Rubble, Rubble, Toil and Trouble

Stability of Cohesionless “Rubble Pile” Asteroids

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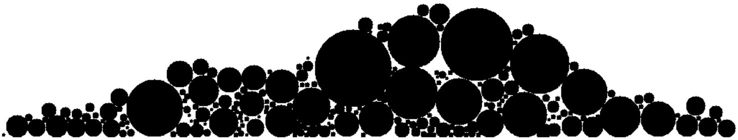
Rubble Pile Asteroids

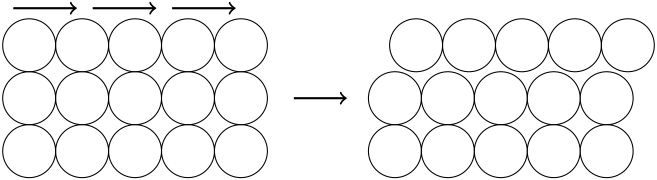
Self-gravitating aggregate of solid ‘pebbles’

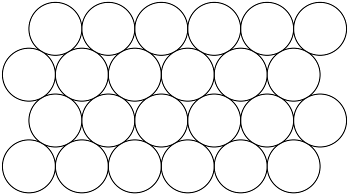
No cohesive forces, but the packing of discrete particles gives some shear resistance

Need not exist in an equilibrium configuration for a fluid

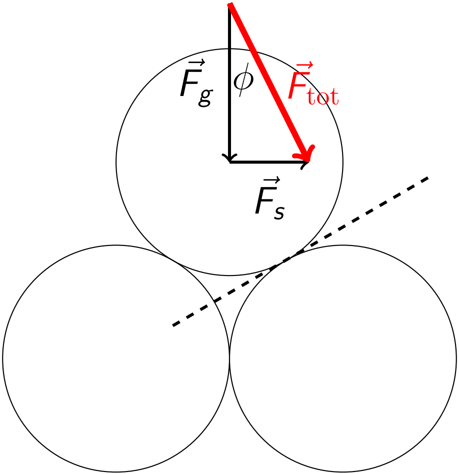


Effective Friction





Angle of Friction, $\phi := \tan^{-1}\mu$



Modeling a Rubble-Pile Asteroid

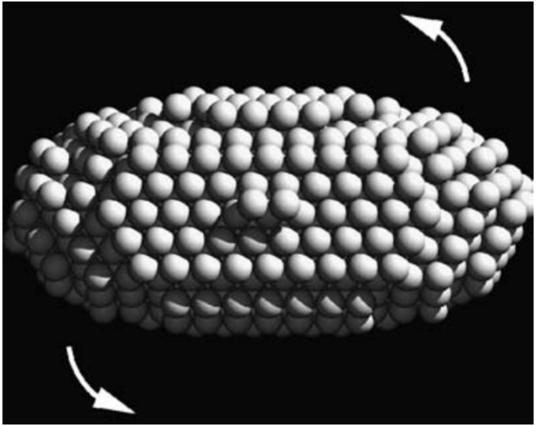


Figure from Richardson et al. (2005).

Modeling a Rubble-Pile Asteroid

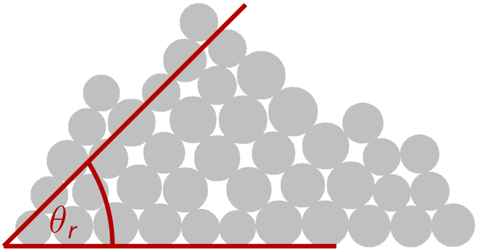
Holsapple (2001) expressed the set of stable configurations of a rubble pile asteroid as a function of the angle of friction.

The simulated behavior of a rubble pile asteroid consisting of equal-mass, equal-size, spherical particles is consistent with an angle of friction $\phi \sim 40^\circ$.

Angle of Repose

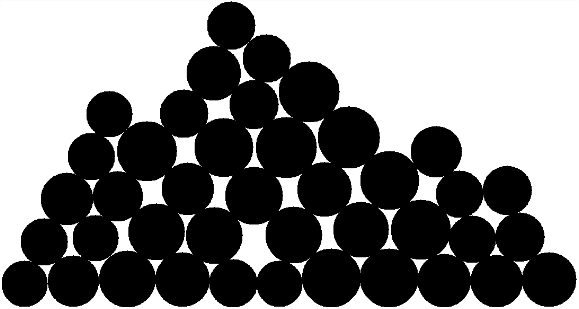
To estimate the angle of friction: pile particles at random, and measure the slope of the cone created.

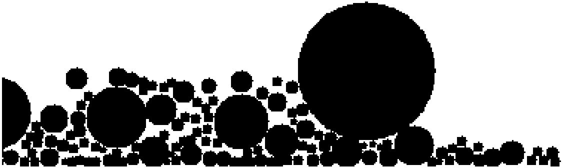
Here, $\theta_r \sim 40^\circ$.



Studying these piles should give a *qualitative* view of the effect of particle shape and size distribution.

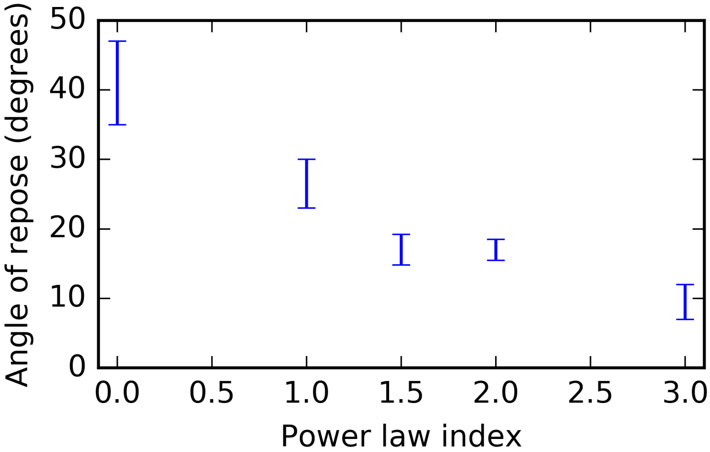
Different Particle Size Distributions





Effect of Particle Size Distribution

$$p(r) = \left(\frac{r}{r_0}\right)^{-\alpha}$$



Non-Spherical Particles

Modeled oblate particles by attaching pairs of equal-size spherical particles with a strong spring

For the $\alpha \sim 0$ case, the new angle of repose is found to be $\theta_r \sim 40^\circ$ — so no clear difference.

Not a complete surprise: equilibrium positions with dumbell particles are generally nearly at equilibrium without the springs.

Conclusions

Adding a broad distribution of particle sizes dramatically reduces the angle of friction.

A steeper power law reduces the angle of friction further still.

No substantial differences seen for dumbbell-shaped particles.

For the future: examine realistic particle shapes, and differing particle densities

References

Albert, R. et al. *Maximum angle of stability in wet and dry spherical granular media*. Phys. Rev. E 56 R6271-R6274 (1997).

Holsapple, K.A. *Equilibrium configurations of solid cohesionless bodies*. Icarus 154, 432-448 (2001).

Richardson, D.C. et al. *Numerical experiments with rubble piles: equilibrium shapes and spins*. Icarus 173, 349-361 (2005).