EPSC Abstracts
Vol. 13, EPSC-DPS2019-1017-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Experiments on propagation of impact induced seismic waves into an agglomerated asteroid

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Abstract

Several, or may be most, of the asteroids are thought to be agglomerates of irregular boulders, so-called rubble or gravel piles. These are examples of granular media, sustained by a tenuous self-gravity.

Impact processes on agglomerated asteroids are critical to understand the collisional evolution of this population; as well as for the deflection of an incoming asteroid with a kinetic impactor.

To study the impact process in a granular media, we have performed laboratory experiments and numerical simulations in different granular material and in a wide set of physical conditions.

These results are relevant for the kinematic impactor experiment to deflect an asteroid, as it will be tested with the NASA DART mission.

1. Introduction

Asteroids are subjected to frequent impacts of smaller boulders that produce consequences on the surfaces as well as on the interior of the objects. Material is ejected and an impact induced seismic wave propagates into the interior. Due to compression of the material caused by the overlaying layers, we are interested on the propagation of the impact induced seismic wave under different confining pressure.

We have performed laboratory experimental results as well as numerical simulations on the study of propagation of impact-induced seismic waves in a granular media. The influence of a static compression on wave propagation is studied to mimic the pressure variations induced by self-gravity in the asteroid interior. Pressure in the interior of a 200m asteroid are in the range 1-10 Pa; while for 2km asteroids, the pressure grows up 100-1000 Pa.

2. Experiments

2.1 Laboratory experiments

In the laboratory experiments, granular material such as sand, gravel and glass spheres is placed into a 50x50x50-cm acrylic cubic box. Pressure inside the box is controlled by a movable floor with a hydraulic jack (and monitored by pressure sensors).

Impacts are produced onto the upper face of the box, through a 10-cm diameter circular hole. Projectile velocity ranges from a ~60 m/s up to ~300 m/s, attainable with a crossbow, CO2 gun and a nitro-piston rifle. The projectile have diameters from 4.5 to 5.5 mm, and they are made of steel or lead. Impact velocities are measured with a chronometer. An array of accelerometers are placed at several depths inside the granular material to detect the mechanical wave. The pressure of the hydraulic jack is monitored, as well as the confining pressure inside the box with several pressure sensors on the floor and on a side wall.

The different granular media are first characterized statically: displacement and pressure are monitored as a function of an increasing static load applied to the floor. Second, a shaker generates low amplitude mechanical wave to measure the dynamic response of the propagating media: wave amplitude and velocity are measured for frequency ranging from 50 Hz to 1500 Hz.

Finally, impact generated waves are studied by estimating velocity and attenuation of the wave. A parameter study is then performed changing impact energy (projectile mass and velocity), properties of the granular material and static pressure.

2.2 Numerical experiments

We compare these results with numerical simulations using the DEM package ESyS-Particle.

The mechanical properties of the granular material and the projectile as well as the impact velocity of the projectile are varied in a wide range of values.

Numerical results regarding velocity, attenuation and energy transmission are compared with the experimental ones. With these numerical experiments we can expand the results obtained of the laboratory under Earth surface gravity to the low-gravity environments of agglomerated asteroids.

3. Results

We observe a strong increase of the velocity of wave in the media with increasing confining pressure. The lowest confining pressure attained, under Earth gravity, is a few tens kPa. For these pressures, the velocity is on the order of 200 m/s for all the granular media. The velocity increases up to 500-1000 m/s for confining pressures of ~200 kPa.

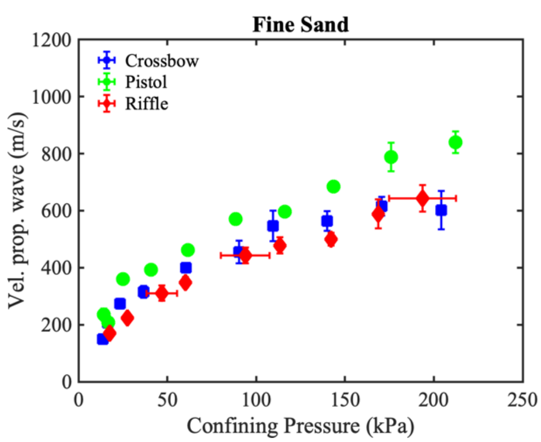

Figure 1: Velocity of the impact induced seismic wave versus the confining pressure of the material (fine sand) for different gunshots.

Similar results were obtained with the propagation of waves generated by the shaker.

Due to the dependence of the index of refraction with the inverse of the velocity of the seismic wave, and due to the increase in pressure with depth, the wave would propagates in a convex curve.

Extrapolating these results to the very low internal pressure, typical of km size asteroids, would imply very low wave velocities. The waves propagated into the interior, but refracted back to the surface, could induce the ejection of material at low speeds at places far from the impact point.

These predictions can be confirmed with numerical experiments under low-gravity conditions.

4. Summary and Conclusions

These results are relevant to understand the outcomes of impacts in rubble/gravel pile asteroids. In particular, they could be useful to discuss the feasibility of the kinematic impactor alternative to deflect an incoming hazardous asteroid, as it will be tested in the NASA DART mission.

Another application of these results is related to the ejection of low-velocity dust (~1 m/s) from the so-called Activated Asteroids.

Laboratory experiments under low-gravity conditions, like in the Space Station facilities, would be very useful to confirm these results.

Acknowledgements

Many students have collaborated in the past years in the implementation of these experiments. We acknowledge them: Andrea Maciel, Fiorella Ghiardo, Magela Pérez, Nicolas Lluch, Francisco López.