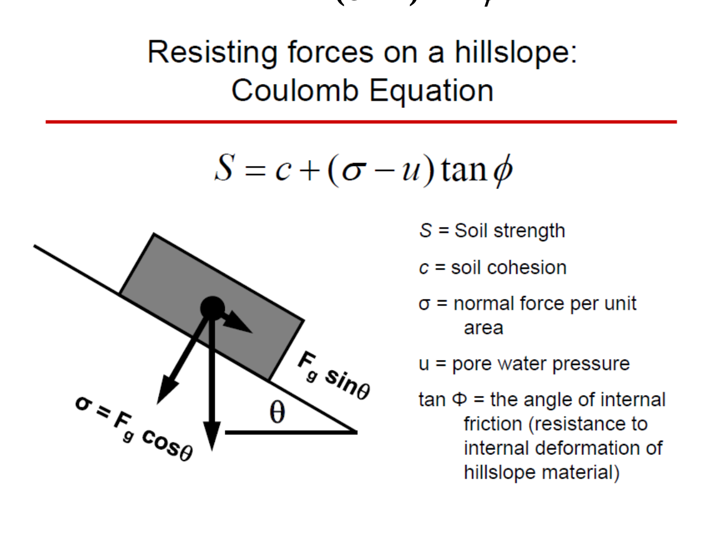
Introduction to Geomorphology (GEOG 213)

LABORATORY 4
SLOPE STABILITY ANALYSIS

The purpose of this exercise is to illustrate the roles of shear stress, friction, cohesion and pore water pressure on slope stability.

The Coulomb equation for shear strength (S) is given by

$$\boldsymbol{S = c + (\sigma - u) \tan \phi}$$



wherein c is cohesion, σ is normal stress, u is pore water pressure, and ϕ is the angle of internal friction. Cohesion is the part of shear strength that is independent of the normal effective stress. In shallow soils it may derive from cementing of the soil particles (*true cohesion*) or from root strength of the vegetation.

At depth h, the gravitational stress, W, or weight per unit area, is $\rho_b\, g\, h \cos\theta$, wherein ρ_b is bulk density of the soil or rock mass and g is the acceleration of gravity. $\rho_b\, g$ is the *specific weight* of the soil. (ρ_b for soils is about 1650 kg m^{-3}, and for rock it is about 2650 kg m^{-3}).
For a slope of angle θ, the normal stress is

$$\boldsymbol{\sigma = \rho_b\, g\, h \cos\theta}$$

the pore water pressure is

$$\boldsymbol{u = \rho_w\, g\, h_w \cos\theta}$$

and the gravitationally applied shear stress is

$$\boldsymbol{\tau = \rho_b\, g\, h \sin\theta}$$

The effective normal stress, $\sigma - u$, is the difference between the normal stress and the pore water pressure (which is positive below the water table). **If shear stress (τ) exceeds the shear strength (S), the slope will fail.**

Assignment (12 marks):

g = 9.81 N/kg; angle of internal friction $\phi = 35^o$
the mineral density is ρ_r = 2650 kg m^{-3}; water density is ρ_w = 1000 kg m^{-3}
Wet bulk density is $\rho_b = v_r\rho_r + m(1- v_r)\rho_w$
v_r is the volume fraction of solid material, $v_r = 0.6$
m is the portion of saturated thickness of the slide; m = 1 for a fully saturated slide and m = 0 for a completely dry slide

1) Consider a slope of **unconsolidated** material which contains a potential failure plane (e.g., a layer of low cohesion) at a depth of 5 m (measured normal to the surface) below the surface. Slope angle and failure plane angle are both 30^o.

(a) Calculate the shear stress, τ, and the shear strength, S, at the base of the 5m layer, for the following conditions:

cohesion $c = 0$
the water table is at 5 m depth, so $u = 0$

(2 marks)

(b) Suppose the water table rises to 2.5 m above the potential failure plane. Recalculate τ and S. (Notes: You will need to calculate $u = \rho_w g\, h_w \cos\theta$. You will also need to calculate the wet weight of the soil column). (3 marks)

(c) Is the slope subject to failure in either case above (case(a) and case (b))? (2 marks)

(d) In order for the slope with the water table to be stable (Factor of safety, FS = S / τ = 1.0, how much cohesion must be generated by root strength and interparticle cohesive bonds in either case above (case(a) and case (b))? (2 marks)

2) When rock breaks down it first forms relatively large blocks which pile up as talus. Voids between the blocks are large so water drains freely and does not contribute to sensible pore water pressures ($S = \sigma\ \tan\phi$ and the angle of repose, $\theta = \phi \approx 35^o$ for most materials). As weathering continues, sandy and silty grus develop, organic and aeolian material enter the pile, and the voids are filled. Again, the dry strength has $\theta \approx 35^o$ and $c = 0$. However, significant pore water pressure may develop in the fine matrix material. Suppose that the slope fails when the material is saturated. For failure at depth h, the *factor of safety* is

$$FS = 1.0 = \frac{S}{\tau} = \frac{(\rho_b - \rho_w)\, g\, h \cos\theta \tan\phi}{\rho_b g\, h \sin\theta}$$

Find θ, the repose angle, for $\phi = 35^o$. In considering ρ_b, remember that *the soil is saturated.* (3 marks)

REMINDER: DON'T JUST GIVE A NUMBER FOR THESE QUESTIONS, PLEASE SHOW THE PROCESS OF CALCULATION.