

### GRANULAR MEDIA

Media is plural; medium is singular. (You would never know it from watching or listening to the media.) Fine sand and coarse sand share roughly the same angle of repose when submerged in either air or water (30-35°); some claim that larger sand grains or gravel can hold a slightly steeper slope. Although shape and surface roughness both have a hand in setting the coefficient of static friction for sliding of grains down hill, and rolling as well as sliding can get involved, the observed range is usually 30-35° for either dry material or completely submerged material. Smooth spheres not only slide more easily, they also roll more easily, and so have a considerably lower angle of repose (18-25°). The weight of a grain is supported by the grains below through arch-like chains of support (photo below) and by static friction. The angle of repose is the angle that will just hold due to static friction with surrounding grains. The reason that the angle does not change under water versus under air is that even though water provides some buoyancy (gravity acting on the grains in proportion to their volume and excess density), it decreases the downward hill and the effective coefficient of friction proportionally. (You might argue a lubrication effect to reduce friction, but experimentally that's undetectable for sand and gravel.) Visualize the problem by putting an object on a large book and tipping the book until the object starts to slide. As you are tipping, gravity provides increasing force down the slope and the decreasing force perpendicular to the book decreases friction between the object and book until you exceed the angle of repose.

I asked you to start thinking about how granular materials respond to shear stresses, but there is no shear in granular material at rest, just as there is no shear in water that is not moving. If  $u = 0$  everywhere, then  $du/dz = 0$ . If you were very careful not to move the liquid, you would get the same angle of repose for submerged and dry particles.

Hydrostatic pressure can have nothing to do with angle of repose because it pushes the pile up as much as it pushes the pile down (same in all directions). It cannot "flatten" the pile. Moving water (or a mixture of moving water and sand) can flatten the pile. Water under pressure moving from below can force up a grain or impermeable layers of grains and cause slope failure, *i.e.*, mud slides. When the grains or layers are "floated" by this pore pressure, their coefficient of static friction drops.

The angle of repose of wetted (but not submerged) grains increases. Surface tension increases the pull between adjacent grains through a chain of adhesion to the grain, cohesion of the water and adhesion to the next grain, but it pulls only on the outer layer of grains in the pile because inside the pile pressures are balanced in all directions (and there is no air-water interface except for bubbles that don't have any real influence on the angle of repose. If you add enough water to submerge the grains, the forces on the water molecules pull equally in all directions and not selectively between the outer grains.

Also, I should comment on experimental design and statistical inference. Despite the imprecision of the protractor, it should be accurate. If we made repeated measures and averaged, we should get a precise and accurate mean. With two measurements that are not very different, little can be concluded. Absence of evidence should not be confused with evidence of absence.