Slope Stability Analysis

- Infinite Slopes
  - – Constant slope of infinite extent
    - Mountain face
- Finite Slopes
  - – Slopes with heights approaching critical values
    - Embankments, earth dams

Causes of Slope Failures

- Gravitational Force
- Seepage Pressures
- Undercutting by Rivers
- Sudden Drop of Water Levels
- Earthquakes


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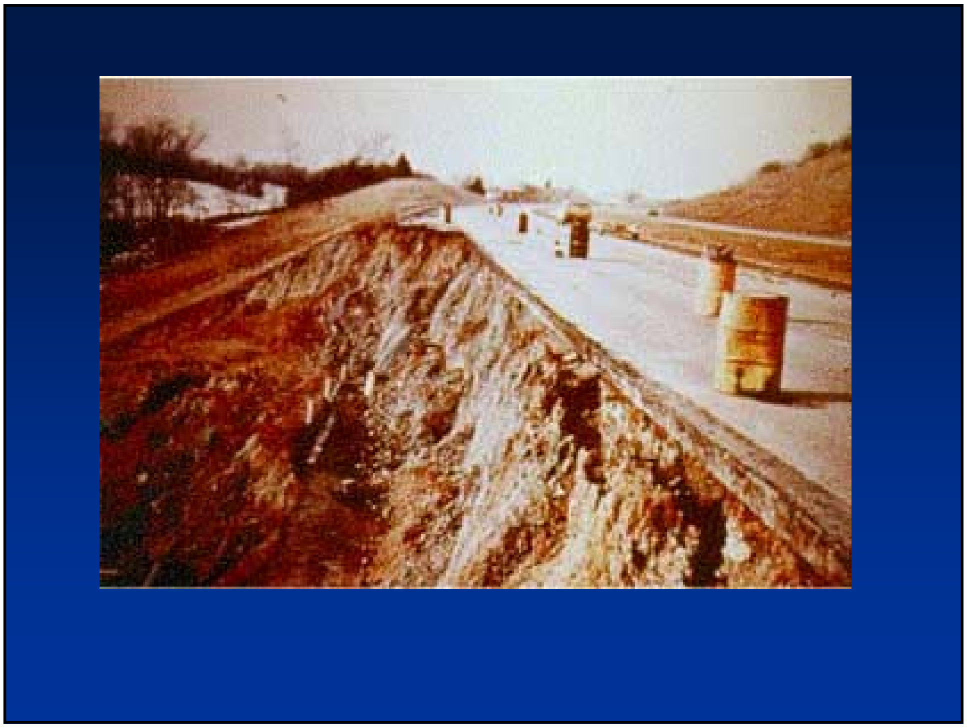


Factor of Safety

- Factor of Safety w.r.t. Strength
  - $FS_s = \tau_f / \tau_m$
  - $\tau_f = c' + \sigma' \tan \phi'$
  - $\tau_m = c_m' + \sigma' \tan \phi_m'$

- $FS_s = [c' + \sigma' \tan \phi'] / [c_m' + \sigma' \tan \phi_m']$

Factor of Safety

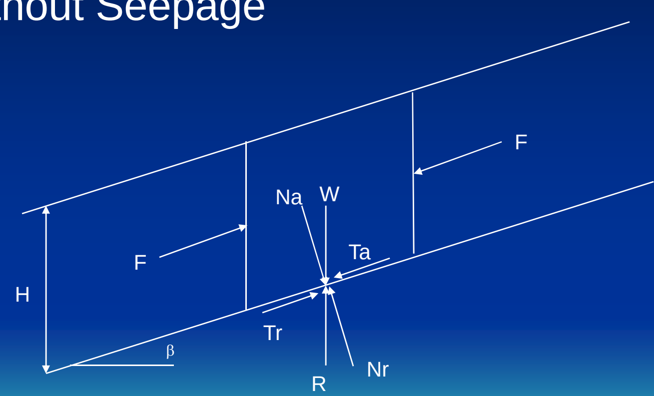
- Factor of safety w.r.t. Cohesion
  - $FS_{c'} = c' / c_m'$
  - $c_m' = c' / FS_{c'}$
- Factor of Safety w.r.t. Friction
  - $FS_{\phi'} = \tan \phi' / \tan \phi_m'$
  - $\tan \phi_m' = \tan \phi' / FS_{\phi'}$
- For $FS_{c'} = FS_{\phi'} = FS_s$

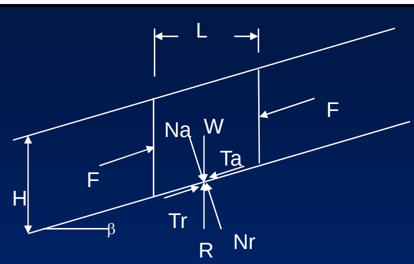
Factor of Safety

- When FS_s = 1, the slope is in the state of impending failure
- Generally, $FS_s \simeq$ 1.25 to 1.5 is acceptable for design – up to 1.75 for earth dams

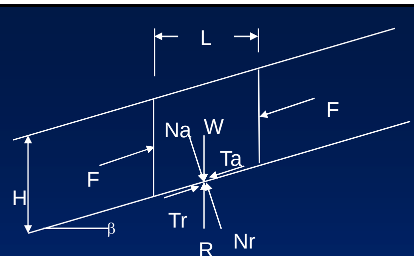
Stability of Infinite Slopes

- Without Seepage





- W = γLH
- Na = W cos $\beta = \gamma$LH cos β
- Ta = W sin b = γLH sin β
- $\sigma' = N_a/\text{area} = \gamma LH\cos\beta/(L/\cos\beta) = \gamma H\cos^2\beta$
- $\tau = T_a/\text{area} = \gamma LH\sin\beta/(L/\cos\beta) = \gamma H\cos\beta\sin\beta$
- Nr = R cos β = W cos β
- Tr = R sin b = W sin β



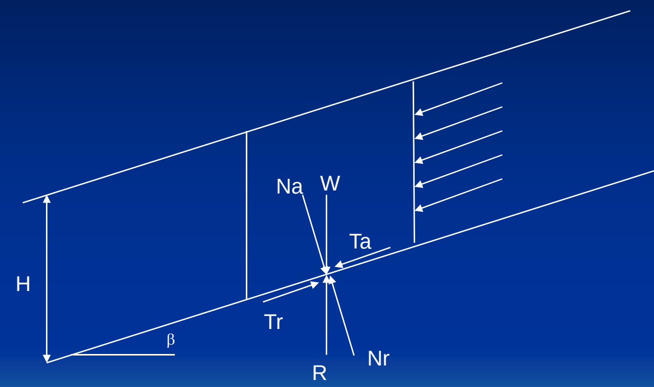
- For equilibrium, Tr = Ta
- $\tau_m = c'_m + \sigma' \tan \phi'_m$
- $\tau_m = c'_m + \gamma H \cos^2\beta \tan \phi'_m$
- $\gamma H\sin\beta\cos\beta = c'_m + \gamma H\cos^2\beta \tan\phi'_m$
- $c'_m/\gamma H = \cos^2\beta(\tan\beta - \tan\phi'_m)$
- $FS_s = [c'/(\gamma H\cos^2\beta\tan\beta)] + \tan\phi'/\tan\beta$

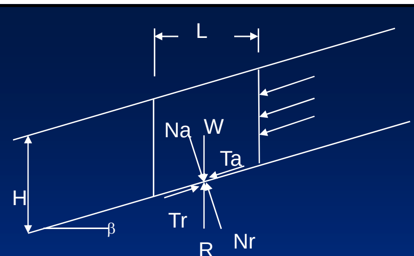
- $FS_s = [c'/(\gamma H\cos^2\beta\tan\beta)] + \tan\phi'/\tan\beta$
- For granular soils, c'=0
  - $FS_s = \tan\phi'/\tan\beta$
  - Independent of H and stable as long as $\beta < \phi'$
- For soils with cohesion and friction
  - Depth of plane with critical equilibrium corresponds to $FS_s = 1$ and $H = H_c$
  - $H_c = c' / [\gamma\cos^2\beta(\tan\beta-\tan\phi')]$
  - $F_c = H_c / H = F_H$

Example Analysis

- Infinite slope with soil on rock
- H=8m, $\beta=20^o$, $\gamma=18.64 kN/m^3$, $c'=18 kN/m^2$, $\phi'=25^o$
- Find FS against sliding
- If $\beta = 30^o$, find H_c

Infinite Slopes with Seepage





- $W = \gamma_{sat}LH$
- $Na = W \cos \beta = \gamma_{sat}LH \cos \beta$
- $Ta = W \sin \beta = \gamma_{sat}LH \sin \beta$
- $Nr = R \cos \beta = W \cos \beta = \gamma_{sat}LH \cos \beta$
- $Tr = R \sin b = W \sin \beta = \gamma_{sat}LH \sin \beta$

- Pore pressure acts to reduce effective normal force

$\gamma_{sat} H \sin\beta \cos\beta = c'_m + \gamma' H \cos^2\beta \tan\phi'_m$

$c'_m / \gamma_{sat} H = \cos^2\beta (\tan\beta - (\gamma' / \gamma_{sat}) \tan\phi'_m)$

$FS_s = [c' / \gamma_{sat} H \cos^2\beta \tan\beta] + (\gamma' / \gamma_{sat}) \tan\phi' / \tan\beta$

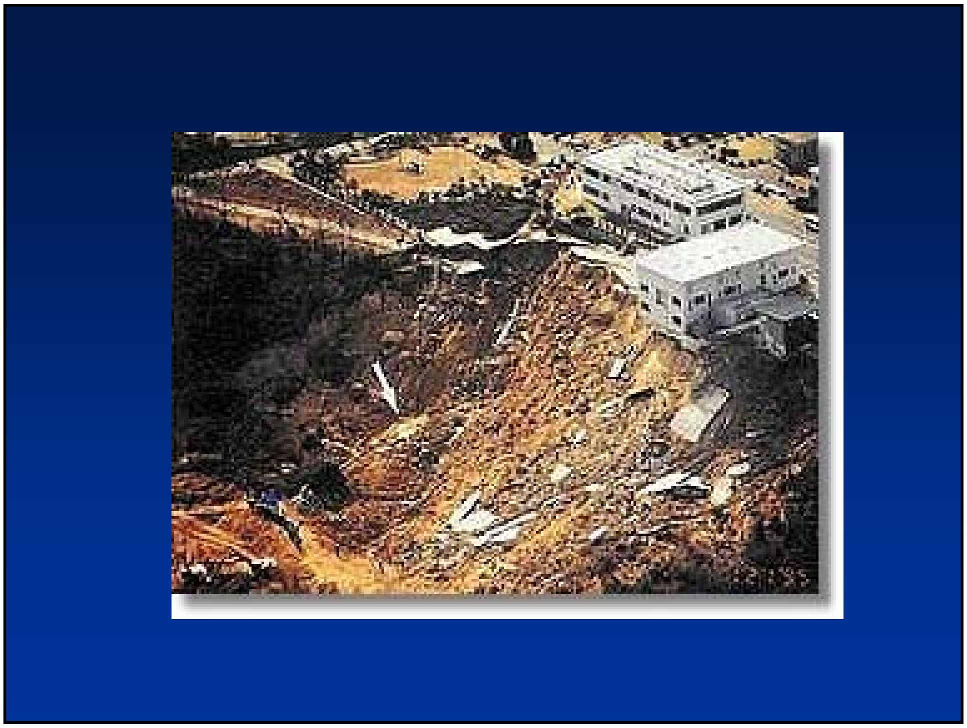
Example Analysis

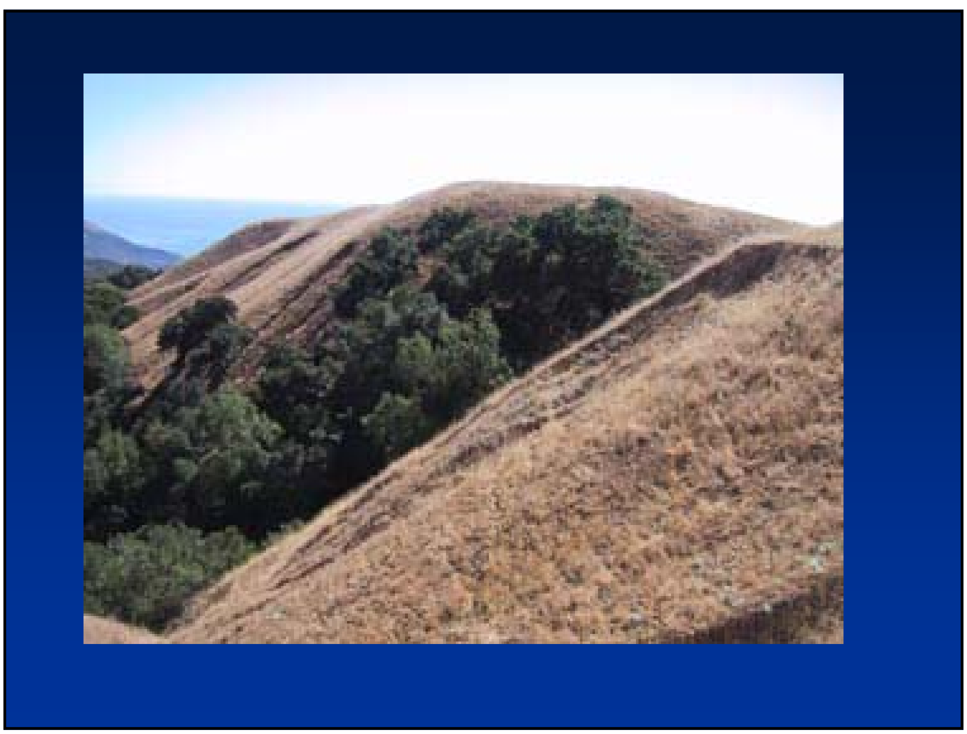
- Infinite slope with soil on rock with seepage
- $H=8m$, $\beta=20^o$, $\gamma_{sat}=19.5kN/m^3$, $c'=18kN/m^2$, $\phi'=25^o$
- Find FS against sliding

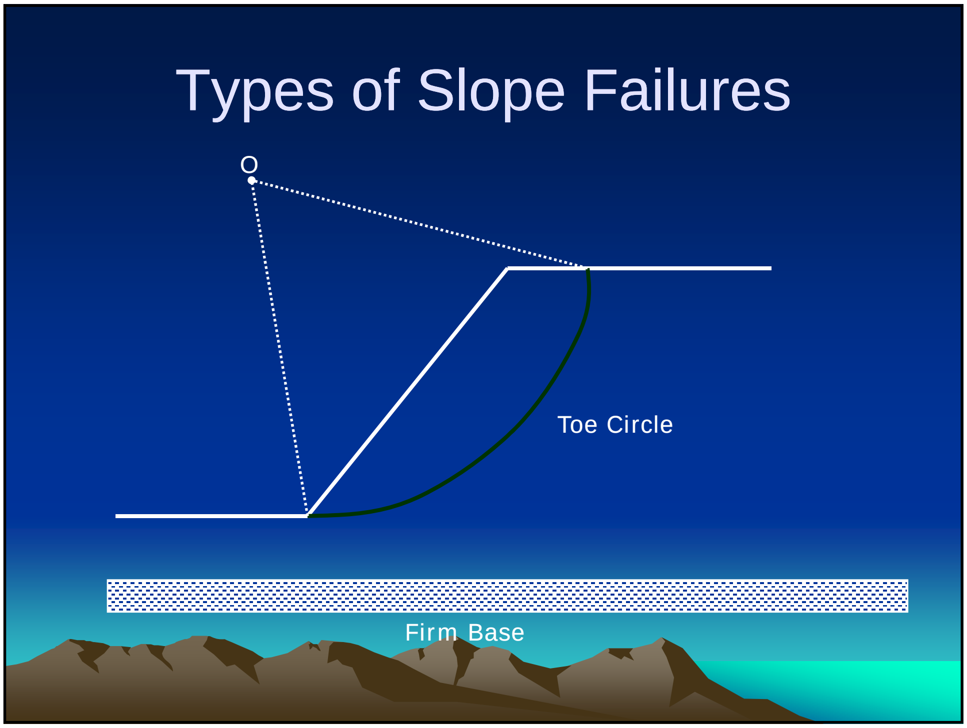
Finite Slopes

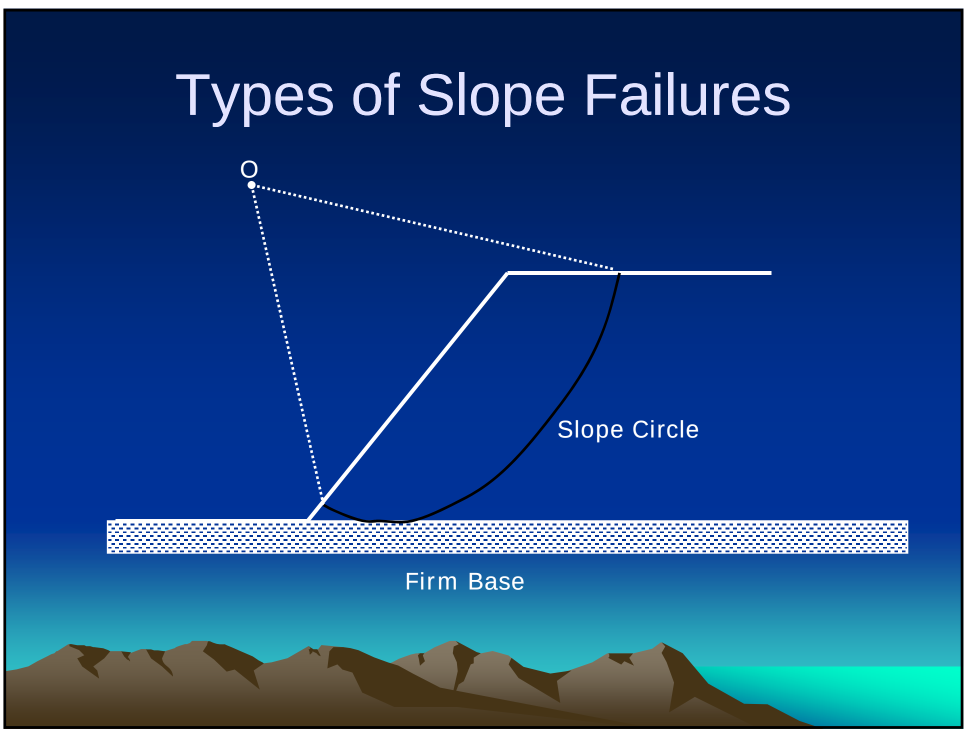
- Culman Method – Planar failure surface
  - Fairly good results for near vertical slopes only
- Swedish Method – Circularly cylindrical sliding surface
  - Good for analysis of embankments and their foundations
- Method of Slices

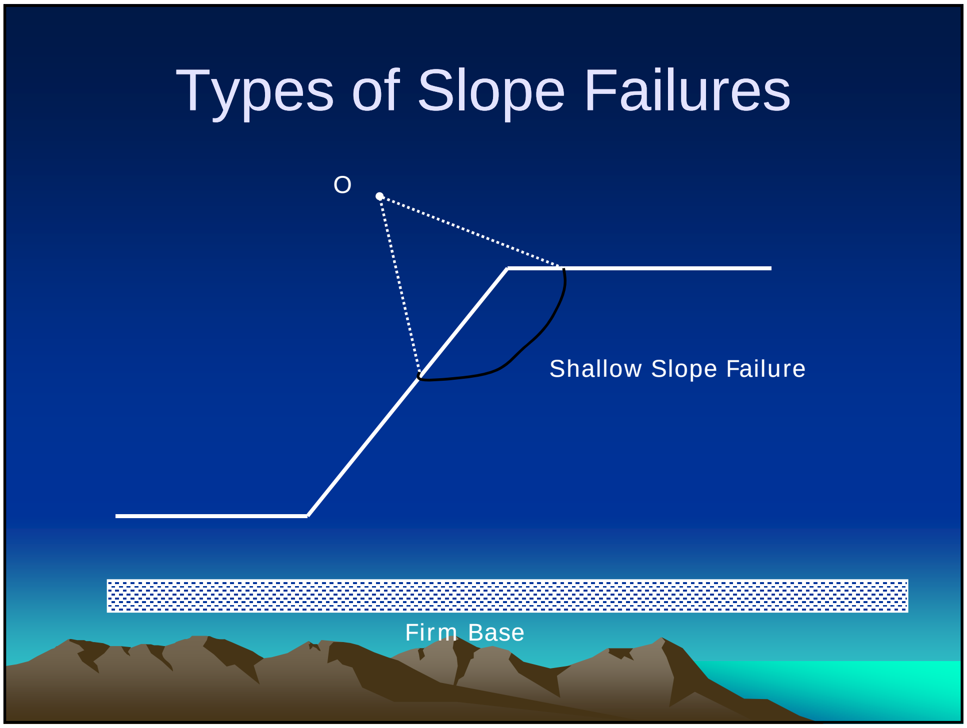
Finite Slopes with Circularly Cylindrical Failure Surfaces

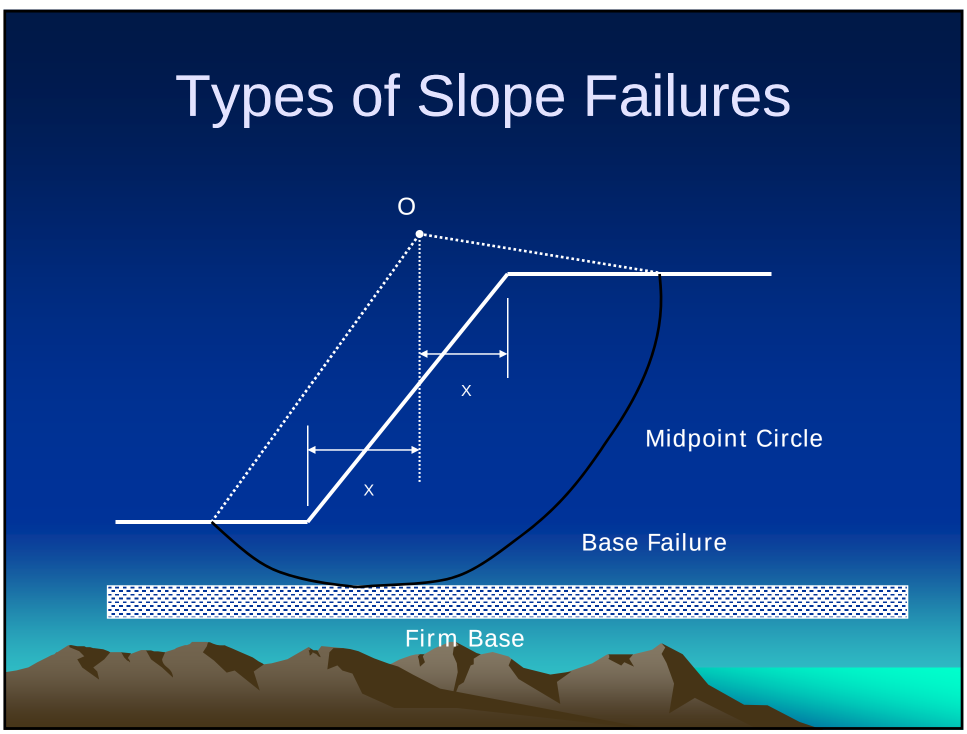




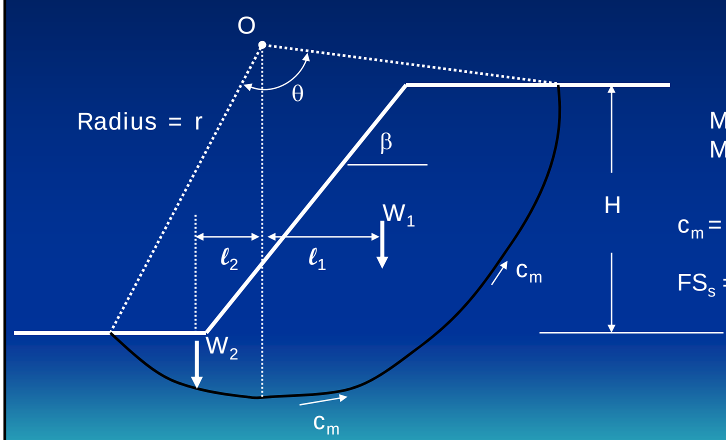

Types of Slope Failures
O
Toe Circle
Firm Base


Types of Slope Failures
O
Slope Circle
Firm Base


Types of Slope Failures
O
Shallow Slope Failure
Firm Base


Types of Slope Failures
O
x
x
Midpoint Circle
Base Failure
Firm Base

Homogeneous Clays
ϕ = 0, (Undrained)



$M_d = W_1\ell_1 - W_2\ell_2$
$M_R = c_m r^2\theta$

$c_m = [W_1\ell_1 - W_2\ell_2] \ / \ r^2\theta$

$FS_s = c_u / c_m$

Critical Circles (ϕ=0)

- $FS_s = 1$
- $c_m/\gamma H_c = m$ (Stability Number)
- m = fn {slope angle, depth to firm base)
- $\beta > 53^o$
  - All circles are toe circles
  - Center of circle found using
    - Fig 10.9 (Handout)

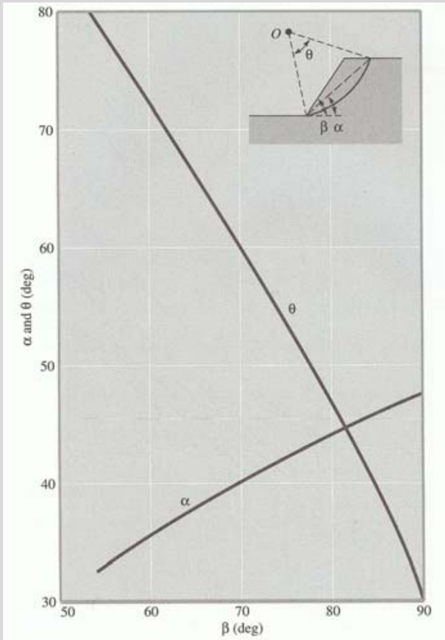


FIGURE 10.9 Location of the center of critical circles for $\beta > 53°$

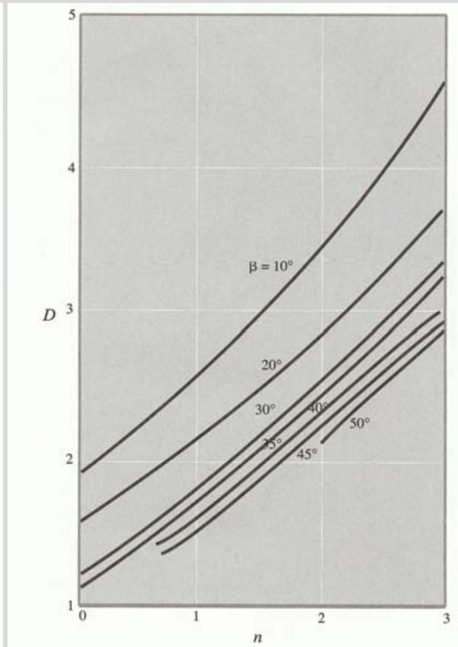


FIGURE 10.10 Location of midpoint circle

Critical Circles (ϕ=0)

- For $\beta < 53^o$
- Critical circle may be a toe, slope or midpoint circle depending on depth to firm layer
- Depth = DH; x = nH
- Fig 10.8a, 10.10 (handout)
- Max m = 0.181 (Fig 10.8a-handout)

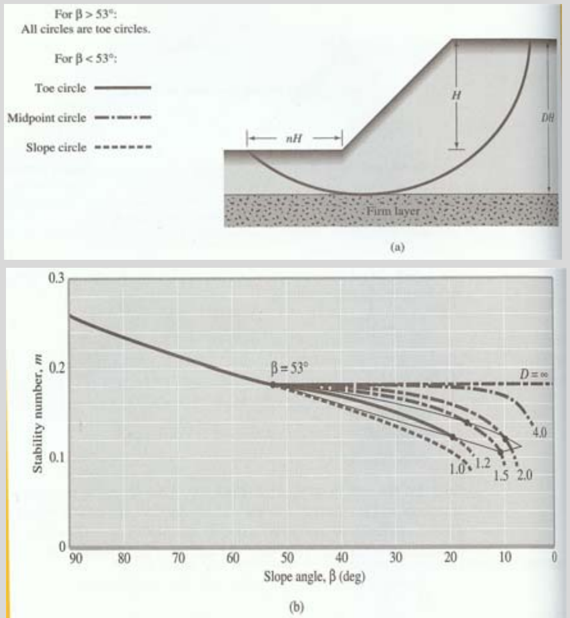


FIGURE 10.8 (a) Definition of parameters for midpoint circle-type failure; (b) plot of stability number against slope angle (Redrawn from Terzaghi and Peck, 1967)

For $\beta < 53^o$:
Above region=mid-point circle
Within region=toe circle
Below region=slope circle

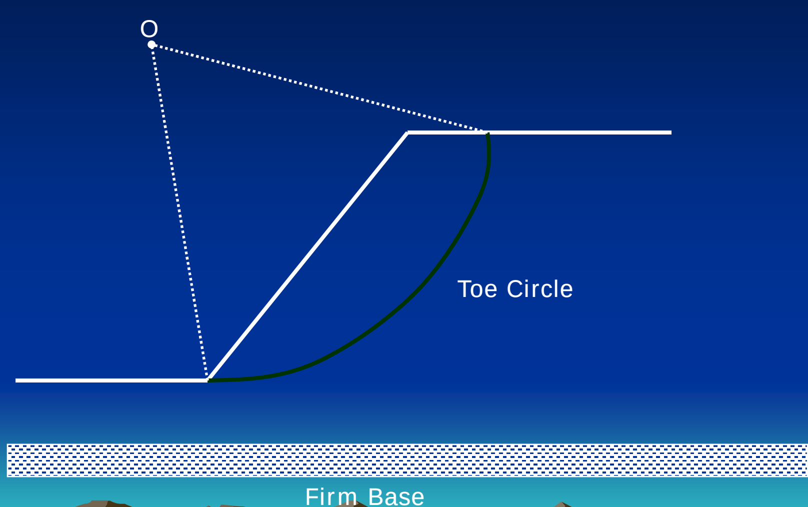
Example Analysis

- 75^o cut in soft clay
  - c_u=31kN/m^2; γ=17.3 kN/m^3
- Determine maximum cut depth, H_c
- Determine FS_s if cut is 3 m

Example Analysis

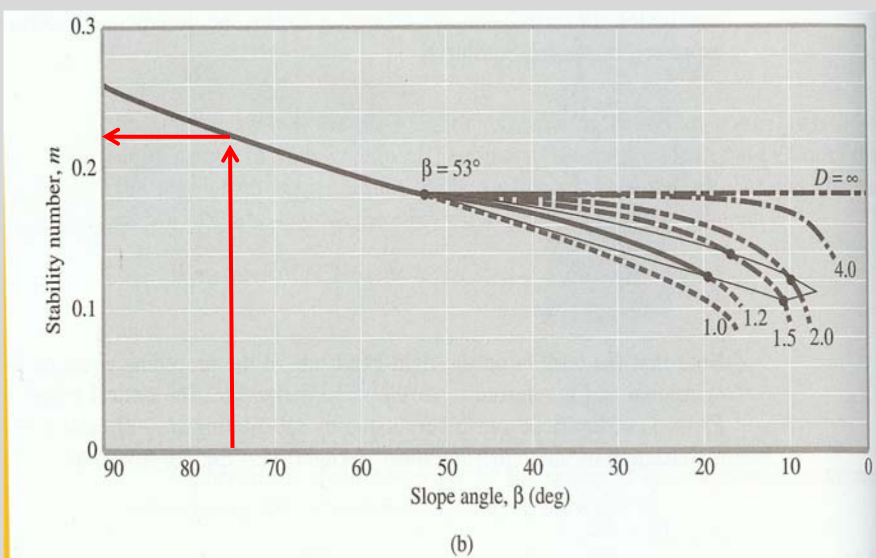
- H_c = ?
- $\beta = 75^o > 53^o$, so critical circle is toe circle

Types of Slope Failures



Example Analysis

- H_c = ?
- $\beta = 75^o > 53^o$, so critical circle is toe circle
- From Fig 10.8b (handout)
- m=0.222



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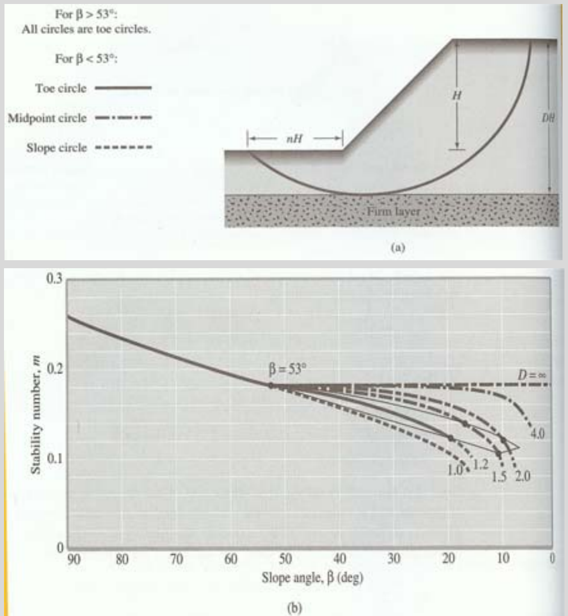
Example Analysis

- H_c = ?
- $\beta = 75^o > 53^o$, so critical circle is toe circle
- From Fig 10.8b (handout), m=0.222
- $m = c_u / \gamma H_c$
- $H_c = c_u / \gamma m$ = 31kN/m^2 / [17.3kN/m^3 x 0.222]
- H_c = 8.07 m

Example Analysis

- FS_s = ? for H = 3 m
- $m = c_m / \gamma H$
- $c_m = m \gamma H$
- c_m = 0.22*17.3*3 = 11.4 kN/m^2
- $FS_s = c_u/c_m$ = 31/11.4 = 2.7



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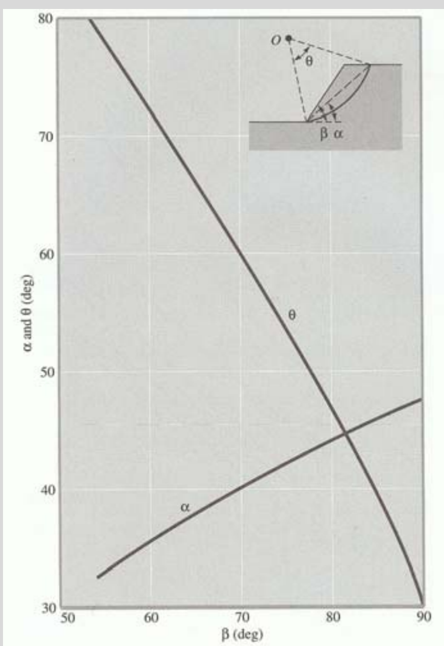

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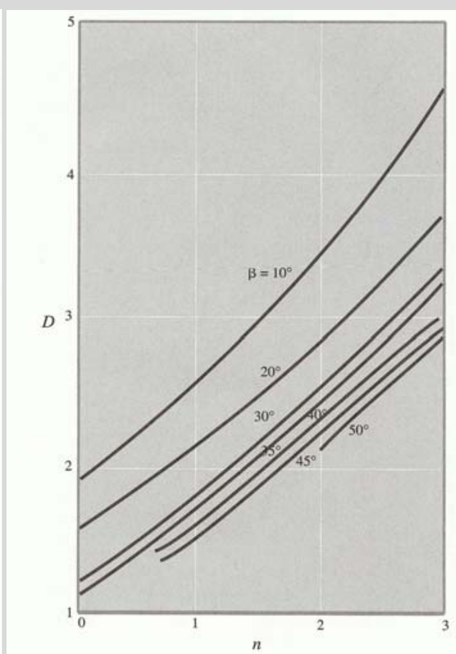

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