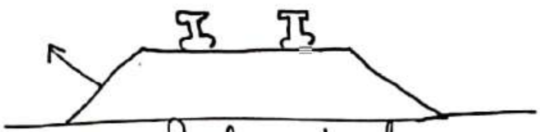
UNIT-5 (Part-1)

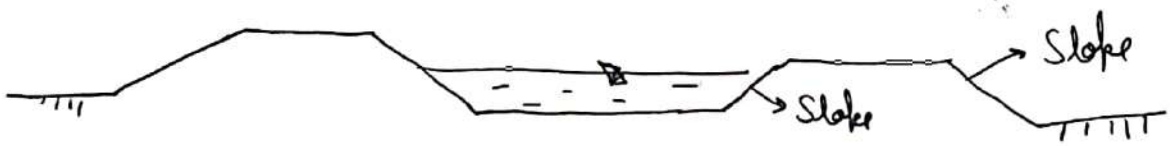
Stability of Slopes

→ An earth slope is an unsupported, inclined surface of a soil mass. Earth slopes are formed for railway formations, highway embankments, earth dams, canal bank, levees and at many other locations.

Highway



Railway track



Canal

→ Cost of earth work would be minimum if the slopes are made steepest. However, very steep slope may not be stable.

→ So slopes are provided neither too steep nor to ~~flat~~ flat.

→ Failure of slopes may lead to loss of life and property. Therefore it is essential to check the stability of proposed slopes.

→ With the development of modern methods of testing of soils and stability analysis, a safe and economical design of a slope is possible.

→ The factors leading to the failure of slopes may be classified into two categories:

1) <u>The factors which cause an increase in the shear stresses.</u> The stresses may increase due to weight of water causing saturation of soils, surcharge loads, seepage pressure or any other cause. The stresses are also increased due to steepening of slopes either by excavation or by natural erosion.

2) The factors which cause a <u>decrease in the shear strength of soil.</u> The loss of shear strength may occur due to an increase in water content, increase in pore water pressure, shock or cyclic loads, weathering or any other cause.

→ Most of the natural slope failures occur during rainy seasons, as the presence of water causes both increased stresses and loss of strength.

** <u>Basis of analysis:</u>

The soil must be safe against slope failure on any conceivable surface across the slope. Although the methods using the theory of elasticity or plasticity are also being increasingly used, the most common methods are based on limiting equillibrium in which it is assumed that the soil is at the verge of failure.

The method of limiting equillibrium are statically indeterminate.

Following assumptions are generally made:

1) The stress system is assumed to be two-dimension
2) Assumed at Coulomb equation for shear strength is applicable and strength parameters c and ϕ are known.
3) It is further assumed that the seepage conditions and water levels are known, and the corresponding pore water pressure can be estimated.
4) The conditions of plastic failure are assumed to be satisfied along the critical surface.
5) Depending upon the method of analysis, some additional assumptions are made regarding the magnitude and distribution of forces along various planes.

→ The factor of safety of the slope is determined from the available resisting forces and the actuating forces.

** IMP Different definitions of factor of safety:

Three different definitions of the factor of safety are used:

a) Factor of safety with respect to shear strength:

In common usage, the factor of safety is defined as the ratio of the shear strength to the shear stress along the surface of failure.

$$F_S = \frac{S}{\tau_m}$$

F_S = F.O.S

S = shear strength

τ_m = applied shear stress or mobilized shear strength

The equation can be written in terms of cohesion intercept and the angle of shear resistance as :

$$F_s = \frac{C + \bar{\sigma}\tan\phi}{C_m + \bar{\sigma}\tan\phi_m}$$

C_m = mobilized cohesion, ϕ_m = mobilized angle of shear resistance
$\bar{\sigma}$ = effective pressure.

$$c_m = c/F_s$$
$$\tan\phi_m = \tan\phi/F_s$$

2) <u>Factor of Safety with respect to cohesion:</u>
F_c is the ratio of the available cohesion intercept (c) and the mobilised cohesion intercept.

$$F_c = \frac{c}{c_m}$$

c = cohesion intercept, c_m = mobilized cohesion intercept
F_s = F.O.S with respect to cohesion.

3) <u>Factor of Safety with respect to friction:</u>
The F.O.S with respect to friction is the ratio of the available frictional strength to the mobilised frictional strength.

$$F_\phi = \frac{\bar{\sigma}\tan\phi}{\bar{\sigma}\tan\phi_m} \quad \text{(or)} \quad F = \frac{\tan\phi}{\tan\phi_m}$$

F_ϕ = F.O.S with respect to friction
ϕ = angle of shearing resistance
ϕ_m = angle of mobilised shearing resistance.

** Types of Slope Failures :

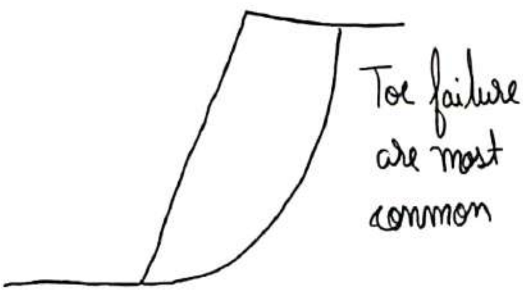
A slope may have one of the following types of failures:

1) <u>Rotational Failure</u>: This type of failure occurs by rotation along a slip surface by downward and outward movement of the soil mass. Rotational slips are further divided into 3 types: (Slip Surface is generally circular)

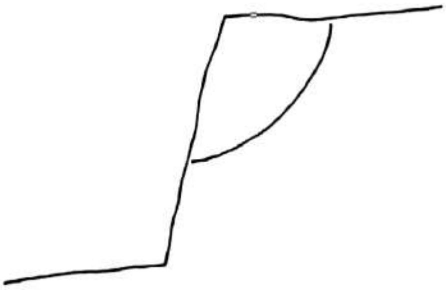
a) Toe failure, in which the failure occurs along the surface that passes through the toe.

b) Slope failure, in which the failure occurs along a surface that intersects the slope above the toe.

c) Base failure, in which the failure surface passes below the toe.

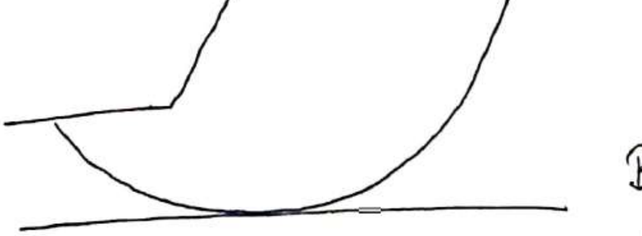


a) Toe Failure



(b) Slope failure

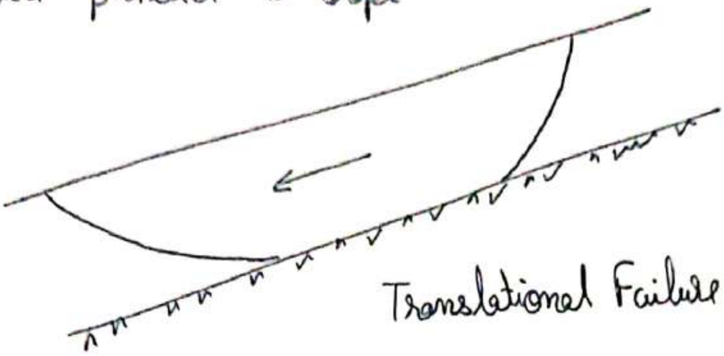
The slope failure occurs when a weak plane exist above toe.



c) Base Failure

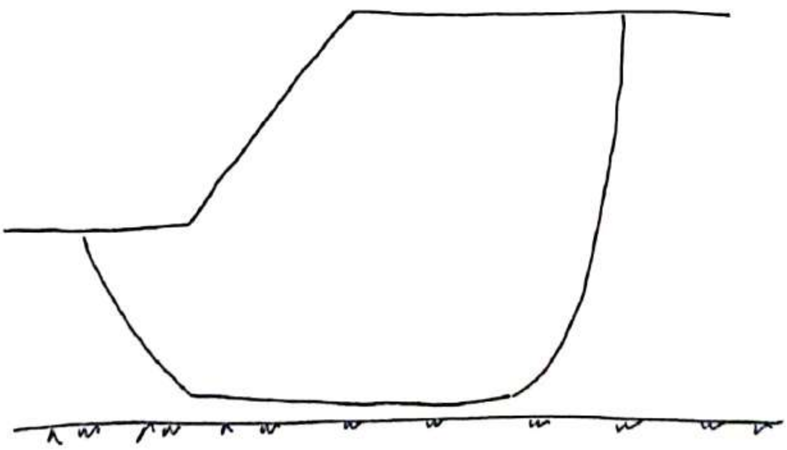
Base failure occurs when stratum is weak beneath toe.

2) <u>Translational Failure</u>: A constant slope of unlimited extent and having uniform soil properties at the same depth below the free surface is known as an infinite slope. ~~The~~ Translational failure occurs in an <u>infinite slope</u> along a long failure parallel to slope.

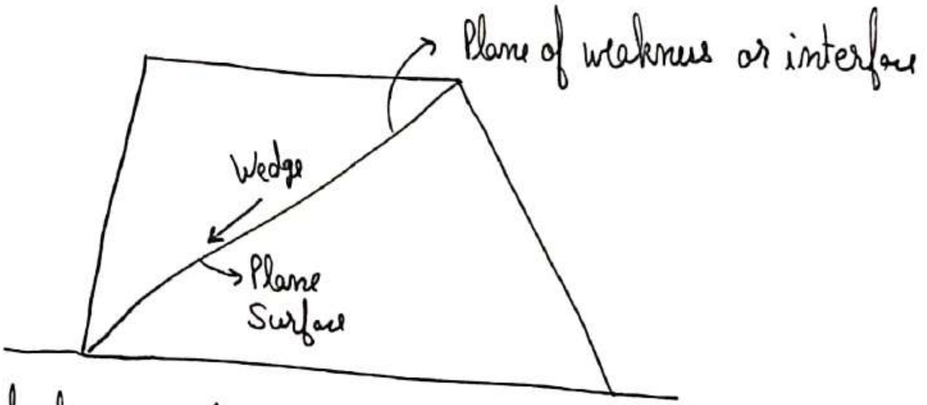


Translational Failure

3) <u>Compound Failure</u>: It is a combination of the rotational slips and the translational slip. A compound failure surface is curved at the two ends and plane in the middle portion. A compound failure generally occurs when a hard stratum exists ~~at~~ at considerable depth below the toe.



4) <u>Wedge Failure</u>: A failure along an inclined plane is known as plane failure or block failure. It occurs when distinct block & wedges of soil mass become separated.
Similar to translational failure in many respects. But unlike translational failure occurs in an infinite slope, a plane failure may occur even in a finite slope consisting of two different materials.



5) <u>Miscellaneous failures</u>: In addition to above four types of failures, some complex types of failures in the form of spreads & flows may also occurs.

Limit Equillibrium Method:

→ Limit Equillibrium Method investigate the equillibrium of a soil mass tending to slide down under the influence of gravity.

→ Translational or rotational movement is considered on an assumed or known potential slip surface below the soil or rock mass.

→ Limit equillibrium method assumes that the shear strengths of the materials along the potential ~~fo~~ surface are governed by linear (Mohr-Coulomb) or non-linear relationship between shear strength and normal stress on the failure surface.

→ The most commonly used variation is Terzaghi's theory of shear strength which states

$$\boxed{\tau = \bar{\sigma} \tan \phi' + c'}$$

τ = shear strength of interface
$\bar{\sigma}$ = effective stress
ϕ' = eff. friction angle
c' = eff. cohesion

→ Limit Equillibrium analysis is one of the conventional methods of slope stability analysis.

** Method of slices :

→ The method of slices is the most popular limit equillibrium technique.

→ In this approach, the soil mass is discretized into vertical slices.

→ Several versions of the method are in use. These variations can produce different factor of safety because of different assumptions and boundary condition.

⇒ There are some Analytical techniques of Method of slices such as Bishop simplified, ordinary method of slices (Swedish Circle) etc.

Swedish Slip circle Method of Analysis :

→ The swedish slip circle method assumes that the friction angle of soil or rock is equal to zero; i.e

$$\boxed{\tau = c'}$$

→ In other words, when friction angle is considered to zero, thus equating the shear strength to the cohesion parameter of given soil.

→ Swedish slip circle method assumes a circular failure interface, and analyses strength and stress parameters using circular geometry and statics.

→ The moment caused by the internal driving force of a slope is compared to the moment caused by forces resisting slope failure. If resisting forces are greater than driving forces, the slope is assumed stable.

→ In ordinary method of slices, the interslice forces are neglected.

<u>Bishop's Simplified Method</u>: → uses method of slices to discretize soil mass & determine F.O.S

→ The conventional Swedish circle method satisfies only the overall moment equation of equillibrium.

→ It neglects the moment equillibrium of the individual slices.

→ It also disregards the effect of forces acting on the sides of individual slices and therefore, only approximates the force equillibrium of each slice.

→ Methods of ~~and~~ analysis which satisfy all the equillibrium equation are complicated & not convenient to use.

→ <u>Bishop</u> gave a <u>simplified method</u> of analysis which considers the forces on the <u>sides of each slice</u>.

→ The requirement of equillibrium are applied to the slices.

→ The Factor of safety is defined as the ratio of the maximum shear strength (s) possessed by soil on the trial surface to the shearing resistance mobilised (τ_m).

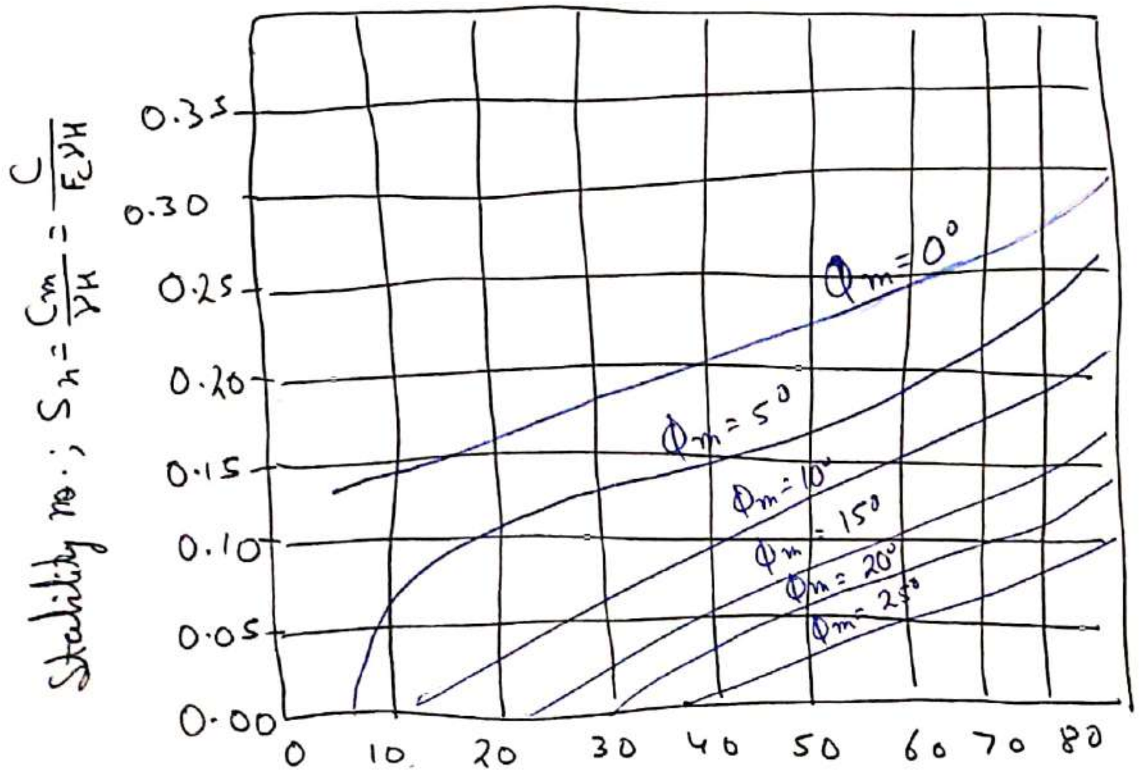
$$F_s = S/\tau_m$$

* Imp Stability Chart / Taylor's Stability Number :

The stability number (S_n) ; is given by :

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

- The reciprocal of the stability number is known as stability factor.
- The stability number is a dimensionless quantity.
- Taylor determined the value of S_n for finite slopes using the friction circle method.
- Slopes that are of simple sections and of homogenous soils may be analyzed using the slope stability charts given by Taylor.
- The charts are prepared indicating stability number and slope angle i for various value of ϕ_m



→ There are 5 parameter, $c_m, \gamma, H, i, \phi_m$. However if $\phi_m = 0$ (purely cohesive soils) a sixth parameter D_f becomes also important.

$$D_f = \frac{\text{Depth of hard stratum below top of slope}}{\text{Height of slope}}$$

Q. A vertical cut is made in a clay deposite, $c = 30 \text{ kN/m}^2$, $\phi = 0$, $\gamma = 16 \text{ kN/m}^3$. Find max. height of cut.

$S_n = 0.261$

⇒ From Taylor's Stability no;

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

$$H = \frac{c}{F_c \gamma S_n} \qquad \text{Taking } F_c = 1.0$$

$$H = \frac{30}{1 \times 16 \times 0.261}$$

$$H = \underline{\underline{7.18}} \text{ m}$$

Q. A cutting is to be made in clay which has cohesion of 35 kN/m^2 and $\phi = 0$. The density of the soil is 20 kN/m^3. Find the max. depth for cutting the side slope $1\frac{1}{2}$ to 1; if F.O.S = 1.5

Take Stability no., $S_n = 0.17$

$\Rightarrow$ $c = 35 \, kN/m^2$; $\phi = 0$

$\gamma = 20 \, kN/m^3$; $S_n = 0.17$

$F_c = 1.5$

$$c_m = \frac{c}{F_c} = \left(\frac{35}{1.5}\right) = \frac{70}{3} \, kN/m^2$$

$$S_n = \frac{c_m}{\gamma H}$$

$$0.17 = \frac{70}{3 \times 20 \times H}$$

$$H = \underline{\underline{6.86 \, m}}$$