Names: **ESS 315**

Lab #4 Slope processes: Erosion Prediction and Landslides

In this lab we will investigate two important hillslope processes: soil loss due to sheet and rill erosion, and shallow landsliding. Both of these processes can be investigated quantitatively. NOTE: If you have a laptop and are very comfortable using a spreadsheet (like Excel) to solve math problems, you may want to bring your computer with you to lab. Otherwise, you will need a calculator.

Part 1: Soil Loss

The Universal Soil Loss Equation (USLE) is useful for estimating long-term average annual sheet and rill erosion. In this lab you will use this equation to calculate the soil loss of a given basin and will use that information to evaluate the effects of the mobilized sediment on a downstream reservoir. You will also use it to consider the long-term effects of erosion on different soil horizons within a single soil profile.

Because soil normally forms very slowly from underlying materials, only small amounts of erosion can be tolerated without decreasing the thickness of productive soil. Sheet and rill erosion to a depth of 1/10 inch equals about 15 tons of soil loss per acre. This 15-ton rate is approximately the point where visual evidence of erosion can first be seen, yet this is already many times the rate at which replacement soil will form.

It is important to remember that this equation is <u>exclusively for long-term average annual sheet and rill erosion</u> only and does not estimate:

- ✓ erosion from individual storm events (although it can be modified to do this)
- ✓ gully erosion
- ✓ soil loss from landslides and other mass wasting processes

HELPFUL REMINDERS

Total soil loss per year = "A" times the total site area in acres

1 ton = 2000 pounds

43,560 ft^2 = 1 acre

640 acres = 1 sq. mile

1 acre foot = 1 acre, 1 foot deep (volume) = 43,560 ft^3

SOIL LOSS EQUATION:

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

A is the computed soil loss per unit area per unit volume. This is expressed in tons per acre per year if tons per acre is the unit used for K and a year is the period used for R. Different units and periods can be used, but we will use tons per acre per year, the most common units for this equation.

R is the rainfall and runoff factor. This factor reflects the impact of raindrops and the relative amount and rate of runoff, and it is different in different areas. They have been calculated for the United States by the Department of Agriculture and are shown in the map provided (Figure 4-1).

K is the soil erodibility factor. This value reflects the unique erodibility of a given soil if all other factors stay the same (area, length and steepness of slope, cover, and support factor). K is determined using a nomographic device shown in Figure 4-2.

L is the slope-length factor, which adjusts for the slope length assumed in the tabulated value for K. Use the LS chart* (Figure 4-3) provided to find the L value.

S is the slope-steepness factor, which adjusts for the slope steepness assumed in the tabulated value for K. Use the LS chart* (see above) provided to find the S value.

C is the cover and management factor, which adjusts for the cover assumed in the value for K. To find the accurate C value for your site you must use the appropriate table. Table 4-1 gives the values for the types of cover presented in this exercise.

P is the support practice factor, which adjusts for the support practice assumed in the tabulated value for K. Because neither of our sites are agricultural, use a tabulated value of 1 for the support practice. If, in the future, you need to know the P value for a given site, see the U. S. Department of Agriculture's Agricultural Handbook Number 537, "Predicting rainfall erosion losses," page 34.

The L and S factors are combined in one chart-the LS chart. We are assuming that the sheet-wash flows over constant slopes that do not vary in angle over their length. In reality, of course, this is rarely the case. If there is a 200-foot slope that changes from, say, a 3% slope to a 6% slope 100 feet from the top you cannot simply calculate for a 100 foot, 3% slope and a 100 foot 6% slope and add the two together. This is because once the sheet has reached the beginning of the second slope it has already gained a substantial thickness-the LS chart assumes that the sheet is beginning at a thickness of zero. If you do ever need to calculate the LS factor for a variable slope you can find the method for doing so in the U.S. Department of Agriculture's Agricultural Handbook Number 537 "Predicting Rainfall Erosion Losses" page 16.

Problem 1-1

Consider a drainage basin in central Missouri with the following characteristics:

Soil: 2% organics, 18% clay, 30% sand, (0.1-2.0 mm), 50% silt and very fine sand (0.002-0.1 mm); fine granular texture, slow permeability.

Hillslopes: constant 8% slope, most slopes 300 ft long

Land use:

- 10 sq. miles of forest (90% canopy cover, 95% forest litter ground cover, managed to prevent fires)
- 2 sq. miles of fields with 100% ground cover (RH-most column of the "C factors for pasture---"table): the area is covered with weeds about 0.5 m tall, providing about 50% canopy cover
- 100 acres of construction site for a shopping mall; bare ground (has recently been cleared from the forest)

a) Calculate the amount of erosion in the basin in tons/year.

b) A town downstream has a reservoir with a volume of 100 acre-feet. Assuming 70% of the sediment from the drainage basin reaches the reservoir and settles out and that the deposited sediment has a density of 100lbs/ft^3, what percent of the reservoir volume would the sediment occupy after 1 year?

c) If this sedimentation rate continues in future years, what is the lifetime of the reservoir?

d) Is this a reasonable prediction?

e) The town brings suit against the shopping mall developer, demanding that the construction site be managed (mulching, sediment trapping ponds, etc.) to protect the lifetime of the reservoir. The judge declares that if the sediment from the construction site by itself is responsible for more than 1/5 of the infilling caused by the total sediment load, such management practices must be used. You are engaged by the city to determine this matter. What is your finding?

Problem 1-2

On a 400-foot-long, 5% slope, a cover factor of 0.8, a support practice factor of 1.0, and R of 200, we find the following soil:

A Horizon 2 feet thick	4% organic 16% clay 70% silt 10% sand	Very fine granular Rapid draining Density 80 lbs/ft^3
B Horizon	0% organic 30% clay 65% silt 5% sand	Medium granular to coarse granular Slow to moderate drainage

a) How long will it take to entirely erode the A horizon?

b) When the A horizon is gone, by what factor will the rate of soil erosion increase (all else remaining constant)?

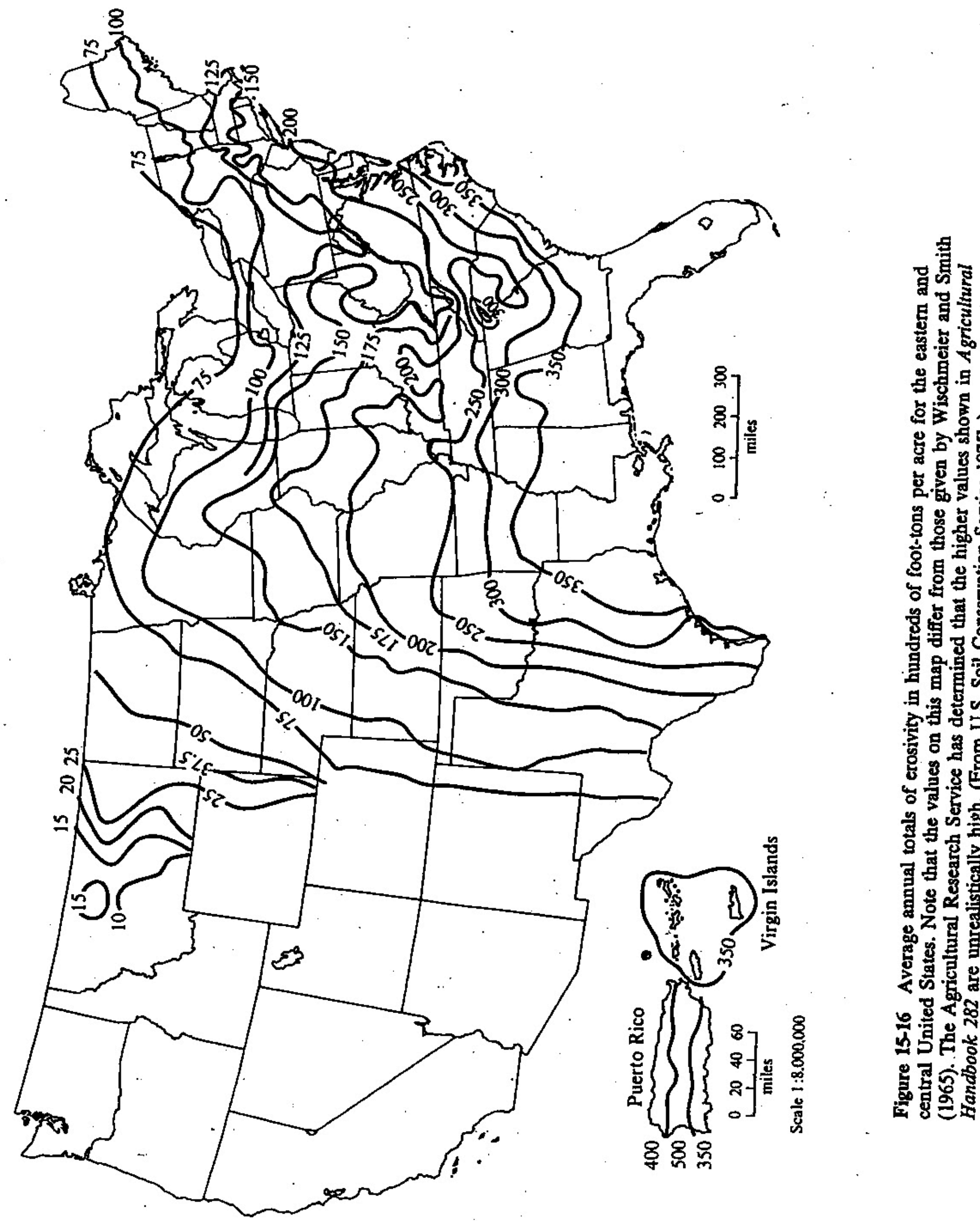


Figure 4-1. Rainfall and Runoff Factor (R) for the United States

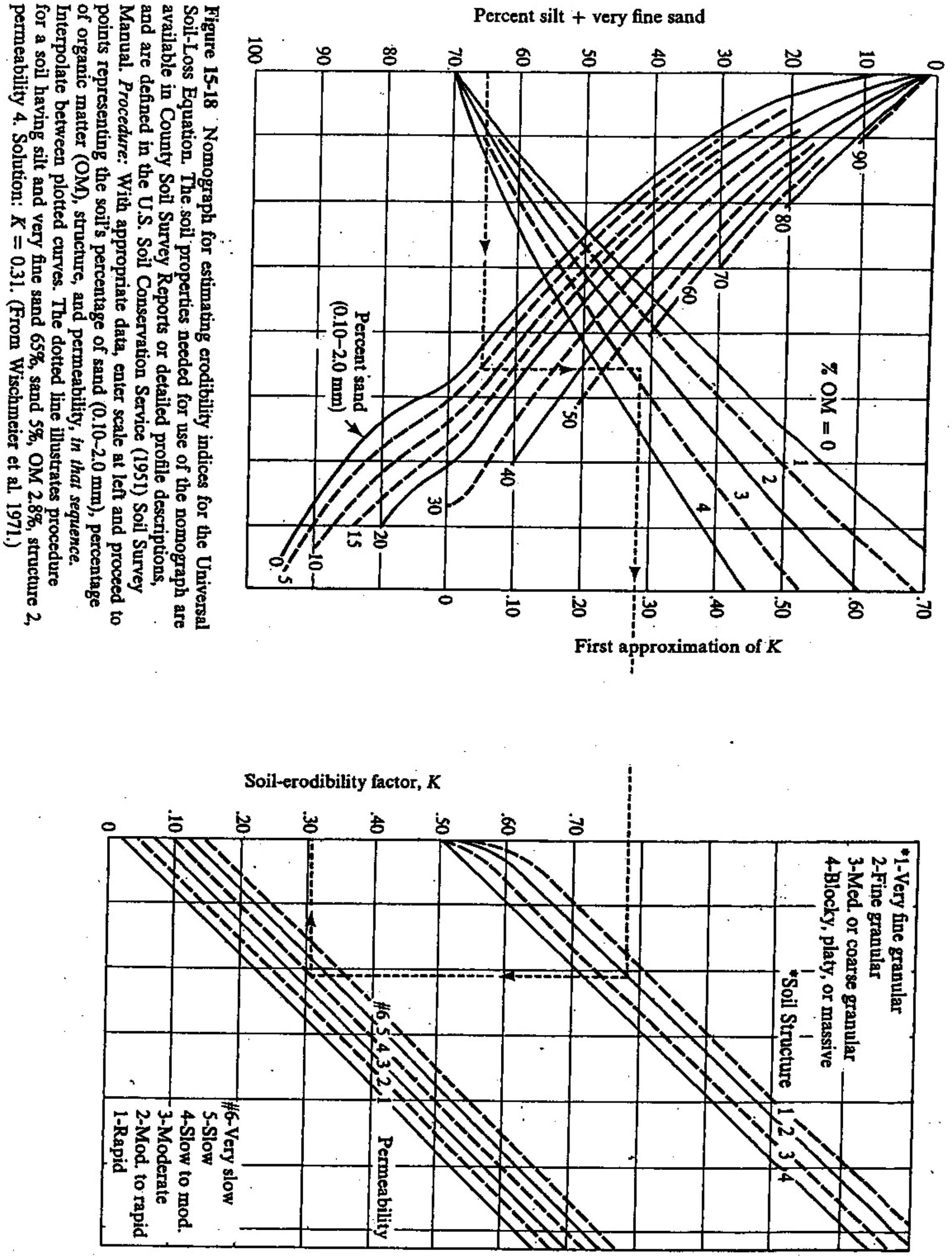


Figure 4-2. Nomograph for determining the soil erodibility factor (K).

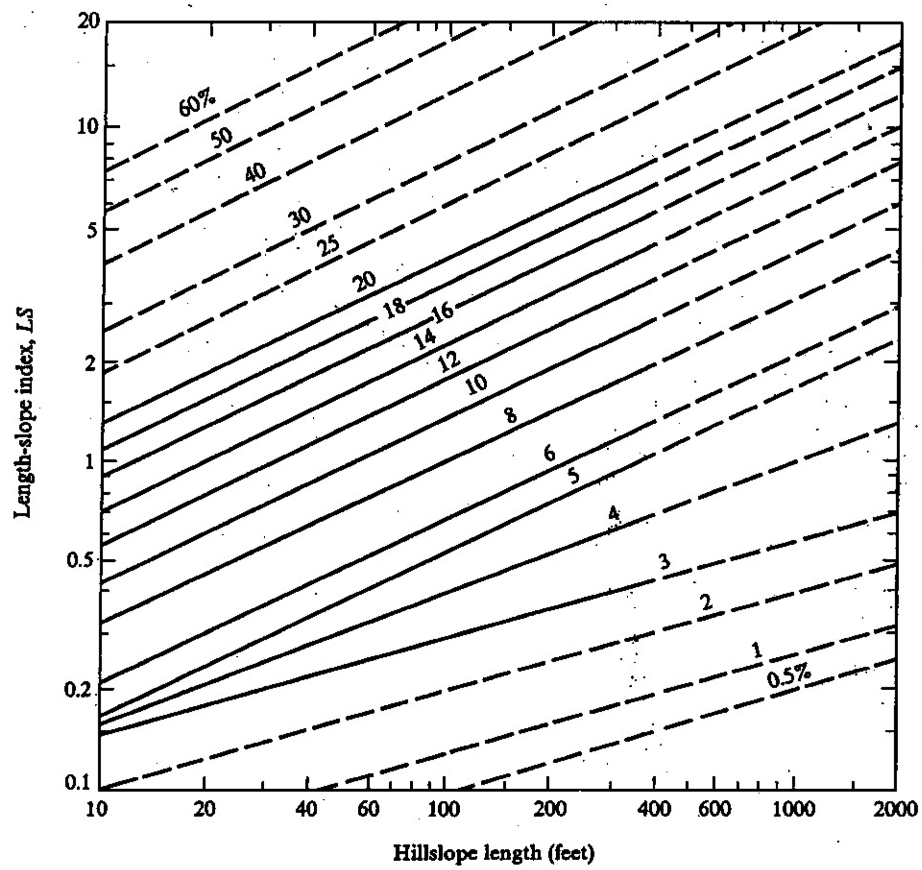


Figure 15-19 Chart for evaluating the length–slope factor, *LS*, in the Universal Soil-Loss Equation. The solid lines represent conditions within the range of data from which the curves were derived. The dashed lines are based on extrapolations and should be used with care. (From U.S. Soil Conservation Service 1975b.)

Figure 4-3. Length-slope factor (LS) chart.

Table 15-3 Cropping-management factors, *C* in the Universal Soil-Loss Equation, for woodland. (From U.S. Soil Conservation Service 1975b.)

TREE CANOPY (% OF AREA)	% OF AREA COVERED BY > 2 INCHES OF FOREST LITTER	UNDERGROWTH	*C*
100–75	100–90	Grazing and burning controlled	0.001
		Heavily grazed and burned	0.003–0.011
70–40	80–75	Grazing and burning controlled	0.002–0.004
		Heavily grazed and burned	0.01–0.04
35–20	70–40	Grazing and burning controlled	0.003–0.009
		Heavily grazed and burned	0.02–0.09
<20	Treated as grassland or cropland		

Table 15-4 Cropping-management factors, *C* in the Universal Soil-Loss Equation, for pasture, rangeland, and idle land. (From U.S. Soil Conservation Service 1975b.)

TYPE OF CANOPY AND AVERAGE FALL HEIGHT OF WATER DROPS	CANOPY COVER (%)	GROUND COVER*	PERCENT GROUND COVER 0	20	40	60	80	95–100
No appreciable canopy		G	.45	.20	.10	.042	.013	.003
		W	.45	.24	.15	.090	.043	.011
Canopy of tall weeds or short brush (0.5 m fall ht)	25	G	.36	.17	.09	.038	.012	.003
		W	.36	.20	.13	.082	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.075	.039	.011
	75	G	.17	.10	.06	.031	.011	.003
Appreciable brush or brushes (2 m fall ht)	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.085	.042	.011
	50	G	.34	.16	.085	.038	.012	.003
		W	.34	.19	.13	.081	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.077	.040	.011
Trees but no appreciable low brush (4 m fall ht)	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.087	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.085	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.083	.041	.011

*G = Cover at surface is grass, grasslike plants, decaying compacted duff, or litter at least 2 inches deep.
W = Cover at surface is mostly broadleaf herbaceous plants (as weeds with little lateral-root network near the surface, undecayed residue, or both).

Table 4-1. Table for determining the cover and management factor (C).

Part 2: Landslide Hazards

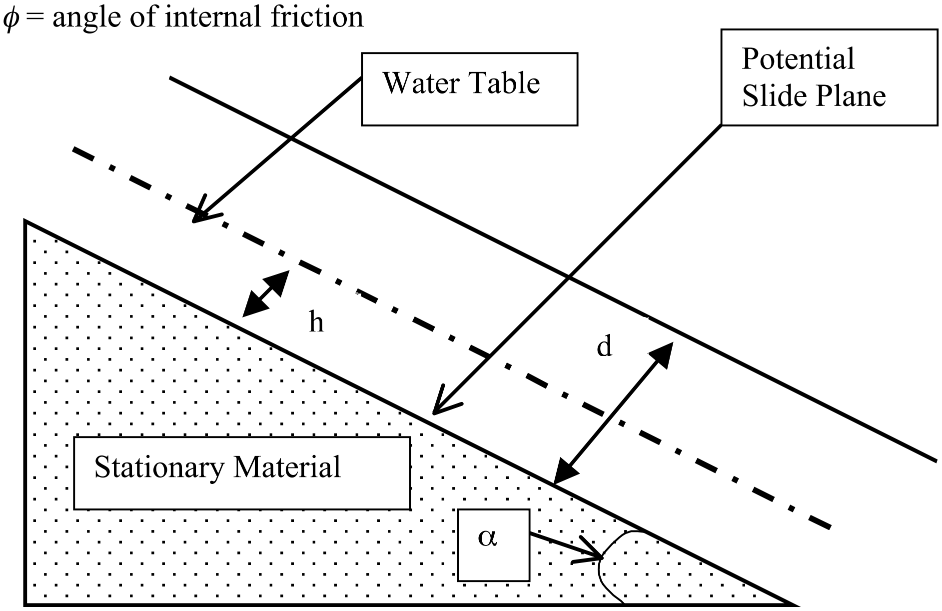
Now you will use a quantitative process to determine the stability of debris slides, which are a common type of slide in the Seattle area. These failures occur on slopes of approximately constant inclination, are shallow relative to their areal extent, and involve a fairly uniform thickness of material. Typically, the zone of weakness (slide plane) will be at the base of the root zone or at the contact between soil and bedrock. The slide plane can thus be considered to lie parallel to the slope.

You will use the relationship between the shear stress (τ) and shear strength (S) of a given slope to determine the *Factor of Safety* (F_s). If F_s is greater than 1.0, then the slope is considered safe. If F_s is near or below 1.0, it is potentially unstable. The steepest angle at which the slope is still marginally stable (e.g., $F_s = 1.0$) is called the *critical angle*.

The **Factor of Safety** is:

$$F_s = \frac{S}{\tau} = \frac{C + (\gamma_s d \cos\alpha - \gamma_w h)\tan\phi}{\gamma_s d \sin\alpha}$$

where S = shear strength
τ = shear stress
C = effective cohesion of the material
γ_s = unit weight of material (e.g. weight per unit volume of soil)
d = thickness of material above the slide plane
α = angle of slope in degrees
γ_w = unit weight of water (62.4 lbs/ft^3)
h = hydraulic head at the slide plane (distance of slide plane below water table)
ϕ = angle of internal friction



Shear Stress

Shear stress (τ) consists of the forces acting on a mass of material to pull it down a slope.

Shear stress is given by the denominator of the above equation:

$$\tau = \gamma_s d \sin\alpha .$$

Shear stress increases as:

- the unit weight of the material (γ_s) increases, such as when dry soils absorb water
- the depth of the material (d) increases
- slope (α) gets steeper

Shear Strength

Shear strength (S) consists of the forces that hold a mass of soil in place, resisting down-slope movement.

Shear strength is more complex than shear stress. It must account for such things as *cohesion* (the tendency of the material to stick together), *pore water pressure* (water between the individual grains exerts a pressure that tends to push the grains apart), and the *internal friction* (how hard it is for grains to slide over each other). The internal friction depends on the size, shape, roundness, and sorting of the grains that compose the material.

Shear strength is given by the numerator in the above equation:

$$S = C + (\gamma_s d \cos\alpha - \gamma_w h)\tan\phi$$

Shear strength increases if:

- C increases
- γ_s increases
- d increases
- α decreases (cos α increases as the slope angle decreases)
- h decreases, or groundwater is absent altogether (h=0)
- ϕ is high

Problem 2-1

Two prominent geologic units in Seattle that tend to be associated with landslides are the Lawton Clay and the Esperance Sand (you can find these on the Surficial Geology of Seattle maps if you like). In this section, you will use the F_S equation to calculate the stability of slopes made of these deposits given different groundwater and hillslope angle conditions.

a) Calculate the factor of safety for a 3^o slope on the Lawton clay, given that γ_w =62.4 lbs/ft^3, and assuming that the weakest plane lies 4 ft below the surface and 1 ft below the water table. For the weathered Lawton, typical for the upper part of this unit, C = 0, ϕ = 15^o, and γ_s = 120 lbs/ft^3.

Show your calculation of the F_S here:

b) Is the slope stable or unstable?

c) Do the same calculation for an 8 ^{o} slope (keep all of the other variables the same).

d) Now try a "worst case", where the water table is right at the surface of an 8^o slope.

Problem 2-2

The Esperance Sand has an effective angle of internal friction (ϕ) of 35°, a density (γ_s) of 120 lbs/ft^3, and an effective cohesion (C) of 0.

a.) Applying the same worst-case conditions as above (water table is right at the surface of the slope), what would its steepest safe slope be? As stated on Page 9, the steepest safe slope is known as the “critical angle,” and is the angle at which $F_S = 1.0$. You will need to calculate the F_S for a variety of angles or use a “solver” function in your calculator to determine this.

b.) Considering the permeability of sand, how likely is it that groundwater would rise to the surface, saturating the soil completely? How will this affect the value of *h* in the equation? Calculate a new critical angle, assuming no groundwater.

Additional Questions

1.) What factors that affect slope stability does the Factor of Safety equation take into consideration? (Please name at least 3)

2.) What factors that affect slope stability does the Factor of Safety equation *not* take into consideration? (Please name at least 3)

3.) Please list at least three activities of humans that could increase the potential for landslides.

Now look at the Preliminary Landslide Map for Seattle
The USGS report containing this map can be found at:http://pubs.usgs.gov/of/2000/ofr-00-0303/

4.) First, let's get acquainted with this map. What do the following map features represent?

a. The yellow-to-red shading

b. The blue line

c. The black contour lines

5.) What neighborhoods of Seattle are at the highest risk of landslides?

6.) What two physical factors exert the most control over *where* the landslides occur?

7.) What factor probably controls *when* landslides are likely to occur?