SLOPE STABILITY

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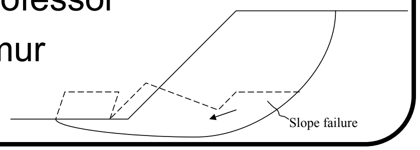


SLOPE STABILITY

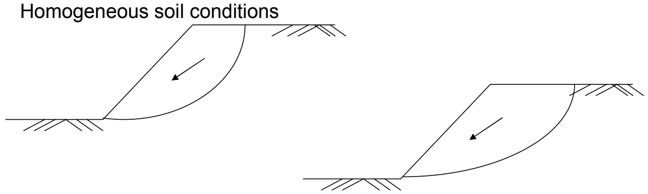
- An exposed ground surface that stands at an angle with the horizontal is called an *unrestrained slope*.
  - The slope can be natural or man-made.
- Slope failures cause damage and loss of lives
- Need to check the shear stress that can develop along the most likely rupture surface with the shear strength of the soil.
  - called slope stability, most likely rupture surface is the critical plane that has the minimum factor of safety.

Types of Slope Failure

Rotational slips

Failure surface is circular arc

Homogeneous soil conditions



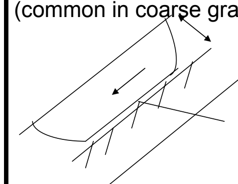
Failure surface is non-circular arc

Non-homogeneous soil conditions

Types of Slope Failure

Translational slip

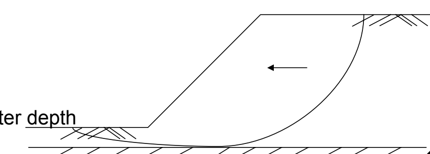
(common in coarse grained soils)



Adjacent stratum is at shallow depth

Failure surface parallel to slope

Compound slip



Adjacent stratum is at greater depth

Modes of Failure

- When the surface of sliding intersects the slope at or above its toe, then it is called a slope failure. The failure circle is a toe circle if it passes through the toe of the slope and a slope circle if it passes above the toe of the slope. Sometimes shallow slope failure occurs as well.
- When the surface of sliding passes at some distance below the toe of the slope, it is called a base failure. The failure is called a midpoint circle.

Factors that influence slope stability

- Soil and rock strength (Soil type and stratification)
- 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
  - Excavated Slopes
  - Fill Slopes
- Rapid Drawdown
- Increment of pore water pressure
- The 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 pressures in the slope
- Use of driven or cast-in place piles
- Retaining wall or sheet piling provided to increase resistance to sliding
- Soil improvement → compaction, jet grouting

Types of Stability Analysis Procedures

- *Mass Procedure*: The mass of the soil above the surface of sliding is taken as a unit.
  - Soil is assumed to be homogeneous.
- *Method 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.
  - Nonhomogeneity 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: $F_s = \frac{\tau_f}{\tau_d}$

F_s: Factor of safety w.r.t strength

τ_f: Average shear strength of soil

τ_d: Average shear stress developed along the potential failure surface

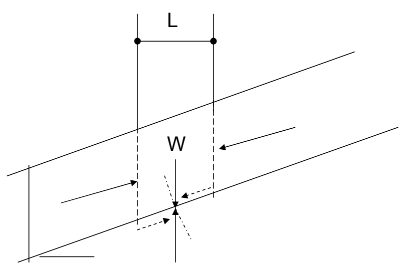
The shear strength of soil: $\tau_f = c + \sigma\tan\phi$ and $\tau_d = c_d + \sigma\tan\phi_d$

Therefore; $F_s = \frac{c + \sigma\tan\phi}{c_d + \sigma\tan\phi_d}$

When $F_s=1$, the slope is close to failure.

▪Generally $F_s=1.5$ is acceptable for the design of a stable slope. $F_s>1.5$ is safe.

Stability of Infinite Slopes Without Seepage (u=0)



W=LHγ

N_a

T_a

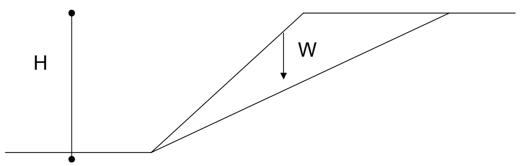
$$F_s = \frac{\tau_f}{\tau_d} = \frac{c + \gamma H\cos^2\beta\tan\phi}{c_d + \gamma H\cos^2\beta\tan\phi_d} = \frac{c}{\gamma H\cos^2\beta\tan\beta} + \frac{\tan\phi}{\tan\beta}$$

Stability of Infinite Slopes With Seepage

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

Culmann's Method

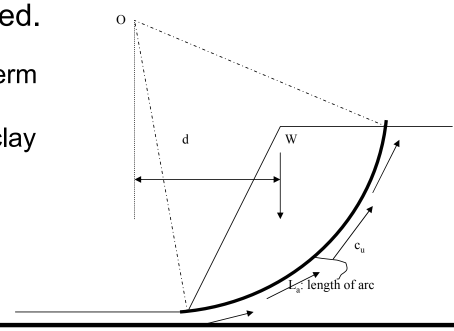
Failure of a slope occurs along a plane when τ_{av} tending to cause the slip is more than the shear strength of the soil.



Analysis for the case of ϕ_u=0

- In terms of total stress, fully saturated clay under undrained conditions (i.e. during and immediately after construction). Moment equilibrium is considered.

For short term stability of saturated clay slopes.



Analysis for the case of ϕ_u=0

- For equilibrium the shear strength which must be mobilised along the failure surface is expressed as: $\tau_d=\tau_f/F_s=c_u/F_s$
- Equating moments about O: $W_d=(c_u/F_s)L_a r \rightarrow F_s=(c_u L_a r)/Wd$

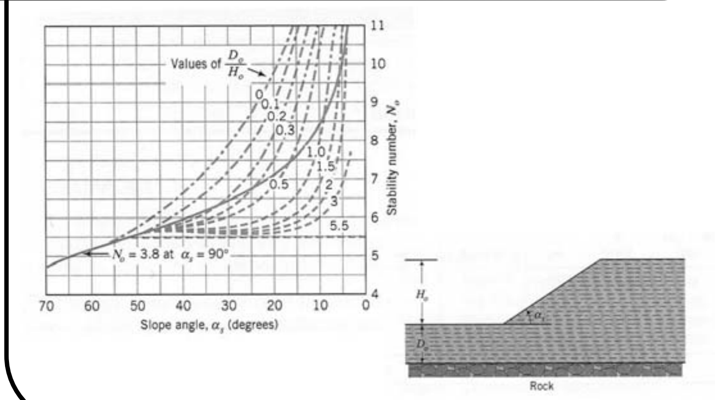
$$F_s = \frac{M_{Restoring}}{M_{Disturbing}}$$

Taylor's Stability Coefficient (ϕ_u=0)

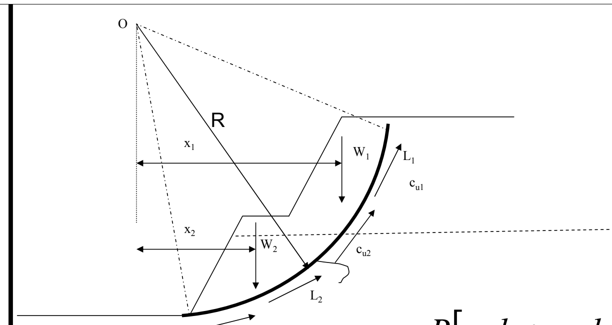
- Taylor (1937) published stability coefficients for the analysis of homogeneous slopes in terms of total stress.
- H= height of slope,
- N_s = stability coefficient (depends on α (slope angle) and D (Depth)).
- F_s = minimum factor of safety

$$N_s = \frac{c_u}{F_s \gamma H}$$

Taylor's Stability Coefficient (ϕ_u=0)

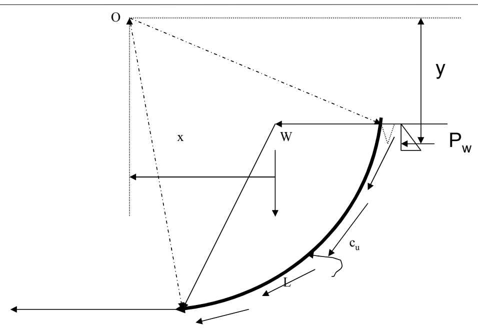


Rotational Slips



$$F_s = \frac{R[c_{u1}l_1 + c_{u2}l_2]}{W_1x_1 + W_2x_2}$$

Rotational Slips



$$F_s = \frac{R[c_{u1}l_1 + c_{u2}l_2]}{W_1x_1 + W_2x_2 + P_w y}$$

Add $P_w y$ to disturbing moments

The Method of Slices

The soil mass above a trial failure surface is divided by vertical planes into a series of slices of width b.

$$F_s = \frac{1}{\sum W\sin\alpha}\sum\left[c'l + (W\cos\alpha - ul)\tan\phi'\right]$$

For total stress, c_u and ϕ_u used and u=0.

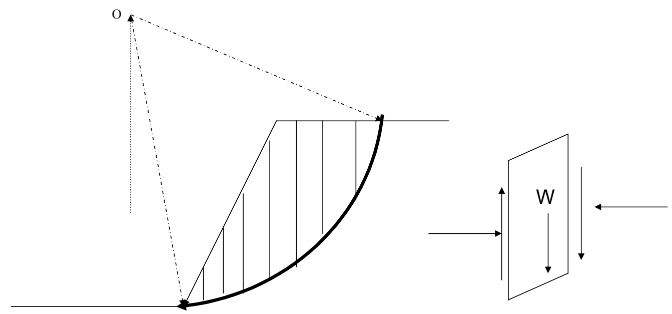
Swedish Solution: Assumes that the resultant of the interslice forces is zero.

Bishop Routine Solution: Assumes resultant forces on the sides of the slices are horizontal.

Procedure for the Method of Slices

1. Draw the slope to scale and note the positions and magnitudes of any external loads.
2. Draw a trial slip surface and identify its point of rotation.
3. Divide the soil mass above the slip surface into a convenient number of slices. More than five slices are needed for most problems.
4. For each slice:
   a) Measure the width of slice (b)
   b) Determine W (weight of a slice)
   c) Measure α_j for each slice
   d) Calculate r_u.
5. Calculate F_s.

The Method of Slices
(Fellenius/Swedish Solution)



Method of Slices

- Bishop's Method

$$F_s = \frac{\sum \left[\left\{ c'b + (W - ub)\tan\phi' \right\} \frac{\sec\alpha}{1 + (\tan\alpha \tan\phi' / F_s)} \right]}{\sum W \sin\alpha}$$

$$u = \frac{r_u W}{b}$$

Summary:

- For temporary slopes and cuts in fine-grained soils with low permeability choose the undrained strength c_u and carry out an analysis in total stresses.
- For permanent slopes, choose an effective stress strength and calculate pore pressures separately.
- Bishop (1955) assumed a circular slip plane and considered only moment equilibrium.
  - He neglected seepage forces and assumed that the lateral normal forces are collinear.
  - In Bishop's simplified method, the resultant interface shear is assumed to be zero.