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SPH simulations of impacts on rubble pile asteroids

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Abstract

Many rubble pile asteroids with low bulk densities, like Itokawa, must include a high level of macroporosity, probably more than 40 % [1]. Although little is known about their internal structure, numerical simulations of impact events on these rubble pile asteroids rely on assumptions on how the voids are distributed. While most hydrocodes do not distinguish between micro- and macroporosity, Benavidez et al. [2] introduced a rubble pile model where the asteroid is represented as a spherical target shell filled with an uneven distribution of basalt spheres ranging in radius from 8 % to 20 % of the asteroid's radius.

In this study, we present a new approach to create rubble pile simulants for the use in impact simulations and quantify the dependence of impact outcomes on the internal structure of the target. The formation of the asteroid is modelled as a gravitational aggregation of spherical 'pebbles', that form the building blocks of our target. This aggregate is then converted into a high-resolution Smoothed Particle Hydrodynamics (SPH) model, which also accounts for macroporosity inside the 'pebbles'. To simulate high-velocity impacts on these models, we use the SPH solver in the code `Autodyn`.

We will compare impact event outcomes for a large set of internal configurations to explore the parameter space of our model-building process. The analysis of the fragment size distribution and the disruption threshold will quantify the specific influence of each set-up parameter. This work is ongoing and we will present preliminary results at the meeting.

1. Creating a rubble pile simulant

The size distribution of the building blocks used in the formation of an asteroid, the 'pebbles', is only poorly constrained. As a starting point, we use a power law $N_r \propto r^\alpha$ to model the radius of the pebbles: Given a uniformly distributed variable $X = [0, 1]$, the radius of the i^{th} sphere is given by

$$r_i = \left((r_{\text{max}}^{\alpha+1} - r_{\text{min}}^{\alpha+1}) \cdot x_i + r_{\text{min}}^{\alpha+1}\right)^{\frac{1}{\alpha+1}}, x_i \in X \quad (1)$$

Reasonable values for the slope α range from $\alpha = -2.5$, as found in the size distribution of main belt objects [4, 3], to around $\alpha = -4$ in remnant fragments after catastrophic disruptions [7]. The cut-off values for the pebble radii r_{min} and r_{max} are given by practical considerations: In the SPH formalism, properties are represented by weighted averages of particles within their smoothing length h, preventing the resolution of structures below that scale. Using spheres with radius in the range of h results in a practically monolithic body, as well as using spheres of a radius similar to the asteroid itself. Therefore the influence of these values on the outcome of the simulations must be quantified, and best values have to be found by using appropriate test cases.

The pebbles are initially randomly distributed in space, the collapse due to gravitational interaction is simulated using the GPL licensed code `Rebound` [6]. An illustration of the resulting rubble piles can be found in Fig. 1, and the corresponding size distribution in Fig. 2.

To include a second level of macroporosity and to account for already porous pebbles, the pebbles are not treated as solid spheres. Each pebble is filled with SPH particles. Rather than distributing the SPH particles uniformly, a local probability function is used which falls off with increasing distance from the centre of the pebble. This results in spheres that are more 'fuzzy' and porous rather than solid ones.

2. SPH test simulations on two different models

Two example impact simulations are presented here to highlight the influence of the internal structure on the propagation of the impact wave. The impact velocity is chosen to be $5.5\,\text{km}\,\text{s}^{-1}$, the mean collision velocity in the main belt [3], the material used is dunite, a material

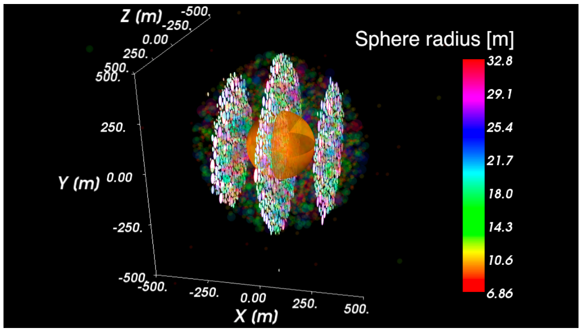

Figure 1: Three slices through a gravitational aggregate of spherical pebbles forming a rubble pile asteroid with a radius of approximately 500 m. The power law slope of the radius distribution is $\alpha = -2.5$, the limiting radii $r_{\text{min}} = 6.7$ m and $r_{\text{max}} = 32$ m. The orange sphere is the shell of an asteroid with $r = 170$ m that is cut out and converted to the SPH model seen in Fig. 3 (a). A variant using different slope and r_{max} is shown in Fig. 3 (b).

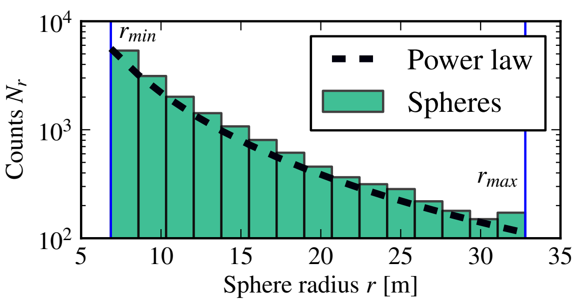

Figure 2: Histogram of the sphere radii in the gravitational aggregate shown in Fig. 1. The dotted line represents the power law function $N_r \propto r^{-2.5}$.

used in studies on asteroid families [5]. The impactor is a solid sphere of the same material with a radius of 4 m.

In Fig. 3 we can see how the propagation of the compression depends on the pebble size distribution, especially the upper limit of their radii, r_{max}. The large pebbles in Model (b) transmit the shock wave further into the structure, resulting in a steeper crater, while the small pebbles in Model (a) result in a more evenly distributed and localised compression front and a wider crater.

3. Summary

We present a new approach to modelling rubble piles in hydrocode impact simulations as aggregates of spherical, porous pebbles following a realistic size distribution of the radii and a spatial distribution that is determined due to gravitational aggregation. We quantify the dependence of the SPH simulations on the characteristics of these aggregates. This will provide a range of rubble pile representations, that can be used in further impact studies.

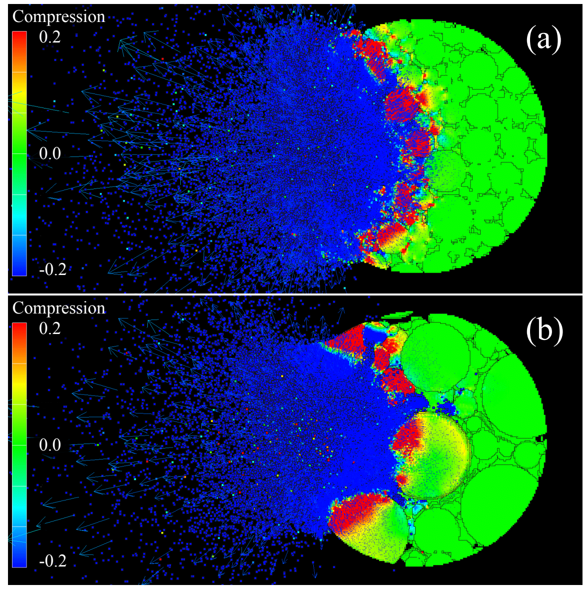

Figure 3: Distribution of material compression in impact simulations for two different internal structures after 2.8 seconds. Model **(a), top** was created using the gravitational aggregate shown in Fig. 1 ($\alpha = -2.5$, $r_{\text{min}} = 6.86$ m and $r_{\text{max}} = 32$ m). Model **(b), bottom** was created using an aggregate differing in the maximum radius of the pebbles used ($\alpha = -2.5$, $r_{\text{min}} = 6.86$ m and $r_{\text{max}} = 82$ m).
There is currently no surface regolith included, but this will be added in further studies.

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