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STABILITY OF SLOPES ON CLAYS OF VARIABLE STRENGTH BY LIMIT EQUILIBRIUM AND FINITE ELEMENT ANALYSIS METHODS

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ABSTRACT: This paper presents an evaluation and comparative study on the stability analysis of simple slope models founded on undrained clay soils. The analysis was performed according to the limit equilibrium (LE) and finite element (FE) methods utilizing “Slide 2D” and “Plaxis 2D” computer programs respectively. Forty five slope models with different geometries based on soft, medium stiff and very stiff clay soil foundations were considered for stability analysis. The comparison made between four LE methods indicated that the Bishop and Spencer methods produced practically similar FOS results whereas the Fellenius and Janbu methods gave FOS values lower than the Spencer method by 3.0% and 7.4% respectively. For slopes founded on soft clays, the difference in FOS computed by the LE and FE methods is negligible but the FOS values computed by the LE methods were 8.5% higher than the FE method for slopes on medium and very stiff clays. Based on the results of linear regression analysis of all data, the Fellenius, Bishop, and Spencer methods gave FOS values higher than the FE method by 1.4, 5.3 and 5.7% respectively whereas the Janbu method gave FOS lower than the FE method by 4.3%. Evaluation of the effects of slope geometry and foundation soil properties on slope stability revealed a reliable relationship between FOS and a variable combining four slope and soil parameters.

Keywords: Slope Stability Analysis, Factor of Safety, Undrained Clay Soils, Limit Equilibrium, Finite Element

1. INTRODUCTION

Slope stability problems are normally encountered when the balance of natural or engineered soil slopes is disrupted. The stability of a slope may be defined as the resistance of an inclined surface within the soil mass to failure by sliding, overturning or collapsing. Soil stability analysis is performed to assess equilibrium conditions and achieve safe design of slopes. The factor of safety (FOS) against slope instability is defined as the ratio of the resisting forces (strength) to the driving forces (loading) along a potential failure surface. The slope is said to be in a limit equilibrium condition when FOS = 1 whereas higher values correspond to stable slopes.

Slope stability analysis can be evaluated by the limit equilibrium (LE) and finite element (FE) methods. The LE methods are based on the static equilibrium of the forces and/or moments whereas the FE methods utilize the constitutive law or stress-strain relationship concept. The LE approach involves different methods depending on the type of problem to be solved and the required accuracy of analysis results. More attention has been directed in the recent decades to the use of the FE in slope stability analysis to model cases with complex slope geometry, soil behavior and loading sequences and to visualize soil deformations in place. Many design computer software packages have been developed to enhance the application of the LE and FE methods in slope stability analysis.

This paper presents an evaluation and comparison of the results of slope stability analysis carried out according to certain LE and FE methods for a simple slope with variable geometries founded on undrained clay soils with different strength characteristics. The analysis was performed utilizing the “Slide” and “Plaxis” computer software programs for the LE and the FE approaches respectively. Some important aspects are given below on the two slope stability analysis methods.

2. METHODS OF SLOPE STABILITY ANALYSIS

2.1 Limit Equilibrium Stability Analysis Methods

In the LE slope stability analysis, the soil mass above the slip surface is divided into slices and the shear and normal inter-slice forces are determined by applying appropriate forces and/or moment equilibrium equations for each slice to satisfy the static equilibrium conditions. The FOS computation procedure involves comparing the available soil shear strength along the sliding surface with the force required to maintain the slope in equilibrium. The LE methods are commonly adopted in routine design due to their simplicity, accuracy and the small number of parameters required for analysis. The first LE method, known as the Fellenius method or the ordinary method of slices, was developed in 1927 by the Swedish engineers and is applicable to circular slip surfaces [1]. A revised method of circular slip analysis was developed by Bishop in 1955 [2] for improving the accuracy of FOS computations. The latter requires an iterative procedure to calculate the minimum FOS. To undertake analysis of non-circular slips, Janbu's method [3] is normally used. More refined LE methods which account for both force and moment equilibrium have been developed by Spencer [4] to further improve the FOS calculation accuracy.

2.2 Finite Element Stability Analysis Methods

The main feature of the FE is using soil stress-strain behavior for slope stability modeling which changes the problem from a static-indeterminate to a static-determinate one. In FE methods there is no pre-assumption about the shape and location of the failure surface. FE modeling starts by dividing the slope into a finite number of zones or elements. Forces and strains are then calculated for each element using the appropriate constitutive laws for the materials in the slope.

The FE method uses the strength reduction method (SRM), to calculate/simulate failure limit state of slope and safety factor. The SRM is based on progressive reduction of soil strength parameters; φ and c, by a "strength reduction factor" (SRF) until convergence occurs within a specified number of iterations and tolerance or failure of slope occurs. The SRF which corresponds to the point at the last convergence state is equivalent to the safety factor.

3 MODELLING OF SLOPE STABILITY PROBLEM

3.1 General

A description of the methodology followed for modeling the slope stability problem analyzed is given hereunder. The main aspects included the slope geometry, characteristics of slope and foundation soils and the computer programs used for FOS computations.

3.2 Slope Geometry and Soil Properties

The slope geometry assumed is comprised of a two soil layers model with variable strength parameters as schematically illustrated in Fig. 1. The upper slope layer comprises a sandy soil whereas the lower foundation layer is a homogeneous clay of variable shear strength. The clay soils were modeled in an undrained condition with zero internal friction angle (φ = 0) and cohesion values of 20, 40 and 140kN/m^2 representing soft, medium stiff and very stiff soils.

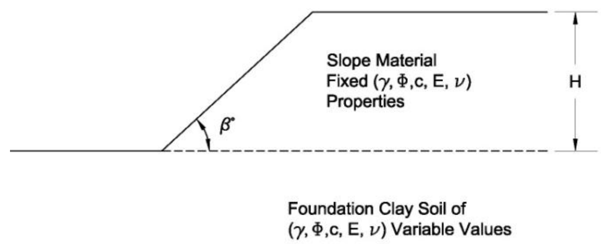

Fig. 1 Two soil layers model assumed for slope stability analysis.

Table 1 lists the input parameters used for stability analysis which include the properties of the slope material and foundation soil types. These properties are typical of those normally obtained from testing of such soil materials.

Table 1 Properties of the slope material and foundation soil types used for stability analysis

Soil properties		c_u kN/m^2	Φ_u (°)	γ_b kN/m^3	E MPa	ν
Slope material		10	30	18.0	15	0.17
Base Soil	Soft clay	20	0	17.3	14	0.30
	Medium stiff clay	40	0	18.9	33	0.30
	Very stiff clay	140	0	20.4	75	0.30

Simple slope geometries of variable heights (H) and inclination angles (β) were assumed such that different slope models are covered in the analysis. Slope heights of 12m, 20m and 28m were chosen to represent low, medium and high slopes and for each case the angle β was varied from 10° to 24°. In total, forty five study cases were considered for analysis.

3.3 Slope Stability Computer Software Used

3.3.1. Limit Equilibrium "Slide 2D" Software

The LE methods chosen in this study included the Fellenius's (FM), Bishop's method (BM), Spencer's method (SM) and Janbu's method (JM). The input and features of models included the slope geometry and soils parameters, selection of the number of slices (25 slices) and adoption of the Mohr-Coulomb soil shear strength model without tension cracks. The slope models were analyzed using "Slide 2D" computer Software from Rocscience Inc. [5] for computing FOS using vertical slice limit equilibrium methods of circular or non-circular failure slip surfaces. The Slide 2D software is simple to use, and yet complex models can be created and analyzed quickly and easily. Searching of the critical slip surface is realized with the help of a grid or as a slope search in user-defined area. Individual slip surfaces can be analyzed, or search can be applied to locate the critical slip surface for a given slope.

3.3.2. Finite Element "Plaxis 2D" Software

The stability of the slope was analyzed using the finite element Plaxis 2D software [6] normally used with plane strain model for stability and deformation analysis to determine the minimum FOS. The assumed slope models were drawn with 15 nodes and the standard fixities were used to define the boundary conditions. Plaxis 2D uses a convenient graphical user interface that enables users to quickly generate a geometry model and finite element mesh based on a representative vertical cross section of the situation in question. Standard boundary conditions are automatically generated by the program. All soil types are modeled through Mohr-Columb yield criterion in Plaxis. Once the geometry model and boundary conditions are defined, automatic mesh generation is applied with the bandwidth optimizer for the finite element discretization refinement.

To apply the FEM, the appropriate meshes were generated for the various slope geometry models by dividing each model into a number of elements. Each element consists of a number of nodes and each node has a number of degrees of freedom. When the geometry model is complete, the finite element mesh can be easily generated. The mesh generation takes full account of the elements and nodes in the geometry model. PLAXIS 8.2 allows for a fully automatic mesh generation procedure when the mesh generation is complete, the finite element model is complete. Examples of meshes generated for models with small, intermediate and relatively large slope heights (H) and inclination angles (β) are presented in Figures 2, 3 and 4 respectively.

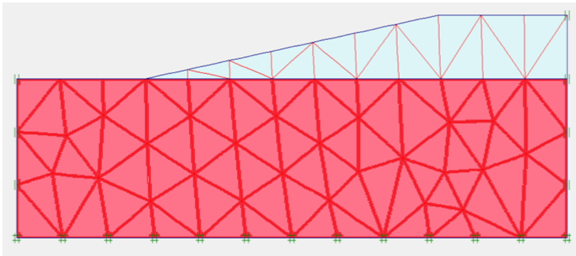

Fig. 2 PLAXIS mesh generated for slope model with H = 12m and β = 10°.

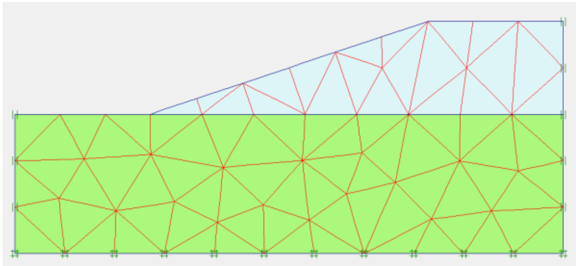

Fig. 3 PLAXIS mesh generated for slope model with H = 20m and β = 18°.

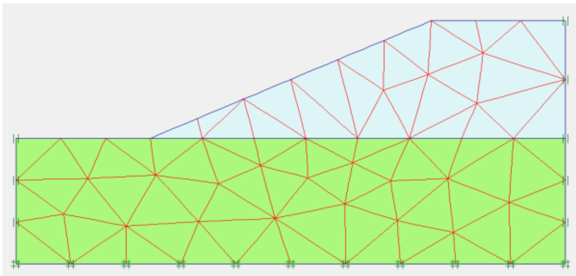

Fig. 4 PLAXIS mesh generated for slope model with H = 28m and β = 24°.

4. RESULTS AND DISCUSSION

4.1 Slope Stability Analysis Results

The results of the slope stability analysis performed according to the LE and FE methods are presented in Tables 2, 3 and 4 for the slopes founded on soft, medium stiff and very stiff clays respectively. The discussion presented herein is focused on comparisons of computed FOS values, the shapes and locations of established slip surfaces and evaluation of the slope geometry and soil properties effects on slope stability.

Table 2 Computed FOS values for slope models founded on soft clay soil foundations

Slope Geometry	H	12m					20m					28m				
	β	10°	14°	18°	20°	24°	10°	14°	18°	20°	24°	10°	14°	18°	20°	24°
Limit Equilibrium Methods Slide 2D	BM	0.60	0.56	0.54	0.54	0.53	0.46	0.39	0.36	0.35	0.34	045	0.33	0.29	0.28	0.26
	SM	0.60	0.56	0.54	0.54	0.53	0.46	0.39	0.36	0.35	0.34	0.45	0.33	0.29	0.28	0.27
	FM	0.59	0.56	0.54	0.54	0.53	0.47	0.39	0.36	0.36	0.34	0.46	0.36	0.31	0.30	0.28
	JM	0.55	0.51	0.50	0.50	0.50	0.43	0.36	0.33	0.32	0.31	0.42	0.31	0.27	0.26	0.25
FEM Plaxis 2D		0.61	0.57	0.54	0.53	0.52	0.45	0.38	0.36	0.35	0.33	0.39	0.36	0.30	0.28	0.26

Table 3 Computed FOS values for slope models founded on medium stiff clay soil foundations

Slope Geometry	H	12m					20m					28m				
	β	10°	14°	18°	20°	24°	10°	14°	18°	20°	24°	10°	14°	18°	20°	24°
Limit Equilibrium Methods Slide 2D	BM	1.16	1.09	1.07	1.06	1.05	0.84	0.84	0.69	0.68	0.66	0.73	0.77	0.55	0.53	0.50
	SM	1.16	1.09	1.06	1.06	1.04	0.84	0.73	0.68	0.67	0.66	0.77	0.61	0.55	0.53	0.50
	FM	1.12	1.06	1.03	1.03	1.01	0.81	0.70	0.66	0.65	0.63	0.73	0.59	0.52	0.51	0.49
	JM	1.05	0.99	0.97	0.96	0.95	0.77	0.67	0.62	0.61	0.60	0.72	0.56	0.50	0.48	0.46
FEM Plaxis 2D		1.09	1.01	1.04	1.03	1.01	0.75	0.66	0.62	0.61	0.59	0.60	0.51	0.47	0.45	0.43

Table 4 Computed FOS values for slope models founded on very stiff clay soil foundation

Slope Geometry	H	12m					20m					28m				
	β	10°	14°	18°	20°	24°	10°	14°	18°	20°	24°	10°	14°	18°	20°	24°
Limit Equilibrium Methods Slide 2D	BM	3.85	3.24	2.60	2.37	2.02	2.61	2.34	2.24	2.13	1.80	2.16	1.83	1.70	1.66	1.61
	SM	3.84	3.23	2.60	2.37	2.02	2.60	2.33	2.22	2.12	1.80	2.14	1.81	1.68	1.64	1.60
	FM	3.76	3.12	2.49	2.27	1.94	2.51	2.23	2.12	2.05	1.73	2.04	1.71	1.58	1.54	1.48
	JM	3.38	3.10	2.46	2.24	1.92	2.32	2.04	1.94	1.91	1.72	1.93	1.60	1.47	1.43	1.38
FEM Plaxis 2D		3.82	3.31	2.60	1.76	1.61	2.62	2.34	2.19	1.52	1.33	2.14	1.83	1.68	1.39	1.23

For slopes founded on soft clays it may be noted from Table 2, that the LE and FE methods yielded FOS values smaller than one in all cases indicating unstable slopes due to inadequate shear strength of the foundation soils. The analysis results showed that the slopes were even more unsafe for the cases with higher H and β values. The FOS values in Table 2 may be useful if it is required to improve the resistance of such weak soils against slope failures through the application of certain stabilization techniques.

The FOS pertaining to slopes supported on medium stiff clay foundations (Table 3) varied from 0.45 to 1.15 with the lower and upper values pertaining to inclination angles of 24° and 10° respectively. Such a slope foundation represents a marginal situation for the analyzed slope models. The results indicate that stability could be achieved by some methods with FOS ≥1 only in slopes with heights of 12-14m and mild inclinations (β = 12-14°).

For slopes on very stiff clay foundation soils, the FOS (Table 4) varied from 1.23 to 3.7 indicating that all analysed models were stable even for the cases of maximum H and β values. The highest and lowest FOS values pertain to slope geometries with the lowest and highest values of H and β respectively.

4.2 Comparisons of Stability Analysis Results

4.2.1 General FOS Comparisons of Computed

For all slopes founded on soft clays there is a very good agreement between the FOS values computed according to the LE methods except for the JM which gave consistently low FOS with a discrepancy reaching 10% for the 12m high slope.

Generally, the FE method indicated FOS values that are similar to or slightly lower than those of the LE methods for slopes founded on these soils. Therefore, both analysis methods seem to produce similar FOS values.

For slopes founded on medium stiff clays, there is a perfect agreement between the FOS computed by the BM and SM methods which gave the highest FOS followed by the FM whereas the JM gave the lowest values. The FE method showed a reasonable comparison with the LE methods for slopes of low to moderate heights but gave significantly lower FOS for relatively high slopes.

As noted for the slopes founded on soft and medium stiff clays, the BM and SM gave the highest FOS values for very stiff clays, followed by the FM whereas among the LE methods the JM indicated the lowest values. There is a very good agreement between the FOS values deduced from the FE method on one hand and the BM and SM methods on the other for slopes of low to moderate inclinations (β =12 to 18°). For slopes of inclination angles β ≥ 20°, the FE method gave FOS significantly lower than the LE methods. The differences in FOS computed by the two methods become more pronounced for slopes with steep inclinations (β = 24°) and large heights (H >20m).

4.2.2 Failure Slip Surfaces

Typical failure slip surfaces obtained from stability analysis based on the Bishop's LE method using SLIDE software and the FE method using PLAXIS software are presented in Figures 5, 6 and 7 for slopes with small, medium and relatively large heights (H) and inclination angles (β) placed on soft medium stiff and very stiff clay soils.

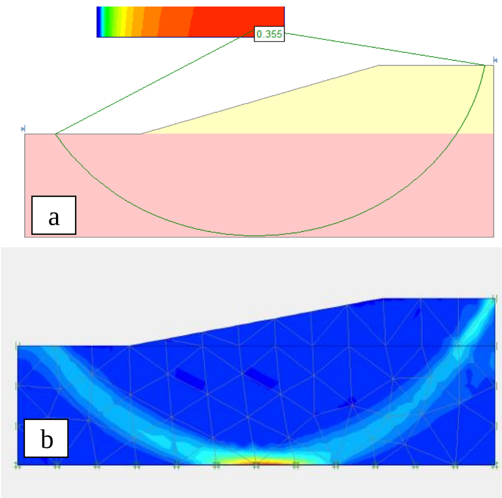

Fig. 5 Failure slip surfaces from LE SLIDE (a) and FE PLAXIS (b) methods for a slope model with H = 12m and β = 10° on soft clay soil.

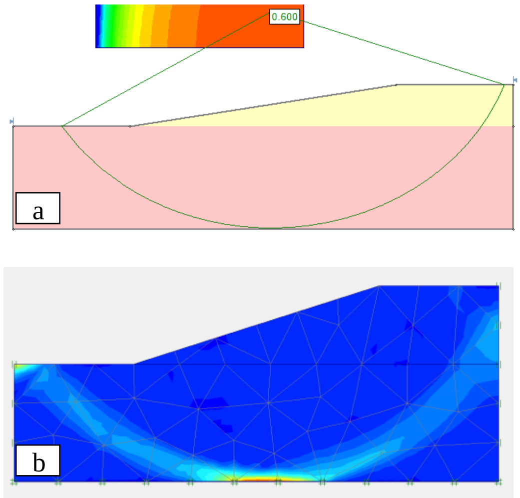

Fig. 6 Failure slip surfaces from (a) SLIDE software and (b) PLAXIS software for slope model with H = 20m and β = 18° on medium stiff clay.

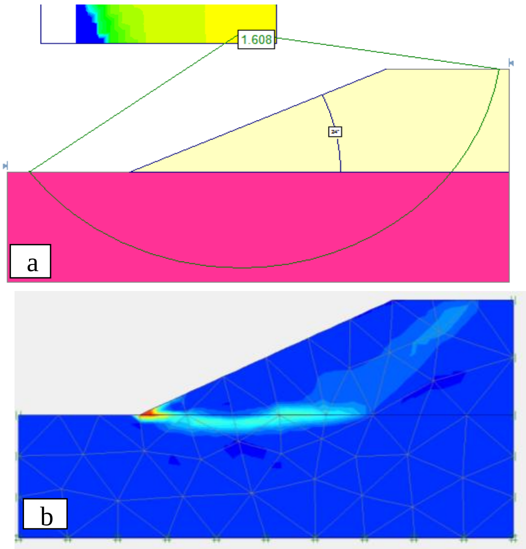

Fig. 7 Failure slip surfaces from (a) SLIDE LE software and (b) PLAXIS FE software for slope model with H = 28m and β = 24° on very stiff clay.

Figs. 5, 6 and 7 show that the failure slip surfaces established from slope stability analysis utilizing the SLIDE and the PLAXIS software packages are typical of the rotational deeply seated circular shape normally observed in the case of slopes founded on homogeneous undrained clay soils. Similar shapes and locations of the critical slip surfaces were revealed by the LE and FE methods for virtually all slope models on soft to medium stiff clay soils of low to moderate shear strength. This is clearly illustrated in Figs. 5 and 6 presented as examples of slopes of low to medium heights and slope inclination angles on soft to medium stiff clays. Critical slip surfaces of similar shapes and locations were also noted for the cases of slope models with low inclination angles founded on very stiff clay foundations.

For the models with relatively large β values (20 to 24°), some differences were noticed between the LE and FE analysis methods with respect to the location of the critical slip circle. Fig. 7(a) indicates that a deeply seated slip surface was revealed from the analysis by the LE SLIDE software whereas a very shallow and nearly toe-type failure mode was revealed in Fig. 7(b) for the same slopes analysed by the FE PLAXIS software

4.2.3 Comparisons of FOS Computed by Different LE Methods

The FOS values computed from the Spencer method (SM) were compared to those obtained from by the other three LE methods. The SM was selected as a basis for comparison because it satisfies both the force and moment requirements for static equilibrium. Moreover, the SM can be applied for circular as well as non-circular slip surfaces [4]. The comparison criterion was the discrepancies between FOS values deduced from the SM and other methods. The LE-LE comparison results show that the FOS values computed by the BM and the SM are practically the same for all slope models and foundation soil conditions. The FOS values computed using the FM were on average 3% lower than SM values for slopes on clays with different strength characteristics. The JM gave FOS values lower than the SM by 4.5 to 9.1% with an average of 7.4%. For the medium and very stiff clay foundations, the discrepancy between the JM and SM methods were higher than the previously reported maximum difference of 6% [7] between various LE methods.

4.2.4 *Comparisons of FOS Computed by the LE and FE Methods*

The average FOS values obtained for the LE methods for each slope model were compared to the values deduced from the FE method. The results indicated that the FE method gives FOS values which are in all cases smaller than the average LE values. The difference in FOS computed by the LE and FE methods is negligible (0.9%) for slopes founded on soft clays. However, the discrepancy between the two approaches becomes more pronounced (8.5%) for slopes on medium and very stiff clay foundations.

To examine whether the FOS computed from the LE methods can be related to the FOS according to the FE method the two data sets were analyzed by the regression method. Four linear equations were established between the FOS data pertaining to each LE method and the LE method. Equations of the best fit lines indicated that the Fellenius, Spencer and Bishop methods gave FOS values higher than the FE method by 1.4, 5.3 and 5.7% respectively. The Janbu method gave FOS lower than the FE method by 4.3%. The coefficient of determination R^2 varied from 0.958 to 0.967 indicating a perfect linear relationship between the LE and FE methods.

It has been reported in a previous study [8] that the differences in FOS computed by the FE and LE are negligible for simple slopes founded on undrained clay soils. The results of this study reveal that such a finding is only applicable for the slopes founded on soft clays. For slopes founded on medium and very stiff clays the FE method tends to give FOS values lower than the LE method. The differences may be attributed to the degree of accuracy of the inter-slice forces calculation [9]. The inter-slice forces are more accurately calculated by the FE software packages which take into account the local stress distribution in the soil mass. On the other hand, the LE methods have limitations with regards to the inter-slice shear forces computation. It has been indicated that the forces computed in the FE method are higher than in the LE methods; thus lower FOS are produced by the former. Another possible reason for the discrepancies in FOS values may be related to the differences in location of the critical slip surfaces obtained from analysis of input data using the SLIDE and PLAXIS computer programs pertaining to the LE and FE methods respectively. Such an observation was referred to earlier and illustrated in Fig. 7 for a slope with high height and inclination angle on a very stiff clay soil foundation.

It is known that both the LE and FE methods have their advantages and limitations when used for slope stability analysis. The geotechnical engineers should understand the limitations, choose the method that best fits the slope stability problem that they intend to perform and assess the analysis results accordingly. It has been suggested in many studies that the FE methods have greater benefits compared to the LE methods. However, the application of LE methods in practice is much simpler and requires less effort and time in establishing a slope model. This may outweighs some FE method drawbacks as the latter requires an increased time to deduce input parameters and follow the correct procedure to perform computations. In summary, the LE analysis seems to be favorable for solving a simple slope problem; however, if the problem to be solved is complicated and the input parameters are numerous, the FE methods are more appropriate.

4.3 Prediction of FOS for Simple Slopes on Undrained Clay Soils

The effects of slope geometry and foundation soil characteristics on the computed FOS were evaluated using the data pertaining to the LE and FE slope stability methods. The parameters considered for evaluation included the slope height (H) and inclination angle (β) and the undrained cohesion (c_u) and bulk unit weight (γ) of foundation soils. For a given slope the stability increases with soil strength and unit weight (c_u and γ) and deceases with slope height and inclination angle (H and β). Hence, the FOS may be expressed as a function of slope and soil parameters by the following equation:

$$\text{FOS} = f\left(\frac{\gamma * c_u}{H * \tan\beta}\right) \quad (1)$$

To define the type of relationship in above equation, the FOS values computed by each method were plotted against the results of the product of ($\gamma * c_u / H * \tan\beta$) as shown in Fig. 8 with H, c_u and γ expressed in m, kN/m^2 and kN/m^3 units respectively

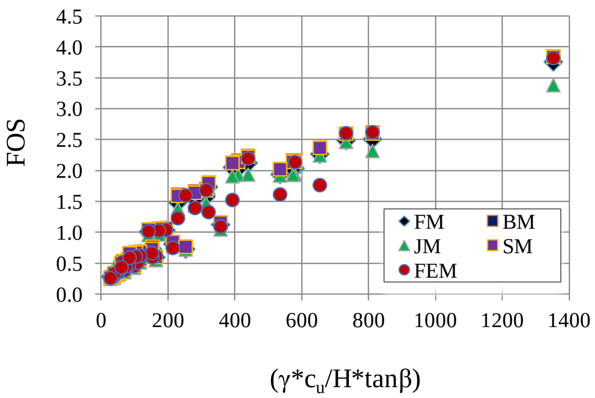

Fig. 8 Relationship between FOS and ($\gamma * c_u / H * \tan\beta$)

The trends depicted in Fig. 8 indicate that a sound linear relationship exists between the FOS and ($\gamma * c_u / H * \tan\beta$) variables for each analysis method. Linear regression analysis was carried out using data pertaining to different slope and foundation conditions to quantify such relationships. The following general equation was developed for estimating the FOS from slope and soil parameters:

$$\text{FOS} = A\,\frac{\gamma * c_u}{H * \tan\boldsymbol{\beta}} + B \quad (2)$$

For each method of analysis, the constants A and B are dependent on the slope geometry and soil properties and they respectively represent the slope and y-intercept of the best fit lines for the data sets plotted in Fig. 8. Their values were determined for each method as given in Table 5. The data in Table 5 confirm the previously stated conclusion that the FE method tends to give lower FOS compared to all LE methods and particularly the Bishop and Spencer methods.

Equation 2 may be used in conjunction with the values of A and B in Table 5 to predict the FOS using the LE and FE methods for slopes of simple geometry founded on homogeneous undrained soft to very stiff clay soils with similar characteristics.

Table 5 Values of A, B and R^2

Analysis Method		A	B	R^2
LE methods based on SLIDE software	BM	0.003	0.361	0.902
	SM	0.003	0.361	0.904
	FM	0.002	0.353	0.913
	JM	0.002	0.336	0.903
FE PLAXIS 2D method		0.002	0.317	0.921

5. CONCLUSIONS

The stability of simple slope models founded on clay soils with variable undrained strength characteristics was analyzed using the LE and the FE methods utilizing the “Slide” and “Plaxis” software programs respectively. The main conclusions drawn from analysis and discussion of study results are given below.

The results of comparison between the FOS computed using four LE analysis methods revealed that the Bishop and Spencer LE methods produced similar results; whereas the Fellenius and Janbu methods gave FOS lower than the Spencer’s method by 3.0% and 7.4% respectively.

The FOS computed using LE and FE methods compared very well for the slopes founded on soft clays. However for slopes on medium and very stiff clay foundations, the LE methods tend to give higher FOS values compared to the FE method.

The results of linear regression analysis of data deduced from the LE and FE methods showed that the FOS obtained from Bishop, Spencer and Fellenius LE methods are higher by 1.4 to 5.7% than those deduced from the FE method.

The effects of soil geometry and foundation soil properties on the FOS computed according the two slope stability analysis approaches were evaluated. A simple and reliable linear relationship was developed from regression analysis of data between FOS and a variable combining four parameters of slope geometry and soil properties. The constants A and B given in Eq. 2 are dependent on slope geometry, soil properties and applied analysis method.

Finally, the study results indicate that the LE slope stability analysis methods which are simple and relatively fast can produce accurate and reliable results. Such methods may be applied with confidence in routine design for slopes with simple geometry founded on undrained clays. The FE method is an advanced and reliable and valuable analysis technique in modeling design cases with complex slope geometry, heterogeneous soil behavior and different loading patterns.

6. REFERENCES

[1] Fellenius, W. "Erdstatische Berechnungen mit Reibung and Kohaesion", Ernst, Berlin, 1927.
[2] Bishop, A.W. "The Use of the Slip Circle in the Stability Analysis of Slopes". Géotechnique,, Vol. 5, No. 1, 1955, pp. 7-17.
[3] Janbu, N. "Slope stability computations", Soil Mech. Found. Engng Report, Trondheim: Technical University of Norway, 1968.
[4] Spencer, E. "A Method of Analysis of the Stability of Embankments Assuming Parallel Interslice Forces" Géotechnique, Vol. 17, No. 1, 1967, pp. 11-26
[5] Rocscience Inc., 2008, SLIDE version 5.0 User Manual.
[6] PLAXIS, "Finite Element Code for Soil and Rock Analysis," PLAXIS-2D Version 8, 2004, Manual, DUT, Netherlands.
[7] Duncan, J., M. State of the art: Limit equilibrium and finite element analysis of slopes. J.of Geotech. Engng., Vol. 122 (7), 1996, 577-596.
[8] Khabbaz, B., Fatahi, B. and Nucifora C "Finite Element Methods against Limit Equilibrium Approaches for Slope Stability Analysis" Proc. ANZ Conf. , 2012, pp. 1293-1298.
[9] Aryal, K.P., Differences between LE and FE Methods used in Slope Stability Evaluations, The 12th Int. Conf. of Int. Association for Computer Methods and Advances in Geomechanics , 2008.