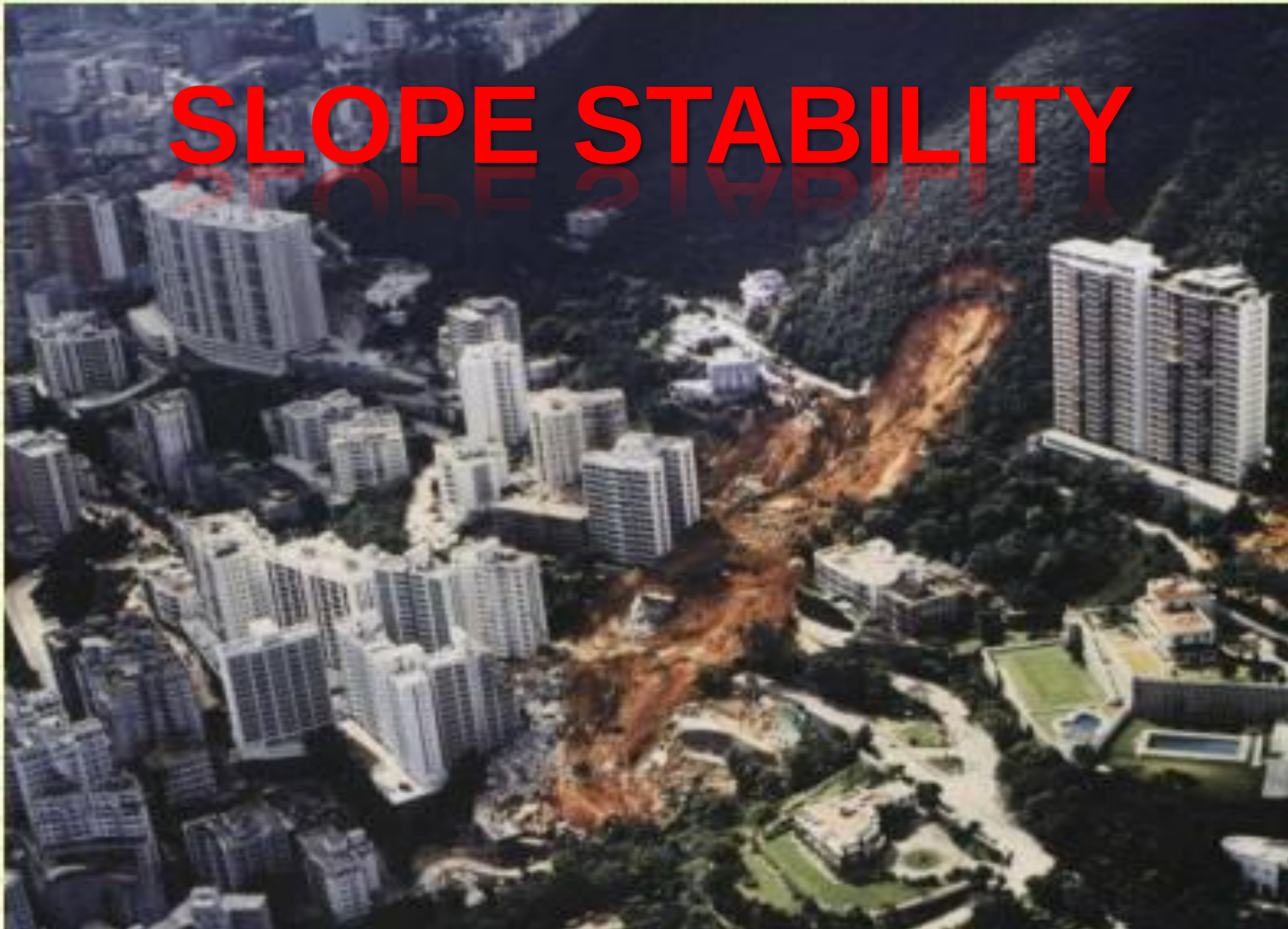
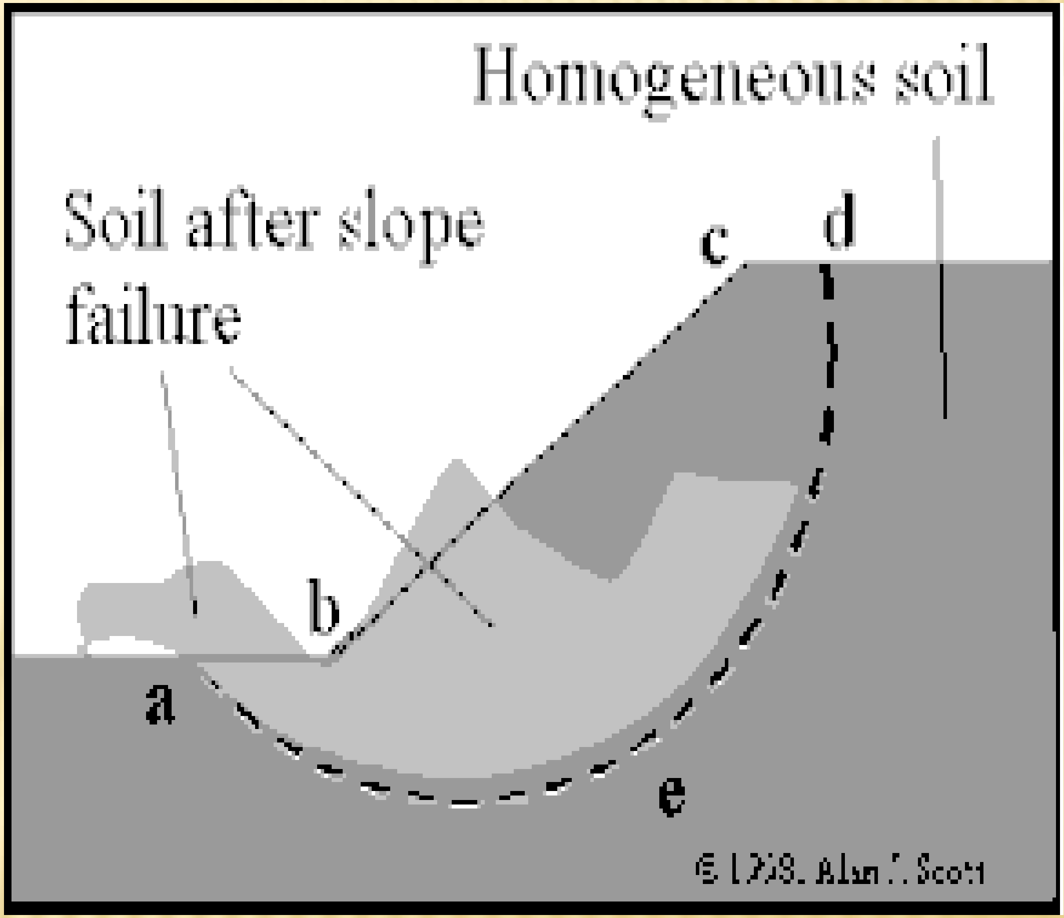
SLOPE STABILITY



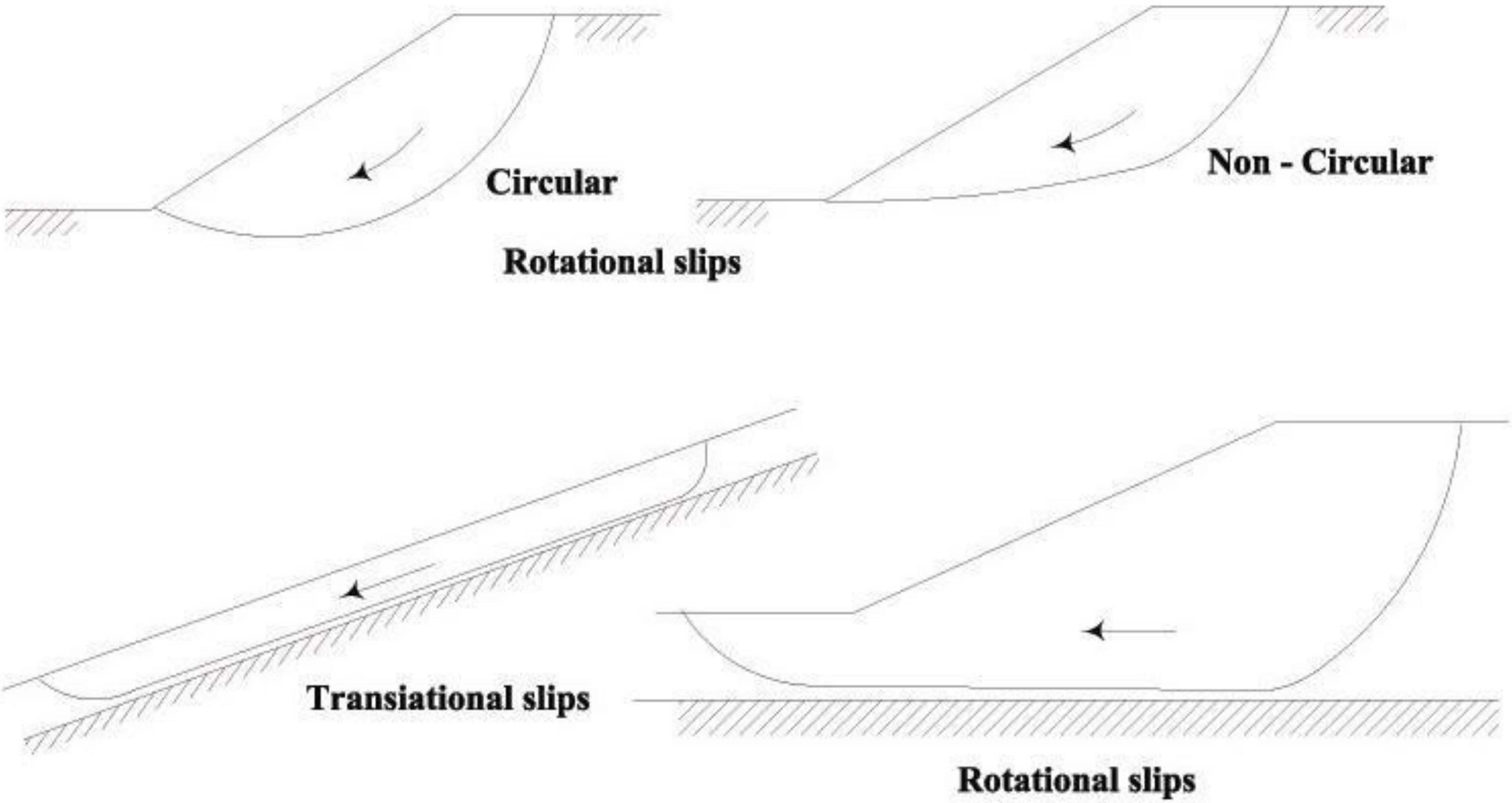
❖An exposed ground surface that stands at an angle with the horizontal is called *unrestrained slope.*

▪Slope failures cause damage and loss of lives.

▪ Need to check the shear stress that can be develop along the most likely rupture surface with the shear strength of the soil.

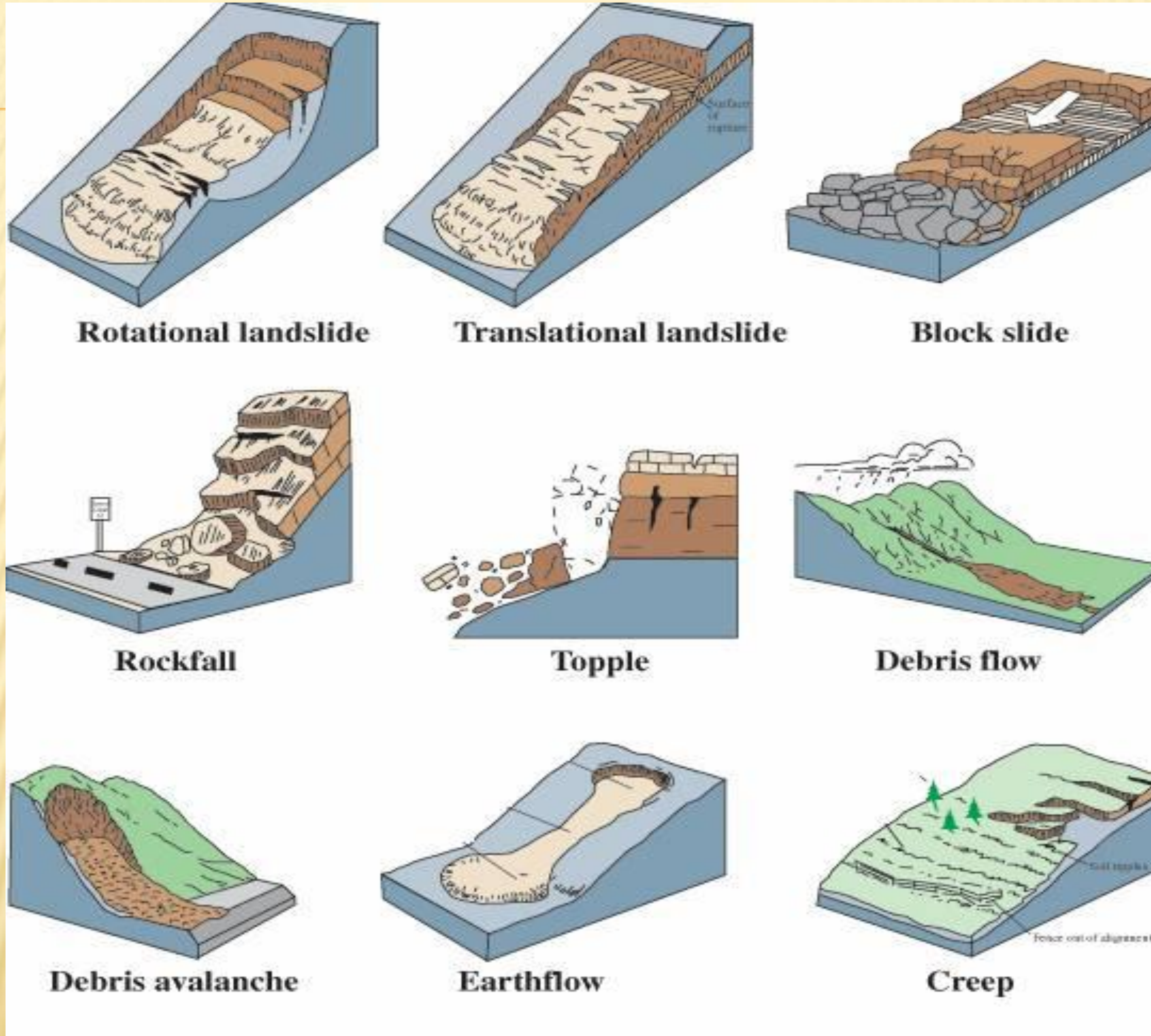


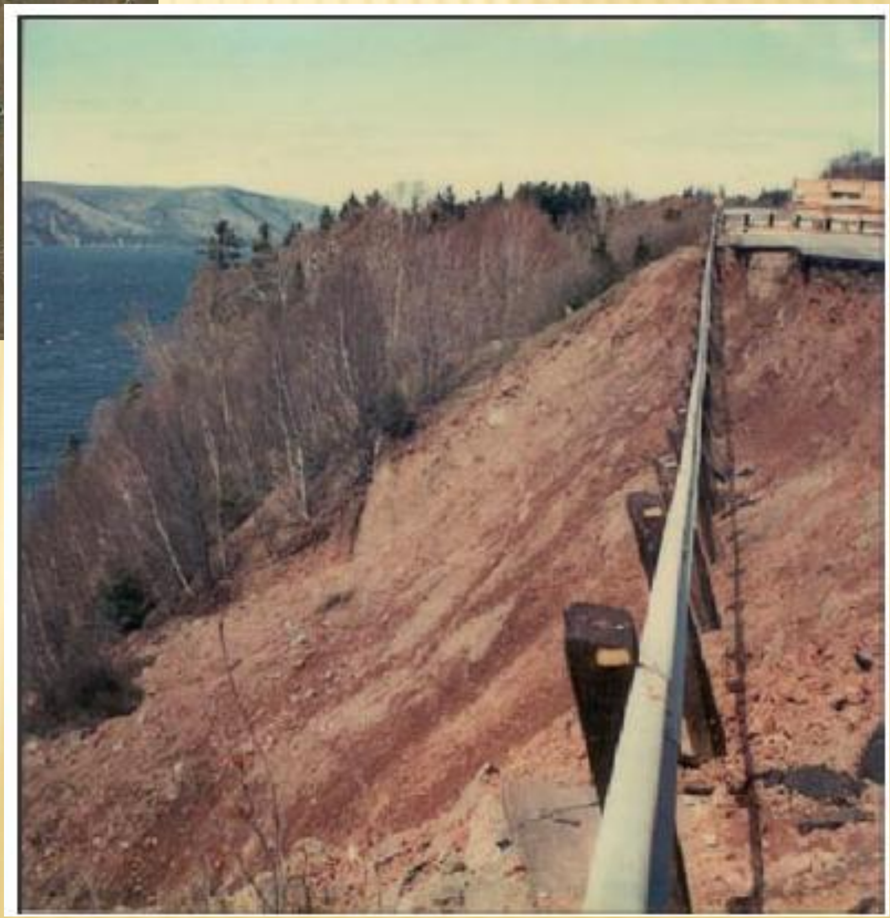
TYPES OF SLOPE FAILURES



Types of slope failure

Fig. (1)


Rotational landslide
Translational landslide
Block slide
Rockfall
Topple
Debris flow
Debris avalanche
Earthflow
Creep

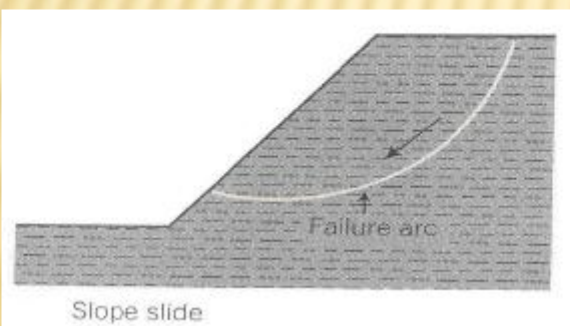



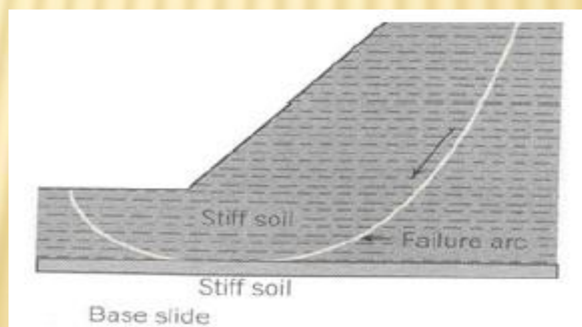


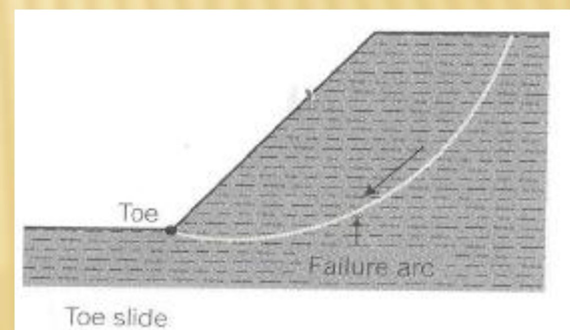
MODES OF FAILURE

- When the surface of sliding intersects the slope at or above its toe, **Slope of failure**
- when the surface of sliding passes at some distance below the toe of the slope, **base failure**

  the failure is called, **midpoint circle**







FACTORS THAT INFLUENCE SLOPE STABILITY

- Soil and rock strength
- Discontinuities and planes of weakness
- Groundwater and seepage
- External loading
- Slope geometry

TRIGGERING FACTORS (CAUSES OF SLOPE FAILURE)

- erosion
- Rainfall
- Earthquakes
- Geological factors
- External loading
- Construction activities
- Increment of pore water pressure
- Change in topography

METHODS TO IMPROVE AND PROTECT SLOPE STABILITY

- Slopes flattened or benched
- Weight provided at toe
- Lowering of groundwater table to reduce pore water pressures in the slope
- Use of driven / cast in place piles
- Retaining wall or sheet piling provided to increase resistance to sliding
- Soil improvement

TYPES OF STABILITY ANALYSIS PROCEDURES

- *Mass Procedure* – The mass of the soil above the surface of sliding is taken as a unit.

- *Methods of Slices* – The soil above the surface of sliding is divided into a number of vertical parallel slices.
  - The stability of each slice is calculated separately.
  - Non-homogeneity of the soils and pore water pressure can be taken into consideration.
  - It also accounts for the variation of the normal stress along the potential failure surface.

FACTOR OF SAFETY

Factor of safety of a slope is defined as the ratio of average shear strength (τ_f) of a soil to the average shear stress (τ_d) developed along the potential failure surface.

$$FS = \frac{\tau_f}{\tau_d}$$

Where:

FS = factor of safety

τ_f = shear strength

τ_d = shear stress

Cohesion and Friction may be expressed as,

$$\tau_f = c' + \sigma' tan\Phi'$$

Where:

c' = cohesion

$\boldsymbol{\Phi}$' = angle of friction

$\boldsymbol{\sigma}$' = effective normal stress

We can also use,

$$\tau_d = c'_d + \sigma' tan\Phi'_d$$

By substituting the equations,

$$F.S. = \frac{c' + \sigma' tan\Phi'}{c'_d + \sigma' tan\Phi'_d}$$

Factor of safety with respect to cohesion,

$$FS_{c'} = \frac{c'}{c'_d}$$

Factor of safety with respect to friction,

$$FS_{\Phi'} = \frac{tan\Phi'}{tan\Phi'_d}$$

When those three equations are compared,

$$\frac{c'}{c'_d} = \frac{tan\Phi'}{tan\Phi'_d}$$

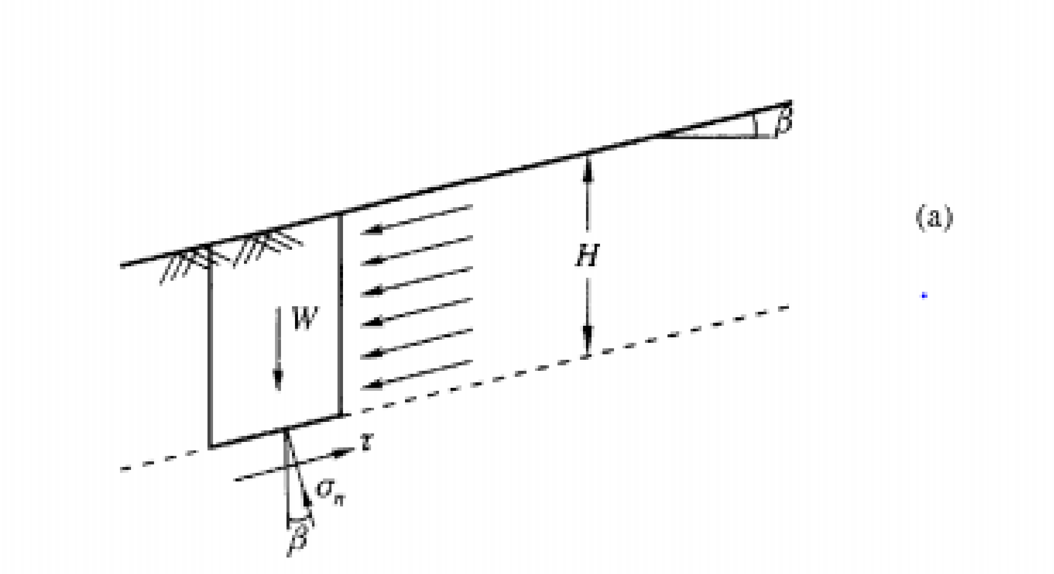
Or,

$$FS = FS_{c'} = FS_{\Phi'}$$

When FS is equal to 1, the slope is in state of impending failure.

A value of 1.5 for the FS with respect to strength is acceptable for the design of a stable slope.

ANALYSIS OF INFINITE SLOPE (without seepage)



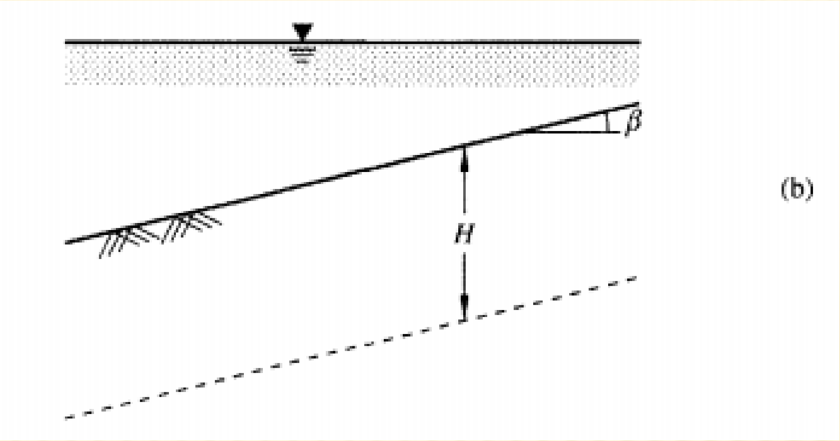
$$F.S. = \frac{c}{\gamma H \cos^2\beta \tan\beta} + \frac{\tan\phi}{\tan\beta}$$

ANALYSIS OF INFINITE SLOPE (without seepage)

Max. height of the slope for which critical equilibrium occurs

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

ANALYSIS OF INFINITE SLOPE (with seepage)



$$F.S. = \frac{c}{\gamma_{sat} H \cos^2 \beta \tan\beta} + \frac{(\gamma_{sat} - \gamma_w)\tan\phi}{\gamma_{sat} - \tan\beta}$$

What will be the factors of safety with respect to average shearing strength, cohesion and internal friction of a soil, for which the shear strength parameters obtained from the laboratory test are $c' = 32$ kN/m^2 and $Ø' = 18°$, the expected parameters of mobilized shearing resistance are $c'_\alpha = 21$ kN/m^2 and $Ø'_\alpha = 13°$ and the average effective pressure on the failure plane is 110 kN/m^2 . For the same value of mobilized shearing resistance determine the following:

1. Factor of safety with respect to strength
2. Factor of safety with respect to friction when that with respect to cohesion is unity; and
3. Factor of safety with respect to strength.

SOLUTION:

1. Factor of safety with respect to strength

$\tau_f = c' + \sigma' \tan\phi'$
$= 32 + 110\tan 18°$
$=$ **$67.8\ kN/m^2$**

$\tau_\alpha = c'_\alpha + \sigma' \tan\phi'_\alpha$
$= 21 + 110\tan 13°$
$= 46.4\ kN/m^2$

FACTOR OF SAFETY = $\frac{\tau_f}{\tau_\alpha} = \frac{67.8\ kN/m^2}{46.4\ kN/m^2} = \mathbf{1.46}$

SOLUTION:

$$\text{FACTOR OF SAFETY} = \frac{\tan \varnothing'}{\tan \varnothing_{\alpha}} = \frac{\tan 18^{\circ}}{\tan 13^{\circ}} = 1.41$$

Factor of safety with respect to cohesion

$$\text{FACTOR OF SAFETY} = \frac{c'}{c_{\alpha}} = \frac{32}{21} = 1.52$$

SOLUTION:

3. Factor of safety with respect to height

$F_H = F_c$ Will be at $F_ø = 1.0$

$\tau_\alpha = 46.4 = \frac{32}{Fc} + \frac{110 tan 18°}{1.0}$, therefore $Fc = \frac{32}{46.4 - 35.8} = 3.0$

Factor of safety with respect to friction at $F_ø = 1.0$ is

$\tau_\alpha = 46.4 = \frac{32}{1.0} + \frac{110 tan 18°}{F_ø}$, therefore, $F_ø = \frac{35.8}{46.4 - 32} = 2.49$

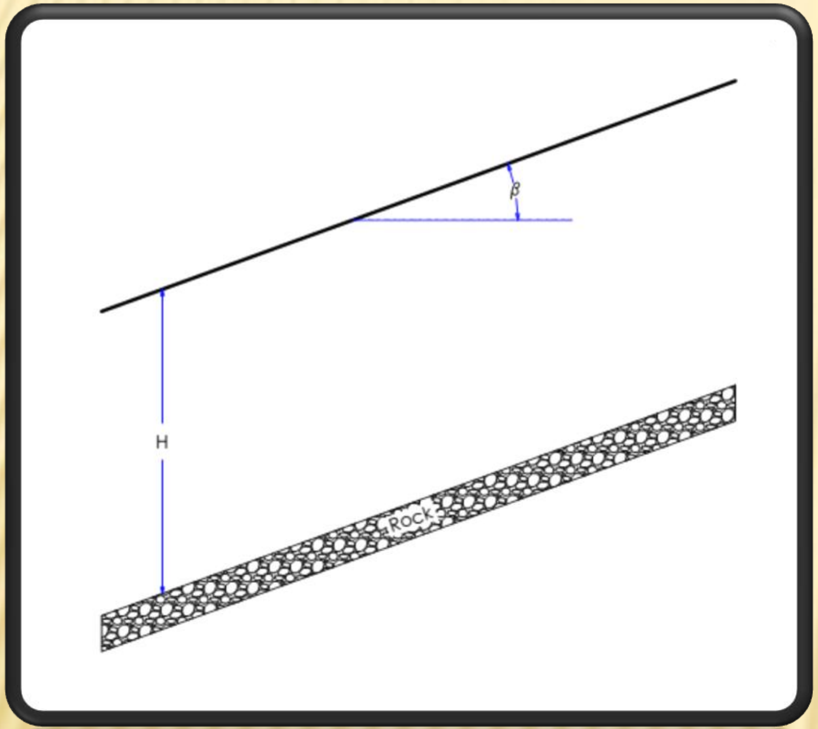
Factor of safety with respect to strength F_s is obtained when $F_ø = F_c$ we may write;

$\tau_\alpha = 46.4 = \frac{32}{F_s} + \frac{110 tan 18°}{F_s}$, OR $F_s = 1.46$

An infinite slope is shown in the Figure. The shear strength parameters at the interface of soil and rock are as follows:

Cohesion, c = $16\ kN/m^2$

Angle of shearing resistance, Φ = 25°

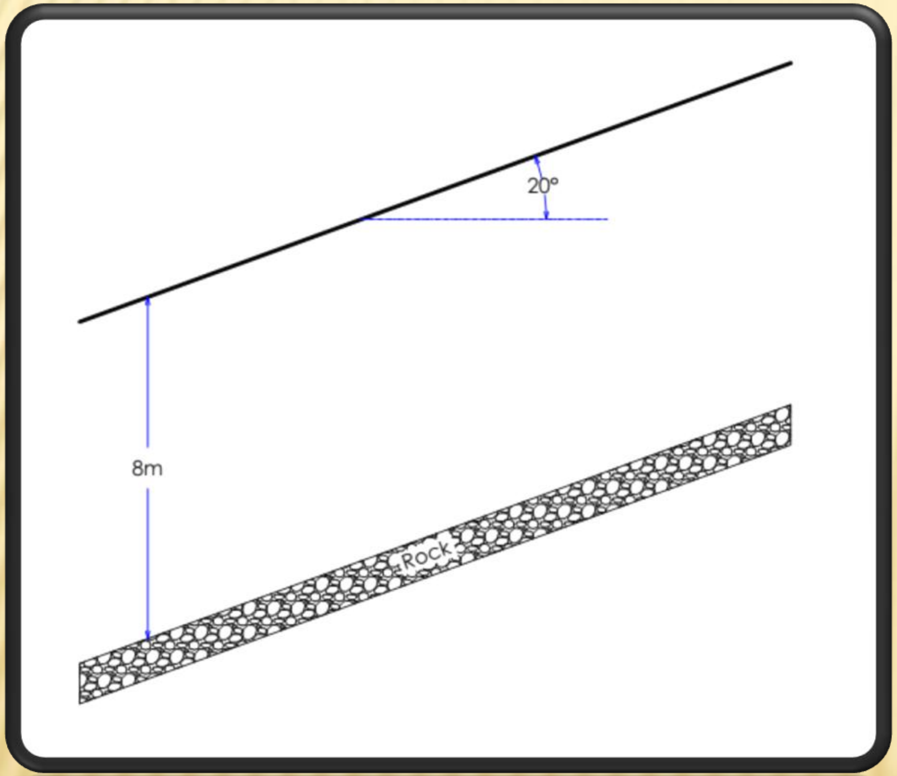


a. If H = 8m and β = 20°, find the factor of safety against sliding on the rock surface. Assume no seepage

b. If β = 30°, find the critical height H. assume no seepage

c. If there were seepage through the soil, and the groundwater table coincide with the ground surface, and H = 5m, β = 20°, what would be the factor of safety. Assume $\rho_{sat} = 1900\ kg/m^3$

a. If H = 8m and β = 20°, find the factor of safety against sliding on the rock surface. Assume no seepage

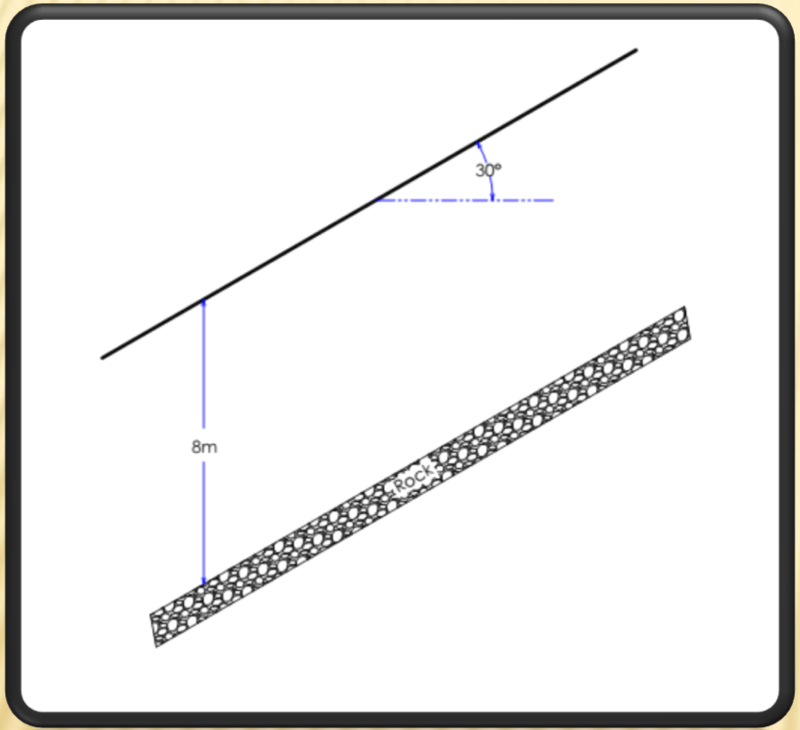


$$F.S. = \frac{c}{\gamma H\, cos^2\beta\, tan\beta} + \frac{\tan\Phi}{\tan\beta}$$

$$F.S. = \frac{16}{18.639(8)\, cos^2 20\, tan20} + \frac{\tan 25°}{\tan 20°}$$

$$\boldsymbol{F.S = 1.615}$$

b. If β = 30°, find the critical height H. assume no seepage

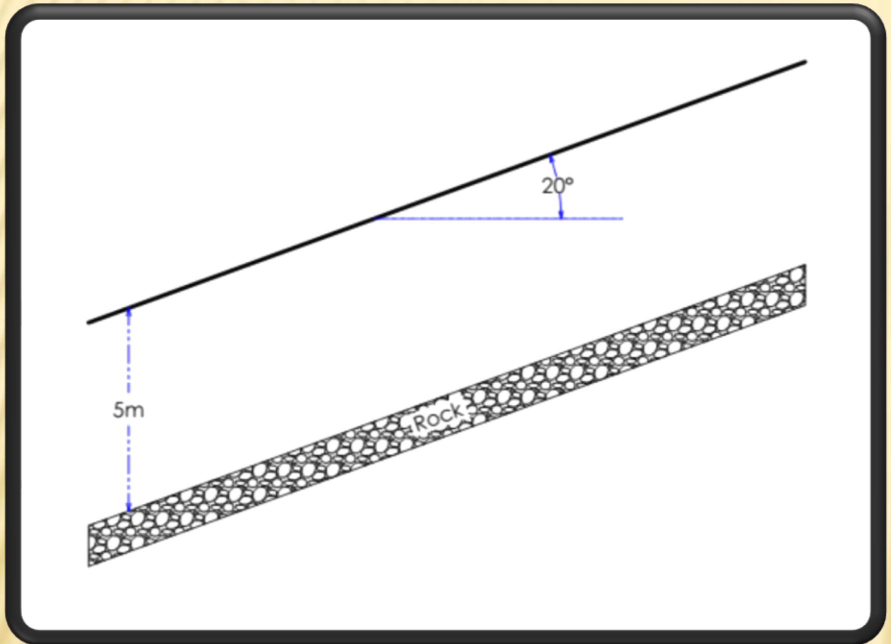


$$H = \left(\frac{c}{\gamma}\right)\left(\frac{1}{cos^2\beta\ (tan\beta - \tan\Phi)}\right)$$

$$H = \left(\frac{16}{18.639}\right)\left(\frac{1}{cos^2 30°\ (\tan 20° - \tan 25°)}\right)$$

$$\boldsymbol{H = 10.31\ m}$$

c. If there were seepage through the soil, and the groundwater table coincide with the ground surface, and H = 5m, β = 20°, what would be the factor of safety. Assume $\rho_{sat} = 1900\ kg/m^3$



$$\gamma_{sat} = 1900\ x\ 9.81 = 18{,}639\ N/m^3$$

$$\gamma_{sat} = 18.639\ kN/m^3$$

$$\gamma' = \gamma_{sat} - \gamma_w = 18.639 - 9.81$$

$$\gamma' = 8.829\ kN/m^3$$

$$F.S. = \frac{c}{\gamma H\ cos^2\beta\ tan\beta} + \frac{\gamma'}{\gamma_{sat}}\frac{\tan\Phi}{\tan\beta}$$

$$F.S. = \frac{16}{18.639(5)\ cos^2 20\ tan 20} + \frac{8.829}{18.639}\frac{\tan 25°}{\tan 20°}$$

$$\boldsymbol{F.S = 1.141}$$