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NPTEL ONLINE CERTIFICATION COURSES

NPTEL

SOIL MECHANICS/GEOTECHNICAL ENGINEERING I

SLOPE STABILTY

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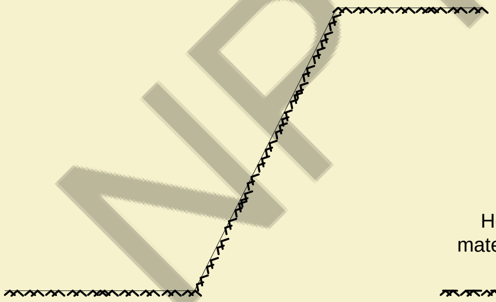
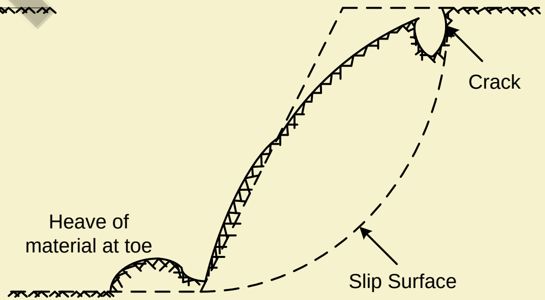
SLOPE STABILTY

Soils with Two Strength Component: Contemporary methods of investigation are based (a) assuming a slip surface and a centre about which it rotates (b) studying the equilibrium of the forces acting on this surface and (c) repeating the process until the worst slip surface is found. The worst slip surface is that surface which yields the lowest factor of safety, F where F is the ratio of restoring moment to the disturbing moment, each moment considered about the centre of the rotation.





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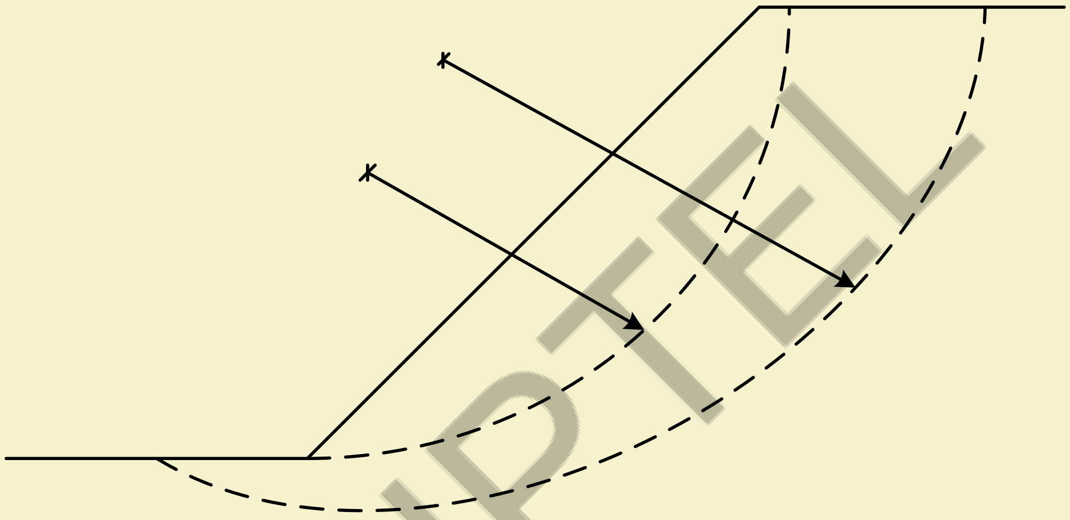
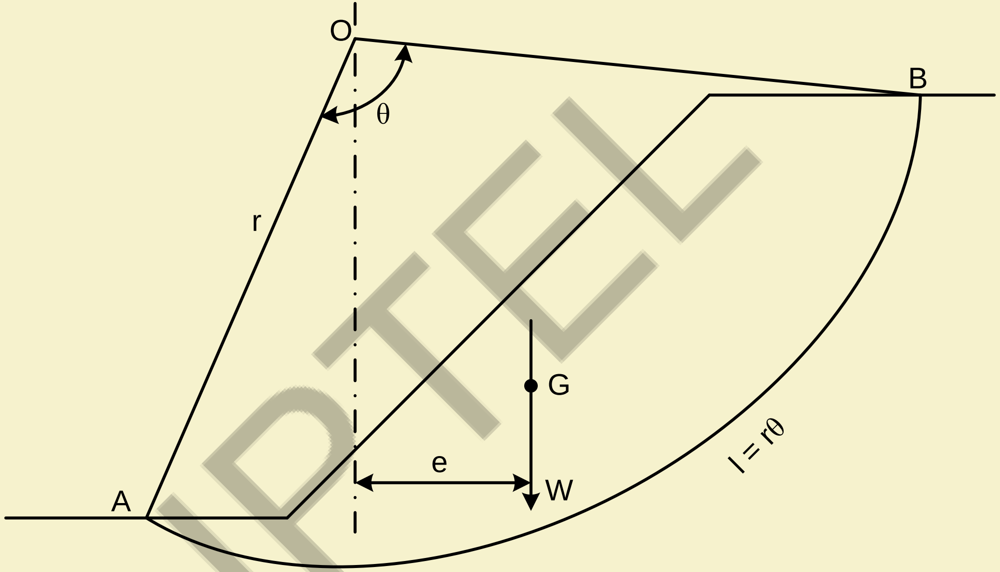
SLOPE STABILTY



SLOPE STABILTY



SLOPE STABILTY

This analysis intend to give the stability of an embankment immediately after its construction. At this stage it is assumed that the soil in the embankment has had no time to drain and the strength parameters used in the analysis are the ones representing the undrained strength of the soil which are found either from UCC or and Undrained triaxial test without pore pressure measurements.

Considering the Figure the sector of soil cut off by arc AB of radius r. Let W equal the weight of the sector and G the position of its center of gravity. As undrained condition is considered, shear strength component = cu

Taking moment about O, the center of rotation: $W_s = c_u r\theta r = c_u r^2\theta$

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SLOPE STABILTY

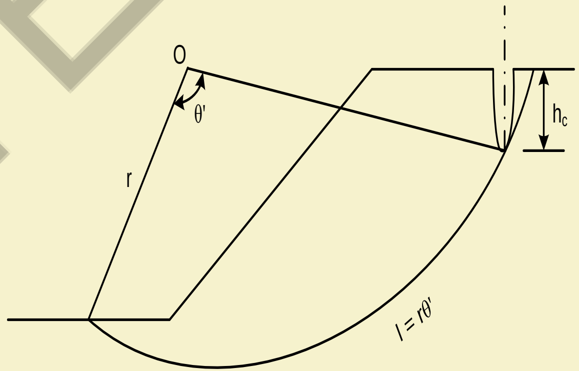
For equilibrium $$F = \frac{Restraining\ moment}{Disturbing\ moment} = \frac{c_u r^2 \theta}{We}$$

Effect of Tension Cracks

With a slip in a cohesive soil there will be a tension crack at the top of the slope along which no shear resistance can develop. In a purely cohesive soil the depth of the crack , hc, is given by the formula: $h_c = \dfrac{2c_u}{\gamma}$

SLOPE STABILTY

The effect of the tension crack is to shorten the arc AB to AB’. If the crack is to be allowed for, the subtended angle to be reduced as shown in the figure but full weight W of the sector is still used in order to compensate for any water pressure that may be exerted if the crack fills with rain water



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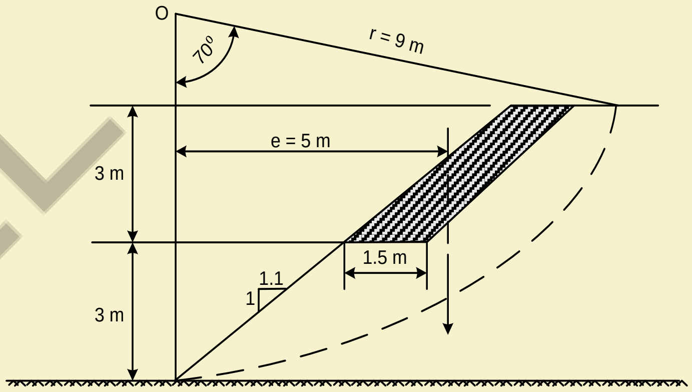
SLOPE STABILTY

The figure gives details of an embankment made of cohesive soil with ϕu = 0.0 and cu = 20 kN/2. The unit weight of the soil is 19 kN/m3.

For the trial circle shown, determine the factor of safety against sliding,. The weight of the sliding sector is 346 kN acting at an eccentricity of 5 m from the center of rotation. What would the factor of safety be f the shadded portion of the embankment were removed? In both cases assume no tension crack develops.



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SLOPE STABILTY

With partially saturated soils the undrained strength envelope is no longer parallel to the normal stress axis and the soil has a value of both c and ø.

The total stress analysis can be adopted to cover this case by assuming a slip circle procedure and dividing the sector into a suitable number of vertical slices, the stability of one such slice being considered in the Figure in next slide.

At the base of the slice set off its weight to some scale. Draw the direction of its normal component, N, and by completing the triangle of forces determine its magnitude, together with the magnitude of the tangential component T

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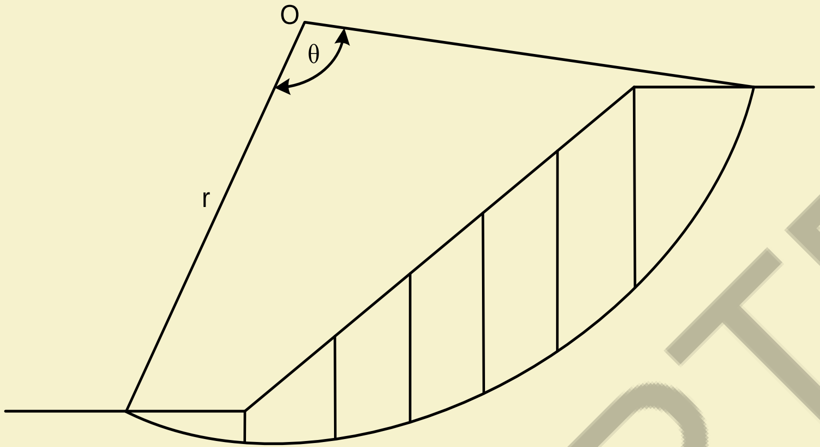
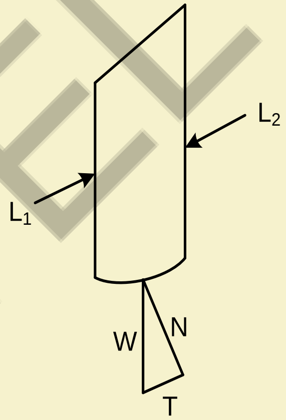
SLOPE STABILTY





The effect of a tension crack can again be allowed for, and in this case;

$$h_c = \frac{2c}{\gamma} tan\left(45^\circ + \frac{\emptyset}{2}\right)$$

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Taking moment about the centre of rotation, O:

Disturbing moment = $r\sum T$

Restraint moment = $r\left(cr\theta + \sum N\, tan\emptyset\right)$

Hence, $$F = \frac{cr\theta + \sum N\; tan\emptyset}{\sum T}$$

Thank You!!

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SLOPE STABILTY

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The center of the most critical circle can only be found by trial and error, various slip circles being analysed and the minimum factor of safety eventually obtained.

A suitable procedure is suggested in the Figure below. The centre of each trail circle is plotted and the F value for the circle is written alongside it. After several points have thus been established it is possible to draw contours of F values., which are roughly elliptical so that their centre indicates where the centre of the critical circle will be. Note that the value of F is more sensitive to horizontal movements of the circle's centre than to vertical movements.

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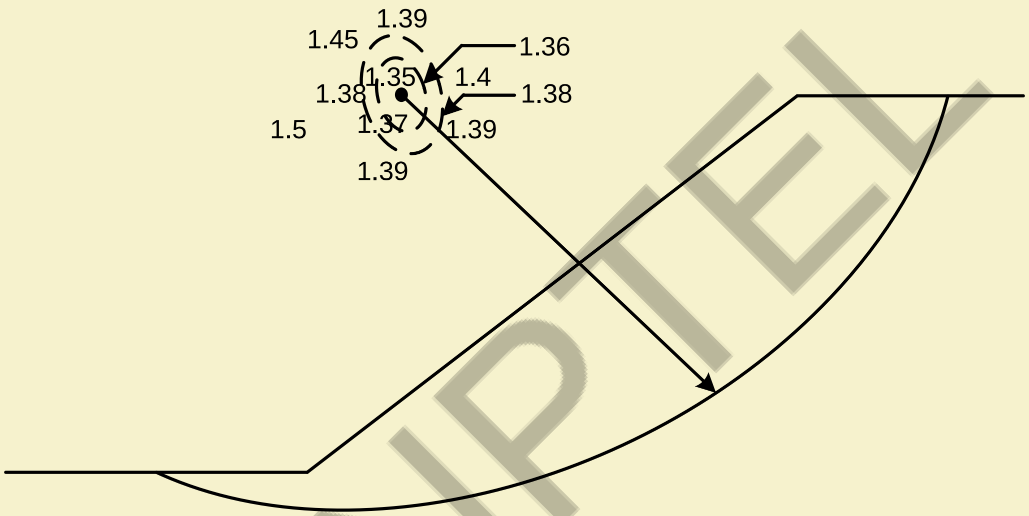
SLOPE STABILTY



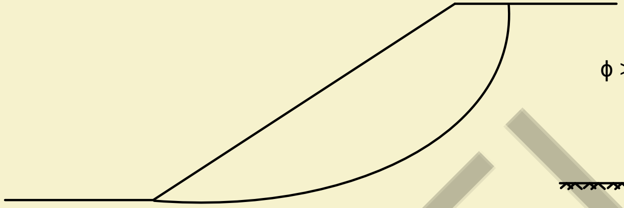
SLOPE STABILTY

To determine a reasonable position for the centre of a first trial slip circle is not easy, but a study of the various types of slips that can occur is helpful. In the case of soils with angles of shearing resistance that are not less than 3°, the critical slip circle is invariably through the toe-as it is for any soil if the angle of slope exceeds 53°. An exception to this rule occurs when there is a layer of relatively stiff material at the base of the slope, which will cause the circle to be tangential to this layer.

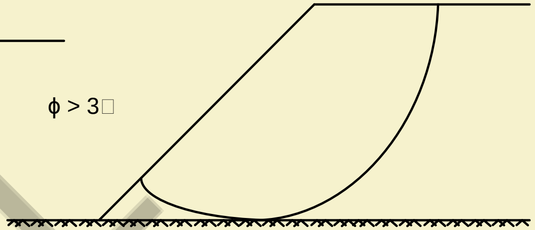
SLOPE STABILTY

For cohesive soils with little angle of friction the slip circle tends to be deeper and usually extends in front of the toe; this type of circle can of course be tangential to a layer of stiff material below the embankment which limits the depth to which it would have extended.

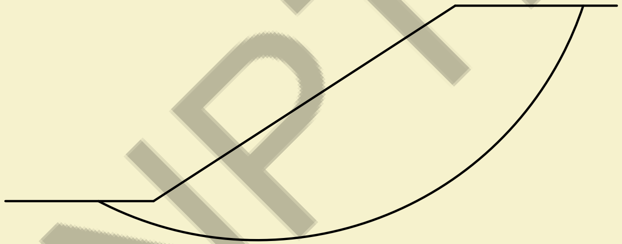
SLOPE STABILTY



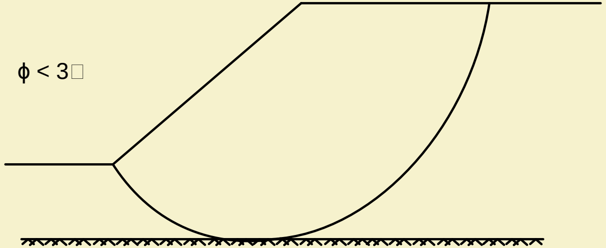
(a) Toe failure



(b) Circle tangential to base



(c) Deep slip circle



(d) Circle tangential to deep stiff layer

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SLOPE STABILTY

Method proposed by Fellenius for locating the center of rotation for cohesive soil

Slope	Angle of slope	Angle α	Angle β
1:0.58	60	29	40
1:1	45	28	37
1:1.5	33.79	26	35
1:2	26.57	25	35
1:3	18.43	25	35
1:5	11.32	25	37

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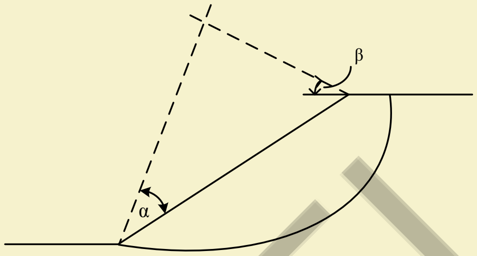
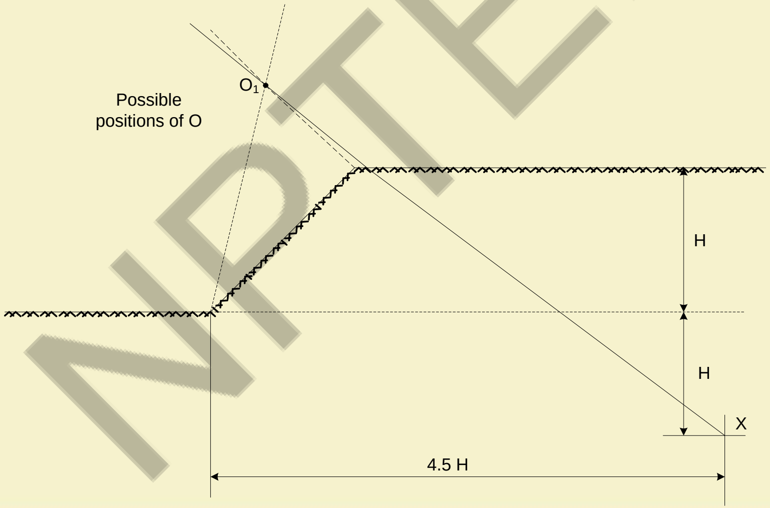
SLOPE STABILTY





SLOPE STABILTY

This technique is not applicable in its original form to frictional cohesive soils but has been adapted by Jumikis (1962) to suit them, provided that they are homogeneous. It is necessary first to obtain the centre of the Fellenious circle, O1 as before after which a point X is established such that X is 2H below the top of the slope and a distance of 4.5H horizontally away from the toe of the slope (H is the vertical height of the slope). The centre of the critical circle O lies on the line XO1 extended beyond O1, the distance of O beyond O1 becoming greater as the angle of friction increases.

SLOPE SABILITY

Such a method can only be used as a means of obtaining a set of sensibly positioned trial slip circles. When the slope is irregular or when there are pore pressures in the soil, conditions are no longer homogeneous and the method becomes less reliable

SLOPE STABILTY

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SLOPE STABILTY

The embankment in the figure is made up of soil with ϕ = 20 deg and c = 20 kN/m2. The soil on which the embankment sits has a ϕ of 7 deg and c = 75 kN/m2. For both soils unit weight is 19.3 kN/m3. Determine the factors of safety for the slip circles shown

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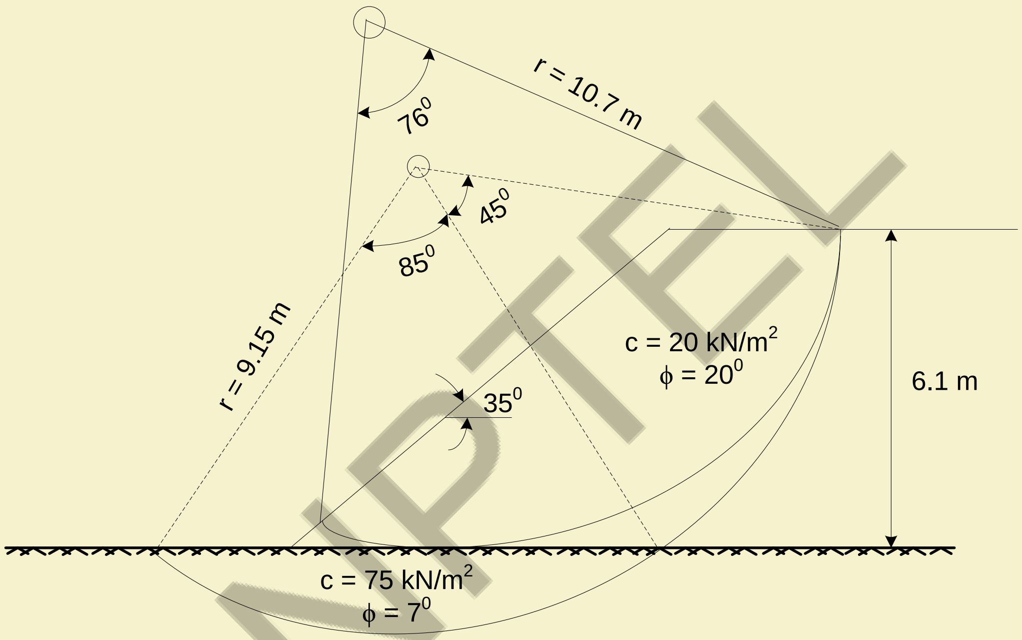
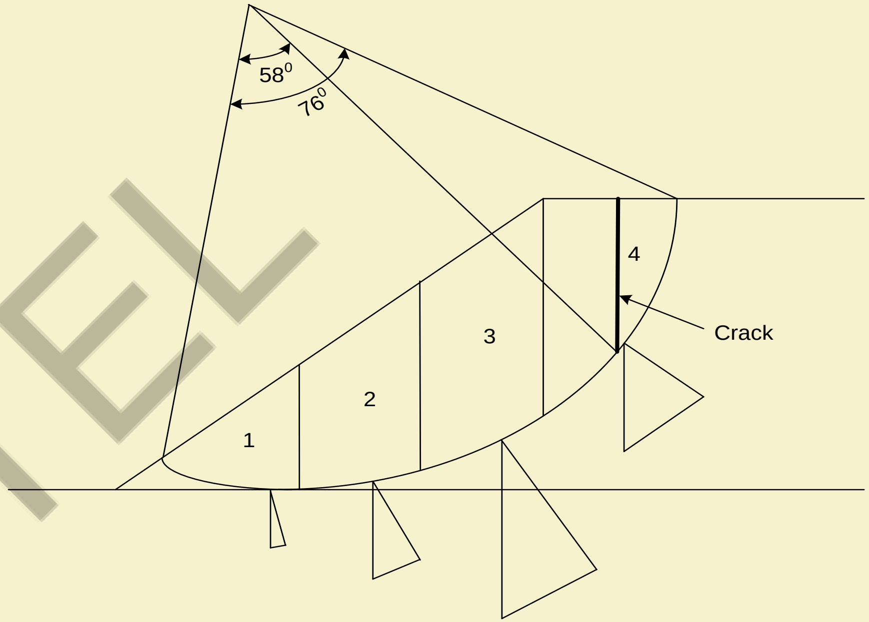
SLOPE STABILTY



SLOPE STABILTY

This example is the classic case of an embankment resting on a stiff layer. The slip circle tangential to the lower layer will give a lower factor of safety.



Slip surface tangential to the lower layer

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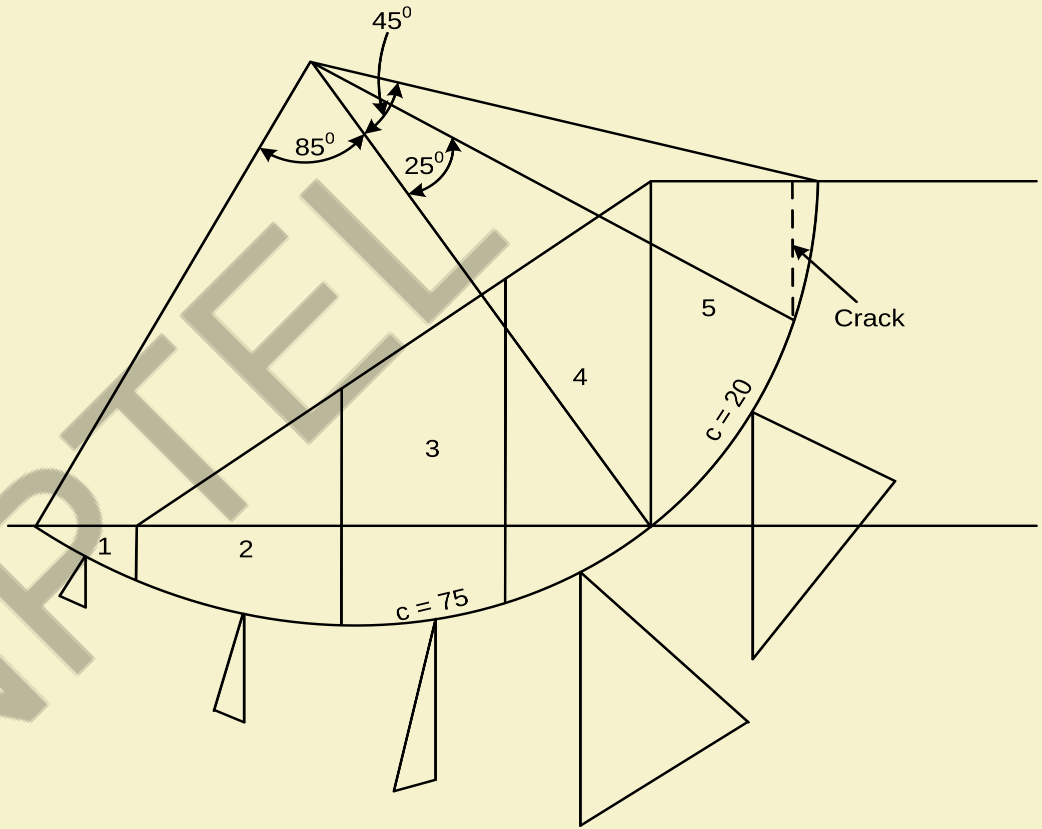
SLOPE STABILTY

Deep slip surface



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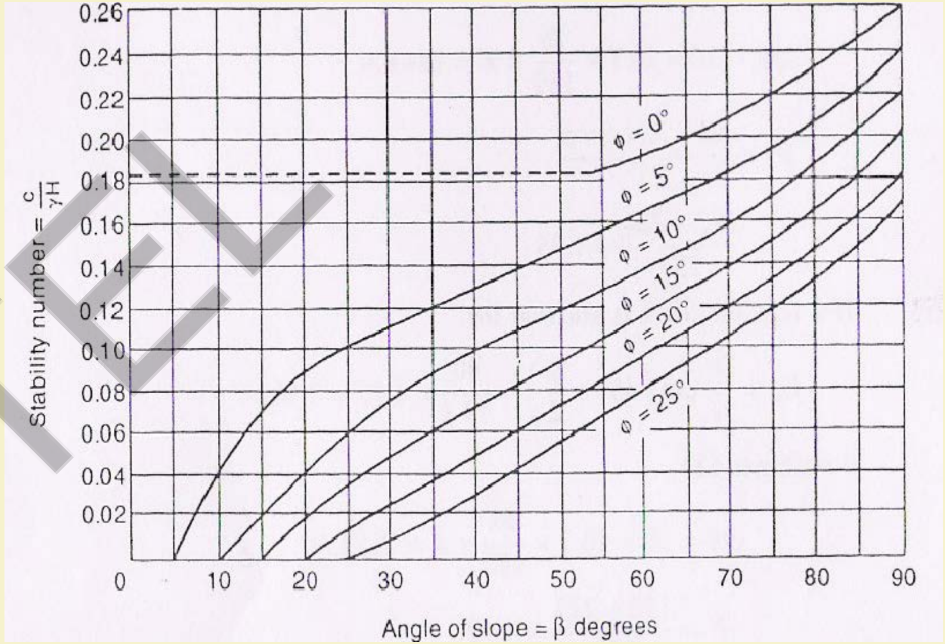
SLOPE STABILTY

Rapid determination of F for a homogeneous, regular slope:

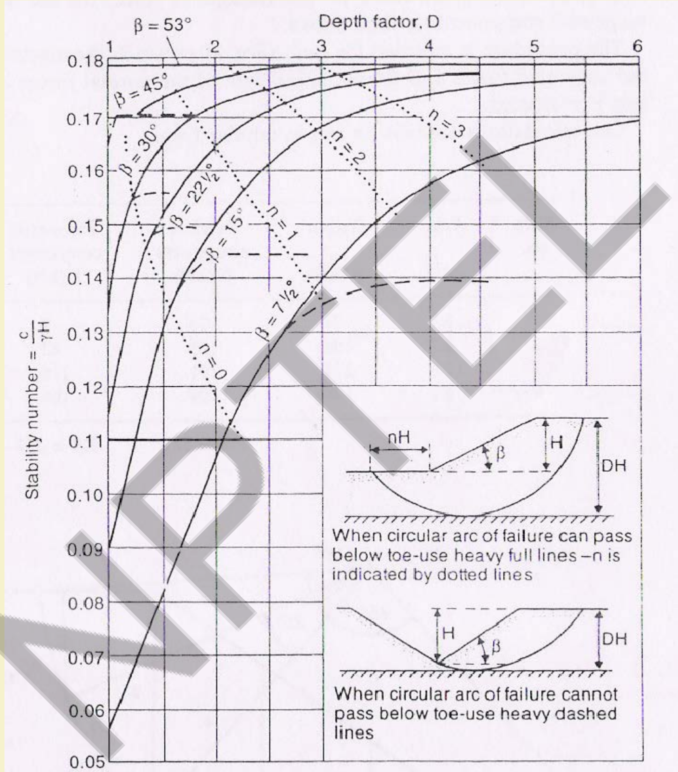
It can be shown that for two similar slopes made up of two different soils the ratio cm/ϒh is the same for each slope provided that the two soils have the same ange of friction. The ratio cm/ϒH is known as the stability number and is given the symbol, N, where cm is the cohesion mobilised in regard to total stress, ϒ is the unit weight of soil and H is the vertical height of the embankment.

SLOPE STABILTY

Taylor prepared two curves that relate the stability number to the angle of slope: the first is for the general case of a c-ϕ soil whilst the second is for a soil with ϕ = 0 with a layer of stiff material or rock at a depth DH below the top of the embankment.



SLOPE STABILTY



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SLOPE STABILITY

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SLOPE STABILTY

An embankment has a slope of 1 vertical to 2 horizontal. The properties of the soil are c = 25 kN/m2, ϕ = 20 deg, ϒ = 16 kN/m3, and H = 31.

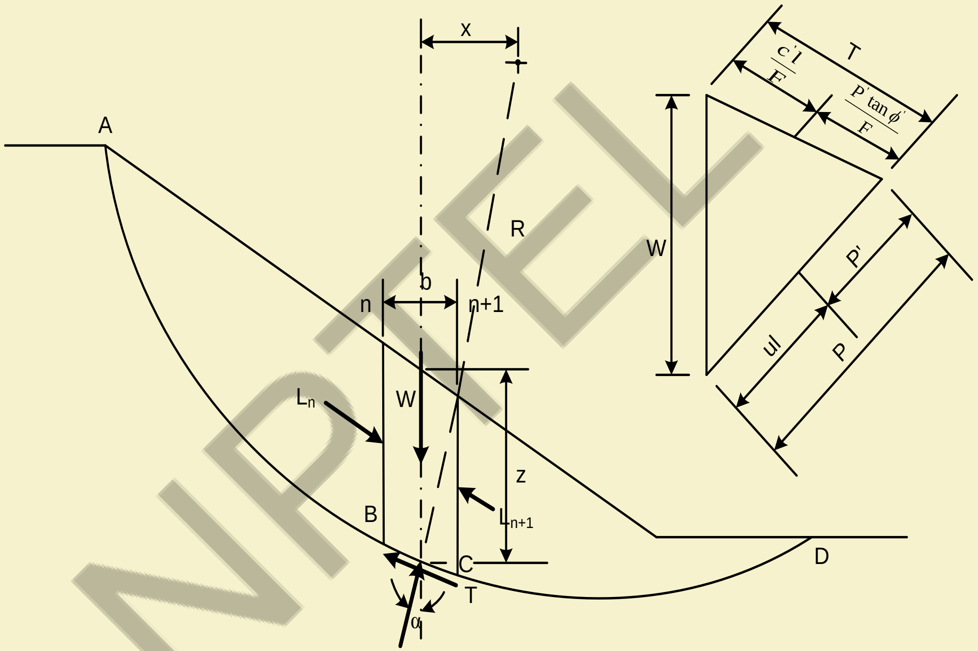
Using Taylor's chart, determine the F value for the slope.

SLOPE STABILITY

Bishops's conventional method: Use effective stress method of analysis. Figure in the next slide shows a circular failure arc, ABCD, and shows the forces on a vertical slice through the sliding segment. Ln and Ln+1 are equal or diff between these two assumed negligible.

$$F = \frac{1}{\sum W sin\alpha} \sum [c'l + W(cos\alpha - r_u sec\alpha) tan\emptyset']$$

SLOPE STABILITY



Te solution is known as Bishop's conventional method. It gives error s of up to 15% in the value of F obtained. However the error is on the safer side since it gives a lower value than is the case.

Rigorous Method

$$F = \frac{1}{\sum W sin\alpha} \sum \left[(c'b + W\{1 - r_u\} tan\emptyset') \frac{sec\alpha}{1 + \frac{tan\emptyset' tan\alpha}{F}} \right]$$

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SOIL MECHANICS/GEOTECHNICAL ENGINEERING I

Summary

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SLOPE STABILTY

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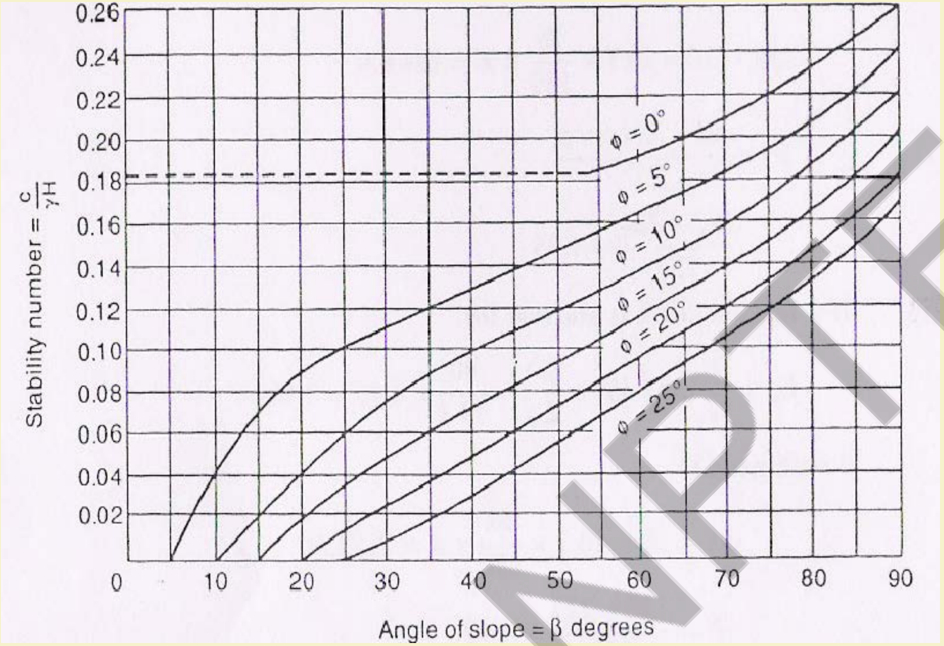
SLOPE STABILTY



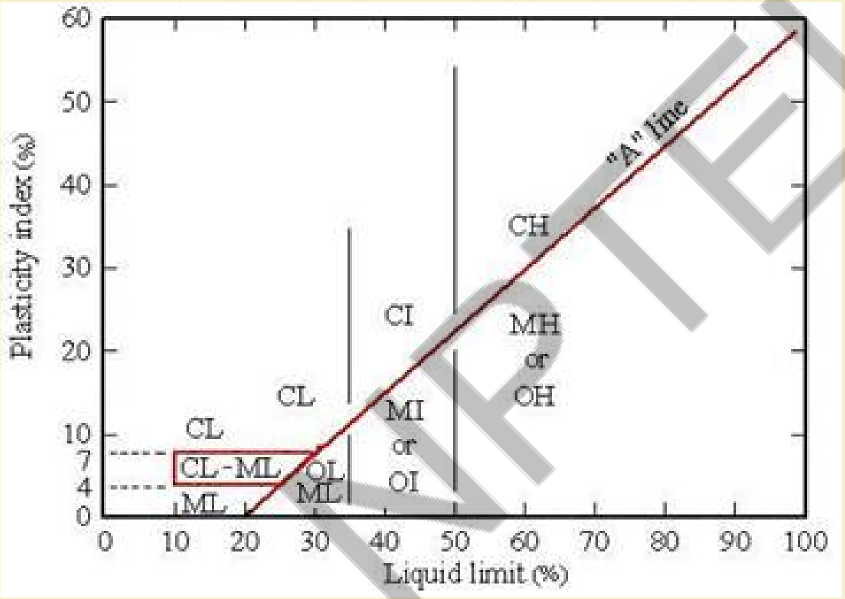
Summary

Origin and Classification of soil: Igneous, sedimentary, and metamorphic rock ⟹ gravel, sand, silt and clay ⟹ mix

Soil Type	Prefix	Sub group	Suffix
Gravel	G	Well graded	W
Sand	S	Poorly gradded	P
Silt	M	Silty	M
Clay	C	Clayey	C
Organic	O	wl > 35 per cent 35<wl<50	L I
Peat	Pt	Wl < 50 per cent	H

Summary

Plasticity Chart



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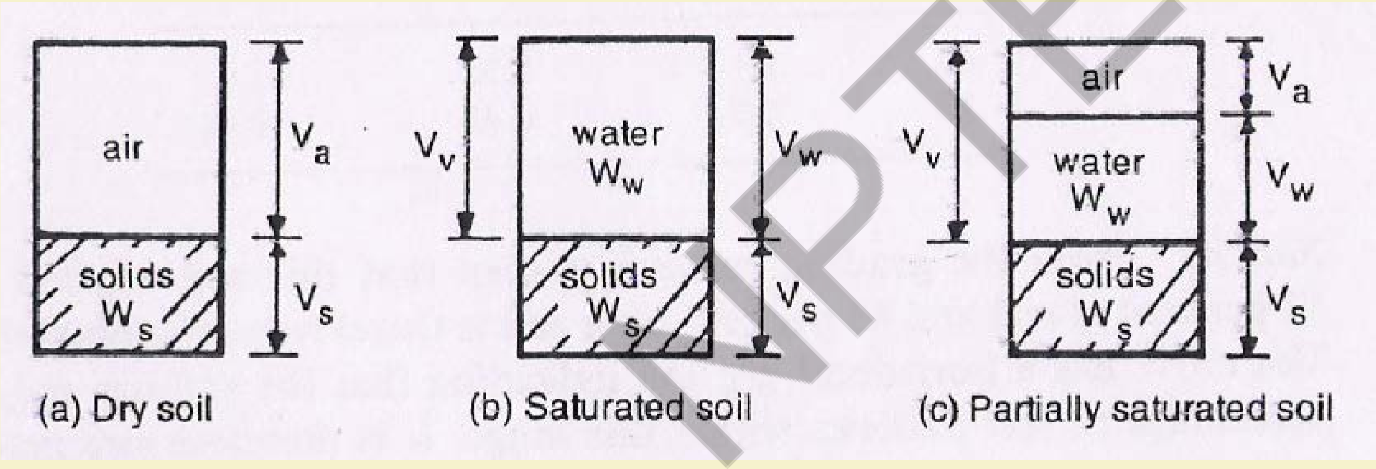
Summary

$$Void\ ratio, e = \frac{volume of voids}{volume of solids} = \frac{V_v}{V_s}$$

Weigh volume relationships:

$$Porosity, n = \frac{Volume\ of\ Voids}{Total\ Volume} = \frac{V_v}{V} = \frac{V_v}{V_V + V_s} = \frac{e}{1+e}$$



Summary

$$Degree\ of\ \ satration, S_r = \frac{Volume\,of\ \ water}{Volume\,of\ \ voids} = \frac{V_w}{V_v}$$

$$S_r e = wG_s$$

$$\gamma_{bulk} = \frac{(G_s + S_r e)}{1+e}\gamma_w$$

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Summary

Permeability Test: Lab Method

$$k = \frac{q}{Ai} = \frac{Ql}{Ath}$$

$$t = \frac{al}{Ak}\ln\frac{h_1}{h_2} \quad or \quad k = \frac{al}{At}\ln\frac{h_1}{h_2}$$

Field Method:

$$k = \frac{q\ln\left(\frac{r_2}{r_1}\right)}{\pi\left(h_2^{\ 2} - h_1^{\ 2}\right)}$$

$$k = \frac{q\ln\left(\frac{r_2}{r_1}\right)}{2\pi H\left(h_2 - h_1\right)}$$

Summary

$$k_{xe} = \frac{H_1 k_{x1} + H_2 k_{x2} + H_3 k_{x3} + \cdots \ldots + H_n k_{xn}}{H_1 + H_2 + H_3 + \cdots \ldots + H_n} = \frac{\sum_1^n H_n k_n}{\sum_1^n H_n}$$

$$k_{ze} = \frac{H}{\frac{H_1}{K_{z1}} + \frac{H_2}{k_{z2}} + \frac{H_3}{k_{z3}}}$$

$$q = kh\frac{N_f}{N_d}$$

$$\sigma' = \sigma - u$$

$$\frac{h}{l} = \frac{G_s - 1}{1 + e}$$

Summary

$$\sigma' = \sigma - u$$

$$\sigma_z' = \sigma_a'\frac{z}{z_1} = (z_1\gamma_{sub} + h\gamma_w)\frac{z}{z_1} = z\gamma_{sub} + \frac{hz\gamma_w}{z_1} = z\gamma_{sub} + iz\gamma_w$$

$$\sigma_z' = z\gamma_{sub} - iz\gamma_w$$

$$i_c = i = \frac{\gamma_{sub}}{\gamma} = \frac{G_s - 1}{1 + e}$$

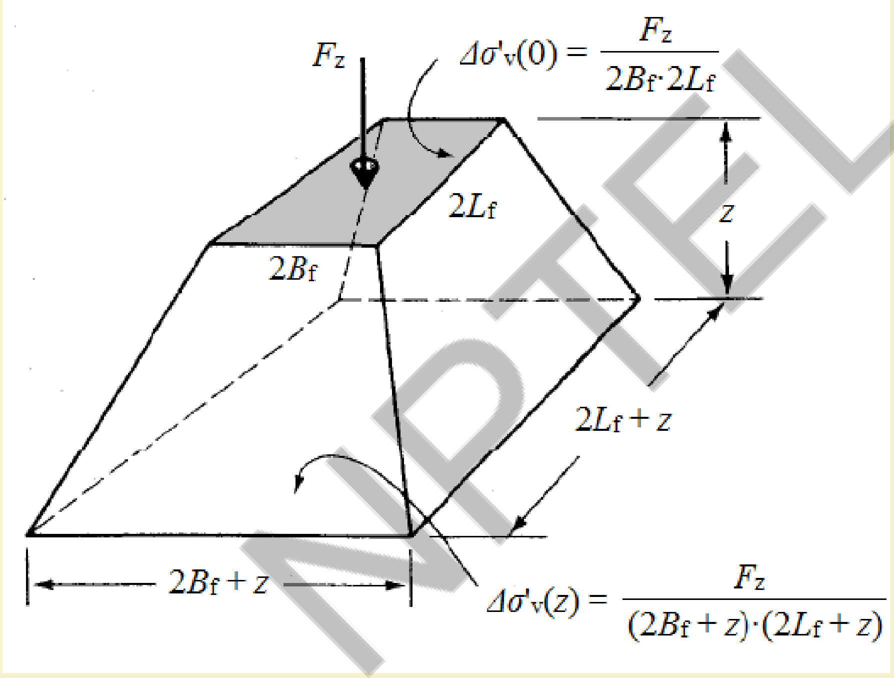
Summary

$$\sigma_z = \Delta\sigma = \frac{3Q}{2\pi z^2}\frac{1}{\left[1+\frac{r^2}{z^2}\right]^{5/2}}$$

$$\sigma_z = q\left[1 - \frac{1}{\left(\frac{r^2}{z^2}+1\right)^{3/2}}\right]$$

$$\sigma_z = \frac{q}{4\pi}\left[\frac{2mn\sqrt{m^2+n^2+1}}{(m^2+n^2+1+mn)}\frac{(m^2+n^2+2)}{(m^2+n^2+1)} + \sin^{-1}\frac{2mn\sqrt{m^2+n^2+1}}{m^2+n^2+1+m^2n^2}\right]$$

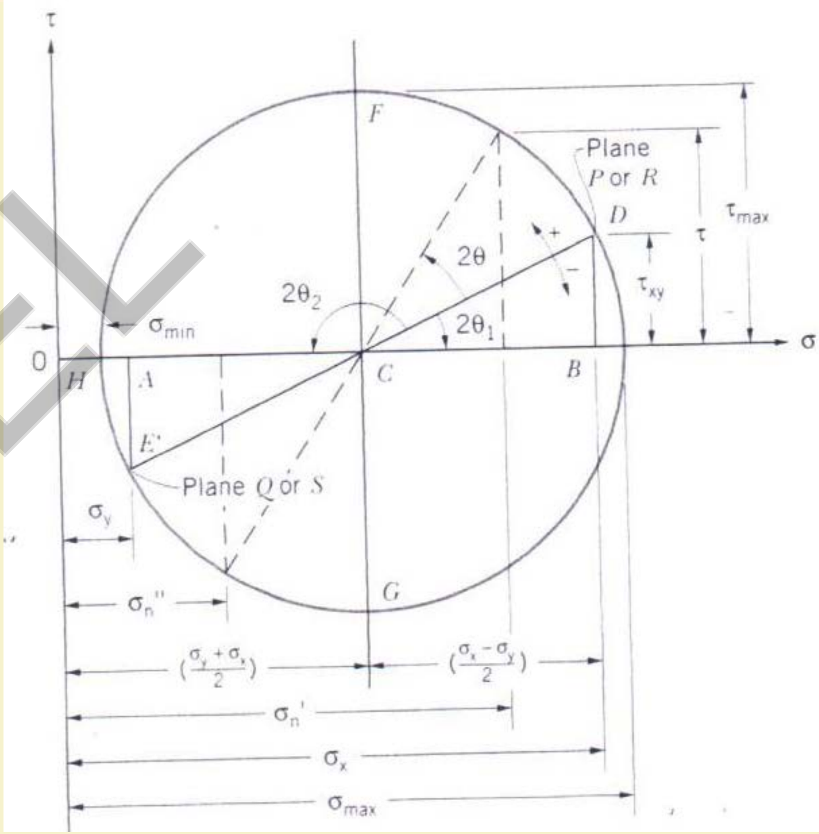
Summary



F_z
$\Delta\sigma'_v(0) = \frac{F_z}{2B_f \cdot 2L_f}$
$2L_f$
$2B_f$
z
$2L_f + z$
$2B_f + z$
$\Delta\sigma'_v(z) = \frac{F_z}{(2B_f + z)\cdot(2L_f + z)}$

SHEAR STRENGTH: summary

The positive angles on the circle are obtained when measured in the counterclockwise sense; negative on the circle are obtained in the clockwise sense. An angle of 2θ on the circle corresponds to an angle θ on the element



Summary

$$\tau_f = c + \sigma \tan\varphi$$

$$\sigma_1 - \sigma_3 = 2c\cos\emptyset + (\sigma_1 + \sigma_3)\sin\emptyset$$

1. **Direct Shear Test**
2. **Tri-axial Shear Test**
3. **Unconfined compression Test**
4. **Vane Shear Test**

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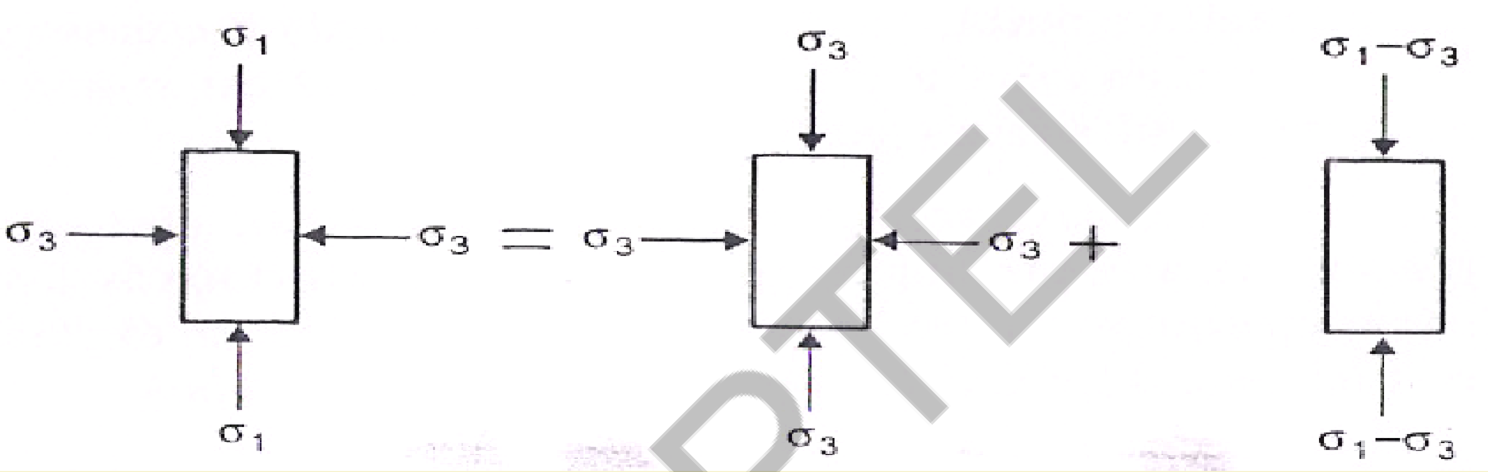
Summary



$$T = \pi c_u \left(\frac{d^2 h}{2} + \frac{d^3}{6} \right)$$

Summary

$$m_v = \frac{a\,dp}{(1+e_1)}\frac{1}{dp} = \frac{a}{(1+e_1)}$$

$$total\ settlement = \rho_c = m_v\,dp\,H$$

$$\rho_c = \frac{c_c H_1}{1+e_1}\log_{10}\frac{p_2}{p_1}$$

Summary

$$T = \frac{\pi}{4}\left(\frac{U\%}{100}\right)^2$$

$$T = 1.781 - 0.933\ log_{10}(100 - U\%)$$

Thank You!!