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Discrete Element Simulations of Test Scenarios for Studying Landslides on Asteroids

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Introduction

Our overall aim is to investigate the physics of volatile-related surface features on asteroids and comets. One form of mass wasting are landslides – the fast movement of a large mass of regolith and rock down a slope – as observed on the large asteroids Vesta and Ceres by NASA's Dawn spacecraft [1, 2]. Here we focus on numerically simulating landslides under the physical conditions on the dry asteroid Vesta. This study complements and continues a previous work [3], where we have been investigating dynamical processes that are implied by surface features on comet 67P/Churyumov-Gerasimenko.

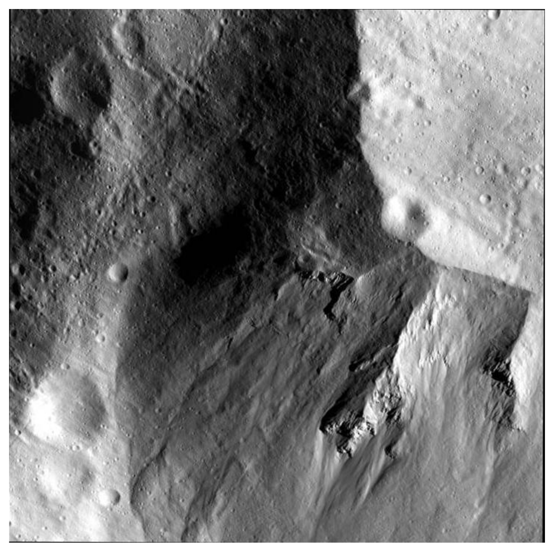

Figure 1: Close-up view of the wall of the Rheasilvia impact basin on asteroid Vesta, image credit: NASA/JPL-Caltech/UCLA/MPS/DLR/IDA, PIA15494.

Methods

We treat the material on the surface of the asteroid as granular material. The dynamics of the particles are modeled with the open source Discrete Element Method (DEM) simulation code LIGGGHTS [4]. Generally, we assume that the grains are small polydisperse spheres with sizes in the micro- to millimeter range, which consist of silicates and interact according to the Hertz contact model. Additionally, we consider friction, rolling friction [5] and cohesion as well as the ambient surface acceleration on the asteroid. The large number of simulated particles needed to describe macroscopic structures is reduced by applying the method of 'coarse graining' [6]. Here groups of physical particles are represented as computational parcels, whose contact force parameters are scaled in a way that the parcels have statistically the same dynamics as the original particles. The parameters of the model are calibrated by comparing its results to laboratory experiments [7, 8].

Notation	Description	Default value
p/np	Periodic/non-periodic boundaries	
ρ	Mass density of the particles	
Y	Young's modulus of the particles	
ϕ	Filling factor	$\sim 60\%$
cn	Coordination number	~ 6
cof	Coefficients of friction (normal/rolling/viscous damping)	
ced	Cohesive energy density	

Acknowledgements

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References

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Test Scenario 1 – Coarse Graining Test

Landslides on asteroids have been observed to occur from cliffs that are up to several kilometers high. To check the scaling of the coarse graining over several orders of magnitude, we use a tensile strength test. In this test, a tall cylinder made up of small particles is mounted to a plate with one of its flat sides, while a gradually increasing force is pulling on the opposite side until the cylinder breaks apart (Fig. 2). The force at the breaking point normalized over the cylinder's cross-sectional area is defined as the material's tensile strength. We found that the tensile strength is virtually independent of the coarse graining factor for laterally periodic boundaries and varies by a few percent for non-periodic boundaries. Additionally, we simulated the tensile strength of various materials (Fig. 3) and determined its dependence on the friction coefficients (Fig. 4).

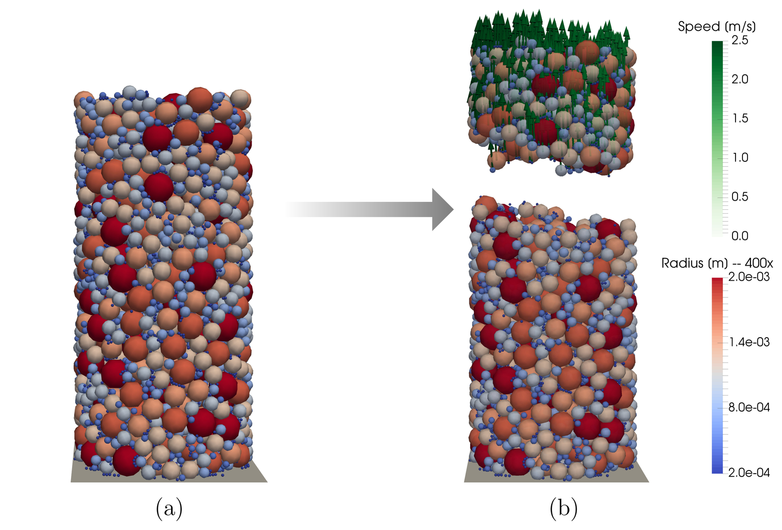

Figure 2: DEM simulation of a tensile strength test with a 5 cm-high and 2.5 cm-wide test cylinder, before (a) and after (b) breaking apart due to stress induced by an upward directed force field. Cylinder made up of spherical silicate particles with eight different sizes between $s = 1\,\mu$m and $10\,\mu$m (400x coarse graining) distributed according to a power-law with differential index $q = -1.5$ (*fly ash*).

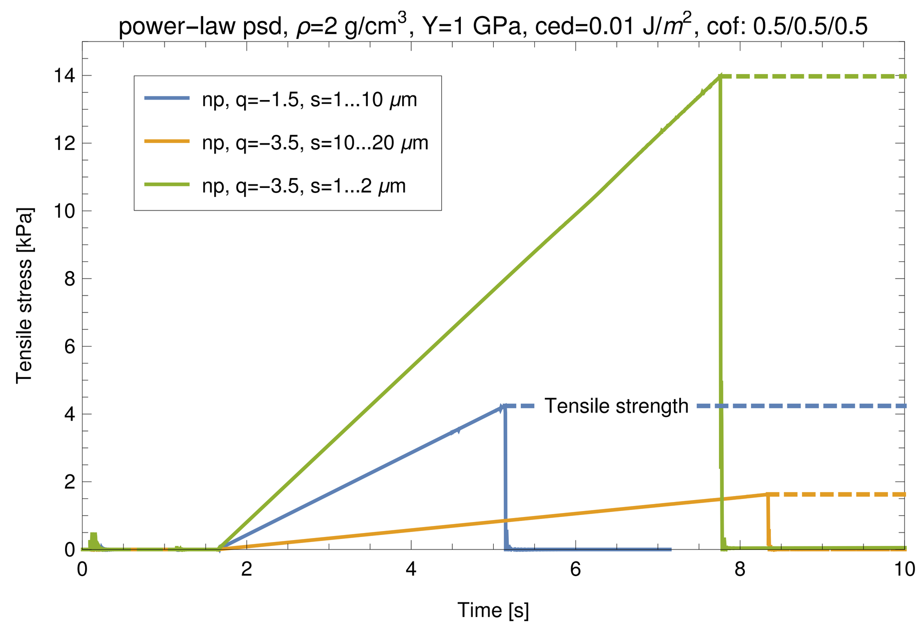

Figure 3: Tensile stress – time evolution for *fly ash* and other materials with different particle size distributions. The horizontal dashed line pointing to the maximum of a curve is the stress at the breaking point, which is defined as the material's tensile strength.

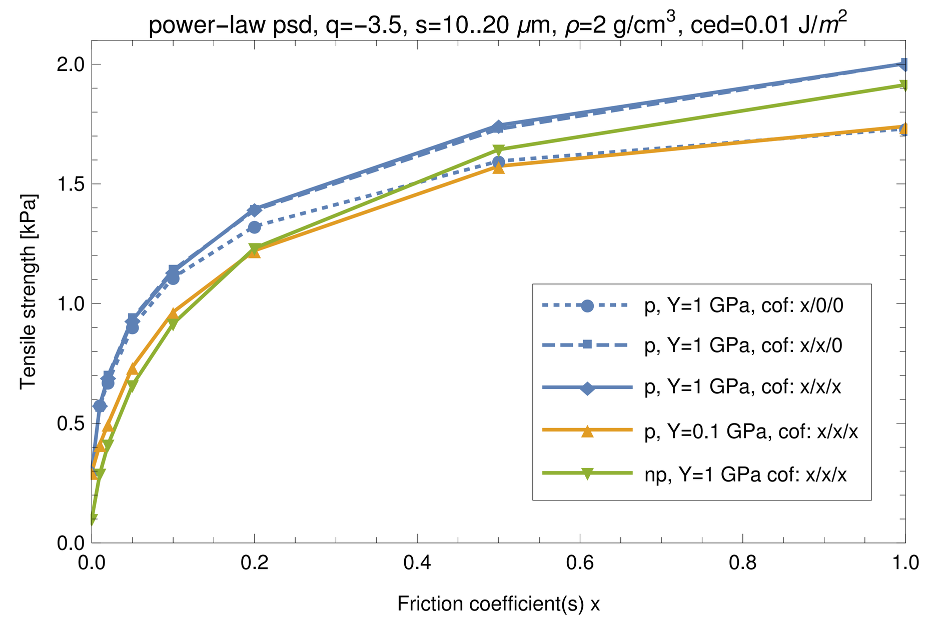

Figure 4: Tensile strength as function of the normal and/or rolling friction coefficients. The friction coefficients have a larger influence on the tensile strength if they are small (< 0.2).

Test Scenario 2 – Brazilian Disc Test

In order to calibrate the mechanical parameters of the material, we compare laboratory measurements (Fig. 5) of well-controlled Brazilian disc tests to corresponding results of DEM simulations (Fig. 6). In these tests, a centimeter-sized disc of compacted micrometer-sized ice and/or silicate particles is exposed to gradually increasing pressure against its curved side [8]. The force at which the disc cracks can be used to estimate the material's tensile strength [7], which mainly depends on the inter-particle forces and the geometrical configuration of the particles. Using plausible values for the mechanical parameters of the material, we were able to obtain a reasonably realistic behavior of the material of suddenly developing a crack (instead of being slowly cut) as well as order-of-magnitude estimates for the material's tensile strength.

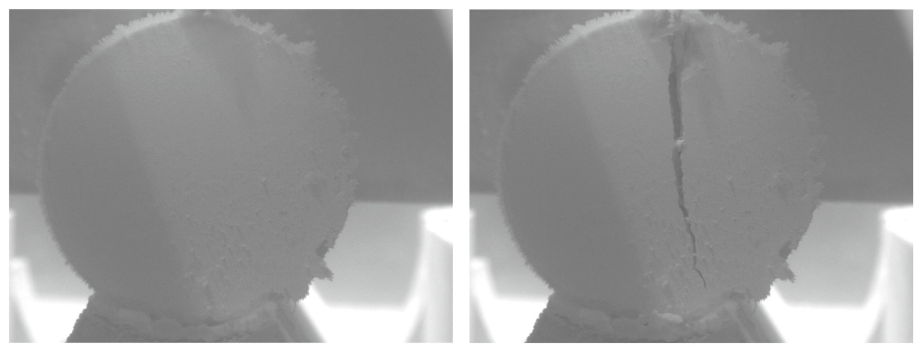

Figure 5: Brazilian disc test in laboratory [8]. 2.6 cm-sized cylindrical disc of a ice-silicate mixture before (a) and after (b) breaking into two major parts due to stress exerted by a blade pushing from above onto the upper curved side of the disc.

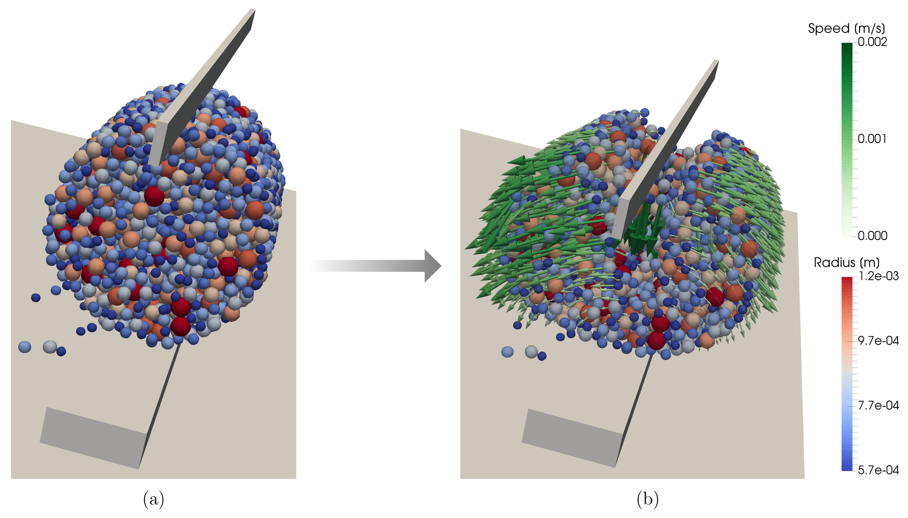

Figure 6: Corresponding DEM simulation of the Brazilian disc test. Disc made up of spherical ice particles in eight different sizes between 2.4 μm and 4.8 μm (240x coarse graining) distributed according to a Gaussian function with a mean of 2.47 μm and a standard deviation of 1.13 μm.

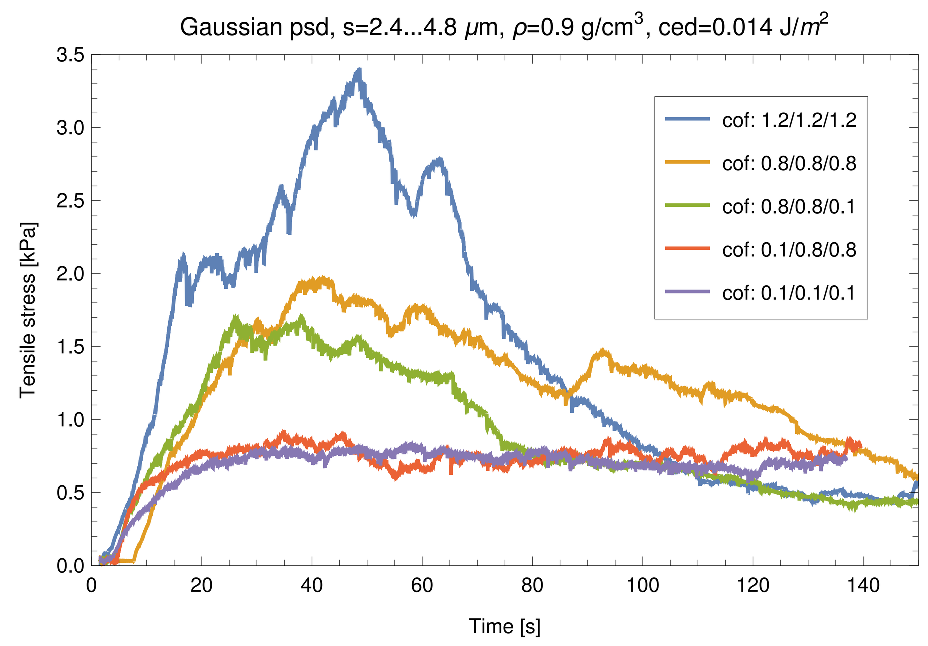

Figure 7: Tensile stress – time evolution for various combinations of the friction coefficients. Only certain combinations (upper three) lead to the abrupt formation of a crack as observed in the laboratory.

Test Scenario 3 – Landslides on Vesta

Finally, we use our experience gained with the previous two scenarios to study landslides on Vesta. In particular, we investigate the stability of a cliff against its own gravity and simulate its collapse caused by seismic activity, e.g. due to the nearby impact of a meteoroid onto the asteroid [9]. For this purpose, we construct a cliff of a given height and front face slope angle using coarse graining factors and material properties as studied in the previous two scenarios. Then we expose the cliff to an oscillating acceleration of increasing magnitude and measure the run-out length and the angle of repose of the landslide.

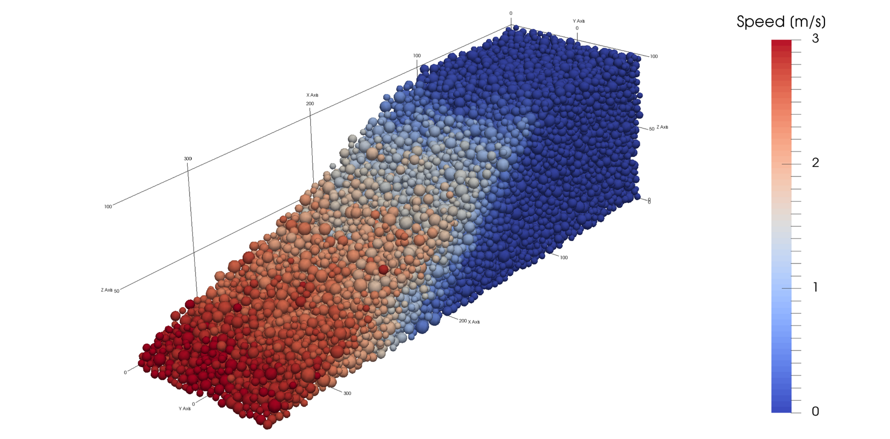

Figure 8: DEM simulation of a landslide from a 100 m-high cliff. Cliff made up of spherical silicate particles with eight different sizes between $s = 10\,\mu$m and $20\,\mu$m (400 000x coarse graining) distributed according to a power-law with differential index $q = -3.5$.

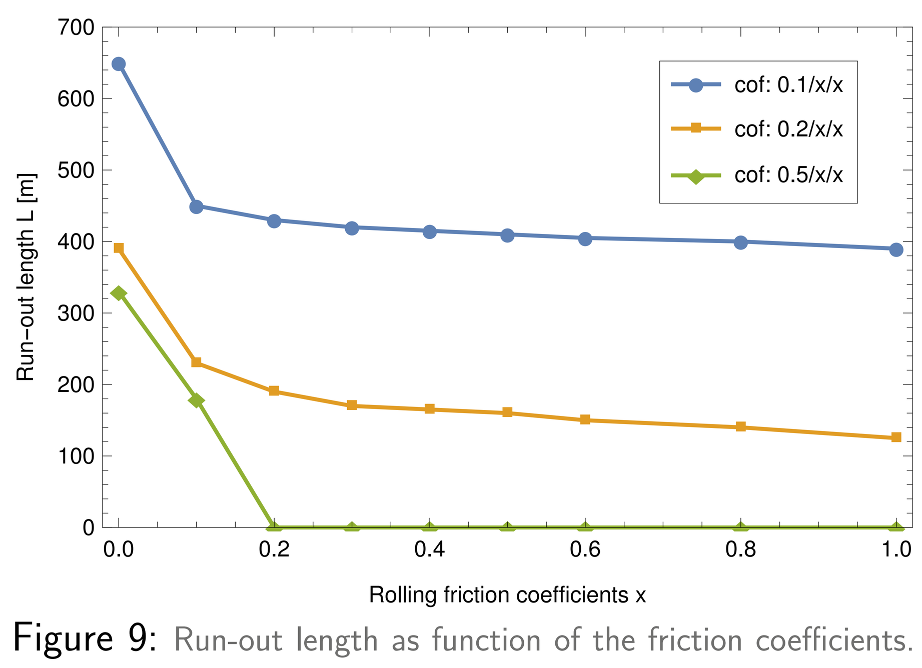

Figure 9: Run-out length as function of the friction coefficients. Both normal and rolling friction play a role for the stability of the cliff and the run-out length of the landslide.

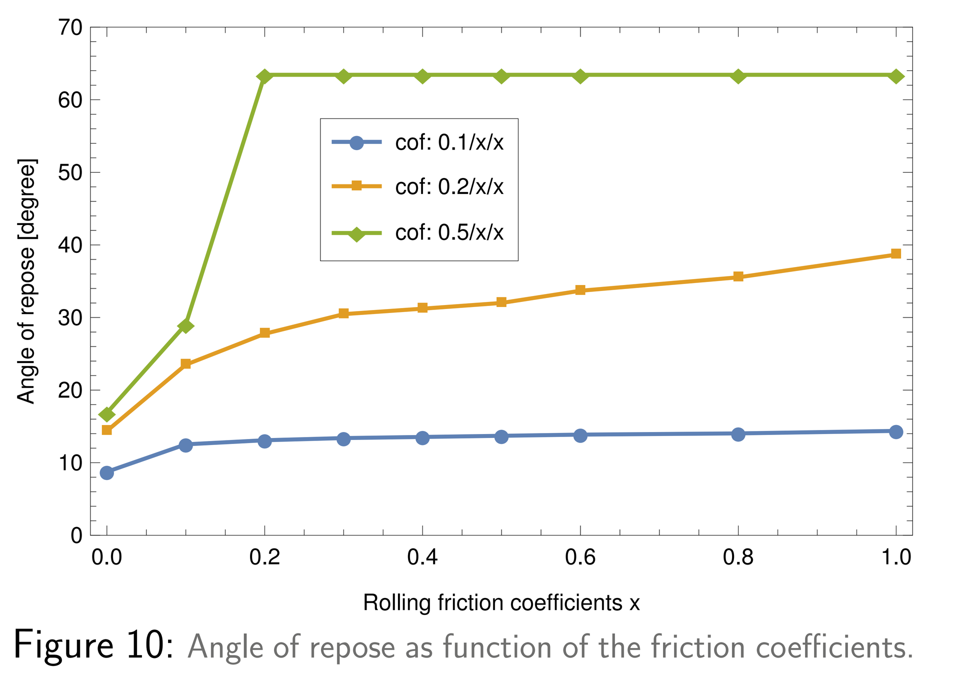

Figure 10: Angle of repose as function of the friction coefficients. The initial angle of repose of the cliff is $\sim 63°$.

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