Discrete Element Modeling of Oblique Impacting

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Introduction

Impact craters are ubiquitous in the solid bodies of the solar system [1-4]. Previous research has conducted hypervelocity-projectile experiments to simulate the impact process and summarized a set of scaling rules on the impact process [5,6]. However, despite the experimental results, the mechanism of impacting is still far from being understood. For instance, proper models are needed to describe the formation of craters on porous targets [7]. Given that the numerical modeling can precisely control all the inputs and trace the state of individual particles, it provides a new perspective to the formation mechanics [8].

Method

This study uses the Discrete Element Method (DEM) to study the impact process [9]. The YADE, an open-source DEM program, is used in this study [10]. The particle material used in the study is the Jointed Cohesive Frictional particle material (JCFpm) [11,12].

Target: 381022 particles deposit on a plane and form a target with the size of $200\ \mathrm{m} \times 200\ \mathrm{m} \times 72\ \mathrm{m}$. Due to the characteristic of the granular material, the target has porosity of 44.5%. Its material is set as the natural basalt [13].

Projectile: The projectile in this study comprises of 972 particles (Fig. 1). It can simulate the inner deformation, fracture and energy dissipation during impacting. Its material coefficients is also set as the natural basalt [13].

Initial Condition: the projectile is set to impact at 30°, 45°, 60° and 90°, respectively, with the velocity from 3.0 km/s, 5.0 km/s, 7.0 km/s, 10.0 km/s to 12.0 km/s. The gravity is set as $9.81\ \mathrm{m/s^2}$.

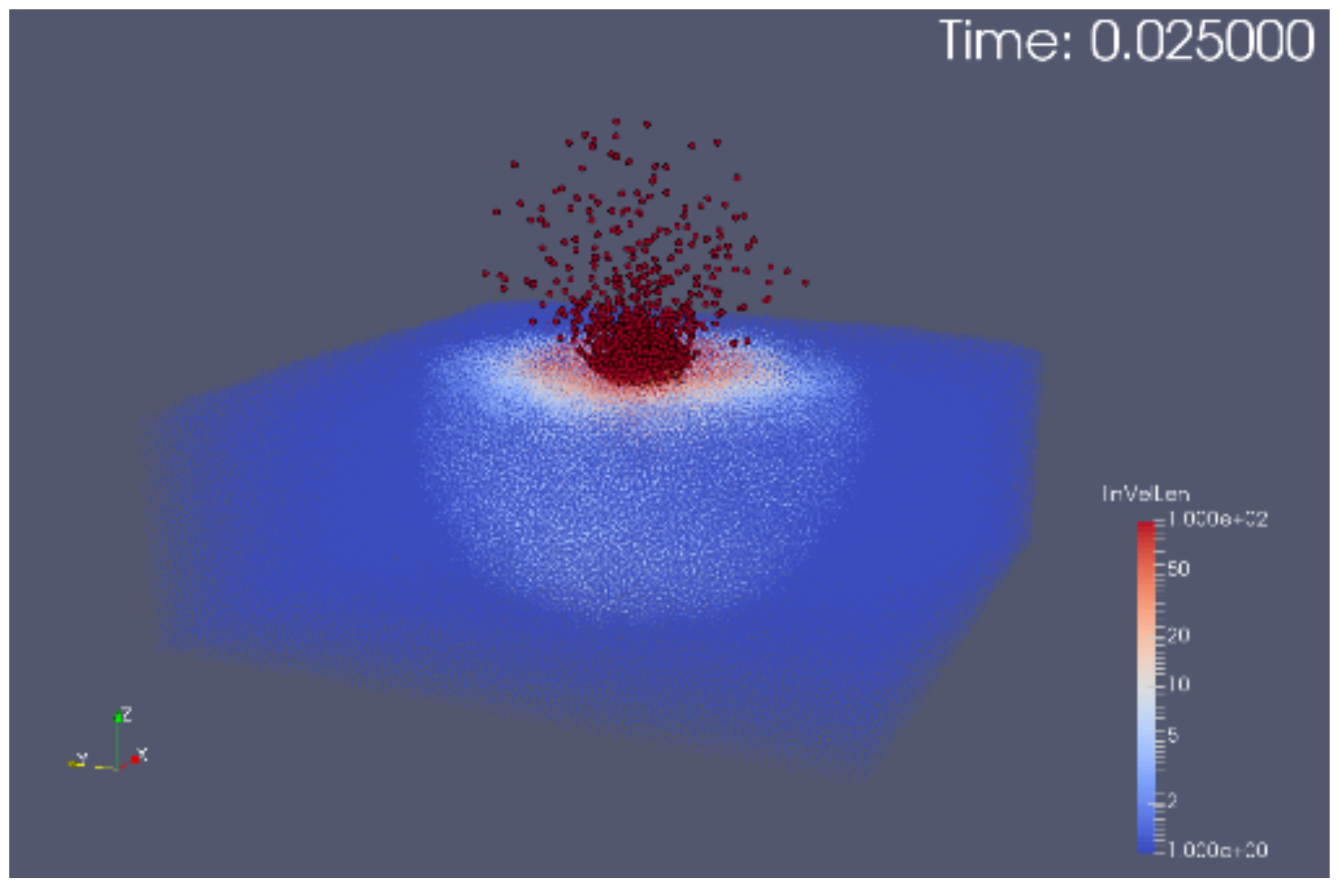

Figure 1. The 3-D render figure of a breakable projectile, made up of 972 particles, and a target, made up of 381022 particles.

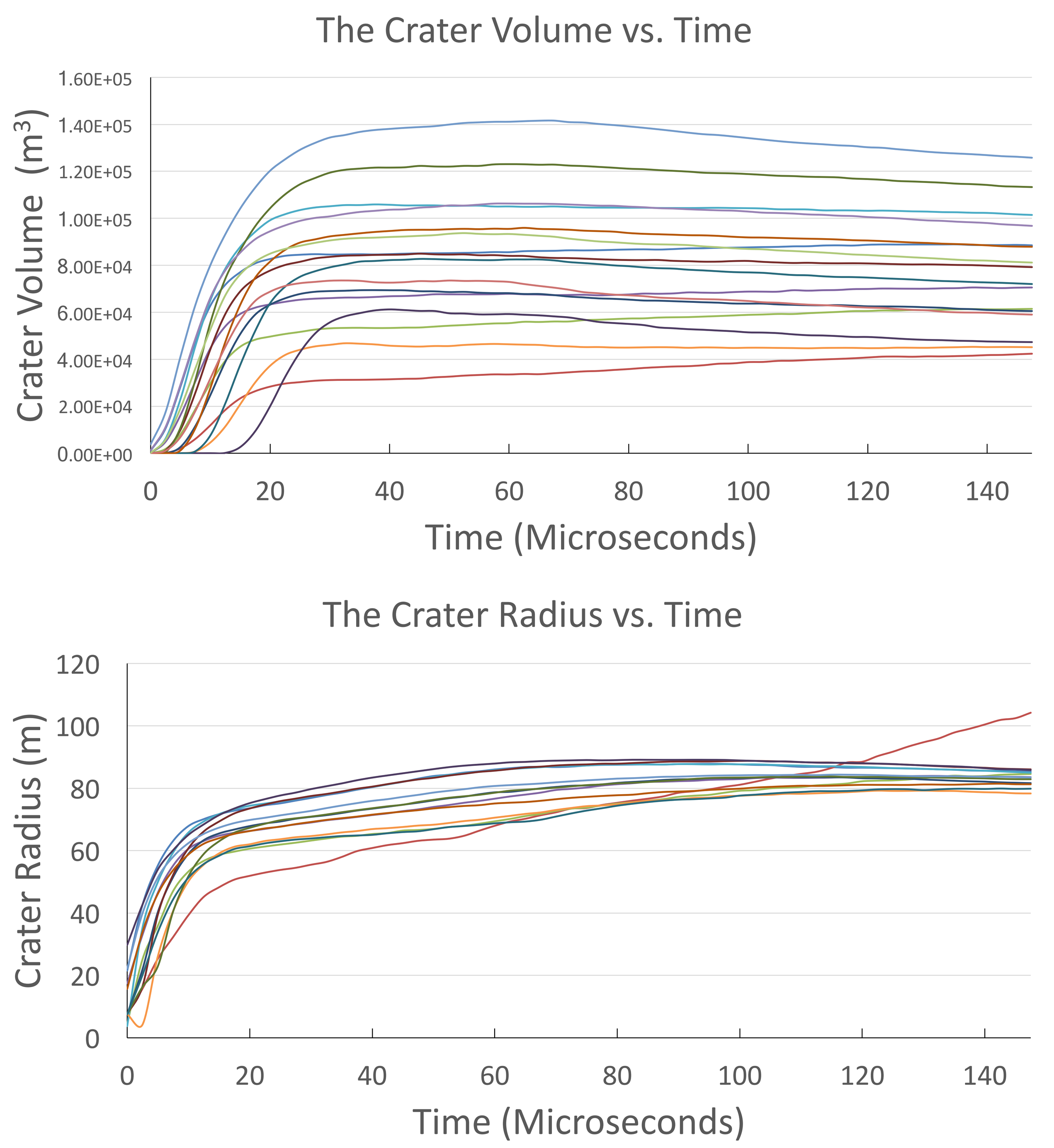

Figure 2. The time evolution of the (up) volume and (down) radius of all simulated impact craters. Among different impact velocities and inclined angles, they all exhibit a similar pattern: the crater volume and radius increase rapidly in the beginning and their increment slows down nearly at the same time.

Results

Despite the impact velocity and angle, the crater volume increases sharply in the early stage, reaches the maximum around 50 μs after impacting, and then decreases gradually and mildly (Fig. 2). The maximum of the volume indicates the formation of a transient crater. The crater radius shares a similar evolution pattern, but it grows a little faster than the volume.

In terms of the transient crater, higher impact velocity and larger angle result in larger crater volume and radius. To quantify this relationship, the π-group scaling rules obtained from the laboratory are used [5,6]. The crater volume, crater radius and impact velocity can be represented by three dimensionless scalars π_V, π_R, and π_2. Details are described in [5]. The π_V, π_R, and π_2 have following relationships:

$$\pi_V {\pi_2}^{\alpha} = A$$

$$\pi_R {\pi_2}^{\beta} = B$$

where α, β, A and B are constants. For the π_V - π_2 and π_R - π_2 plots (Fig. 3), the data with the same impact angle presents a linear relationship, indicating that our model obeys the π-group scaling rules. The fitted equations are shown in Table 1.

Table 1. The trend lines of the π_V - π_2 and π_R - π_2 at different impact angles.

Impact angle (°)	$\pi_V - \pi_2$	$\pi_R - \pi_2$
30	$\pi_V {\pi_2}^{0.4305} = 20.3360$	$\pi_V {\pi_2}^{0.1410} = 2.3784$
45	$\pi_V {\pi_2}^{0.3379} = 99.1235$	$\pi_V {\pi_2}^{0.1456} = 2.3341$
60	$\pi_V {\pi_2}^{0.2840} = 247.383$	$\pi_V {\pi_2}^{0.1516} = 2.3030$
90	$\pi_V {\pi_2}^{0.2628} = 379.429$	$\pi_V {\pi_2}^{0.1402} = 2.8272$

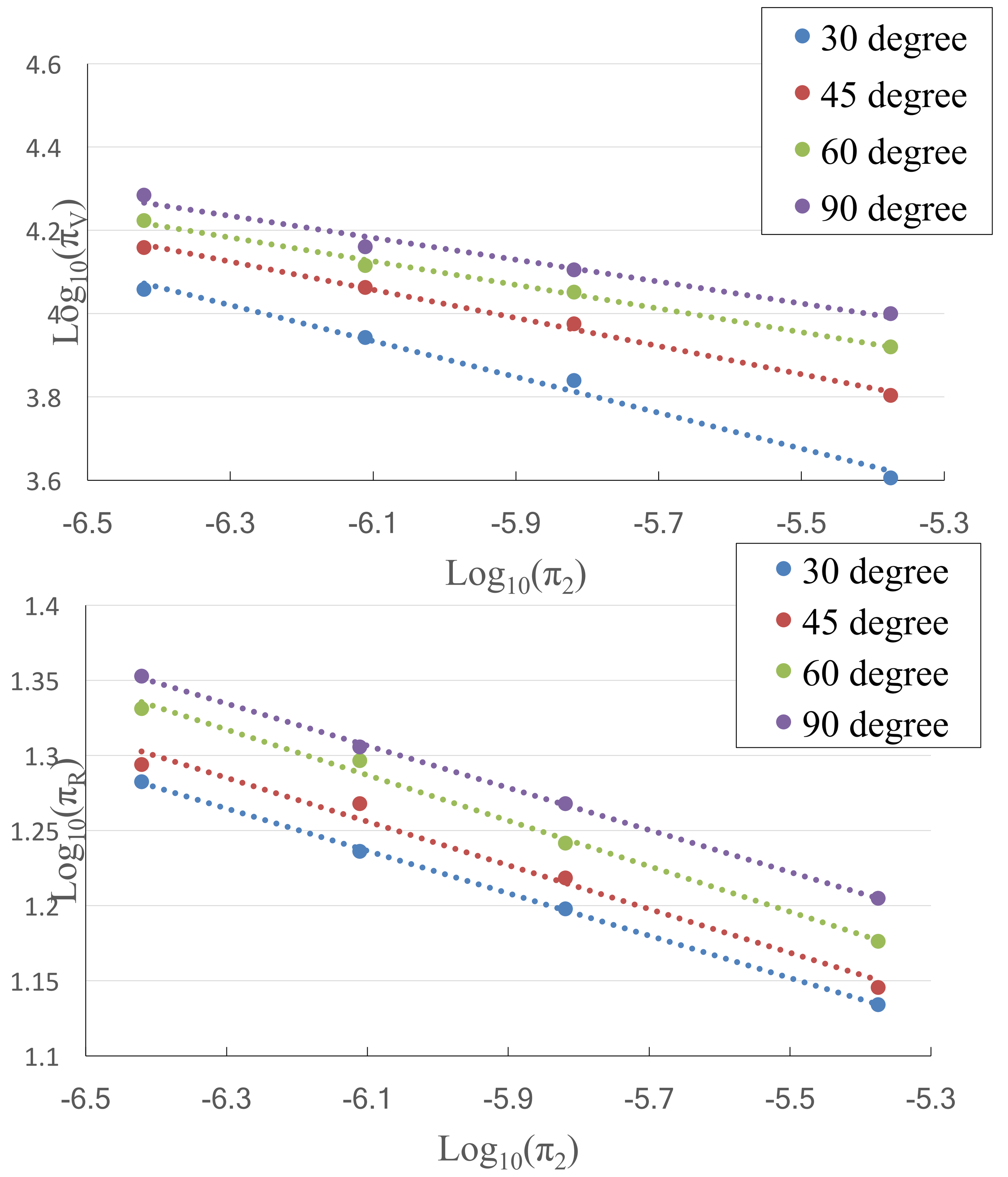

Figure 3. (up) The plot of volume scalar π_V and velocity scalar π_2. (down) The plot of radius scalar π_R and velocity scalar π_2. The points sharing the same impact angle are linear fixed. The results of the linear fitness are listed in Table 1.

(Continued) Higher impact velocity and larger angle also lead to higher peak pressure. The peak pressure is defined as the highest pressure generated by an impact. When the impact velocity ranges from 3.0 km/s to 12.0 km/s, the peak pressure is proportion to the impact velocity (Fig. 4). The peak pressure rises over 10 GPa when the impact velocity is larger than 10 km/s even impacting in a low angle.

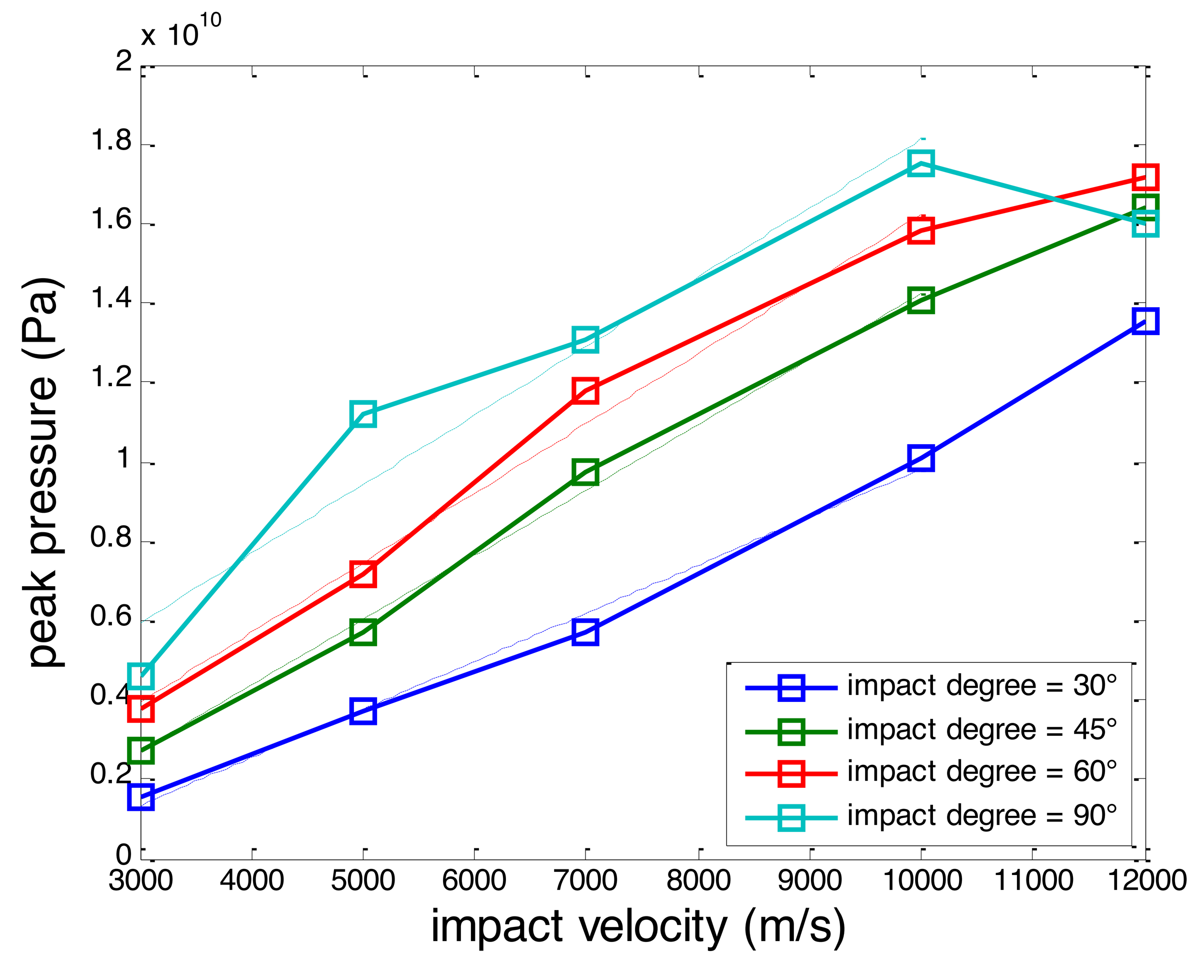

Figure 4. The plot of peak pressure and impact velocity. An abnormal low peak pressure is formed at 12 km/s and 90° because the peak pressure is achieved in a shorter time than the first record time.

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References

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