

The Geology of Pacific Northwest Streams, Lakes, & Deserts

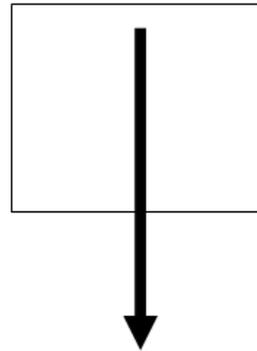
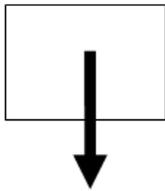
Lab 6: Landslides and Slope Stability

Name: _____ Date: _____

Part I. Vector Addition

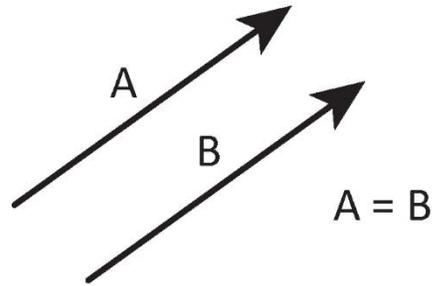
Forces are usually represented by vectors; graphically we draw these as arrows. The length of the arrow represents the amount of force, and the while the direction of the arrow is the direction of the force. So a gravitational force is represented by an arrow downward, and the larger the arrow the larger the mass of the object.

A small mass object has a smaller arrow. In this case the arrow on the second object is twice as long showing the object is twice as heavy.



Two vectors are equal if they have the same magnitude and direction, regardless of whether they have the same starting points.

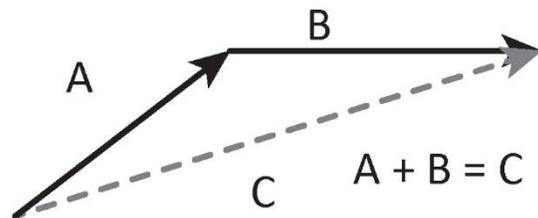
$$(A = B)$$



Vectors are added graphically by placing the initial point of one vector on the final point of the other. This is sometimes referred to as the "Tip-to-Tail" method.

Notice that you could also have moved the tail of A to be at the head of B and still get the same result:

$$(A+B = C)$$



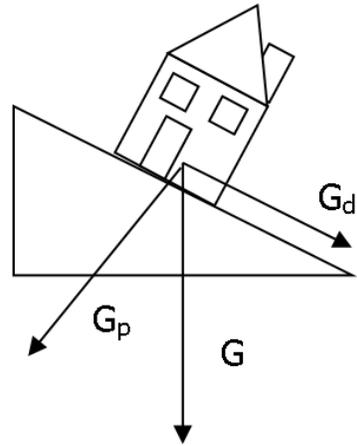
The length of A plus the length of B does NOT equal the length of C. Vectors are not just lengths, but lengths AND directions!

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Just as you can add vectors, you can divide them into multiple forces. This is called “resolving a vector.” In the above example, you can divide C into two components A and B.

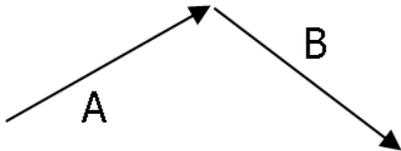
When dealing with landslides, we are interested in the interplay between two forces, friction (F), which works against objects moving downslope, and the pull of gravity down-slope (Gd). To find Gd we must resolve the gravitational force (G) into two components, one perpendicular to the slope (Gp) and one down the slope (Gd).



1. Which of the following vectors are equal?

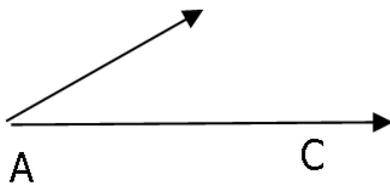


2. Draw the vector created by adding vectors A and B.



3. What is the length of vector A? What is the length of vector B? What is the length of vector C? (Use a ruler and measure in millimeters.)

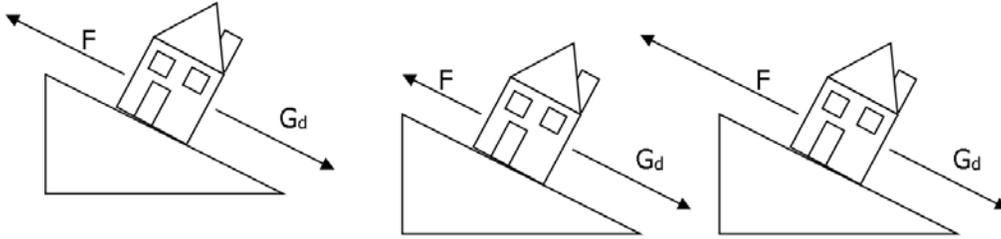
4. What vector must be added to vector A to get vector C? Draw it in. What is its length?



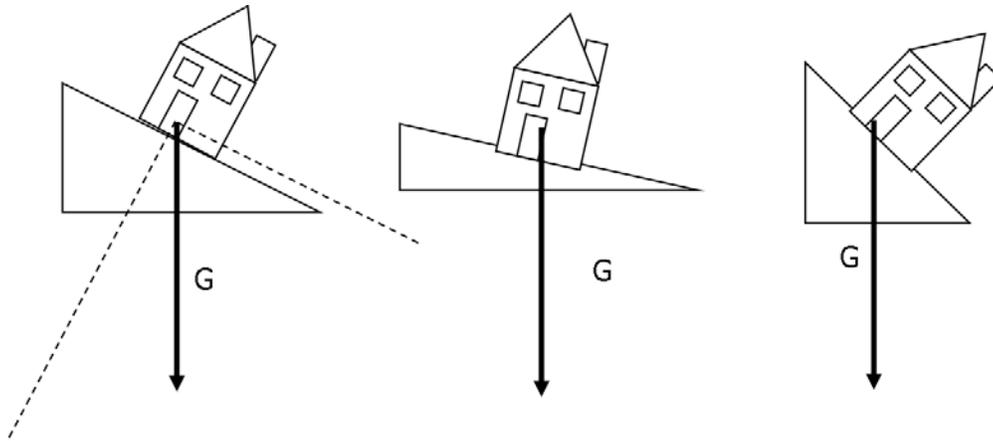
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5. Mark the following diagrams of houses on slopes as “stable” “unstable” or “just about to slide”.



6. On the following diagrams, resolve the gravitational force (G) into a downslope (G_d) and a perpendicular (G_p) force. In the first example, the dashed lines show the direction of the G_d and G_p forces. You just need to draw the two vectors so that they add up to G . In the others, you will need to make sure the directions and lengths are correct. Please label the vectors you draw.



7. The G vectors in the previous example are all the same length, 40 mm.

If the house weighs 40,000 pounds, then each millimeter of length of the vector in this diagram equals how many pounds? _____

How long would the G vector be if the house was 60,000 pounds? _____

Measure G_d in each diagram in problem 6. How many pounds of force are pulling the house downhill in each case?

8. A boring (drilling) into the ground examines the friction on the slope below the house and finds that the friction is equal to 21,000 lbs. Draw this force into the pictures above, then label each figure as stable, unstable, or just about to slide.

9. A developer buys a plot of land with a 25° slope. The friction in the slope is measured at 60,000 kilograms. Draw a diagram of this and figure out what the maximum weight a house can be on this property. (BONUS! Show how you can calculate this using trigonometry instead of graphically.) stable or just about to slide.

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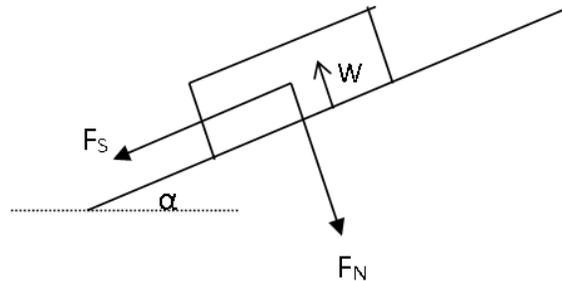
Part II. Factor of Safety

A. Assessing Slope Stability Using Factor of Safety

Engineering geologists often use the relations between shear stress (the component of stress that operates in the down-slope direction, F_s) and shear strength (the properties that resist shear stress, i.e., cohesion + normal stress (F_N)) to carry out a slope stability analysis. The ratio of shear strength to shear stress is called the factor of safety. We can consider this ratio for the simplified case of a planar failure on an infinite slope as pictured below.

When this ratio is greater than 1, shear strength is greater than shear stress and the slope is considered stable.

When this ratio is close to 1, shear strength is nearly equal to shear stress and the slope is unstable.



F_s = shear stress
 F_N = normal stress
 α = slope angle
 W = height of water table

In this exercise, you will consider the different variables that go into calculating the factor of safety. You will then assess which variables are likely to change over the relatively short time scale of weeks to years and which variables are intrinsic to the slope or the material making up the slope. The primary goal of this exercise will then be to carry out a sensitivity analysis. This analysis will allow you to determine which variables most affect the factor of safety (and thus slope stability) when they change.

.1. Write out the equation for the factor of safety and define all of the variables. The Numerator is the shear strength and the denominator is the shear stress.

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.2. You own a geotechnical engineering firm in central California and your company has been hired to conduct a slope stability analysis. Consider a 10.0 m-thick mass of regolith sitting on top of a bedrock surface with a slope of 14 degrees. A home is located at the top of this slope (and set back from the edge only 20 m). Upon an initial visit, you determine that the regolith is unsaturated. You also estimate the following additional parameters for this site:

- regolith cohesion = 1100 N/m²
- regolith angle of internal friction = 15°
- density of regolith = 2200 kg/m³
- (density of water = 1000 kg/m³)

.a. Calculate current values for shear strength and shear stress on this slope. Show your work.

.b. What is the value for the Factor of Safety? Would you consider the slope currently stable? Explain your answer.

.c. What advice would you give to the homeowners regarding the safety of their home? What remediation can you suggest if any is needed?

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Part III. Angle of Repose

In this activity you will measure the maximum slope at which grains are stable (angle of repose). You will explore how different properties of the sediment influence slope stability and lead to different slope failures (mass movements).

Materials:

- Pan or tray
- Sediment samples: dry sand, damp sand, angular gravel, rounded gravel
- protractor
- small scoop
- container of water

Instructions (Read these carefully or you will have to redo your responses!):

1. Slowly pour a stream of dry sand into the center of your pan or tray. Avoid disturbing your pile and carefully measure the maximum angle, or steepest slope, of the dry sand. This slope is called the angle of repose. Record your answer on the data sheet (1).
2. Add a few grains (a pinch) of dry sand to the top of your pile and see how the grains move. Repeat, observing the movement again. Describe the downward movement of the dry sand on the data sheet (2). Note whether the sand grains move individually or in large groups.
3. Put all your dry sand back into its container. Sweep your tray clean (use the garbage cans).
4. Repeat the experiment using damp sand. Place a pile of damp sand in the center of your pan or tray. You will probably have to scoop the sand instead of pour it. You can gently pack the pile together, but use only gentle pressure. What is the maximum angle of the damp sand? (3)
5. Add a pinch of the damp sand to the top of the pile and see how the grains move. Repeat, observing the movement again. Describe the downward movement of the damp sand on the data sheet (4). Note whether the grains move individually or in large groups.
6. With the cup, slowly pour water onto the pile of damp sand and observe what happens to the sand pile as the sand becomes saturated. Can the saturated sand maintain its angle of repose? (5).
7. Again, clean up your mess and answer questions (6) – (9).
8. Slowly pour the rounded gravel into the center of your tray or pan. Make sure your pile is large enough to get the true angle of repose! Carefully measure the angle of repose, without disturbing the pile. Record angle (10). Pour the rounded gravel back into the container.
9. Repeat the experiment using the angular gravel and record the results (11). Answer questions (12 and 13).

.1. Dry sand angle of repose is _____ degrees.

.2. Dry sand movement:

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- .3. Damp sand angle of repose is _____ degrees.
- .4. Damp sand movement:
 - .5. Can the saturated sand maintain a steep angle of repose?
 - .6. Which sediment condition – dry or damp – permits steeper slope angles?
 - .7. Which sediment condition – dry or damp – lends itself to the most dramatic, quickest, and therefore most dangerous style of slope failure?
 - .8. Explain why you think the damp sand can maintain a higher angle of repose than the dry sand.

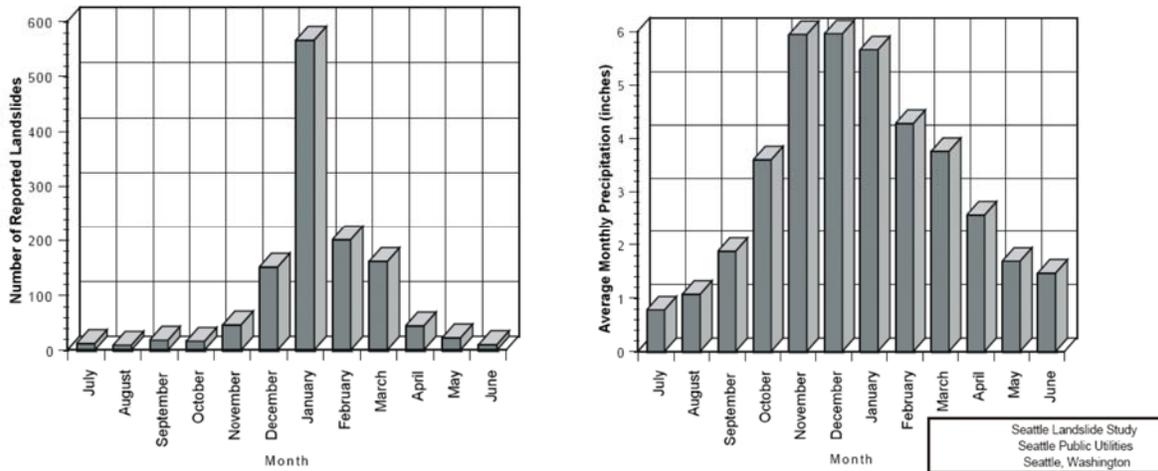
- .9. Suppose a house is built on a slope made of sediment. The slope is slightly greater than the angle of repose. Is this house at risk from mass movement?

- .10. Rounded gravel angle of repose is _____ degrees.
- .11. Angular gravel angle of repose is _____ degrees.
- .12. Compare the angle of repose for the dry sand and the dry gravel. What impact does grain size have on the angle of repose?

- .13. Compare the angle of repose for the rounded gravel and the angular gravel. What impact does grain shape have on the angle of repose?

Use the results of your experiments and the graphs below to answer the following questions.

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Source of data: City of Seattle, 1999. Seattle Landslide Study

.14. In the Seattle area, which four months experience the greatest amount of rainfall?

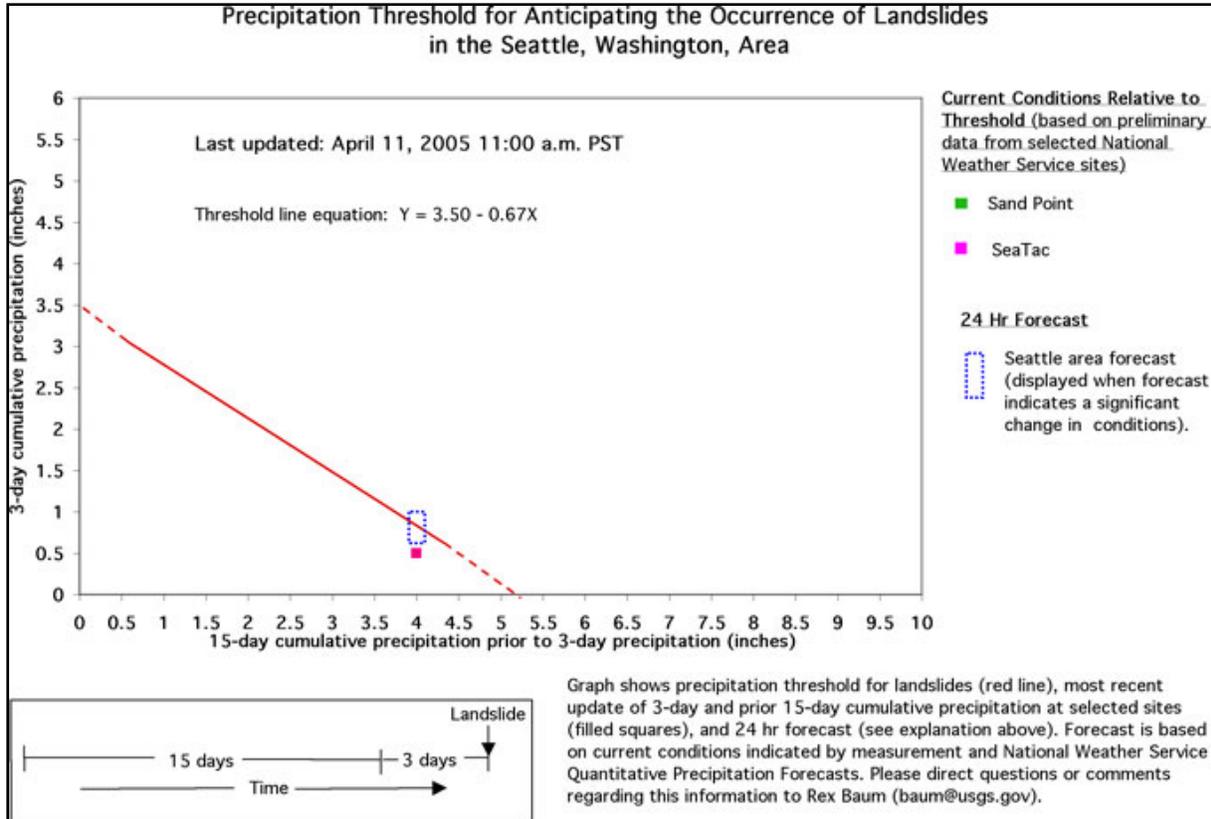
.15. In the Seattle area, which four months experience the highest number of landslides?

.16 Thinking about the results of your experiments (especially in Step 6), explain why the peak landslide activity occurs later than the peak rainfall activity.

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The USGS has recently developed and tested a model that establishes a precipitation threshold for the Puget Sound Area as it relates to landslides. In this area, landslides tend to occur if the precipitation amount for a 15 day period exceeds a specified level, and that 15 day period is followed by 3 days of rain at certain levels. The graph below shows the Precipitation Threshold for Anticipating the Occurrence of Landslides.



Source: Chleborad, A.F., (2003) Preliminary Evaluation of a Precipitation Threshold for Anticipating the Occurrence of Landslides in the Seattle, Washington, Area. U.S. Geologic Survey OFR 03-463. <http://pubs.usgs.gov/of/2003/ofr-03-463/ofr-03-0463.html>

.17. Place and label a point on the graph for the following days

Date	15 day cumulative precipitation	3 day cumulative precipitation	Landslides expected? (Yes, no, maybe)
1/5/56	4.73	3.38	
1/6/96	1.27	0.55	
1/7/96	1.33	1.27	
2/11/96	4.94	0.07	
2/21/96	5.87	0.56	

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.18. Explain why the 15 day and 3 day cumulative precipitation would be critical in determining when landslides might occur.

.19. Why might landslides not occur after even several inches of rain in 3 days if the amount of rain in the preceding 2 weeks has been low?

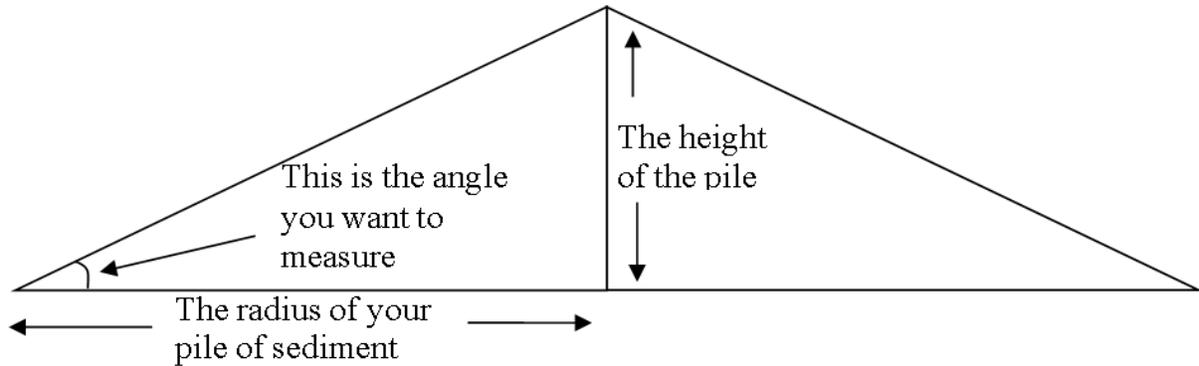
.20. Why would landslides not occur even if there had been a large amount of rain in the previous 2 weeks, but little rain in the last 3 days?

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How to measure the angle of repose

You can measure the angle one of two ways, with a protractor or by using simple trigonometry.



To measure with a protractor, carefully line up the center point of the protractor with the edge of the pile and determine the angle.

An easier way to measure the angle is to use trigonometry. As you can see from above, the pile of sand can be thought of as 2 right triangles. For a right triangle,

$\text{TAN}(A) = h/r$, where A = the angle, h = height of sediment pile, and r = radius of sediment pile

To find the angle, you need to take the inverse tangent of both sides....

$$A = \text{TAN}^{-1}(h/r)$$

For most calculators you will need to first divide the height by the radius and then press the TAN^{-1} button on your calculator. If the number comes out to something that doesn't make sense, make sure your calculator is in degree mode, not radian mode!