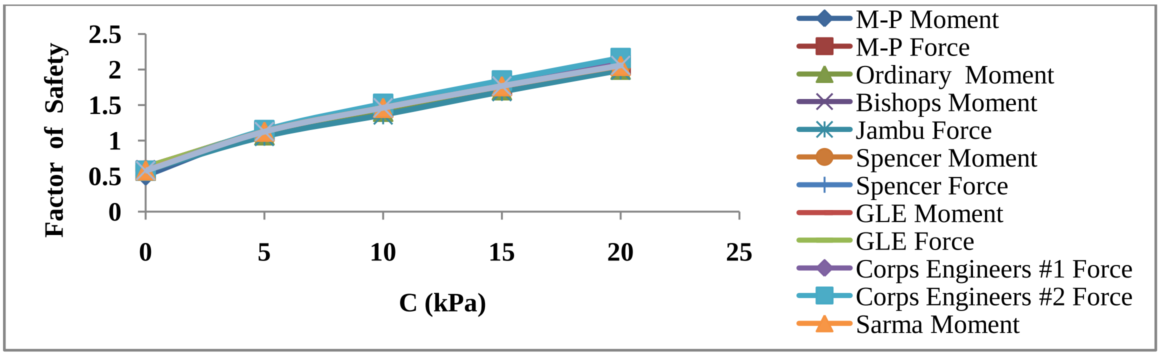

Fig. 4: Varying Cohesion v/s FOS (Exit and Entry)

slope (Table 1 and Table 2) will be unsafe if the FOS is less than one. Fig. 3 exhibits graphs showing varying cohesion v/s FOS (Auto locate) and Fig. 4 varying cohesion v/s FOS (Exit and Entry) respectively.

The old methods (Fellenius method and Swedish Circle method) give lower factor of safety (FOS) and therefore requires a flatter slope for the specified FOS compared to the earth slope obtained on the basis of Morgenstern-Price method which takes inter-slice forces (normal and shear) into account and satisfies closed force polygon indicating equilibrium condition of the slice in a free body force diagram.

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