*IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*
*ISSN: 2278-1684 Volume 3, Issue 5 (Sep-Oct. 2012), PP 01-10*
*www.iosrjournals.org*

# Use of Graphical Technique for Stability Analysis of Embankment

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***Abstract:*** *To authenticate the stability of homogeneous slopes, a simplified version of the friction circle method is presented in the proposed investigation. By introducing few simplified assumptions, the original friction circle method has been modified to provide a simpler and user-friendly technique for slope stability analysis of finite slopes. The graphical technique has been incorporated for the stability analysis of embankments in (c-$\phi$) soils. The use of this method recompenses the drawbacks of other methods of their suitability for performing stability analysis in the field.*

*The endeavor has been made in this work to make available the most critical slip surface that occurs in the field for the particular conditions. By using computer program these critical slip surfaces are originated and their correlation with the height, slope, and seepage conditions of the embankment has been established. Both toe circles and slope circles that envisage above the toe have been analyzed using this technique. Base circles are less critical unless the friction angle is less than $3^0$ ( Terzaghi and Peck, 1984). Therefore, this method is most appropriate for analyzing slopes in c-$\phi$ soils. This method itself lends to back of the envelope type calculations useful for back calculating the geo-mechanical parameters such as c,$\phi$, $\gamma$ and $r_u$ of known slides or imminent slides.*

***Keywords:*** *c - cohesion, $\phi$ - friction angle of soils, $\gamma$ - density of soil, $r_u$ - pore pressure ratio.*

## I. Introduction

Earthen embankments are commonly required for railways, roadways, earth dam, levees and river training works. It is necessary to analyze these slopes for stability because their failure may lead to loss of human life as well as heavy economical loss. In the case of highways construction, at the stage of preliminary location survey itself the slopes should be analyzed, otherwise the entire road project may get bogged down for need of a stable embankment. No design should be considered comprehensive unless safety against failure is ensured.

1.1.1 Necessity of Stability Analysis

The failure of a mass of soil is a downward movement of a slope is called slide. It is usually caused by a gradual disintegration of the structure of the soil, by an increase of the pore water pressure in a few exceptionally permeable layers, or by a shock that liquidizes the soil.

The factor leading to the failure of the slopes may be classified into two categories: the factors, which cause an increase in shear stresses. The stress may increase due to weight of water causing saturation of soils, surcharge loads, seepage pressure or any other cause. The stresses are also increased due to steepening of slopes either by excavation or by natural erosion.

The factors which cause a decrease in the shear strength of the soil. The loss of shear strength may occur due to an increase in water content, increase in pore water pressure, shock loads, weathering or any other cause.

Most of natural slope failure occurs during rainy season, as the presence of water causes both increased stresses and the loss of strength. With the development of modern methods of technique of stability analysis, a safe and economical design of a slope is possible. The geotechnical engineer should have a through knowledge of the various methods for checking the stability of slopes and their limitations.

Two types of slope problems occur in clays, short term stability (end of construction case) and long term stability (steady seepage case). Based on field observation and laboratory analysis, it is concluded that for short term stability analysis the $\phi$=0 total stress method is satisfactory. The effective stress method of analysis should be used for long term stability analysis.

Stability analysis determines whether the proposed slope meets the safety requirements. The analysis must be made for the worst conditions, which seldom occur at the time of investigation. There are different methods of slope stability analysis such as Taylor's method, Swedish slip circle method, Bishop's method, Bishop and Morgenstern method and Morgenstern & Price method.

1.1.2 Aims of Slope Analysis

To verify the stability of different types of slopes under given conditions.

To verify the probability of land slides involving natural or existing man made slopes.

To enable redesign of field slopes and the planning design of preventive and remedial Measures wherever necessary.

To enable a study of the effect of exceptional loading such as earth quakes on slopes.

**1.1.3 Ease of application**

Another matter of considerable interest to an engineer selecting a method for analysis of slope stability is ease of application. Factors that are related to ease of application include:

The amount of time required arriving at an answer. The frequency of problem of non convergence occurrence that requires special attention. The number of steps necessary to develop results in final form for the reports or other documents

All of the methods of analysis that consider side forces between slices are subjected to problem of non convergence under some conditions. When such problem arises the solution may calculated the factor of safety, which may be unreasonable. These convergence problems are often associated with slip surfaces that have unreasonable shapes as noted by Ching and Fradlund (1983). Problems are most frequently encountered where there is a layer of soil with large cohesion at the top of the slope and tension tends to develop in the upper part of the slip surface or where there is a layer of soil with a high friction angle at the base of the slope and the slip surface emerges through this layer at an angle that is nearly vertical. Adding tension crack at the top of the slope can eliminate the tension and flattering the exit angle at the lower end of the slip surface often eliminates the tension that arises there.

Analysis of the stability of earth slopes with regards to slips along general surfaces, lead to the solution of a pair of nonlinear equations. The methods of solution usually adopted involved certain factors which have great bearing on the success of the solution procedures. These factors may be regarded as per requisites for the solutions and entail a thorough study with regard to their section. Bhattacharya and Basudhar (1992) attempted to highlight these pre requisites and proposed guidelines for selecting them based on experience in solving numerous slope stability problems with particular reference to the Spencer's method.

Table 1.1: Characteristic of Equilibrium Methods of Slope Stability Analysis

| Method | Characteristic |
|---|---|
| Slope Stability Charts (Janbu, 1986) | Accurate enough for many purposes. Faster than detailed computer analysis |
| Ordinary Method of Sices (Fellenius, 1927) | Only for circular slip surface.Satisfies moment equilibrium<br>Does not satisfy horizontal or vertical force equilibrium |
| Bishop's Modified Method (1955) | Only for circular slip surface.Satisfies moment equilibrium<br>Satisfies vertical force equilibrium.Does not satisfy horizontal force equilibrium |
| Morgenstern and Price's Method (1965) | Any shape of slip surface.Satisfies all condition of equilibrium.Permits side force orientation to be varied |
| Spencer's Method (1967) | Any shape of slip surface.Satisfies all condition of equilibrium.Side force are assumed to be parallel |
| Janbu's Generalized Procedure of Slices (1968) | Any shape of slip surface.Satisfies all condition of equilibrium.Permits side force orientation to be varied |

**1.1.4 Back calculation of Geomechanical Parameters**

Shear strength properties obtained from back analysis of field situations ought in principle to be more reliable than those obtained from laboratory tests and hence any methods that assist the process of back analysis are to be welcomed. The purpose of this is to present some simple concepts that provide a means of extracting shear strength parameters from back analysis of slopes in which single slips have occurred. Yamagami & Ueta (1996) have presented a useful method for doing this, and offers some alternatives that appear somewhat simpler.

**1.1.5 Method for Back calculation**

Figure 1.2 (a) shows a slope in which a single slip has occurred at the location shown. The slip surface is assumed to be circular and the groundwater table is taken to be at the ground surface.

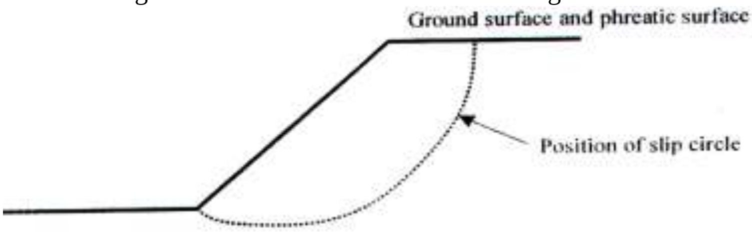


**Fig. 1.2 (a) Geometry Showing Position of an Actual Slip Circle**

(Yamagami & Ueta, 1996)

By carrying out conventional slip circle analysis, it is possible to obtain a range of values of c and ϕ that satisfy the criterion that the safety factor for the slip surface shown in unity. This has been done using the standard Bishop method. The range of values so obtained is shown graphically as curve (a) in Fig. 1.2 (b) by plotting c against tan ϕ the plot is almost linear this appears to be the normal situation when the analysis is of a specific slip surface.

From this point onwards there are several methods for deciding which of these possible combinations the correct one is. Perhaps the simplest is to now ignore the actual slip circle and carry out stability analysis of the slope using as a starting point each of the combinations of parameters shown in Fig. 1.2 (b). Now ignoring the slip and treating the slope as an intact slope. This analysis produces a series of critical slip circles, as shown in Fig. 1.2 (c). Examination of these shows that each circle has a different location and only one of these circles has a safety factor of unity. All the other have safety factors less than unity. Thus the true field values of c and ϕ must be those applying to this one circle, which is compatible with the field situation the values so obtained are $\phi=30^0$ and c=18kpa.

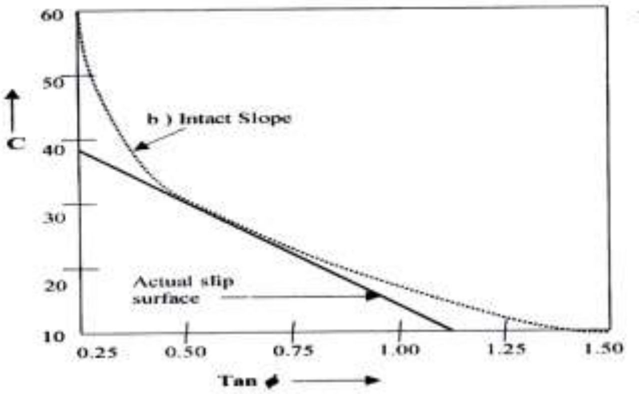


**Fig. 1.2 (b) Combination of c' and tanϕ' Giving Safety Factors of Unity**

(Yamagami & Ueta 1996)

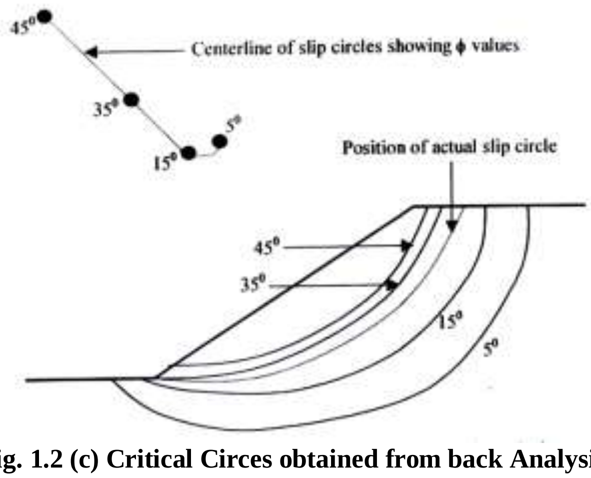


**Fig. 1.2 (c) Critical Circes obtained from back Analysis**

(Yamagami & Ueta 1996)

A second approach is to again ignore the actual slip surface (and the data obtained from it) and to repeat the back analysis treating the slope as intact. The assumption is still made that the factor of safety is unity, this gives a new set of combination of c' and ϕ' that apply to the intact slope. The point where the two sets of values coincide (i.e. where the curves touch in Fig. 1.2(b)). By simply comparing the graphs or placing one on top of the other the envelope common to both the intact slope and the slip surfaces is easily identified.

The review of all the methods of stability analysis and its limitations, drawbacks and ease of application of each method was studied in this chapter. The method to back calculate Geo- mechanical parameters was also studied. In the next chapter the new method of stability analysis named 'Graphical Technique' is studied which is the modified version of 'Friction Circle Method'. This method is very useful on site for known slides or imminent slides. This method is useful in finding out geo-mechanical parameters.

## II. Design Method

### 2.1 Introduction

To verify the stability of known or imminent slides the latest method suggested by Philip S.K. Ooi and Water B. Lum (2001), which is the modified version of friction circle method, named as 'Graphical Technique' is used. This method is very useful to check the stability of embankment in homogeneous soil. This method gives very quick result as compared to the other methods of stability analysis. There is no need to memorize any formula, which is the most important feature of this method. To proceed further, it is essential to known the friction circle method very wel, described as below:

### 2.2 Friction Circe Method

The friction circle method is useful for the stability analysis of slopes made of homogeneous soils. In this method, the slip surface is assumed to be an arc of a circle. The radius of the friction circle is equal to R sinϕ. Any line tangent to the friction circle must intersect the circular failure are at an oblique angleϕ. Therefore any vector ϕ to an element of the failure surface must be tangent to the friction circle. The analysis is based on total stresses and assumes that the cohesion c is constant with depth. For a given value of ϕ the critical height of a slope is given by the equation,

$$\mathbf{H_c = N_s\,(c/\gamma)} \qquad \mathbf{(2.1)}$$

Where,

$H_c$ = Critical height
c = Cohesion
$\gamma$ = Unit weight of soil
$N_s$ = Stability factor

The stability factor Ns is a pure number, depending only on the slope angle β and friction angle ϕ the friction circle; make an angle $\phi_m$ with the normal of the slip surface. These lines represent the direction of the combined normal and mobilized frictional forces on the slip surface. The value of $\phi_m$ is obtained from Eq. 2.2 after choosing a value of $F_\phi$.

$$\mathbf{F_\phi = \tan\phi / \tan\phi_m} \qquad \mathbf{(2.2)}$$

Thus the reaction R is tangential to the friction circle.

[Note: Actually, the reaction R is tangential to the friction circle of a slightly larger radius of K r sin$\phi_m$ where K is a factor with a value greater than unity, as it is evident that the two reaction $d_R$ [Fig. 2.1 (a)] intersect slightly outside the friction circle of radius r sing $\phi_m$ however, this discrepancy is generally disregarded]

The cohesive force $C_m$ is equal to $c_mL_a$ where $c_m$ is the mobilized cohesion and $L_a$ is the circular surface arc. It is convenient to replace this force acting along the arc by an equivalent force C acting along a line. The force along arc AEB is also equal in magnitude to the force $c_m$ x $L_c$ where $L_c$ is the length of the chord AB. The line of action of this force can be determined by taking moments of the actual force and the equivalent force about O.

$$\mathbf{(L_c \times c_m) \times a = (c_m \times L_a) \times r}$$

$$\mathbf{Or\ a = r\,L_a / L_c} \qquad \mathbf{(2.3)}$$

Obviously the distance a is greater than r, as $L_a > L_c$

The intersection of the weight W and the cohesive force $C_m$ establishes a point P through which the reaction R must act. The direction of R is obtained by drawing a line tangential to the $\phi$-circle. The forces $C_m$ and R an be determined from the force triangle.

Fig. 2.1 (a) shows the force triangle. The weight vector W is drawn first. The triangle is completed by drawing the vectors R and $C_m$ is determined. The mobilized cohesion is equal to the cohesive force $C_m$ divided by the length of the cord $L_c$ thus

$$\mathbf{c_m = C_m / L_c} \qquad \textbf{(2.4)}$$

Eq. 2.5 gives the factor of safety with respect to cohesion

$$\mathbf{F_c = c / c_m} \qquad \textbf{(2.5)}$$

If the value of $F_c$ obtained from Eq. 2.5 is not equal to the assumed value of $F_\phi$ the analysis is repeated. The procedure is repeated after taking another trail surface. The slip circle which gives the minimum factor of safety ($F_s$) is the most critical circle. Generally, the analysis is repeated 3-4 times to obtain a curve between the assumed value of $F_\phi$ and the computed value of $F_c$ as shown in fig 2.1 (b). The factor of safety with respect to shear strength $F_s$ is obtained by drawing a line at $45^0$ which gives $F_c = F_\phi = F_s$

For a purely cohesive soil $\phi = 0$ and the friction circle reduces to a point. The factor of safety is determined from the resisting moment due to C and actuating moment due to W. Sometimes, the factor of safety with respect to friction ($F_\phi$) is assumed to be unity and the factor of safety with respect to only cohesion is obtained.

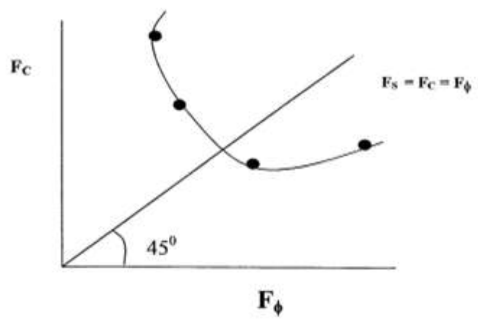


**Figure 2.1 (b) Friction Circle Method**

Factor of Safety (Dr. B.C. Punmia)

**2.3 Use of Graphical Technique for Stability Analysis**

To verify the stability of homogeneous slopes, a simplified version of the friction circle method is presented in this work By introducing few simplifying assumptions the original friction circle method can be modified to provide a simpler and user-friendlier technique for slope stability analysis of finite slopes

The main advantages of this method are

The stability of slopes can be analyzed directly without trial and error for any arbitrary slip surface It can be computed without computer without slope stability charts (JANBU,1968).And without the need to memorize any formula for slope stability analysis thus making it suitable for performing stability analysis in the field.

It can de used for slopes with no seepage and slopes subjected to various seepage conditions

Simple slopes without berms have been selected for analysis and their geometry is specified by the parameters The crest width is left unspecified since the most critical circle in an effective stress analysis begins close to the top of the slope in the cases considered in the problem; the solution is thus applicable to earth dams as well as to cuts and natural slopes.

The factor of safety depends only on the geometry of the section expressed by the values of $\beta$ and H on the pore pressure ratio $r_u$, and on the angle of shearing resistance$\phi$' for a simple soil profile and specified shear strength parameters it has been found that to a close approximation the factor of safety, Fs varies linearly with the magnitude of the pore pressure expressed by the ratio $r_u$ and can be defined by the following expression.

$R_u$ = Area of sliding mass below the pheratic surface x $\gamma$w / Total area of sliding mass x $\gamma$

In this method it is assumed that slope is a simple slope of homogeneous material. The unit weight of the soil is assumed to be constant at twice the unit weight of water, in addition it is assumed that the pore water pressure can be approximated by the product of the height of soil have a given point times the unit weight of water.

### 2.3.1 Main Features of the Method

The main features of the method are (Ref. Fig. 2.2)

A force polygon is drawn below the sliding mass using the following force vectors, the total wt of slope W the shear force required for stability, Sr and the normal force, N. The force, Sr, consist of a cohesion force component and a friction force component. Also plotted within the force polygon is resultant force of intergranular stress, P, which is the vector sum of two forces; the resultant of the available shear force due to friction along the base of sip circle, Fa and N, which act towards the center of rotation, O.

The main assumptions of the method are :

To locate the force polygon at a specific location (point 1 in fig. 2.1)

To orient Fa parallel to S

The factor of safety is defined in terms of sliding and resisting forces (Terzaghi, 1943)

The method can be used to analyze slopes with and without seepage. The method for analyzing slopes without seepage and with steady state seepage is illustrated in figures 2.2 and 2.3 respectively.

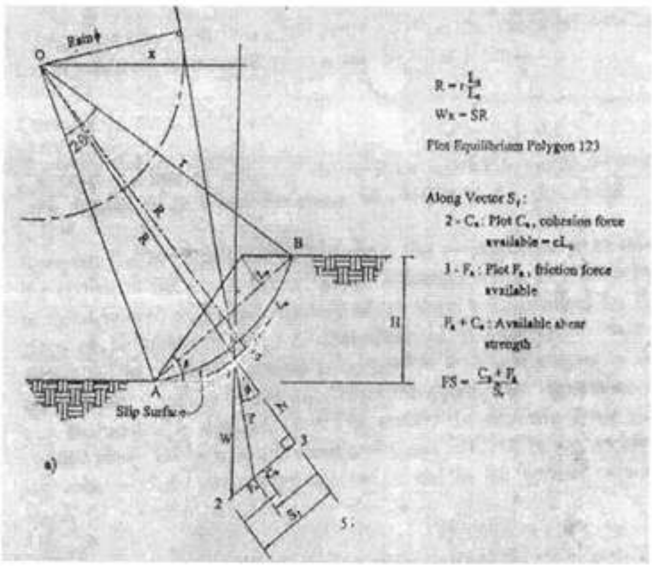


**Figure 2.2 : Essentials of Grpahical Procedure for No Seepage Case**

(Philip S.K. Ooi and Walter B. Lum 2001)

### 2.3.2 Analysis of Slopes without Seepage

For the slopes without seepage it is assumed that there is no water is passing through the embankment. The steps to perform the graphical analysis for a slope without seepage are as follows: (Referring Fig. 2.2)

Draw the slope geometry and the failure arc to scale

Draw line OS of length R from the center of rotation that bisects the central angle 2θ, where R equal r x La / Lc; r = radius of slip circle, La is length of arc AB and Lc is the length of cord AB. The ratio La/Lc can be estimated from the geometry based on the central angle within the failure arc as follows :

$La / Lc = \theta / \sin\theta$

Where θ is in radians

Estimate the weight of soil mass within the slip circle, W and its line of action. One quick way of estimating W is to divide the failure mass into a triangle and a segment of circle as shown in fig. 2.1. The area of circle segment, $A_{seg}$ is equal to

$Aseg = r^2 (\theta - 0.5 \times \sin 2\theta)$ where θ is in radians

However, it is sufficiently accurate for practical ranges of the central angle to approximate the area of the circle segment as follows:

$A_{seg} = 0.7 \text{ x } Lc \text{ x } A$

Where A is the maximum height of the circle segment. The line of action of W acts through the center of gravity of the slide, which is located between the centroid of the triangle and the centroid of the circle segment with a weighted bias towards the centroid of the heavier of the two soil masses. The centroid of the circle segment is approximately 0.4 A from the middle of the chord.

Construct an arc with a radius equal to R from the center of rotation till it intersects with the line of action of W at point 1.

Draw W to scale below point 1

Construct the line of action of the resultant normal force; N.N. must pass through point 1 and the center of rotation of slip circle.

Complete the force polygon by drawing a line perpendicular to N from the bottom of the weight vector, W till it intersects with N. The length of this line represents the magnitude of the shear force required for the slope to be stable, Sr (A key assumption of this method is in the inclination of Fa. Fa is assumed to be parallel to Sr and tangent to the arc at point 1, which is not parallel to the chord. The importance of this assumption is discussed later. In reality the cohesive force acs parallel to the chord with a moment arm equal to R. Therefore, locating the cohesive force tangent to this arc results in the correct moment about the center of rotation)

Draw vector P through point 1 at an angle $\phi$ from N, where $\phi$ is the friction angle of the soil. The length of the shear force vector, Sr to the right of P is the resultant of available shear force due to friction along the base of the slip circle Fa.

Estimate the available cohesion Ca, which is equal to c x Lc where c is the cohesion of the soil.

Estimate the factor of safety, FS with respect to sliding as follows (Terzaghi, 1943)

**FS = Ca + Fa / Sr** **(2.8)**

**2.3.3 Analysis for Steady Seepage Condition**

For the case where there is no standing pool, the factor of safety for a slope with steady state seepage can be approximated very quickly for any prescribed pheratic surface using the pore pressure ratio. A slope experiencing steady state seepage (Fig. 2.3) is analyzed by performing the steps, which are identical to those for slopes subjected to rapid draw down described in table 2.1 addition to steps 1 through 9 for the no seepage case. Using the graphical technique, the factor of safety for the slope experiencing steady state seepage with $r_u$ = 1/6 is estimated and they are in good agreement with the factor of safety obtained from Bishop's modified method. Factors of safety for four slopes experiencing steady state seepage with $r_u$ = 1/6 are summarized in table 3.1 for both the graphical technique and Bishop's modified method. Again, the same slip circle is analyzed for all four slopes.

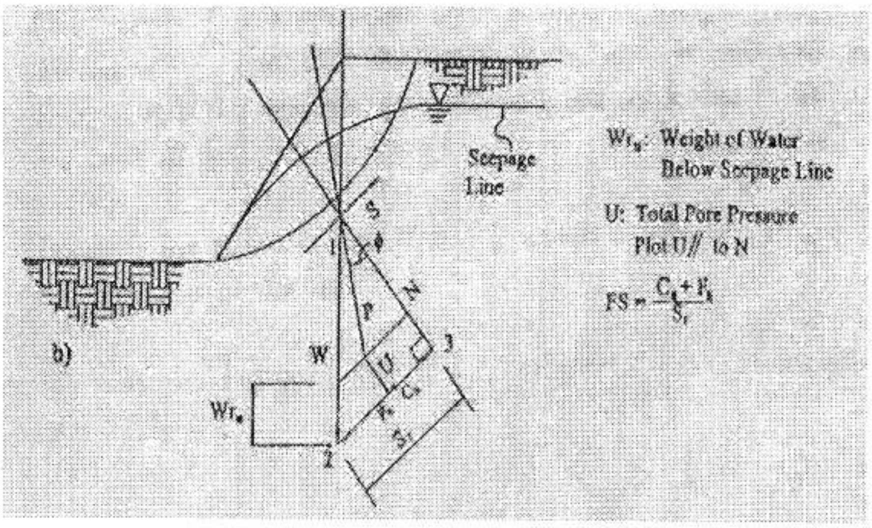


**Figure 2.3: Essential of Graphical Procedure with Steady State Seepage Conditions.**
(Philip S.K. Ooi and Walter B. Lum 2001)

**2.3.4 Analysis of Completely Submerged Slope**

A completely submerged slope does not have any seepage forces. Therefore, it can be solved using the procedure described above for the no seepage case just by changing the unit weight from total to buoyant. An alternative approach is to revise the values of Fa and Sr to account for buoyancy and re computing FS using Eqn 2.8. This is achieved by dividing the weight vector into two components the effective weight of the soil within the sliding mass and the weight of the water within the sliding mass. Submerged slopes can be analyzed by performing the steps described in table 2.1 in addition to steps 1 through 9 for the no seepage case.

FS = Ca + Fa / Sr

**2.3.5 Analysis for Rapid Draw-down Condition**

The worst-case rapid draw down scenario occurs when the standing pool is drained very quickly leaving the soil no time to drain. This case is equivalent to submerged slope without standing pool. It is analyzed by performing steps 1 through 9 for the no seepage case in addition to steps described below :

Estimate the pore pressure ratio $r_u$

From the bottom of vector W (point 2) scale the up-wards the vertical distance Wru

From the top of Wru draw a line perpendicular to N and scale the portion of this line to the right of its intersection with P. This is the resultant of the available shear force due to friction, Fa.

Compute FS using equation : FS = Ca + Fa / Sr

Where Sr is obtained from step 7 for the no seepage case

**Table 2.1 :** Additional Steps for Analyzing Completely Submerged Slopes and Slopes with Steady State Seepage

Completely submerged slopes (Fig. 2.3)

a) Estimate the pore pressure ratio $r_u$ as follows :

$r_u$ =Area of sliding mass below the pheratic surface x $\gamma_w$ / Total area of sliding mass x $\gamma$ (2.9)

In the general case $\gamma$ is the most unit weight ($\gamma_m$) for the soil above the pheratic surface and saturated unit weight ($\gamma_t$) or the soil below the pheratic surface. For completely submerged slope $r_u = \gamma_w / \gamma_t$

b) From the bottom of vector W (point 2) scale upwards the vertical distance W x $r_u$. The upper portion of the weight vector, W x (1 – $r_u$ ) represents the effective weight of the soil, while the lower portion, W x $r_u$ represents the unit weight of the water times the area between the pheratic surface and the slip surface.

c) From the top of W x $r_u$ draw a line perpendicular to N and scale the magnitude of shear force required for stability. Sr equal to the length of this line.

d) Scale, the portion of the line drawn in step c to the right of its intersection with P. This is the resultant of the available shear force due to friction Fa.

e) Compute FS using Eqn. 2.8

FS = Ca + Fa / Sr

**2.4 Back Calculations of Geo mechanical Parameters**

The method can also be used to back calculate geo mechanical parameters such as c,$\phi$,$\gamma$ or $r_u$ for failed slopes by assuming a factor of safety of unit. Back calculation of $r_u$ is described below but the same principles apply when back calculating c,$\phi$,$\gamma$ when the moist and total unit weight are similar, the maximum pore pressure ratio $r_u$ that corresponds to a factor of safety of unit can be determined by graphical construction very rapidly for the slope shown in fig. 2.2 and fig. 2.3 as follows :

After performing steps 1 through 9 for the no seepage case, scale along vector Sr, from the bottom of W a distance equal to Ca.

From the point established in step a, draw the neutral force vector, U parallel to N till it intersects with P.

From the intersection point from step b, draw a line perpendicular to N till it intersects with W.

Scale the distance from the intersection point in step c to the bottom of W. This is the value of W x $r_u$ that corresponds to a factor of safety of 1.0.

Divide W x $r_u$ by W to obtain the value of $r_u$ when the factor of safety is 1.0.

After construction of graphical procedure for $r_u$ yields a maximum allowable pore pressure ratio of say, 0.39 i.e. the slope will be barely stable when 39% of the area of the sliding mass lies below the pheratic surface. The same result has been observed for the slope by using Bishop's modified method. The results from such an analysis will allow the engineer to design an effective drainage system in the field for on the spot remediation of imminent slides. On the same line we can also use other geo mechanical parameters for predicting imminent slides or for failed slopes. The methods described here are applicable only to slopes consisting of homogeneous materials. They are therefore of limited practical application, as only a small proportion of slips occurring in homogeneous materials. If the methods are applied to slopes assumed to be homogeneous when in fact this is not the case then the results may be quite misleading. Hence the methods should be used with caution.

**2.6 Limitations**

For the engineer in the field with no access to a computer or stability charts, the graphical method presented herein provides a very useful tool for performing simple stability computations of known slides or imminent slides. As a result of its simplicity, there are several limitations on the use of the method. They include the following:

It is applicable only to homogeneous slopes.

Failure surfaces are restricted to toe circles and slope circles.

The steady seepage condition is analyzed using the pore pressure ratio concept, which provides a simplicity methodology to account for seepage effects, yielding results that are quite reasonable as a first approximation. However, if a more accurate representation of the effects of seepage forces for a given pheratic surface is required, then a more rigorous slope stability analysis should be performed especially if the pheratic surface is known or can be predicted with a high degree of confidence.

The procedure suggested for rapid drawn is an effective stress approach that assumes a conservative set of pore pressures. It provides approximation of the factor of safety using a single stage analysis in the field. More accurate two stage analyses has been developed by the corp of engineers (1970), Lowe and Karafiath (1960) and Wright and Duncan (1987) for slopes subjected to rapid draw down but this procedures are less amenable to hand computations.

For finite slopes the angle of inclination of the friction force, Fa, with respect to the horizontal is assumed in the graphical technique and may not represent the actual inclination. However, values of factor of safety calculated using the graphical technique are generally in good agreement with Bishop's modified method for all four slopes. Based on the analyses performed, values of factor of safety are typically within 4% for dry and submerged slopes and within about 7% for rapid draw down and steady seepage. The one exception is for the very steep IV : 1/4H slope during rapid draw down. The discrepancy in the factor of safety for this near vertical slope was always the largest for all seepage conditions.

## III. Conclusion

By using the graphs provided, it is easy to determine critical slip circle and hence factor of safety quickly, for homogeneous soil for all seepage conditions.

From the graphs of slope against factor of safety fr embankment height =10m it reveals that as the slope gets flatter the factor of safety has been increasing for all seepage conditions.

From the graph of slope against factor of safety for embankment height =30m it is seen that for no seepage, steady state seepage and partially submerged conditions there is decrease in factor of safety as the slopes gets flatter up to 1:1/2. In completely submerged case the factor of safety increases, as slope gets steeper.

From the graph of slope against factor of safety for embankment height =40m it depicts nearly marginal variation in factor of safety for all three seepage conditions except that for completely submerged case.

The graphs plotted for against 'r' (critical) for different seepage conditions and for particular height can be used for finding any intermediate value of critical radius of slip circle for particular slope.

From the graphs of slope against central angle of rotation for different seepage conditions and for particular height the range of critical central angle of rotation for any slope can be determined.

The range of critical radius of slip circle for any height and for any seepage condition can be predicted by interpolating the intermediate values, for particular slope from the graphs of height against 'r' (critical)

For 1: ½ slope the height 'r' variation for steady state seepage and for partially submerged case is a straight line variation i.e. the 'r' (critical) increases constantly.

For 1: ½ slope the height against 'r' (critical) variation for steady state seepage and for partially submerged case critical radius of slip circle for the respective case is very close to the height of embankment.

By using the part of back calculation within short time the values of soil parameters on the field i.e. the mobilized value can be computed without going for any actual field or laboratory tests.

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