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An Overview on Methods for Slope Stability Analysis

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Abstract: **The analysis of slope stability has received widely attention now days because of its practical importance. To provide steepest slops which are stable and safe various investigations are ongoing. Stability is determined by the balance of shear stress and shear strength. If the forces available to resist movement are greater than the forces driving movement, the slope is considered stable. A factor of safety is calculated by dividing the forces resisting movement by the forces driving movement. A previously stable slope may be initially affected by preparatory factors, making the slope conditionally unstable. The field of slope stability encompasses static and dynamic stability of slopes of earth and rock-fill dams, slopes of embankments, excavated slopes, and natural slopes in soil and soft rock.**

Various methods are available for slope stability analysis. This paper aims an overview on various methods of slope stability on the basis of assumptions, Factor of safety calculation, soil conditions, soil types, applicability of output of the method with its limitations. This paper also aims to focus some new mathematical tools which can be applicable for stability analysis of slope.

I. INTRODUCTION

A slope is defined as a surface of which one end or side is at higher level than another; a rising or falling surface. An earth slope is an un supported, inclined surface of a soil mass. The failure of a mass of soil located beneath a slope is called as slide. It involves a downward and outward movement of the entire mass of soil that participates in the failure. The failure of slopes takes place mainly due to,

The action of gravitational forces, and

Seepage forces within the soil.

They may also fail due to excavation or undercutting of its foot, or due to gradual disintegration of the structure of the soil. Slides may occur in almost every conceivable manner, slowly or suddenly, and with or without any apparent provocation.

Slope stability analysis is performed to assess the safe design of a human- made or natural slopes and the equilibrium conditions. Slope is the resistance of inclined surface to failure by sliding or collapsing. The failure of a slope may lead to loss of life and property. It is therefore, essential to check the stability of proposed slopes. With the development of modern method of testing of soils and stability analysis, a safe and economical design of slope is possible. The geotechnical engineer should have a thorough knowledge of the various methods for checking the stability of slopes and their limitations.

A. The main types of slope are the:

1. Infinite slope: if a slope represents boundary surface of a semi infinite soil mass and the soil properties for all identical depths below the surface are constant is called as infinite slope.
2. Finite slope: if the slope is of limited extent it is called as finite slope.

B. Application:

1. It is used to road cuts, open-pit mining, excavations, and landfills.
2. It is used to earthen dam.
3. It is also used to railway formation, highway embankment, canal bank, levees etc.
4. It is used to deep-seated failure of foundations and retaining walls.

C. Methods of construction:

The conventional method is used for the slope construction in that first earth soil laid on the surface. After that roller is applied on surface of the earth soil, for the compaction of soil. Before, all this procedure some test are required such as OMC (optimum moisture content), dry density using proctor test or modified proctor test methods.

D. Methods for analysis:

1. Limit equilibrium:

a. Analytical technique- Methods of slices

- Swedish slip circle method of analysis
- Ordinary method of slices
- Modified bishop's method of analysis
- Lorimar's method of analysis
- Spencer's method of analysis
- Sarma method of analysis
- Taylors stability number

2. Finite element method:

- The probabilistic FE method:
- Perturbation Method
- Monte Carlo simulation and Direct Coupling Approach.

3. Numerical method of modeling:

- Continuum modeling
- Discontinuum modeling
- Hybrid/coupled modeling

II. LITERATURE REVIEW

1. Carol Matthews and Zeena Farook, Arup; And Peter Helm (2014): Was published "Slope stability analysis– limits equilibrium or the finite element method".

They concluded that, as computers and their application evolve in geotechnical analysis; it seems that we should be looking to more advanced ways to analyses slope stability. This study has shown that there are significant opportunities in using the more comprehensive finite element analysis. However, the traditional Limit Equilibrium method remains able to produce accurate and reliable results. The both have their advantage sand disadvantages with the choice of which method to use depending on some of the considerations described below the method the user selects should be based on the complexity of the problem to be modeled. For example problems with complex geometries or that requires analysis of seepage, consolidation and other coupled hydrological and mechanical behavior (pore water pressure induced with more complex mechanical soil responses (e.g. post failure strain softening and progressive failure) may be better tackled using FE analysis.

2. Khaled Farah, Mounir Ltifi And Hedi Hassis (2015): were published "A Study of Probabilistic FEMs for a Slope Reliability Analysis Using the Stress Fields". In this paper, they were concluded the perturbation method and the spectral stochastic finite element method (SSFEM) using random field theory are presented. These methods are applied to analyze the stability of a homogeneous slope assuming an elastic soil behavior. To overcome the absence of the analytical solution of the mean and standard deviation of the factor of safety, the Monte Carlo simulation combined with the deterministic finite element code is applied. In fact, the perturbation method provides satisfactory results and it is easy to apply even with high random field expansion order.

*3. Bozana Bacicn (2014): "*Slope stability analysis" in that paper they conclude a methodology of slope stability analysis and provide an insight into the basic of landslides and their general terms. Natural process of constant affected by change in relationship for shearing stress and resistance.

4. A. Burman, S. P. Acharya etc. all (2015): "Comparative study of slope stability analysis using traditional limit equilibrium method and finite element method" In that they concluded that present work, limit equilibrium technique (ordinary slice method, Bishop's method, Spencer's method, Morgenstern-Price method) and finite element method have been used to the study different slope stability problems. Also, it is observed that ordinary slice method provides most conservative estimation of factor of safety values amongst all the limit equilibrium techniques considered in this paper. Therefore, any design of slopes carried out with ordinary slice method is likely to be always on the safer side. Other limit equilibrium methods like Ordinary Bishop's Method, Spencer's Method and Morgenstern and Price's method attempt to establish a more realistic estimation of interstice forces which may develop in reality. But they lead to somewhat higher estimation of factor of safety. The FOS values obtained using finite element method compare very well with that obtained from limit equilibrium methods. In finite element method, the FOS for critical slip surface is automatically obtained. In case of limit equilibrium methods, several slip surfaces should be analyzed to find the critical slip surface. These types of trial and error calculations are not required with FEM to find out the critical slip surface because the failure occurs through the zone of weakest material properties and automatically the critical slip surface is determined. Furthermore, finite element method satisfies the equations of equilibrium and compatibility equations from theory of elasticity. Therefore, it serves as a more mathematically robust platform. Also, displacements, stress and strains at various nodes in the slope domain are also obtainable from finite element method. These are few of the additional benefits of using finite element method.

5. Reginald Hammah et, all (1999): " A comparison of finite element slope stability analysis with conventional limit equilibrium investigation" - As stated by Griffiths and Lane, , opinions that the FE SSR may be complex overlook the fact that 'slip circle' analyses may produce misleading results. As such we encourage geotechnical engineers to adopt the SSR as an additional robust and powerful tool for designing and analyzing slopes. It can help uncover important behavior that may otherwise go unnoticed.

III. OBJECTIVES

- To study principles of limit equilibrium methods and finite element methods in slope stability analysis.
- To study the suitability of each method for particular soil type and slope condition with factor of safety.
- To suggest mathematical tools for slope stability analysis.

IV. METHODS OF ANALYSIS

In slope stability analysis the limit equilibrium and finite equilibrium methods these are two basic types. The major difference in between these two methods is following:

TABLE I. COMPARION OF LIMIT EQUILIBRAM METHOD AND FINITE ELEMENT METHOD

Sr. no	Limit equilibrium method	Finite element method
1	In limit equilibrium method currently most stability analysis it involves due to most simplicity and accuracy.	In finite analysis method based on computer performance has improved application of FE in geotechnical analysis.
2	In limit equilibrium method it must search for critical surface by using geometry.	In finite element method the critical surface is automatically find out by various software's.
3	The advantages of limit equilibrium method: The limit equilibrium method of slices is based on purely on the principles of statics; that is, the summation of moments, vertical forces, and horizontal forces. The method says nothing about stress, strain and displacements, and as a result it does not satisfy displacement compatibility.	The advantages of finite element method: In FE method is to for model slopes with a degree of very high realism (complex geometry, sequence of loading, presence of material for reinforcement, action of water, and laws of complex soil behavior) and also better visualizes the deformation of soil in place.
4	It's required only simple Mohr-coulomb soil model.	It must have complete stress-strain model for soil.
5	It cannot compute displacement.	It can compute displacement.
6	Limit equilibrium method cannot model progressive failure.	Finite element method can model progressive failure.

[1][2][8]

1. *Limit equilibrium method:*

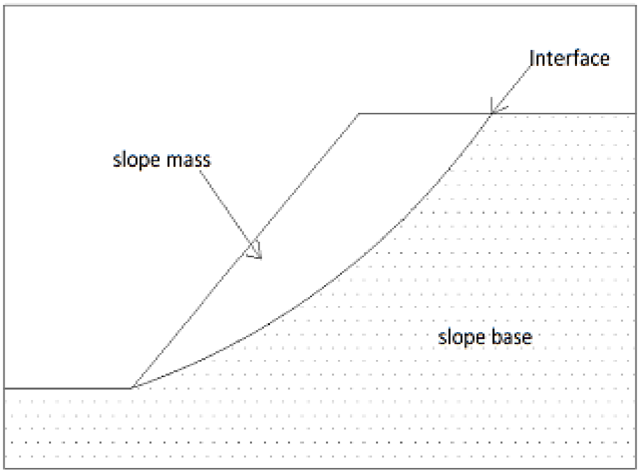

Fig. 1. Limit equilibrium method

In Limit equilibrium methods investigate the equilibrium of a soil mass tending to slide down under the influence of gravity. Transitional or rotational movement is considered on an assumed or known potential slip surface below the soil or rock mass. In rock slope engineering, methods may be highly significant to simple block failure along distinct discontinuities. All these methods are based on the comparison of forces, moments, or stresses resisting movement of the mass with those that can cause unstable motion (disturbing forces). The output of the analysis is a factor of safety, defined as the ratio of the shear strength (or, alternatively, an equivalent measure of shear resistance or capacity) to the shear stress (or other equivalent measure) required for equilibrium. If the value of factor of safety is less than 1.0, the slope is unstable.

A. *GENERAL ASSUMPTION OF LIMIT EQUILIBRIUM:*

The soil mass must be safe against slope failure on any conceivable surface across the slope. In this method using the theory of elasticity or plasticity are also being increasingly used, the most common method based on limit equilibrium in which it is assumed soil is at verge of failure. The limit equilibrium is statically indeterminate analysis. As the stress strain relationship along assume surface are not known, so necessary that system becomes statically determinant and it can be analyzed easily using the equation of equilibrium. Following assumption are generally made,

a) The stress system is assumed to be two-dimensional. The stresses in the third direction (perpendicular to the section of the soil mass) are taken as zero.
b) It is assumed that the column equation for shear strength is applicable and the strength parameters c and φ are known.
c) It is further assumed that the seepage conditions and water level are known, and the corresponding pore water pressure can be estimated.
d) The condition of plastic failure as assumed to be satisfied along the critical surface in other word shearing strains at all points of the critical surface are large enough to mobilize all the available shear strength.
e) Depending upon the method of analysis some additional assumption are made regarding the magnitude and distribution of forces along various planes. **[1]**

B. *ANALATICAL METHODES OF LIMIT EQUILIBRIUM:*

Method of slices:

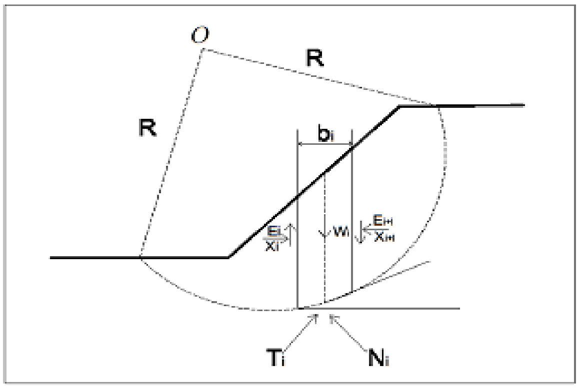

Fig. 2. *Method of slices*

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The slices are the most popular limit equilibrium technique. In this approach, the soil mass is discredited into vertical slices. Several versions of the method are in use. These variations can produce different results (factor of safety) because of different assumptions and inter-slice boundary conditions.

The location of the interface is typically unknown but can be found using numerical optimization methods. For example, functional slope design considers the *critical* slip surface to be the location where that has the lowest value of factor of safety from a range of possible surfaces. A wide variety of slope stability software uses the limit equilibrium concept with automatic critical slip surface determination.

Typical slope stability software can analyze the stability of generally layered soil slopes, embankments, earth cuts, and anchored sheeting structures. Earthquake effects, external loading, groundwater conditions, stabilization forces (i.e., anchors, geo-reinforcements etc.) can also be included. **[1]**

a. Swedish slip circle method:

In Swedish slip circle method assume frictional angle of soil or rock is equal to zero. Due to this assumption the frictional angle is considered to be zero. So the effective stress term goes to zero. Thus equating shear strength to the cohesion parameter of the give soil. In this method assume a circular failure interface and analyze stress and strength parameters using circular geometry and statics. The moment caused by internal driving forces of a slope is compared to the moment caused by forces resisting slope failure. If resisting forces are greater than driving force the slope is assume stable.

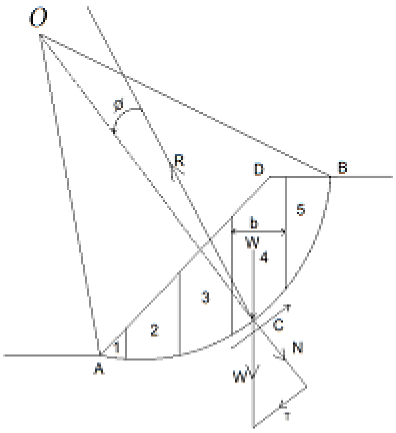

Fig. 3. Swedish slip circle method

Factor of safety for the slice is equal to the ratio of the resisting moment (M_R) and the overturning moment (M_O), Thus

$$F_S = \frac{r[c\,\Delta L + N\tan\varphi]}{Tr} = \frac{c\,\Delta L + N\tan\varphi}{T}$$

Factor of safety of the entire wedge is given by,

$$F_S = \frac{\Sigma c\,\Delta L + \Sigma N\tan\varphi}{\Sigma T}$$

If c and φ are constant,

$$F_S = \frac{c\,L_a + \tan\varphi\,\Sigma N}{\Sigma T}$$

Where, L_a = length of the entire slip surface = $\Sigma\,\Delta\,L$ **[1]**

- Assumption:

1] Infinitely long slope.
2] Slip surface parallel to surface.
3] Friction angle of soil or rock equal to zero.

- Limitation and application:

Un-drained analyses in saturated clays, φ = 0. Relatively thick zones of weaker materials, here circular surface is appropriate.

b. Ordinary method of slices-

Ordinary method of slices is found in 1927 by Fellenius. In the method of slices or the Fellenius method, the sliding mass above the failure surface is divided into a number of slices. The forces acting on each slice are obtained by considering the mechanical (force and moment) equilibrium for the slices. Each slice is considered on its own and interactions between slices are neglected because the resultant forces are parallel to the base of each slice. However, Newton's third law is not satisfied by this method because, in general, the resultants on the left and right of a slice do not have the same magnitude and are not collinear

These allows for a simple static equilibrium calculation, considering only soil weight, along with shear and normal stresses along the failure plane. Both the friction angle and cohesion can be considered for each slice. In the general case of the method of slices, the forces acting on a slice are shown in the figure.

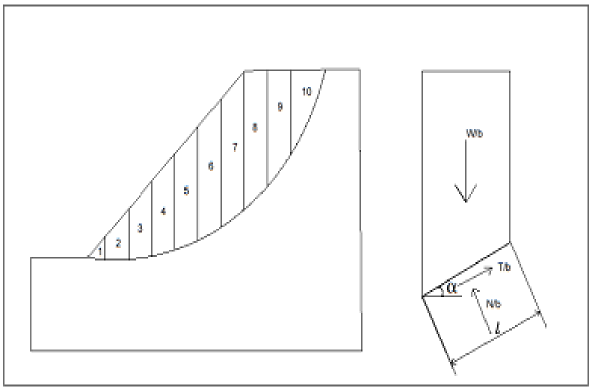

Fig. 4. *Ordinary method of slices*

In this method of slice factor of safety is very low, very inaccurate for flat slopes with high pore pressure, only for circular slip surface, assume that normal forces on the base of each slice is Wcosα. In this method of slice is one equation for the moment of equilibrium in entire mass. In this method of slice only one unknown is found, that is factor of safety. **[3]**

Side forces neglected (statically determinant).
Effective Stress Analysis, (ESA)

$$F_S = \frac{\Sigma\{c'l + [(W/b)\cos\alpha - ul]\tan\emptyset'\}}{\Sigma[(W/b)\sin\alpha]}$$

Total stress analysis, (TSA)

$$F_S = \frac{\Sigma(S_u l)}{\Sigma[(W/b)\sin\alpha]}$$

[3]

- Assumption:

1] Infinitely long slope.
2] Slip surface parallel to surface.
3] Inter slice forces are neglected.

- Limitation and application:

It is very inaccurate for flat slopes with high pore pressure. Non homogeneous slopes and c – φ soils where circular surface is appropriate. It's Convenient for hand calculations. Inaccurate for effective stress analyses with high pore pressures.

c. Modified Bishop's method of analysis-

Modified Bishop's method is found in 1955, it is invented by Bishop. This method is slightly different from the ordinary method of slices. In this normal interaction forces between adjacent slices are assumed to be collinear and the resultant inter slice shear force is zero. The method has been shown to produce factor of safety values within a few percent of the "correct" values. Factor of safety appears both on the left and right hand sides of the equation.

This method satisfies vertical force equilibrium for each slice and overall moment equilibrium about the center of the circular trial surface. Since horizontal forces are not considered at each slice, the simplified Bishop method also assumes zero inter slice shear forces. **[3]**

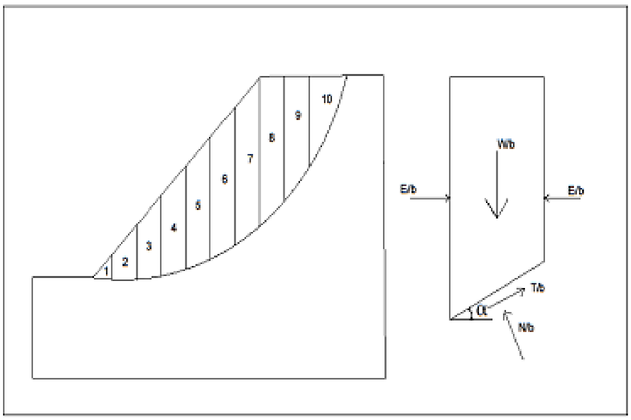

Fig. 5. *Modified Bishop's method of analysis*

Neglecting side forces (OMS) produces FS too low (conservative)

Assume side shear forces are zero but account for side normal forces.

Effective Stress Analysis (ESA)

$$F_S = \frac{\Sigma\{\frac{mc' + [(W/b) - um]\tan\emptyset'}{\psi}\}}{\Sigma[(W/b)\sin\alpha]}$$

$$\psi = \cos\alpha + \frac{\sin\alpha\tan\emptyset'}{F_S}$$

Total stress analysis,

$$F_S = \frac{\Sigma(\frac{ms_u}{\cos\alpha})}{\Sigma[(W/b)\sin\alpha]}$$

[3]

- Assumption:

1] Circular surface.
2] Side forces are horizontal.
3] Collinear and resultant inter slice for shear force equal to zero.

- Limitation and applications:

One important limitation for the Bishop method to be correctly applied is that all failure surfaces must be circular.

d. Lorimar's method-

Lorimar's Method is a technique for evaluating slope stability in cohesive soils. It differs from Bishop's Method in that it uses a clothoid slip surface in place of a circle. This mode of failure was determined experimentally to account for effects of particle cementation.

The method was developed in the 1930s by Gerhardt Lorimar (Dec 20, 1894-Oct 19, 1961), a student of geotechnical pioneer Karl von Terzaghi.

e. Spencer's Method -

Spencer (1967) developed his analysis based on the method of slices of Fellenius (1927) and Bishop (1955). For slope stability analysis with general, arbitrarily shaped failure surfaces, the Spencer's method has been found to provide a reasonably accurate result. This method satisfies both moment and force equilibrium of the sliding mass. However, a number of iterations are required to obtain an accurate value of factor of safety satisfying the complete equilibrium. In addition, problems of non convergence often occur when a search is required to determine the shape of the failure surfaces. Such search was found to be necessary to obtain the lowest factor of safety. A good approach for this type of analysis is to perform the search using a less elaborate method and utilize a more accurate but time consuming method once the critical failure surface is obtained. To implement this approach a subroutine is included in the computer program PCSTABL5M which enables it to search for the most critical surface using the Simplified Janbu method and, subsequently, analyze it with the Spencer's method. In addition, the Ordinary Method of Slices is added for back cut analysis since the Spencer's method was found to yield unreasonable results for this type of analysis. The computer program has been used extensively for a hillside grading project which involved the mitigation of complex landslides and faulting system. The analysis is in terms of effective stress and satisfies two equations of equilibrium, the first with respect to forces and the second with respect to moments. The inter slice

Forces are assumed to be parallel. The factor of safety expressed as,

$$FS = \frac{Shear\ strength\ available}{Shear\ strength\ mobilized}$$

The mobilized angle of shear resistance and other factors are expressed as,

$$\tan \emptyset'_m = \frac{\tan \emptyset'}{F_s} \quad [2]$$

- Assumption:

1] Inter slice forces parallel.

- Limitation and application:

It is Applicable to virtually all slopes. This is simplest full equilibrium procedure for computing the factor of safety.

f. *Sarma method* - The method of Sarma is a simple, but accurate method for the analysis of slope stability, which allows to determine the horizontal seismic acceleration required so that the mass of soil, delimited by the sliding surface and by the topographic profile, reaches the limit equilibrium state (critical acceleration ***Kc***) and, at the same time, allows to obtain the usual safety factor obtained as for the other most common geotechnical methods.

- Assumption:

1]The normal stress acts in the midpoint of the base of the slice.

- Limitation and application:

The Sarma method is generally suited to more complex problems using non-vertical slice boundaries. Slice boundary properties can be set independently of surrounding material properties, thus allowing modelling of discontinuities and faults. It can even be used to simulate foundation problems.

It is a method based on the principle of limit equilibrium of the slices, therefore, is considered the equilibrium of a potential sliding soil mass divided into ***n*** vertical slices of a thickness sufficiently small to be considered eligible the assumption that the normal stress N_i acts in the midpoint of the base of the slice.

g. *Taylor's stability number-*

If the slope angle β, height of embankment H , the effective unit weight of material y, angle of Internal friction φ ', and unit cohesion c' are known, the factor of safety may be determined. In order to make unnecessary the more or less tedious stability determinations, Taylor (1937) conceived the idea of analysing the stability of a large number of slopes through a wide range of slope angles φ' and angles of internal friction, and then representing the results by an abstract number which he called the "stability number". This number is designated as N*s*. The expression used is

$$N_s = \frac{c'}{F_c\, \gamma H}$$

From this the factor of safety with respect to cohesion may be expressed as

$$F_s = \frac{c'}{N_c\, \gamma H}$$

Taylor published his results in the form of curves which give the relationship between *Ns* and The slope angles β for various values of φ' as shown in Fig 6-A. These curves are for circles passing through the toe, although for values of β less than 53°, it has been found that the most dangerous circle passes below the toe. However, these curves may be used without serious error for slopes down to β = 14°. The stability numbers are obtained for factors of safety with respect to cohesion by keeping the factor of safety with respect to friction ($F_\emptyset$) equal to unity. In slopes encountered in practical problems, the depth to which the rupture circle may extend is usually limited by ledge or other underlying strong material as shown in Fig 7-B. The stability number *Ns* for the case when φ'= 0 is greatly dependent on the position of the ledge. The depth at which the ledge or strong material occurs may be expressed in terms of a depth factor n_d which is defined as,

$$n_d = \frac{D}{H}$$

Where, *D* = depth of ledge below the top of the embankment, *H* = height of slope above the toe. For various values of n_d and for the φ'= 0 case the chart in Fig 7-B. gives the stability number N_S for various values of slope angle β. In this case the rupture circle may pass through the toe or below the toe. The distance x of the rupture circle from the toe at the toe level may be expressed by a distance factor $n_x$which is defined as,

$$n_x = \frac{X}{H}$$

The chart shows in fig 7-B the relationship between n_d andn_x. If there is a ledge or other stronger material at the elevation of the toe, the depth factor n_d for this case is unity.

Factor of Safety with Respect to Strength

The development of the stability number is based on the assumption that the factor of safety with respect to friction$F_\emptyset$, is unity. The curves give directly the factor of safetyF_c with respect to cohesion only. If a true factor of safety $F_s$with respect to strength is required, this factor should apply equally to both cohesion and friction. The mobilized shear strength may therefore be expressed as,

$$s_m = \frac{s}{F_s} = \frac{c'}{F_s} + \frac{\sigma \tan(\phi')}{F_s}$$

In the above expression, we may write

$$\frac{s}{F_s} = c'_m \qquad \tan\phi'_m = \frac{\tan\phi'}{F_s} \qquad \text{Or,} \qquad \phi'_m = \frac{\phi'}{F_s}(approx.)$$

c'_m And ϕ'_m may be described as average values of mobilized cohesion and friction respectively. **[2]**

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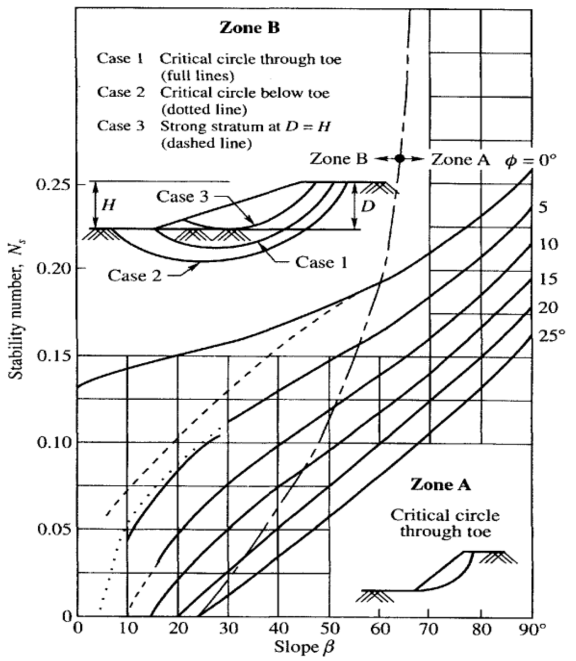

Fig. 6. Taylor's stability number for circles passing through the toe and below or above the toe

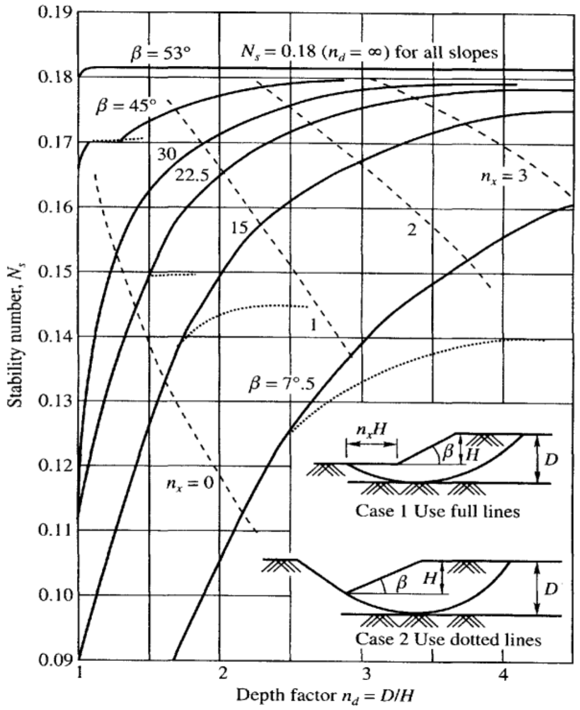

Fig. 7. Taylor's stability number for φ' = 0

2. Finite element method -

As computer performance has improved, the application of FE in geotechnical analysis has become increasingly common. These methods have several advantages: to model slopes with a degree of very high realism (complex geometry, sequences of loading, presence of material for reinforcement, action of water, laws for complex soil behaviour) and to better visualize the deformations of soils in place. However, it is critical to understand the analysis output due to the larger number of variables offered to the engineer. The study used Oasys Safe, a program for soil analysis by finite elements. When developing the strength reduction methodology to be applied in Safe, a comparison was made between three differing techniques.

For all techniques, an initialization run for a given slope model was carried out and the strains and displacements obtained in that run set to zero for the subsequent FOS assessment. In the first method, an incremental strength reduction was applied to the elastic Mohr-Coulomb material whereby for each follow-on increment the same reduction in global strength was applied.

The second method involved specifying separate, independent model runs with revised material parameters corresponding to specific percentage reductions in material strength. The third method used a new feature in Safe, in which the program automatically applies the same strength reduction in successive analysis increments, but once failure is observed, reverts to the last converged increment and refines the strength reduction to obtain an estimate of FOS to an acceptable accuracy.

Methods of finite element:

A. Perturbation Method:

The perturbation method uses the Taylor series expansion of random functions about the mean values. In the context of the FEM and for quasi-static linear problems, the equilibrium is expressed as follow:

$$K.U = F$$

In this equation, K is the global stiffness matrix; *K* is the load vector and *U* is the nodal displacement vector.

The Young's modulus and the soil strength parameters are considered homogeneous random fields'. **[9]**

B. Monte Carlo simulation and Direct Coupling Approach:

The Monte Carlo simulation is used to generate a sample that corresponds to N independent standard normal variables according to the Karhunen-loève expansion of the random fields. For each realization, the factor of safety is calculated using a deterministic finite element code. The element stiffness matrix is computed for each realization of the random field H using the following relation:

$$K^e(\theta_0) = \int_{\Omega_e} H(x,\theta_0)\, B^T(x) D_O B(x) d\Omega_e$$

In this equation, D_O is a constant matrix, B is the matrix that relates the components of strain to the nodal displacements element and H (.)is the random field that represents the soil Young's modulus. The assembling of the elements contributions above Eq. leads to the global stiffness matrix *K*. The Monte Carlo simulation is applied to evaluate the factors of safety, and then their statistical treatment is subsequently performed. In addition, direct coupling approach based on the combination of the deterministic finite code and FORM algorithm is used to assess the reliability index. Thus, the probability of failure can be estimated. In this study, the values evaluated by the Monte Carlo simulation and direct coupling approach are considered as reference values. **[9]**

3. Numerical method of analysis:

Numerical modelling techniques provide an approximate solution to problems which otherwise cannot be solved by conventional methods, e.g. complex geometry, material anisotropy, non linear behaviour, in situ stresses. Numerical analysis allows for material deformation and failure, modelling of pore pressure, creep deformation, dynamic loading, assessing effects of parameter variations etc. however numerical modelling is restricted by some limitations. For example, input parameters are not usually measured and availability of these data is generally poor. Analysis must be executed by well trained user effects Meshing errors, hardware memory and time restrictions.[5]

A. Continuum modelling-

Modelling of the continuum is suitable for the analysis of soil slopes Massive intact rock or healthy jointed rock masses. This approach includes finite element method is discrete the whole mass to finite number of elements with the help of generated mesh (as shown in fig.). Finite element method (FEM) uses the approximation to connectivity elements continuity of displacement and stresses between elements. Most of numerical codes allow modelling of discrete fracture e.g. bedding planes, faults. Several constitutive models are available, for e.g. elasticity, elasto-plasticity, strain-softening, elasto-viscoplasticity etc.

B. Discontinuum modeling:

Discontinuum approach is useful for rock slopes controlled by discontinuity behaviour. Rock mass is consider as an aggregation of distinct, interacting blocks subjected to external load an assumed of undergo motion with time. This methodology is collectively called as the discrete element method (DEM). Discontinuum modelling allows for sliding between the block and particles. The DEM is based on solution of dynamic equations of equilibrium for each block. Repeatedly until the boundary conditions and laws of contact and motion are satisfied. Discontinuum modelling belongs to the most commonly applied numerical approach to rock slope analysis.

C. Hybrid/coupled modeling:

Hybrid codes involve the coupling of various methodologies to maximize their key advantages, e.g. limit equilibrium analysis combined with finite element groundwater flow and stress analysis adopted in the SVOFFICE or GEO-STUDIO suites of software; coupled particle flow and finite-difference analyses used in PF3D and FLAC3D.Hybrid techniques allows investigation of piping slope failures and the influence of high groundwater pressures on the failure of weak rock slope. Coupled finite-/distinct-element codes, e.g. ELFEN provide for the modelling of both intact rock behaviour and the development and behaviour of fractures.[5]

VI. CONCLUSION

This paper aims study of various limit equilibrium methods and finite element methods in slope stability analysis based on significant works by numerous authors have been done with regards to stability of slopes. Various parameters and factor of safety equations used by them have been reviewed and discussed briefly. Some mathematical tools are also suggested which can be used for analysis of slope in particular condition.

VII. REFERENCES

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