Cohesion, granular solids, granular liquids, and their connection to small near-Earth objects

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During the last 15 years or so, the Planetary Sciences community has been using Discrete Element Method (DEM) simulation codes to study small near-Earth objects (NEOs). In general, these codes treat gravitational aggregates as conglomerates of spherical particles; a good approximation given that many asteroids are self-gravitating granular media. Unfortunately, the degree of sophistication of these codes, and our own understanding, has not been high enough as to appropriately represent realistic physical properties of granular matter. In particular, angles of friction (θ) and cohesive strength (σ_c) of the aggregates were rarely taken in consideration and this could have led to unrealistic dynamics, and therefore, unrealistic conclusions about the dynamical evolution of small NEOs.

In our research, we explore the failure mechanics of spherical ($r = 71$ m) and ellipsoidal ($r_1 = 92$ m) self-gravitating aggregates with different angles of friction and values for their cohesive strength, in order to better understand the geophysics of rubble-pile asteroids. In particular we focused on the deformation and different disruption modes provoked by an always increasing angular velocity (spin rate). Scaling arguments allow us to regard simulations with the same aggregate size and different σ_c as equivalent to simulations of aggregates of different size and the same σ_c.

We use a computational code that implements a Soft-Sphere DEM. The aggregates are composed by 3,000 spherical solid spheres (7–10 m) with 6 degrees of freedom. The code calculates normal, as well as, frictional (tangential) contact forces by means of soft potentials and the aggregate as a whole mimics the effect of non-spherical particles through the implementation of rolling friction. Cohesive forces, and a cohesive stress, are calculated as the net effect of the sum of the van der Waals forces between the smaller regolith, sand and dust (powder) that are present in real asteroids [1]. These finer materials form a matrix of sorts that holds the bigger boulders together.

The aggregates were slowly spun up to disruption controlling for angle of friction, cohesion and global shape. Systems with no frictional forces had $\theta \approx 12°$ and are in effect granular liquids in the best case scenario. Systems with only surface-surface friction had $\theta \approx 25°$, which is typical in laboratory experiments with spherical glass beads. Systems that also implemented rolling friction had $\theta \approx 35°$, which is typical of non-cohesive granular media on the Earth. How much each aggregate deformed before disruption was directly related to the angle of friction. The greater θ allowed for much less deformation before disruption.

Cohesive forces on the other hand controlled the mode of disruption and maximum spin rate and showed that the change from shedding to fission is continuous and therefore, they should not be seen as different disruption processes. The figure shows the deformation and disruption of three initially spherical aggregates (left) and three initially ellipsoidal aggregates (right) with increasing cohesive strength from left to right ($\theta \approx 35°$). Through scaling arguments we could also see these aggregates as having the exact same $\sigma_c = 25$ Pa but different sizes. If we do that, the aggregates measure about 1.6 km, 5 km, and 22 km, and the particles, or groups of particles being detached now have similar sizes. This has now become a problem of resolution, i.e., the number and size of particles used in a simulation.

These results start to raise fundamental questions regarding the difference between shedding and fission. Is it shedding when it is dust grain by dust grain ejection from the main body or when it is in groups of 10, 100, or 100,000 dust particles? Is it fission when a 1-m piece of the asteroid detaches or when it splits in the middle? Which values of θ and σ_c are realistic? These and other questions will be explored.

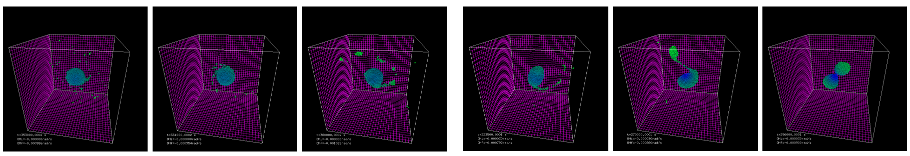

Figure: Deformation and disruption of three initially spherical (left) and three ellipsoidal (right). From left to right the aggregates have greater cohesive strength (or same strength and diminishing size).

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References: P. Sánchez, D. J. Scheeres, *Meteoritics and Planetary Sciences*, 2/2014. in press.