lecture 15
19/11/19

CHAPTER-10

Stability of slope

① Stability of slope

→ Slope for embankment are provided in road ways, rail ways, earthen dam, river training work (GHAT)

→ Slopes are of two types

1) Infinite Slope
2) Finite slope

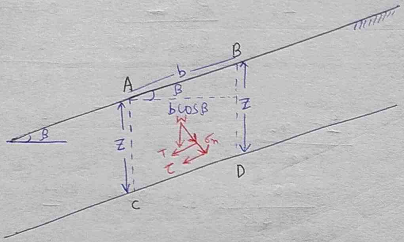
1) Infinite slope - If the slope represent the boundary surface of semi infinite soil Mass then the properties of soil at all the similar depth below the surface will be same then the soil is termed as infinite slope.

→ Failure of infinite slope takes place due to sliding and failure surface is || (Parallel) to ground slope surface

Stability Analysis of infinite slope

① Let AB represent infinite slope having slope angle of β with the Horizontal, failure of which takes place along critical secn CD which is || to ground slope surface and is at the depth of (z) below the surface. consider unit

Length of slope



for Wedge ABCD

- Area (A) = $b\cos\beta . Z$
- Volume (V) = $A * 1 = b\cos\beta . 1$
- Weight (W) = $V.\gamma = (b\cos\beta . Z . 1\gamma) = b\gamma Z\cos\beta$
- Normal component of wt (N) = $W\cos\beta = b\gamma Z\cos\beta . \cos\beta$
- Tangential component of wt (T) = $W\sin\beta = b\gamma Z\cos\beta . \sin\beta$
- Normal stress (σ_n) = $\dfrac{N}{Area} = \dfrac{b\gamma Z\cos^2\beta}{b*1}$

$$\boxed{\sigma_n = \gamma Z\cos^2\beta}$$ ****

- Tangential stress (τ) = $\dfrac{T}{Area} = \dfrac{b\gamma Z\cos\beta\sin\beta}{(b.1)}$

$$\boxed{\tau = \gamma Z\cos\beta . \sin\beta}$$ ****

Note ① If water is present, then normal component of water pressure will be $\gamma_w Z\cos^2\beta$

Note ② Tangential stress will induce shear failure on the critical sech CD, which is being restricted by shear strength of soil

$$f.o.s = \frac{\text{shear strength on soil}}{\text{shear stress on that plane}}$$

$$\boxed{f.o.s = \frac{S}{\tau} = \frac{c + \sigma_n \tan\phi}{\tau}}$$

Stability Analysis for cohesionless soil (c=0)

Case ① Dry / Moist soil slope

① Shear strength $S = \cancel{c}^{0} + \sigma_n \tan\phi = \sigma_n \tan\phi$

$S = \gamma Z\cos^2\beta . \tan\phi$

② Shear strength $\tau = \gamma Z\cos\beta . \sin\beta$

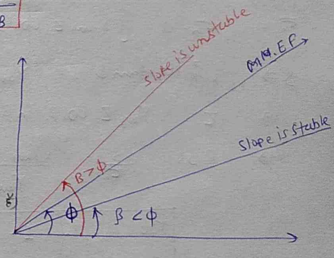
③ F.O.S $= \dfrac{S}{\tau} = \dfrac{\cancel{\gamma Z}\cos^{\cancel{2}}\beta . \tan\phi}{\cancel{\gamma Z}\cancel{\cos\beta} . \sin\beta} = \cot\beta . \tan\phi$

$$\boxed{F.O.S = \frac{\tan\phi}{\tan\beta}}$$

① If $\beta < \phi \rightarrow F.O.S > 1$ (slope is stable)

② $\beta = \phi \rightarrow F.O.S = 1$ (slope is critical) (कभी भी fail हो सकता है)

③ $\beta > \phi \rightarrow F.O.S < 1$ (slope is unstable)



Case ② Submerge slope with no flow cond [G.W.T is above the G.L]

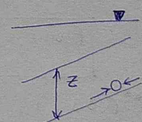
① Shear strength $S = \cancel{c}^{0} + \sigma_n \tan\phi$

$S = \gamma' Z\cos^2\beta \tan\phi$

② Shear stress $\tau = \gamma' Z\cos\beta . \sin\beta$

③ F.O.S $= \dfrac{S}{\tau} = \dfrac{\gamma' Z\cos^2\beta \tan\phi}{\gamma' Z\cos\beta . \sin\beta} = \cot\beta . \tan\phi$

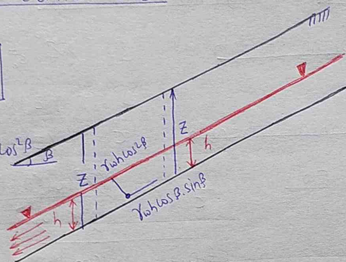
$$\boxed{F.O.S = \frac{\tan\phi}{\tan\beta}}$$



Pascal law is valid

(Important more)

Case ③ Submerge slope with steady seepage of height (h) above the critical secn



$$\boxed{\gamma_{avg} = \frac{\gamma_b (Z-h) + \gamma_{sat} . h}{Z}}$$

$\Rightarrow \sigma_n = \{\gamma_b (Z-h) + \gamma_{sat} . h\} \cos^2\beta$

$= \gamma_{avg} . Z . \cos^2\beta$

$U = \gamma_w h \cos^2\beta$

$\bar{\sigma}_n = \sigma_n - u = [(\gamma_{avg} Z \cos^2\beta) - \gamma_w h \cos^2\beta] = (\gamma_{avg} Z - \gamma_w h] \cos^2\beta$

$S \Rightarrow \cancel{c}^{0} + \bar{\sigma}_n \tan\phi = (\gamma_{avg} Z - \gamma_w . h) \cos^2\beta . \tan\phi$

$\Rightarrow \tau = \gamma_{avg} Z \cos\beta . \sin\beta$

$\Rightarrow F.O.S = \frac{S}{\tau} = \frac{(\gamma_{avg} . Z - \gamma_w h) \cos^2\beta \tan\phi}{\gamma_{avg} Z \cos\beta \sin\beta} = \left\{\frac{\gamma_{avg} Z - \gamma_w h}{\gamma_{avg} Z}\right\} \frac{\tan\phi}{\tan\beta}$

$$\boxed{F.O.S = \left\{1 - \frac{\gamma_w h}{\gamma_{avg} Z}\right\} \frac{\tan\phi}{\tan\beta}}$$ ***

Special case: If seepage takes place at G.L. i.e (G = Z)

$\Rightarrow \gamma_{avg} = \gamma_{sat}$

$\Rightarrow S = (\cancel{\gamma_{avg}}^{\gamma_{sat}} Z - \gamma_w \cancel{h}^{Z}) \cos^2\beta \tan\phi = \gamma' Z \cos^2\beta \tan\phi$

$\Rightarrow \tau = \gamma_{sat} Z . \cos\beta . \sin\beta = \underbrace{\gamma' Z \cos\beta \sin\beta}_{\text{Sub wt}} + \underbrace{\gamma_w Z \cos\beta \sin\beta}_{\text{due to seepage}}$

$\Rightarrow F.O.S = \frac{S}{\tau} = \frac{\gamma' Z \cos^2\beta \tan\phi}{\gamma_{sat} Z \cos\beta \sin\beta}$

$$\boxed{F.O.S = \frac{\gamma'}{\gamma_{sat}} \frac{\tan\phi}{\tan\beta}} \simeq \frac{1}{2} \frac{\tan\phi}{\tan\beta}$$ ***

$\Rightarrow$ *** F.O.S is reduced to half in comparison to F.O.S of dry / moist / submerged slope. F.O.S should always be greater than 2

Stability Analysis for cohesive soil

Case ① dry / moist soil slope

\# Shear strength $S = c + \bar{\sigma}_n \tan\phi = c + \sigma_n \tan\phi$

$S = c + \gamma Z \cos^2\beta \tan\phi$

\# Shear stress $(\tau) = \gamma Z \cos\beta \sin\beta$

\# $$\boxed{F.O.S = \frac{S}{\tau} = \frac{c + \gamma Z \cos^2\beta \tan\phi}{\gamma Z \cos\beta \sin\beta}}$$

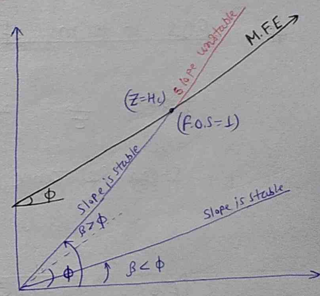
(Z depth पे F.O.S depend करेगा)

$H_c \rightarrow$ critical depth

at $Z = H_c$: F.O.S = 1

$F.O.S = \frac{c + \gamma H_c \cos^2\beta \tan\phi}{\gamma H_c \cos\beta \sin\beta} = 1$

\# $\left[F.O.S = \frac{S}{\tau}\right]$



$\gamma H_c \cos\beta \sin\beta = c + \gamma H_c \cos^2\beta \tan\phi$ if $\beta < \phi \rightarrow$ slope is stable

$(\gamma H_c \cos\beta \sin\beta - \gamma H_c \cos^2\beta \tan\phi = c)$ if $\beta > \phi \rightarrow$ Slope is stable upto the depth of $(Z = H_c)$ $\because \tau < s$

If depth $Z > H_c$ then slope is unstable $\because (\tau > s)$

$\gamma H_c \cos^2\beta [\tan\beta - \tan\phi] = c$

$H_c = \frac{c}{\gamma \cos^2\beta (\tan\beta - \tan\phi)}$

Taylor's Stability Number

$\frac{c}{\gamma H_c} = \cos^2\beta (\tan\beta - \tan\phi) =$ unitless No.

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

F.O.S in terms of depth / height

1) If critical depth of slope is H_c and H is the depth of plan over which F.O.S is required then

$$\boxed{F.O.S = \frac{H_c}{H}}$$ ***

$$\boxed{S_n = \frac{c}{\gamma H_c} = \frac{c}{\gamma (F.O.S) H}}$$ ****

F.O.S in terms of mobilised shear stability

$$F.O.S = \frac{S}{\tau} = \frac{\text{Shear Strength}}{\text{Shear Resistance mobilized}}$$

$$\text{Shear Resistance mobilized} = \frac{S}{F.O.S} = \frac{c + \bar{\sigma}_n \tan\phi}{F.O.S}$$

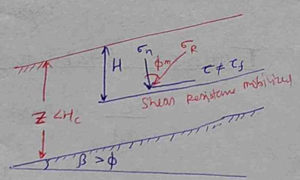
$$= \frac{c}{F.O.S} + \frac{\bar{\sigma}_n \tan\phi}{F.O.S}$$

$$= c_m + \sigma_n \tan\phi_m$$

$$\boxed{F.O.S = \frac{S}{\tau} = \frac{c + \bar{\sigma}_n \tan\phi}{c_m + \sigma_n \tan\phi_m}}$$ *

Mobilised cohesion $\boxed{c_m = \frac{c}{F.O.S}}$ *

Mobilised friction angle $\boxed{\tan\phi_m = \frac{\tan\phi}{F.O.S.}}$ *



② Submerge slope with no flow

$$F.O.S = \frac{S}{\tau} = \frac{c + \bar{\sigma}_n \tan\phi}{\tau} = \frac{c + \gamma' Z \cos^2\beta \tan\phi}{\gamma' Z \cos\beta \sin\beta}$$

③ Submerge slope with steady seepage at G.L

$$S = c + \bar{\sigma}_n \tan\phi = c + \gamma' Z \cos^2\beta \tan\phi$$

$$\tau = \gamma' Z \cos\beta \sin\beta + \gamma_w Z \cos\beta \sin\beta$$

$$F.O.S = \frac{c + \gamma' Z \cos^2\beta \tan\phi}{\gamma_{sat} Z \cos\beta \sin\beta}$$

Note: unit wt used in stability No.

⇒ In submerged condⁿ $\boxed{\gamma = \gamma'}$

⇒ In case of sudden drawdown $\boxed{\gamma = \gamma_{sat}}$ and wt friction angle is used to find stability No.

$$\boxed{\phi_m = \frac{\gamma'}{\gamma_{sat}} \times \phi}$$

Swedish slip circle

Method of slices

① Slices r independent body
② forces b/w slices are neglected
③ Directional angle are used to locate critical circle
④ $F.O.S = \frac{\text{Resisting moment}}{\text{Rotating moment}}$

friction circle method

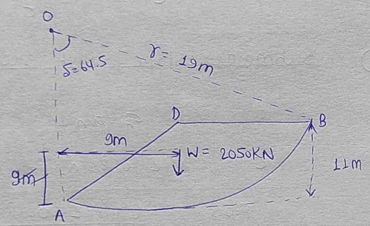
Radius of friction circle = $R\sin\phi$

cohesion is partially mobilised and friction is fully utilized

Resultant Reac^n makes angle ϕ with normal and tangential to friction circle.

CHAPTER- 10

Solution- 21



$C = 55\ KN/m^2$

$\phi = 0$

Radius of slip circle = 19m

wt of Wedge ABD = 2050KN

Distance of W from AO is 9m

F.O.S. against sliding $= \dfrac{M_R}{M_o} = \dfrac{c\,(L\times1)\,r}{W\cdot 9}$

$= \dfrac{55\,(r\cdot\theta\cdot r)}{W\cdot 9}$

$= \dfrac{55\times\left[19\cdot\left(\frac{64.5}{180}\cdot\pi\right)19\right]}{2050\times 9}$

$= 1.21$ Ans

Solution 5

$Z = 10m$

$\phi_u = 15°$

$C_u = 12\ KPa$

$e = 1$

$G_s = 2.65$

$S_n = 0.08$

F.o.s to cohesion

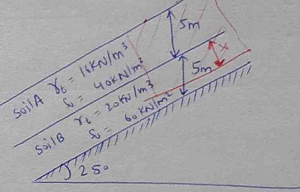
$S_n = \dfrac{c}{\gamma H_c} = \dfrac{c}{\gamma(F.o.S)H}$

$\cancel{\gamma_{sat}}$ $\gamma' =$

$0.08 = \dfrac{12}{\gamma'(F.o.S)\times 10}$

Solution 6 $\quad 0.126 = \dfrac{12}{\gamma_{sat}\times(F.o.S)\times 10}$

Solution 10



H = ?

In soil 1 at 5m

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

$= 16\times 5\cos 25° \sin 25$

$= 30.6$

$\tau(30.6) < s(40)$ No failure in soil 1

For failure in soil 2

$s = \tau$

$60 = (\gamma_1 H_1 + \gamma_2 x)\cos\beta\sin\beta$

$60 = (16\times 5 + 20x)\cos 25 \times \sin 25 \quad x = 3.83m$

depth 8.83 m

Solution 15

$C = 15\ KN/m^2$

$e = 0.9$

$\phi = 20°$

$G = 2.67$

Side slope is 1:1

F.O.S = ?

$\gamma_{sat} = \dfrac{(G+e)\gamma_w}{1+e}$

$S_n = \dfrac{c}{\gamma H_c}$

$\gamma_{sat} = \left(\dfrac{2.67+0.9}{1+0.9}\right)\times 9.81 = 18.43$

$\phi_w = \dfrac{\gamma'}{\gamma_{sat}}\phi = \left(\dfrac{18.43-9.81}{18.43}\right)20° = 9.35°$

$S_n = 0.108 + \left(\dfrac{0.114-0.108}{12-6}\right)\times(9.35-6)$

$= 0.111$

$S_n = \dfrac{c}{\gamma_{sat}(F.o.S)H}$

$= \dfrac{15}{18.847\,(F.o.S)\times 6}$ $\quad$ F.o.S = 1.22 Ans