# SEISMIC WAVES IN THE ASTEROID ENVIRONMENT

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By means of numerical simulations we investigate impact generated seismic wave transmission in granular media under extremely low pressure. This mimics the conditions in the interior of asteroids. We find a dependency not only on the overburden pressure on the medium, but also on the energy of the impact.

**Introduction:** Experimentally, it is known that seismic waves speed in a granular medium is related to the overburden pressure ($P$) applied to it [1, 2]. The theory that has been developed is called Effective Medium Theory (EMT) and is based in considering the media as elastic, thus removing the difficulties presented by particle size and shape. This theory, based on the Hertzian laws for contacts, predicts a sound velocity that has a $P^{\frac{1}{6}}$ dependency, whereas the experiments have found this is true only for high enough pressures and that at low pressures the dependency changes to $P^{\frac{1}{4}}$. However, as far as we are aware, experiments have been limited to kPa and MPa pressures as they have been carried out under Earth's gravity.

Small planetary bodies (asteroids, comets and small moons) produce gravitational fields in the *milli-* and *micro-g* regimes and, as a consequence, their interior pressure vary from zero (on their surface) to just a few Pascals or tens of Pascals in their innermost regions.

In order to investigate seismic wave transmission in the asteroid environment, we carry out granular dynamics simulations that mimic these low pressure conditions. We use an in-house developed soft-sphere discrete element method (SSDEM) code and relate our findings to the missions described above.

**Procedure:** Here, we have chosen to use material parameters close to those of asphalt so that the results are relevant for asteroids; the grains are spherical so that the results can also be related to sound transmission theory (previous sections). We use 3000 grains with diameters between 2-3 cm that follow a uniform, random distribution. Their density is 3200 kg m$^{-3}$, Young modulus is 7.8$\times$10$^{10}$ N m$^{-2}$, Poisson ratio is 0.25 [3]. Two coefficients of restitution are used: 0.1 while the particles are settling and 0.5 for the actual simulations. This reduces the settling time.

The particles are contained in box with a solid bottom, horizontal periodic boundary conditions and a moving top that allows us to impose a very well determined pressure to the system. Though the particles initially settle under Earth's gravity, this is removed at a later stage to avoid pressure gradients. The height of the settled system is approximately 80 cm (see Fig. 1).

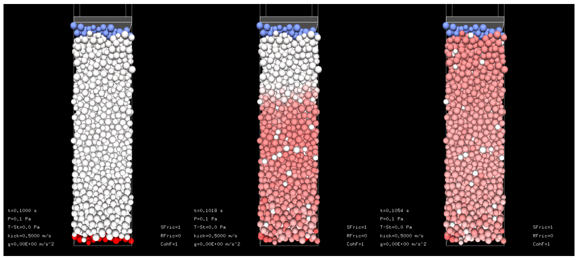

Figure 1: Simulation setup, the redder the particle, the greater its vertical speed component ($P$=0.1 Pa).

To initiate the seismic wave, the particles below a height of 1.5 times their radius are given a vertical velocity (kick) of 0.5 m/s after 0.5 s from the moment the settling procedure is finished. The system is then divided into horizontal slices 5 cm thick to monitor energy transmission. The kinetic energy of each slice is calculated in order to observe the wave transmission. Data is collected every $1\times10^{-4}$ s after the wave is started and this is done for 0.03 s. The sound speed is measured as the ratio between the time that takes the peak of the wave to reach the 15th slice and the height of this slice. The overburden pressure was varied between 0.1 and 50000 Pa, whereas particle-particle tensile strength is varied between 0 and 1000 Pa.

**Results:** Though the simulations correctly predict the wave speeds at high pressures ($>$10 kPa), these speeds plateaued at lower pressures ($\approx$150 m/s), which was not expected. The addition of cohesive forces between the particles was seen to produce no appreciable effects in the investigated range. This prompted us to change the initial vertical velocity of particles that generated the pressure wave to 0.01, 0.1 and 5 m/s. This produced wave speeds that also changed with pressure but plateaued at different values ($\approx$50, 110 and 250 m/s respectively) that also depended on cohesion. This has prompted us to believe that the change in the local pressure produced by the passing wave is responsible for its velocity. At high pressure, the additional pressure provided by the passing of the wave would be inconsequential, but at lower pressures, such as the one existent in small bodies, it is determining. Additional details will be provided at the conference.

**References:** [1] K. Walton (1977) *Geophysical Journal International* 48(3):461 ISSN 0956-540X . [2] P. J. Digby (1981) *Journal of Applied Mechanics* 48(4):803. [3] B. Gundlach, et al. (2013) *Icarus* 223:479.