EPSC Abstracts
Vol. 13, EPSC-DPS2019-764-1, 2019
EPSC-DPS Joint Meeting 2019

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

Dynamics of ejecta during the formation of an impact crater: discrete numerical simulations

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Abstract

We simulate the formation of an impact crater with discrete simulations, and compute explicitly the trajectories of ejecta, allowing us to predict the distribution of secondary craters.

1. Introduction

The ability of crater chronometry techniques to assess ages and evolution of planetary surfaces has been recently challenged, especially in the case of using small impact craters because of the expected secondaries [1]. Many studies have detailed the secondaries formed by a well-recognized primary impact in terms of shape and repartition, based on the high resolution imagery available on the surfaces of the Moon [2] or Mars [3]. However, well-used numerical models of impact crater formation which use continuous approaches (hydrocodes) [4] are not always well suited to reproduce the fragmentation processes at small scales that are required to explain the secondary cratering. Because they rely on a mesh, these models, though very efficient in predicting the deformations within the target and the properties of the subsequent crater, cannot take into account explicitly the fragmentation of material, which leads to the ejection of particles of variable sizes. Therefore, we propose here a new Discrete Element Method (DEM) to simulate impact cratering in order to better understand the fragmentation of ejected material and consequently the secondary craters formed after a primary impact.

2. Numerical method

DEMs do not require any mesh and allow to compute explicitly the dynamics of individual particles [5,6]: in this study we model the behaviour of a target made of a two-dimensional assembly of 800,000 particles after the impact of a projectile (Fig. 1).

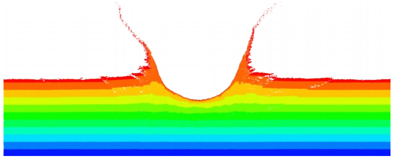

Figure 1 : Example of a transient crater obtained with the DEM simulation. Colour bands only indicate the initial vertical position of particles.

Both within the target and the projectile, neighbour particles are initially linked by cohesive beams. Under elongation and bending, these bonds exert restoring elastic forces and torques on the adjacent particles, giving the material its initial cohesion. To account for its brittleness, a yield strain is assigned to each bond, beyond which it breaks irreversibly. When in direct contact, particles behave as a classical frictional granular material.

3. Characteristics of the crater

The present investigation focuses on the influence of 3 control parameters: size (*a*) and velocity (*V*) of the projectile, and dimensionless strength (*S*) of the target material, defined as the ratio between the tensile force exerted by a bond at yield and the weight of a particle. We first validate our approach by analyzing the properties of the final crater.

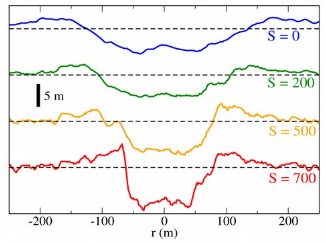

Figure 2 : Final crater obtained after the impact of a projectile of size a=2m at V=2 km/s.

The diameter of the crater decreases and its maximal depth increases when the mechanical strength of the target increases (Fig. 2). For a projectile of given size and a target of given strength, both the diameter of the crater and its total height increase as power laws of the impact velocity (Fig. 3), whose indices are consistent with common estimates [7].

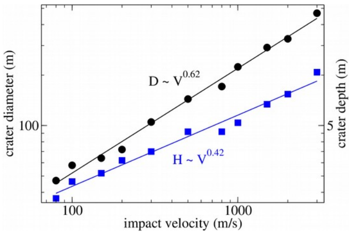

Figure 3 : Diameter and depth of the final crater as a function of impact velocity.

4. Dynamics of ejecta

In the following we define ejecta as all particles that have been ejected above an altitude z = 5 m (let us note that, in consequence, some particles classified as ejecta will fall back between the rims of the crater).

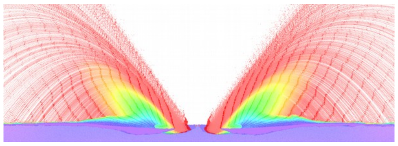

Figure 4 : Integrated trajectories of all particles after impact (colour codes for their velocity).

The volume of ejected particles is found to vary as a nonlinear power law of the impact velocity (index 1.42>1) and to decrease as an affine function with increasing tensile strength of the target (Fig. 5). As can be seen in Fig. 6, only a relatively small fraction of the impact energy is delivered to ejected material. This fraction increases with impact velocity but appears to tend to a constant value of around 15% at high speeds.

5. Secondary craters

Since the size of the ejected fragments is comparable to the size of our unit particles, our simulations do not allow us to model properly the formation of the secondary craters. However, since we have access to the size distribution of the ejected fragments, as well as to their position and velocity at impact we are able to infer the thickness of the continuous ejecta blanket near the crater's rims and to predict the size distribution of secondary craters as a function of distance to the main impact.

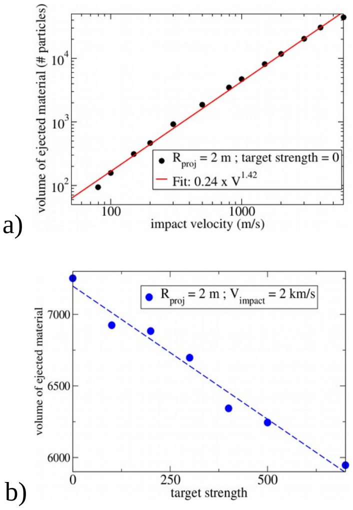

Figure 5 : Volume of ejecta as a function of (a) impact velocity and (b) target strength.

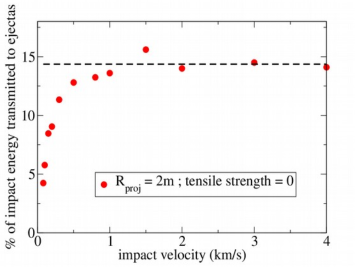

Figure 6 : Fraction of initial kinetic energy of the impactor converted into kinetic energy of the ejecta.

References

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