UNIT - V

SLOPE STABILITY

Slope failure mechanisms - Types - Infinite Slopes - Finite Slopes - Total stress analysis for saturated clay - Fellenius method - Friction circle method - Use of stability number - Slope protection measures.

STABILITY OF SLOPES:

Earth embankments are commonly required for railways, roadways, earth dams, levees & river training works. The stability of these embankments or slopes, as they are commonly called, should be very thoroughly analysed since their failure may lead to loss of human life as well as collosal economic loss.

Failure of mass of soil located beneath a slope is called slide. It involved a downward and outward movement of entire mass of soil that participates in failure.

Failure of slopes takes place mainly due to

i) Action of gravitational forces

ii) Seepage forces within the soil.

iii) Due to excavation or undercutting of its foot

IV) Due to gradual disintegration of structure of soil.

Analysis of stability of slope consists of two parts

i) Determination of the most severely stressed internal surface and the magnitude of shearing stress to which it is subjected.

ii) Determination of shearing strength along this surface.

The shearing stress to which any slope can be subjected depends upon unit weight of material & geometry of slope, while shear strength which can be mobilised to resist shearing stress depends on character of soil, its density & drainage conditions.

Slops

Infinite Slope

Boundary surface of semi-infinite soil mass.

↓

Soil properties for all identical depths below surface are constant.

↓

Slope extending to infinity donot exist in nature.

Finite Slope

Slope of limited extent.

↓

Inclined faces of Earth dam, embankments and cuts, etc.

↓

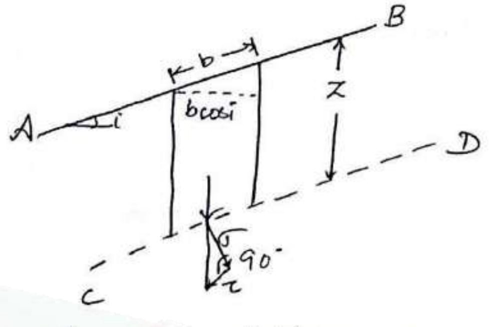
All man made slopes.

STABILITY ANALYSIS OF INFINITE SLOPES:

Figure shows an infinite slope AB, inclined at angle i to the horizontal.

Soil properties & the soil stress on any plane ∥ to slope surface are identical & (2) failure of slope involves a sliding of soil mass along a plane ∥ to slope at some depth.

CD - Failure plane at depth z below surface.



Consider a prism of soil, of inclined length b along slope & depth z upto critical surface.

Horizontal length of prism = $b\cos i$

Volume / unit length of prism = $z b \cos i$

Weight of prism = $W = \gamma z b \cos i$

Vertical stress σ_z on surface CD is given by

$$\sigma_z = \frac{W}{b} = \gamma z \cos i$$

σ - Stress component normal to surface CD.

τ - Stress component tangential to surface CD.

$$\sigma = \sigma_z \cos i = \gamma z \cos^2 i$$
$$\tau = \sigma_z \sin i = \gamma z \cos i \sin i$$

τ - Shear stress which is resisted by shear strength (τ_f).

Factor of safety against sliding due to shear

$$F = \frac{\tau_f}{\tau}$$

τ_f consists of both cohesion & internal friction.

Two cases : i) Cohesion less soil
ii) Cohesive soil.

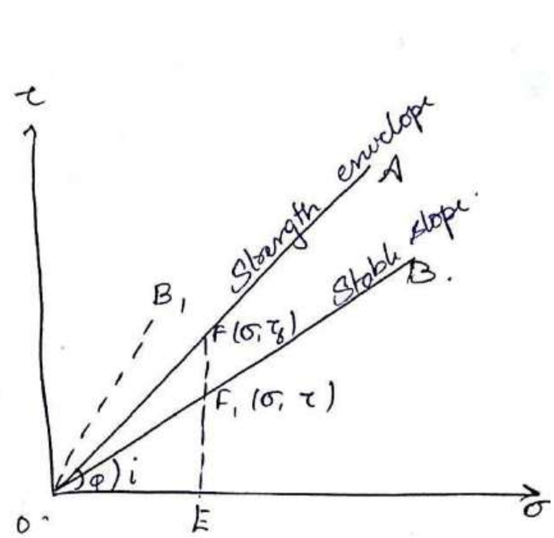
i) Cohesion less soil :

$$\tau_f = \sigma \tan \varphi .$$

$$\frac{\sigma}{\tau} = \frac{\gamma z \cos^2 i}{\gamma z \cos i \sin i}$$

$$= \frac{\cos i}{\sin i}$$

$$\frac{\sigma}{\tau} = \cot i = \text{constant}.$$



$$\sigma = \tau \cot i$$

$$\tau = \frac{\sigma}{\cot i}$$

$$\boxed{\tau = \sigma \tan i}$$

$\tau < \tau_f$ (or) $i < \varphi$ - Failure not occur.

Factor of safety

$$F = \frac{\tau_f}{\tau} = \frac{\tan\varphi}{\tan i}$$

$$\boxed{F = \frac{\tan \varphi}{\tan i}}$$

Submerged Slope :

If slope is submerged, the bulk unit weight γ should be replaced by submerged unit weight γ'

$$\sigma = \gamma' z \cos^2 i$$

$$\tau = \gamma' z \cos i \sin i$$

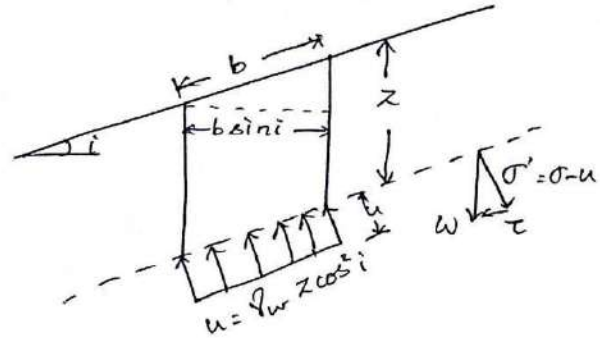
$$\tau_f = \sigma \tan \varphi$$

$$= \gamma' z \cos^2 i \tan\varphi .$$

$$F = \frac{\tau_f}{\tau} = \frac{\gamma' z \cos^2 i \tan\varphi}{\gamma' z \cos i \sin i}$$

$$\boxed{F = \frac{\tan \varphi}{\tan i}}$$

Steady seepage along the slope :



$W = \gamma_{sat} \cdot z\, b \cos i$

$\sigma_z = \frac{W}{b}$

$= \gamma_{sat} \cdot z \cos i .$

$\sigma = \sigma_z \cos i = \gamma_{sat}\, z \cos^2 i$

$\tau = \sigma_z \sin i = \gamma_{sat}\, z \cos i \sin i$

In addition to these, there is an upward force u due to seeping water,

$u = \gamma_w\, z \cos^2 i$

$F = \frac{\tau_f}{\tau}$ $\qquad \tau_f = \sigma' \tan\varphi$

$\sigma' = \sigma - u$

$= \gamma_{sat}\, z \cos^2 i - \gamma_w\, z \cos^2 i$

$\tau_f = \gamma' z \cos^2 i \tan\varphi .$ $\qquad \sigma' = \gamma' z \cos^2 i$

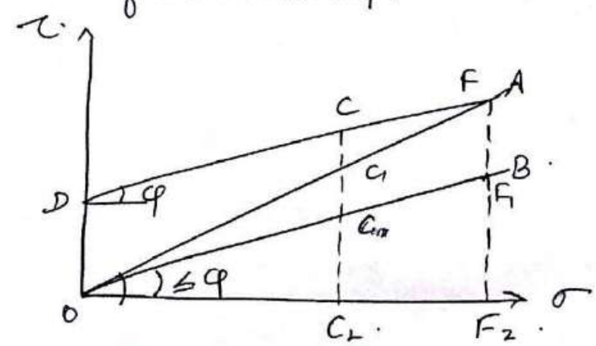
$\tau = \gamma_{sat} \cdot z \cos i \sin i$

$F = \frac{\tau_f}{\tau} = \frac{\gamma' z \cos^2 i \tan\varphi}{\gamma_{sat}\, z \cos^2 i \sin i}$

$$F = \frac{\gamma'}{\gamma_{sat}} \frac{\tan\varphi}{\tan i}$$

ii) Cohesive soil :

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



Slope angle (i) $\le \varphi$, No critical state of stress - Slope Stable.

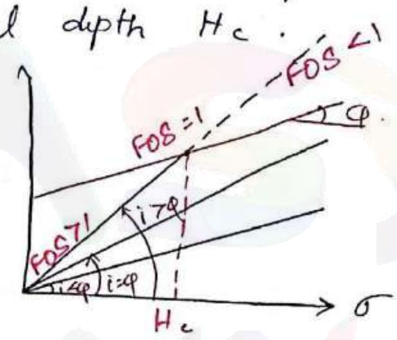
If $i > \varphi$ - it will cut strength envelope at some point F and a state of incipient failure is reached because shear stress corresponding to depth represented by point F equals to shear strength τ_f.

For any depth, $z < F$, $\tau < \tau_f$ - Slope - stable

$i > \varphi$ - Slope is stable upto limited depth known as critical depth H_c.

$$F = \frac{\tau_f}{\tau}$$

$$= \frac{c + \sigma \tan\varphi}{\tau}$$



$$\sigma = \gamma z \cos^2 i$$

$$\tau = \gamma z \cos i \sin i$$

$$F = \frac{c + \gamma z \cos^2 i \tan\varphi}{\gamma z \cos i \sin i}$$

$$= \frac{c}{\gamma z \cos i \sin i} + \frac{\gamma z \cos^2 i \tan\varphi}{\gamma z \cos i \sin i}$$

$$\boxed{F = \frac{c}{\gamma z \cos i \sin i} + \frac{\tan\varphi}{\tan i}}$$

For non-cohesive soil, $c = 0 \Rightarrow F = \frac{\tan\varphi}{\tan i}$

For critical depth $z = H_c$, $\tau_f = \tau$

$$c + \gamma H_c \cos^2 i \tan\varphi = \gamma H_c \cos i \sin i$$

$$c = \gamma H_c \cos i \sin i - \gamma H_c \cos^2 i \tan\varphi.$$

$$= \gamma H_c \cdot \frac{\cos i}{\cos i} \cos i \sin i - \gamma H_c \cos^2 i \tan\varphi.$$

$$c = \gamma H_c \cos^2 i \tan i - \gamma H_c \cos^2 i \tan \varphi$$

$$= \gamma H_c \cos^2 i \, (\tan i - \tan\varphi)$$

$$\boxed{H_c = \frac{c}{\gamma \cos^2 i \, (\tan i - \tan\varphi)}}$$

For given values of i & φ,

$H_c \propto$ cohesion.

$$\frac{c}{\gamma H_c} = \cos^2 i \, (\tan i - \tan\varphi).$$

Stability number $(S_n) = \frac{c}{\gamma H_c}$ - Dimensionless quantity.

$$\boxed{S_n = \frac{c}{\gamma H_c}}$$

F_c - Factor of Safety w.r.to cohesion.

C_m - Mobilised cohesion at depth H.

$$\boxed{C_m = \frac{c}{F_c}}$$

$$S_n = \frac{c}{\gamma H_c} = \frac{C_m}{\gamma H}.$$

$$\boxed{S_n = \frac{c}{F_c \gamma H}} = (\tan i - \tan\varphi)\cos^2 i$$

$$\boxed{F_c = \frac{c}{C_m}} \qquad \boxed{F_c = \frac{H_c}{H}}$$

Submerged Slope:

$$F = \frac{c + \gamma' z \cos^2 i \tan\varphi}{\gamma' z \cos i \sin i}.$$

$$H_c = \frac{c}{\gamma'} \frac{1}{(\tan i - \tan\varphi)\cos^2 i}$$

Steady Seepage along the slope :

$$F = \frac{c + \gamma' z \cos^2 i \tan\varphi}{\gamma_{sat}\, z \cos i \sin i}$$

$$F = \frac{c}{\gamma_{sat}\, z \cos i \sin i} + \frac{\gamma'}{\gamma_{sat}} \frac{\tan\varphi}{\tan i}$$

For critical height, $z = H_c$. $F = 1$.

$$\gamma_{sat} H_c \cos i \sin i = c + \gamma' H_c \cos^2 i \tan\varphi$$

$$c = \gamma_{sat} H_c \cos i \sin i - \gamma' H_c \cos^2 i \tan\varphi$$

$$= \gamma_{sat} H_c \cos^2 i \tan i - \gamma' H_c \cos^2 i \tan\varphi$$

$$H_c = \frac{c}{\cos^2 i \left[\gamma_{sat} \tan i - \gamma' \tan\varphi\right]}$$

PROBLEMS :

A long natural slope of cohesionless soil is inclined at 12° to horizontal. Taking $\varphi = 30°$, Determine FOS of slope. If slope is completely submerged, what will be FOS?

$$F = \frac{\tan\varphi}{\tan i} \qquad \varphi = 30° \quad i = 12°$$

$$F = \frac{\tan 30}{\tan 12} = 2.72 \qquad \boxed{F = 2.72}$$

Submergence :

$$F = \frac{\tan\varphi}{\tan i} = 2.72$$

2. A long natural slope of sandy soil ($\varphi = 25°$) is inclined at 10° to horizontal. The water table is at the surface & seepage is parallel to slope. If saturated unit weight of soil is 19.5 KN/m³, determine factor of safety of slope.

$$F = \frac{\gamma' \tan\varphi}{\gamma_{sat} \tan i} = \frac{(19.5 - 9.81) \tan 25°}{19.5 \times \tan 10°}$$

$$\boxed{F = 1.31}$$

3. A long natural slope in a c-φ soil is inclined at 12° to horizontal. The W.T is at the surface and the seepage is parallel to slope. If a plane slip has developed at a depth of 4 m. determine FOS. Take $c = 8 KN/m^2$, $\varphi = 22°$ & $\gamma_{sat} = 19 KN/m^3$

$$F = \frac{c + \gamma' z \cos^2 i \tan\varphi}{\gamma_{sat} z \cos i \sin i}$$

$$= \frac{8 + (19 - 9.81) \times 4 \cos^2 12° \tan 22°}{19 \times 4 \cos 12° \sin 12°}$$

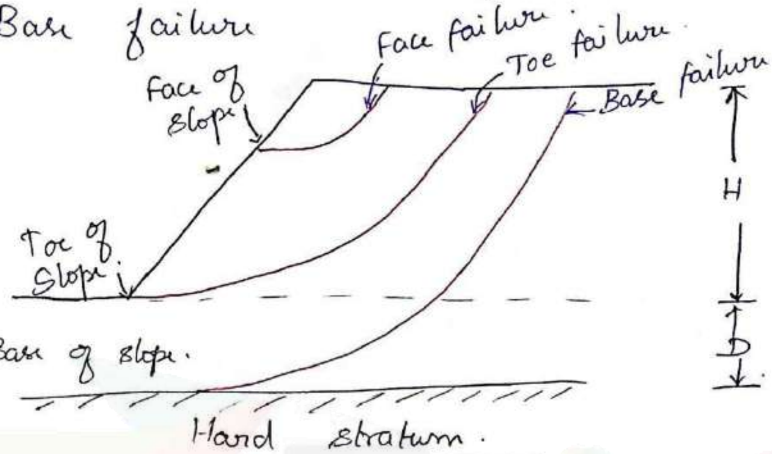
$$\boxed{F = 1.44}$$

STABILITY ANALYSIS OF FINITE SLOPES:

Failure of finite slopes occurs along a surface which is a curve. In stability computations, the curve representing real surface of sliding is usually replaced by an arc of a circle.

Two basic types of failure

* Slope failure < Face Failure / Toe failure.
* Base failure



Depth factor $D_f = \frac{H + D}{H}$

$D_f > 1 \rightarrow$ Base failure

$D_f = 1 \rightarrow$ Toe failure

$D_f < 1 \rightarrow$ Face failure.

Face failure:

When slope angle β is very high. Soil in the upper part of slope is relatively weaker.

Toe failure:

* It occurs in steep slopes.
* It happens when soil mass above and below base is homogeneous.

Base failure:

* Soil below toe is relatively weak & soft.
* The slope is flat.

Types of slip surfaces or failure surfaces:

The rupture of a finite slope may takes

place along one of following failure surfaces. (6)

* Planar failure surface
* Circular failure surface
* Non-circular failure surface.

Planar failure surface - Soil deposit or embankment with a specific plane of weakness.

In composite Earth dams with sloping cores, planes of weakness within the bank may consists of 2 or 3 planar surfaces.

Circular failure surface -

In most cases, actual failure surfaces are curved. The rupture mass slide down a sliding surface, in a definite pattern resembling that of cycloid. Generally, the failure surfaces have arcs somewhat flatter at ends & sharper at centre. For simple idealised problems, the assumption of a circular failure surface is sufficiently accurate.

Non-circular failure surface:

It occurs in many practical cases. It may arise in homogeneous dams having one or more of the following.

i) Foundation of infinite depth.
ii) Rigid boundary planes of maximum or zero shear.
iii) Presence of relatively stronger or weaker layer.

Non-homogeneous earth dams.

i) Presence of soft layer in foundation.
ii) Use of different type of soil or rock in dam

with varying strength & pore pressure condition

iii) Use of drainage blankets to facilitate dissipation of pore pressures.

Methods of Analysis:

Stability of finite slope can be investigated by no. of methods.

1. Fellenius Method (or) Swedish circle method (or) Slip circle Method.
2. Friction circle Method
3. Culmann's method.
4. Bishop's method.

Swedish Slip Circle Method / Fellenius Method:

This method was developed at Swedish Geotechnical Commission headed by Fellenius.

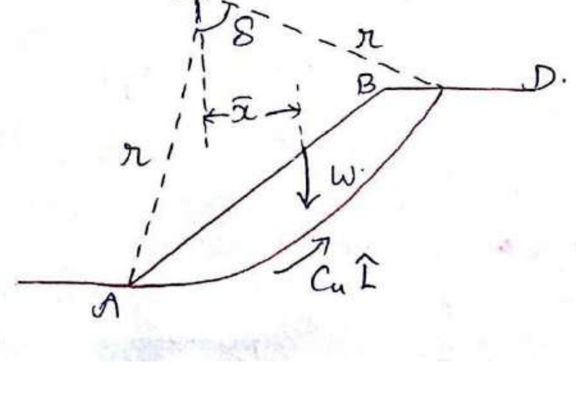
In this method, slip surface is assumed to be cylindrical, i.e.: arc of circle in section.

Two cases:

i) Analysis of purely cohesive soil ($\phi_u = 0$ analysis)

ii) Analysis of a soil possessing both cohesion and friction ($c-\phi$ analysis).

i) Cohesive Soil ($\phi_u = 0$ Analysis)



The method consists in assuming no. of trial slip circles & finding FOS of each. (7)

The circle corresponding to minimum FOS is called critical slip circle.

AD - Trial slip circle.

r - radius

O - Centre of rotation.

W - Weight of soil of wedge ABDA of unit thickness, acting through its centroid.

$\bar{x}$ - Distance of line of action of W from vertical line passing through centre of rotation.

C_u - Unit cohesion.

$\hat{L}$ - Length of slip arc AD.

Driving moment $\boxed{M_D = W\bar{x}}$

$$\hat{L} = \frac{2\pi r \delta}{360}$$

Shear resistance developed along slip surface $= C_u\hat{L}$

Resisting moment $\boxed{M_R = r \cdot C_u \hat{L}}$

FOS, $\boxed{F = \frac{M_R}{M_D} = \frac{r C_u \hat{L}}{W\bar{x}}}$

C_m - Mobilised shear resistance of soil

$F = 1$

$W\bar{x} = r C_m \hat{L}$.

$\boxed{C_m = \frac{W\bar{x}}{\hat{L}} 1/r}$ $\quad F = \frac{C_u}{C_m} = \frac{C_u \hat{L} r}{W\bar{x}}$

$\bar{x}$ from O can be determined by dividing wedge into no. of vertical slices & dividing algebraic sum of moment of weight of each slice by weight of wedge.

Tension crack :

If a tension crack of depth $z_0 = \frac{2c}{\gamma}$ develops, water enter into crack, exerting hydrostatic pressure force P_w acting on the portion DE at the height $z_0/3$ from E. That portion will be ineffective in resisting slide.

ii) C-φ analysis:

It is known as Swedish method of slices.

i) The slip surface is cylindrical

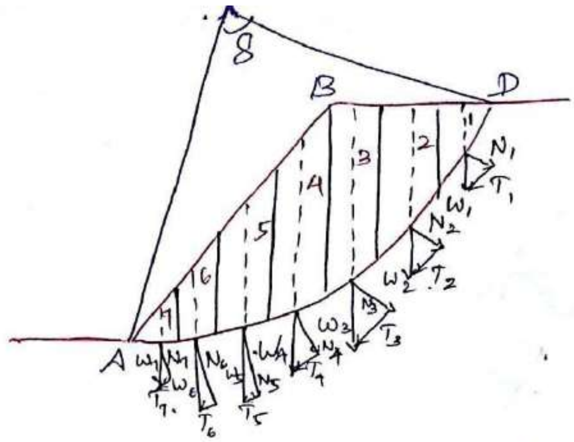
ii) The sliding soil mass is assumed to consist of a number of vertical slices.

iii) The forces of interaction b/w adjacent slices are neglected.

Let AD be a slip circle of radius r, centre O & central angle $\angle AOD = \delta$.

Let sliding soil mass ABDA be divided into no. of vertical slices 1, 2, ...

The weights W_1, W_2 . . . . . of slices 1, 2, ... acting through centre of gravity of respective slices are resolved into normal components N_1, N_2 . . . & tangential components T_1, T_2, . . .



Taking moments about centre of rotation O.

Driving moment

$$M_D = T_1 r + T_2 r + \ldots\ldots$$

$$= r\left[T_1 + T_2 + \ldots\ldots\right]$$

$$\boxed{M_D = r\ \Sigma T}$$

Restoring Moment,

$$M_R = \Sigma c \cdot \Delta L \cdot r + (N_1 \tan\varphi + N_2 \tan\varphi + \ldots)\, r$$

$$= c r\, \Sigma \Delta L + (N_1 + N_2 + \ldots\ldots)\, r \tan\varphi.$$

$$\boxed{M_R = r\left[c \hat{L} + \Sigma N \tan\varphi\right]}$$

$\hat{L}$ - length of arc AD.

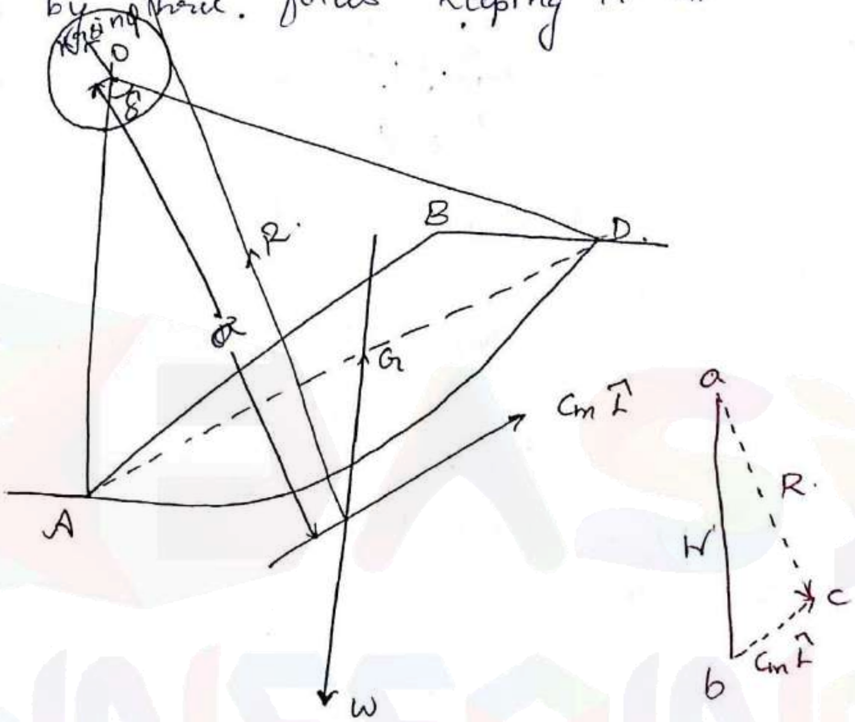
FOS against sliding, $F = \dfrac{M_R}{M_D}$

$$\boxed{F = \frac{c\hat{L} + \Sigma N \tan\varphi}{\Sigma T}}$$

This method is not only applicable to homogeneous soils but also to stratified soils, fully or partially submerged soils with considerations of seepage forces and pore pressures that may exist, and also non-uniform slopes.

Friction Circle Method :

* The slip surface is assumed to be cylindrical. i.e arc of circle in section.
* The sliding soil mass is assumed to be acted upon by three forces keeping it in equilibrium.



* Weight, W of the sliding soil mass ABDA, acting vertically through its centre of gravity.
* The resultant cohesive force, $C_m \hat{L}$, acting parallel to chord AD and at distance a from centre of rotation O, where

$$a = r \frac{\hat{L}}{L}$$ ⇒ $\hat{L}$ - Length of arc AD.
L - Length of chord AD.

* The resultant reaction R passing through point of intersection of the above two forces and tangential to the friction circle.

Procedure :

1. With centre O & radius r, the slip circle AD is constructed. The friction circle is drawn with centre O & radius $K r \sin\varphi$.

$K = 1$.

2. A vertical line is drawn through centroid of section ABDA, to get line of action of weight W.

3. Chord AD is drawn, A line is drawn parallel to chord AD and at distance $a = r\frac{\hat{L}}{L}$ from O, to get line of action of resultant cohesive force $C_m \hat{L}$. The length of arc AD, $\hat{L}$ is computed using equation $\hat{L} = \frac{\pi r \delta}{180}$ The length of chord AD, L is obtained by measurement.

4. Through the point of intersection of lines of action of forces W and $C_m \hat{L}$, a line is drawn tangential to friction circle, to get line of action of resultant reaction R.

5. Weight (W) of sliding soil mass ABDA is computed & plotted to scale. Through the ends of vector representing W, lines are drawn parallel to lines of action of forces $C_m L$ & R to complete triangle of forces.

The value of $C_m L$ is obtained from force triangle and divided by value of L to obtain the value of mobilised cohesion C_m.

FOS : $\boxed{F_c = \frac{c}{C_m}}$ c - Ultimate cohesion.

USING TAYLOR STABILITY NUMBER :

Taylor Stability number is a dimensionless quantity denoted by S_n.

$$\boxed{S_n = \frac{C_m}{\gamma H}}$$

C_m = Mobilised cohesion on slip surface

γ = Unit weight of soil

H - Height of slope.

$$\boxed{F_c = \frac{C}{C_m}} \Longrightarrow C_m = \frac{C}{F_c}$$

$$\boxed{S_n = \frac{C}{F_c \gamma H}}$$ c = Unit Ultimate cohesion.

$$F_H = \frac{H_c}{H} \qquad F_H = F_c$$

$$F_H H = H_c$$

$$\boxed{S_n = \frac{C}{\gamma H_c}}$$

H_c - Critical height of slope.

S_n varies w.r.to slope angle i & angle of shearing resistance φ.

FOS is applicable to both cohesion & friction, we have mobilised shear resistance given by. $\tau_m = \frac{\tau_f}{F} = \frac{c + \sigma \tan\varphi}{F}$

While obtaining S_n from chart, mobilised angle of sharing resistance φ_m should be used.

$$\tan\varphi_m = \frac{\tan\varphi}{F}$$

$$\varphi_m = \tan^{-1}\left(\frac{\tan\varphi}{F}\right).$$

$$\boxed{\varphi_m \simeq \frac{\varphi}{F}}$$

For cohesionless soil ($c = 0$), Taylor stability number $S_n = 0$. Taylor's chart is not applicable.

$$F = \frac{\tan \varphi}{\tan i}$$ & independent of height of slope.

For cohesive soils, c & φ can be obtained from drained test should be used. Use of Taylor's stability number gives an approximate idea of long term stability, if seepage effect can be neglected and no change in water content can be assumed.

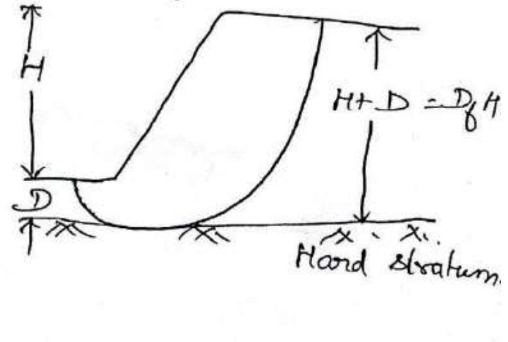
In case of fully submerged slopes, γ' should be used in expression for S_n.

When slope is saturated by capillary water, γ_{sat} should be used in expression S_n. S_n can be obtained from Taylor's chart, corresponding to weighted frictional angle φ_w

$$\varphi_w = \frac{\gamma'}{\gamma_{sat}} \varphi.$$

Taylor also determined stability number S_n for different values of slope angle i and depth factor D_f.

$$D_f = \frac{H + D}{H}.$$



PROBLEMS:

1. Stability analysis by Swedish method of slices gave following values per running metre for a 10m high embankment.

i) Total shearing force = 480 kN.

ii) Total normal force = 1950 kN.

iii) Total neutral force = 250 kN.

iv) Length of arc = 22 m.

If the properties of soil are $c = 24\ kN/m^2$ & $\varphi = 6°$, calculate factor of safety w.r. to shear strength

$\Sigma T = 480\ kN$

$\Sigma N = 1950\ kN$ $\quad C = 24\ kN/m^2$

$\Sigma U = 250\ kN$ $\quad \varphi = 6°$.

$\hat{L} = 22\ m$

$$F = \frac{C\hat{L} + \Sigma(N-U)\tan\varphi}{\Sigma T}$$

$$= \frac{24 \times 22 + (1950 - 250)\tan 6°}{480}$$

$$F = 1.47.$$

2. A slope 1 in 2 with height of 8m has following soil properties.

$C = 28\ kN/m^2$, $\varphi = 10°$, $\gamma = 18\ kN/m^3$.

Calculate i) FOS w.r.to cohesion.

ii) Critical height of slope.

If i is slope angle $\tan i = 1/2$

$i = 26.6°$

From Taylor stability chart, for $i = 26.6°$ (11)

$\varphi = 10°$, $S_n = 0.064$.

$$S_n = \frac{c}{F_c \gamma H}$$

$$F_c = \frac{c}{S_n \gamma H} = \frac{28}{(0.064)(18)(8)}$$

$$\boxed{F_c = 3.04}$$

$$F_c = \frac{H_c}{H} \qquad H_c = F_c H = 3.04 \times 8$$

$$\boxed{H_c = 24.32 m}$$

3. A 5m deep canal has side slopes of 1:1. Properties of soil are $C_u = 20 KN/m^2$, $\varphi_u = 10°$, $e = 0.8$ & $G = 2.8$. If Taylor stability number is 0.108, determine FOS w.r.to cohesion, when the canal runs full. Also find the same in sudden drawdown if Taylor's stability number for the condition is 0.137.

$C_u = 20 KN/m^2$, $\varphi_u = 10°$, $G = 2.8$.

$$\gamma_{sat} = \frac{G+e}{1+e}\gamma_w = \frac{(2.8+0.8)}{(1+0.8)} 9.81$$

$$= 19.62 KN/m^3.$$

$$\gamma' = \gamma_{sat} - \gamma_w = 9.81 KN/m^3.$$

Case (i): When canal runs full the side slopes are submerged.

$$S_n = \frac{c}{F_c \gamma' H}$$

$$\boxed{F_c = 3.8}$$

$$F_c = \frac{c}{S_n \gamma' H} = \frac{20}{(0.108)(9.81)(5)} = 3.8.$$

Case (ii) Sudden drawdown condition, $S_n = 0.137$.

$F_c = \frac{c}{\dots} = 1.5$ $\boxed{F_c = 1.5}$

SLOPE PROTECTION MEASURES:

Slopes that are susceptible to sliding should be protected so that the area will be safe. Slopes which have failed recently are likely to fall under long-term condition.

Slope have been protected by adopting some successful techniques. In general, protective measures involves.

i) Reducing the mass or loading which contributes to sliding.

ii) improving the shearing strength along the anticipated zone of failure.

iii) Providing certain materials which will provide resistance to movement.

The protective measure to be adopted depends on different field conditions, type of soil in slope, the volume or depth of soil involving in sliding, groundwater conditions, assessment of complete area which may require stabilization, the space available to undertake corrective measures, topographical conditions prevailing in the area & the possible changes that could due to vibratory measure undertaken.

* When base failure is anticipated, a berm may be provided near the toe.

* If a zone near the toe is susceptible to erosion, a protective rock-fill blanket followed by a rip-rap can be provided.

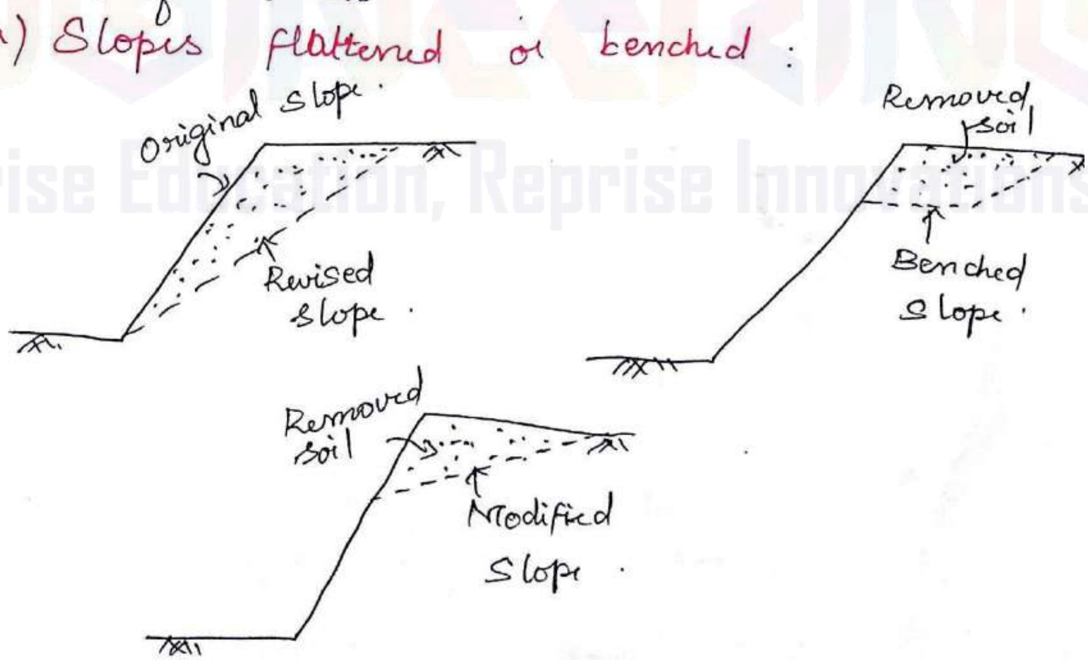
* Soil shearing resistance of soil is reduced due to high groundwater & excess pore-water pressure.

* This could be avoided by lowering the groundwater or intercepting the surface water.

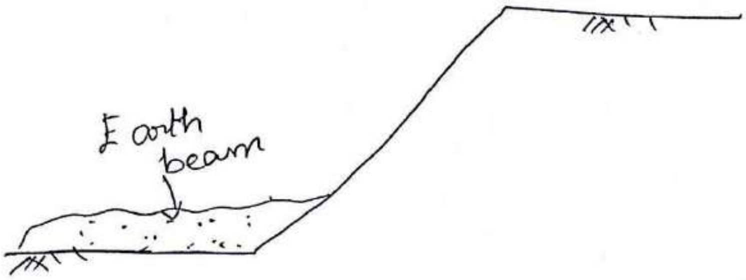
* Driven piles are sometimes used to keep the moving part intact with the original ground. Sometimes driven piles, sheet piling and construction of retaining wall help by providing lateral support and increasing the resistance of slopes to sliding.

* ~~If it is~~

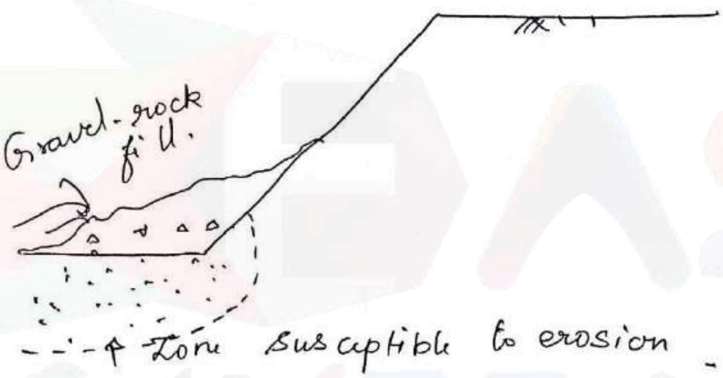
a) Slopes flattened or benched :



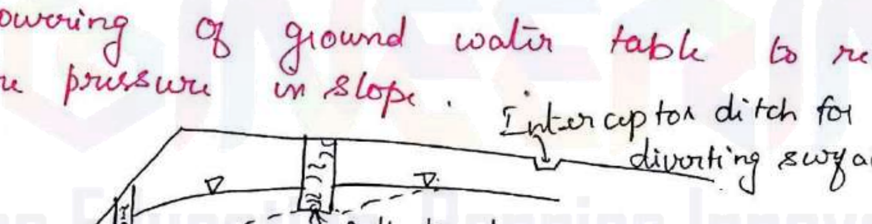
b) Beam provided at toe.



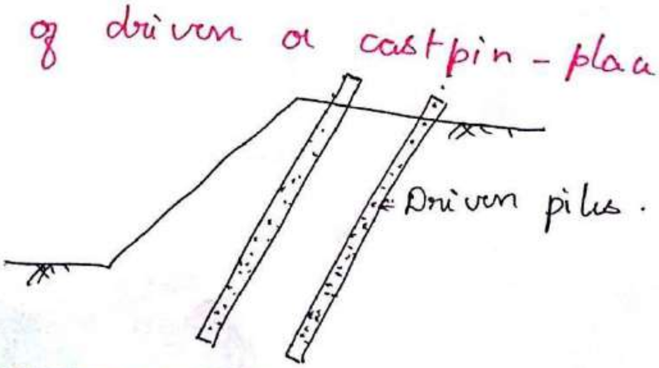
c) Protection against erosion provided at toe.



d) Lowering of ground water table to reduce pore pressure in slope.



e) Use of driven or cast-in-place piles.



Retaining wall or sheet piling