A DISCRETE ELEMENTS MODELING FRAMEWORK FOR THE PARAMETRIC STUDY OF LANDSLIDES IN LOW GRAVITY ENVIRONMENTS. L. Penasa¹, A. Lucchetti¹, R. Pozzobon¹, G. Munaretto¹, M. Pajola¹ and C. Rossi¹
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Introduction: Landslides are almost ubiquitous in the Solar System, with rockfall, avalanches, or landslides that are observed not only on Earth, but also on multiple other terrestrial bodies, such as the Moon [1,2], Mars [3–5], and Mercury [6].

Landslides have been observed also on planetary bodies characterized by extremely low gravity, as for example Vesta and Ceres [7,8]. On comet 67P, landslides produce deposits closely resembling the ones that can be found on Earth or other rocky planets, despite the different cometary composition and the exotic environment [9].

From studies on Earth analogs, it is known that the shape and size of landslide deposits are influenced by a large number of factors: the initial topography, the failure mechanism, the mechanical properties of the collapsing mass, the presence of fluids and volatiles, and the specific environmental conditions [10–12].

The overall dimensions and morphology of the resulting deposits (area, width, and length) are often the only features that can be studied and compared between different sites or planetary bodies, due to the limitations in DEMs resolution and suitable imagery. In particular, plots of the H/L ratio (drop height/runout length of the mass movement) provide a proxy for the average friction coefficient and have been the subject of many investigations. Lower values of the H/L ratio, meaning longer runouts, have been attributed to a variety of different phenomena [13], which could imply a substantial reduction of the friction coefficient of the moving mass.

The behavior of mass movements on relatively small Solar System bodies, where gravity is reduced with respect to Earth, is poorly understood due to the difficulties of recreating low-gravity conditions or identifying satisfactory analogs for the involved materials.

A better understanding of the variables controlling the outcome of mass movements in such conditions could help decipher important parameters of the mobilized material and provide useful constraints for interpreting mass movements on comets, asteroids, or icy moons.

We hereby describe a fully parametric numerical framework based on ESyS-Particle software, which has been specifically designed to explore the outcomes of fragmenting grain flow under different parametric assumptions, in an effort to provide an overview of the different behaviors of mass movements in reduced gravity environments.

Methods: ESyS-Particle [14,15] is an open-source software that can be used to simulate granular flows based on discrete elements (DEM). Particles are modeled as perfect spheres interacting by user-chosen frictional models. Aggregates can also be modeled by bounding particles together by means of breakable bonds to simulate fragmenting flows. The discrete nature of the DEM approach is especially appropriate for approximating brittle deformations in cohesive materials and has been used to simulate rockslides [16,17], investigate landslide triggering on small bodies [18], and study the interaction between debris flows and barriers [19].

Our experimental setup is based on a simplified model of a sliding mass detached from a cliff, similar to the typical chute already used in experimental work [20]. The 3D setup is designed in a parametric CAD¹ in order to be fully configurable (Figure 1).

To achieve a more representative behavior of the frictional interactions the floor of the model is designed to host a secondary volume of particles (particles pool in Figure 1) whose properties can be controlled to simulate different kinds of substrates.

The volumes of the falling landslide body and the particles’ pool are then filled with a randomized tight packing of spheres for which selected density and particles interactions are set (Figure 2a).

Figure 1. An example of the basic configuration for ESyS-Particle modeling. The fully parametric approach makes it possible to obtain any configuration by modifying each parameter independently.

¹ FreeCAD: https://www.freecadweb.org
detachment from a vertical wall. Thanks to the fully parametric approach for the generation of the scene it is possible to test a variety of different configurations, in terms of initial terrain slopes, detached volume, fall height, gravity, and particles interactions.

Figure 2. a) the initial configuration of a model realization and b) the final result after the static conditions are reached.

Snapshots of the entire configuration of particles (position and velocity) are saved at predefined intervals, and together with simulation parameters and additional fields (e.g. the total kinetic energy) can be used for subsequent analysis. The final snapshots, which represent the static configuration reached by the particles, can be post-processed to compute estimates of the total runout or any other measurable quantity (Figure 3).

Furthermore, the complete simulation framework has been produced in the form of docker\textsuperscript{2} containers, which, in conjunction with modern distributed computing technologies (i.e. celery\textsuperscript{3} and rabbitmq\textsuperscript{4}), makes it possible to easily create clusters from any set of sufficiently powerful computing hardware to execute a large number of model realizations in parallel.

Conclusion and future perspectives: A comprehensive understanding of the dynamics of mass movement in low gravity environments can be difficult to achieve due to the limited knowledge of the properties of the involved materials and the difficulties of replicating reduced gravity. With the aim of providing a more consistent picture of the possible outcomes of landslides and other mass movements in relation to simulation parameters, we created a modeling framework based on EyS-particle and leveraging distributed computing on common hardware.

This framework will support the parametrization of numerical models for the upcoming observations of mass-movements of the future JUICE-JANUS camera observations on Jupiter Icy Moons.

Acknowledgments: The activity has been realized under the ASI-INAF contract 2018-25-HH.0.


\textsuperscript{2}https://www.docker.com/
\textsuperscript{3}https://docs.celeryproject.org
\textsuperscript{4}https://www.rabbitmq.com/