SLOPE STABILITY (LIMIT EQUILIBRIUM) ANALYSIS (27)

I Main Topics

A General procedure for slope stability (limit equilibrium) analyses
B Alternative definition of factor of safety
C Types of limit equilibrium analyses
D Comments on analyses for factors of safety
E Example(s)

II General procedure for slope stability analyses

<u>Focus here is on the effect of various conditions that promote slope failure and not on the numerical results.</u>

Short version

A Postulate slip mechanism (failure criterion and failure geometry)
B Calculate shearing resistance by method of statics
C Compare calculated resistance with shear strength
D Find lowest factor of safety by iteration if failure surface is not known

Long version

A Determine geometry of potential slide block, potential failure surface(s), and identify other key factors (whatever they may be).
B Decide on appropriate type of stability analysis and failure criteria.
C Calculate the static vertical force due to the weight of the block.
D Determine the static components of force perpendicular (normal) to the potential slip surface and the driving force parallel to the potential slip surface. Calculate the driving moment if need be.
E If the slide material is saturated, calculate the pore pressure and then calculate the effective normal stress acting on the potential slip surface (divide the appropriate force by the area of the potential slip surface). If the effect of flowing water in a slope is accounted for, the pore pressure used should be for flowing water.
F Calculate the resisting stress using the effective normal stress.

- G Calculate the resisting force by multiplying the resisting stress by the area of the potential rupture surface (or calculate the resisting moment by multiplying the appropriate shear strength by the appropriate lever arm).
- H Calculate the factor of safety by dividing the resisting force (moment) by the driving force (moment).
- I Repeat with different conditions (failure surfaces, strengths, etc.) to test sensitivity of result.

III Alternative definition of factor of safety (F.S.)

- A Gauge for which the shear strength model parameters would be reduced to bring slope into limiting equilibrium (verge of failure) along a given slip surface
- B Usually F.S.= $\frac{\text{Resisting moment}}{\text{Driving moment}}$ or F.S. = $\frac{\text{Resisting shear strength}}{\text{Shear driving stress}}$
- C Moment = Force x lever arm = Stress x area x distance
- D Key Points
  - 1 The factor of safety is not a measure of stability at a point; it is a number that represents averaging
  - 2 The factor of safety cannot be measured in the field
  - 3 The factor of safety is model-dependent
  - 4 A factor of safety higher significantly greater than one is desirable because uncertainty regarding the geologic conditions and pore pressure variability.

Significance of factor of safety (from Sowers, 1979, p. 587)

Factor of Safety	Significance
Less than 1.0	Unsafe
1.0 - 1.2	Questionable safety
1.3 - 1.4	Satisfactory for cuts, fills; questionable for dams
1.5 - 1.75	Safe for dams

IV Three main types of limit equilibrium analyses

- A Planar slip surface (uses resisting/driving forces)
- B Circular slip surface (uses resisting/driving moments): Rahn, p. 183
- C Method of slices (uses resisting/driving moments): Rahn, p. 184-186.

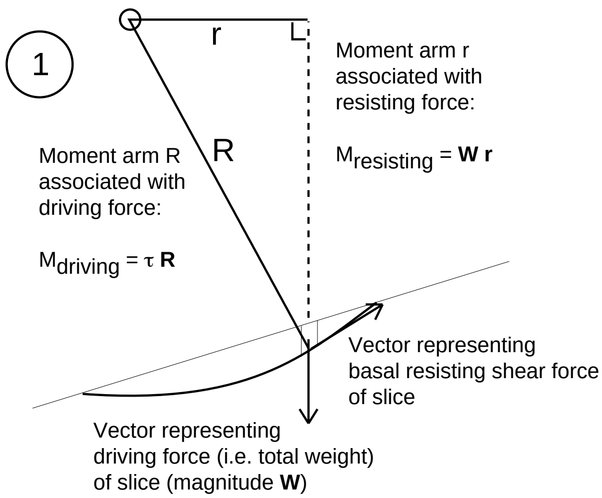
V Some comments on analyses for factors of safety

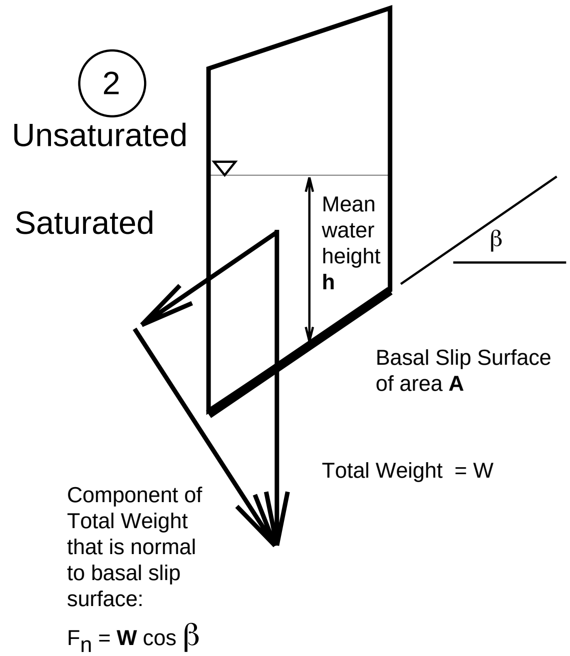
A Sowers (1979, p. 579) on computer analyses by method of slices: "The author has found their indiscriminate use misleading and sometimes unsafe... The computed minimum [factor of safety] is often unrealistic or geometrically impossible, diverting attention from the real answer."

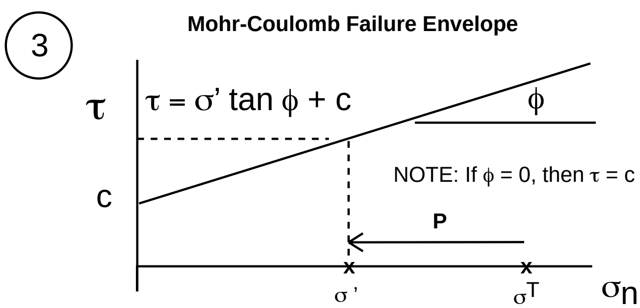
B Morgenstern and Sangrey (SR 176, p. 165-166): "The analysis of a rock slope in terms of a factor of safety is a subordinate activity to achieving a clear understanding of the controlling geology and water-pressure configuration."

C From p. 187 of Rahn (1996): “Most mathematical models and computational abilities are more precise than the ability to determine reliable values for the properties and parameters needed for their application.”

Method of Slices







Total normal stress = $\sigma^T = F_n / \mathbf{A}$

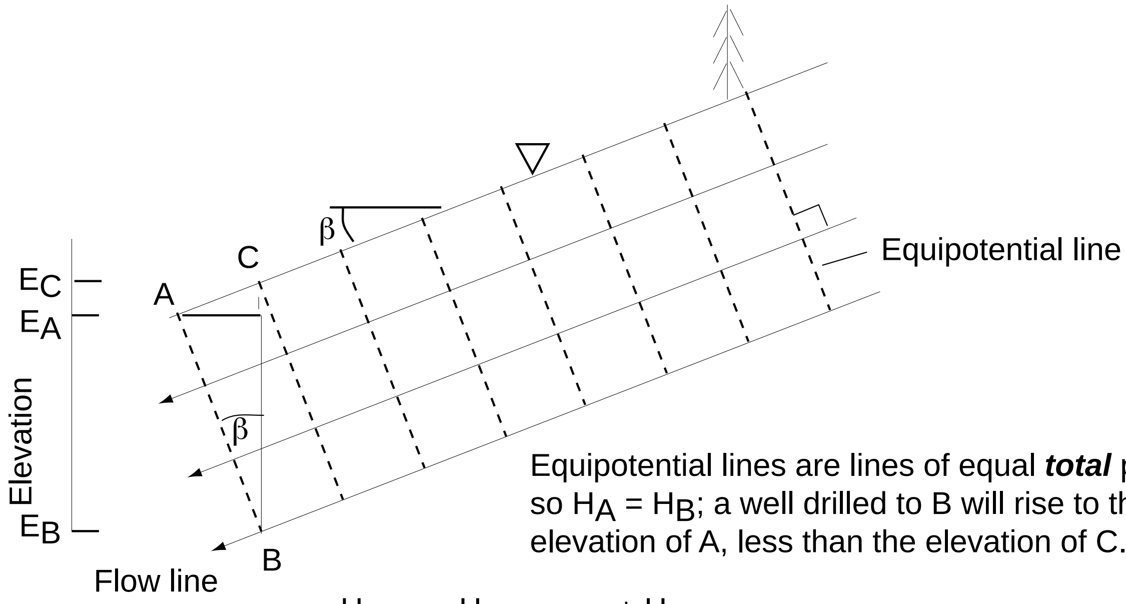
Pore pressure = $\mathbf{P} = \rho_{H_20}\, g\, h$

Effective normal stress = $\sigma' = \sigma^T - \mathbf{P}$

Resisting shear stress = $\tau = \sigma' \tan \phi + c$

Resisting shear force = $\tau\, \mathbf{A}$

Effect of Flow Parallel to a Slope on Water Pressure



Equipotential lines are lines of equal ***total*** potential so $H_A = H_B$; a well drilled to B will rise to the elevation of A, less than the elevation of C.

$H_{total} = H_{elevation} + H_{pressure}$

$H_A \quad = E_A \qquad + 0$

$H_B \quad = E_B \qquad + H_{pressure(B)}$

Because $H_A = H_B$, $H_{pressure(B)} = E_A - E_B$
So the pressure head at B is less than $E_C - E_B$.
Flowing water reduces the pressure.

By examining the geometry of triangle ABC

$E_A - E_B = \{(E_C - E_B) \cos\beta\} \cos\beta = H_{pressure(B)}$

The pressure at B is the pressure head x $(\rho_{H_20})(g)$

$P_B = [\ (E_C - E_B) \cos\beta\} \cos\beta\ ](\rho_{H_20})(g)$

This is the pressure that affects the effective stress at B.