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Low velocity impact simulations with pkdgrav and Chrono

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Abstract

This work presents the results from a set of low-velocity impact simulations that were performed using the soft-sphere Discrete Element Method and two different codes: pkdgrav and Chrono. In these tests, a spherical projectile is dropped onto a bed of glass beads, where the size of the container, the size of the beads, the impact velocity of the projectile, and the gravity-level are varied. First, the simulation results are compared against experimental data and theoretical collision behaviors. Then, the results from pkdgrav and Chrono are examined in more detail and are compared in terms of output and performance differences.

Introduction

The robotic exploration of small-body surfaces often involves the direct interaction between a slow-moving mechanism and a bed of loose regolith. Take, for instance, the two most recent missions to near-Earth asteroids. In 2018 and 2019, the Hayabusa2 spacecraft deployed several landers to the surface of the asteroid Ryugu [9]. In October of this year, the OSIRIS-REx mission will collect a sample from the surface of the asteroid Bennu using a 'touch-and-go' mechanism [2]. One way to develop our understanding of lander-surface interactions is to study low-velocity collisions dynamics for penetrators of diverse shapes and sizes.

The motion of spherical, cylindrical, and conical penetrators through different granular media has been extensively studied for the terrestrial gravity environment [1] but much less so for low-gravity levels. [3] and [4] conducted low-velocity impact experiments under both Earth and reduced-gravity conditions using two different projectile shapes (spherical and cubic) and four different granular surface materials (quartz sand and 1.5 mm, 5 mm, and 10 mm glass beads). The Earth-gravity tests were completed using a static laboratory set-up, while the reduced-gravity tests were performed using an Atwood-type drop-tower [7]. In both configurations, in-situ accelerometers were used to monitor the projectile's motion.

[4] discuss the dependency of certain collision parameters, like collision duration and collision depth, on gravity-level. However, the work examines a limited range of collision cases. Due to internal friction and sizing constraints, the ISAE-Supaéro drop-tower can only reach gravity levels spanning from 0.2 to 1.5 m/s^2. The easiest way to compliment the experimental study is through numerical modeling. This work replicates and expands upon a sub-set of the impact experiments performed by

[3] and [4].

Simulations

The numerical simulations presented in this study are conducted using two different codes. The first code, pkdgrav, is frequently used for small-body related studies [5]. The second code, Chrono, is presented as an open-source alternative to pkdgrav [7, 8]. One objective of this work is to validate the Chrono code by comparing the simulation results against observations from pkdgrav, collision theory, and laboratory experiments. A second objective is to compare Chrono and pkdgrav in terms of input parameters, results, and overall computational performance.

At this time, simulations are restricted to the "static" (1g) set-up with the spherical projectile and the glass-bead surface material. In the static experiments, a 1 kg, 10 cm diameter sphere is dropped into an aluminum bucket with a base diameter of 31.5 cm and a rim diameter of 35 cm (Fig. 1). The fill height of the bucket ranges from 1 to 17 cm, and the impact velocity of the projectile varies from approximately 0 to 1.2 m/s.

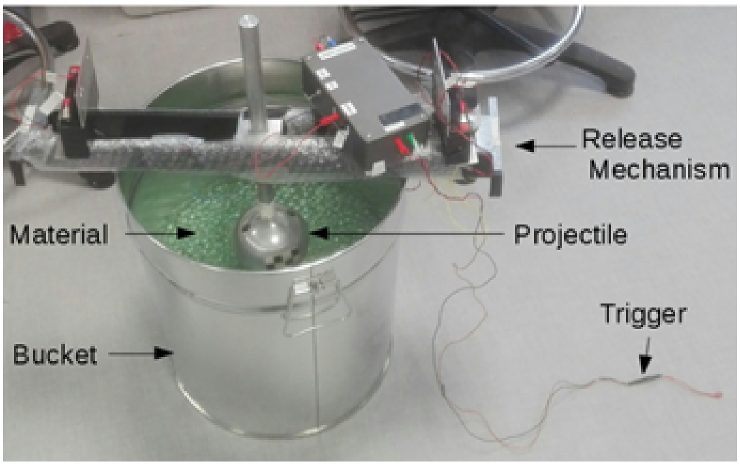

Fig. 1 – Experimental set-up for low-velocity impact testing under Earth-gravity levels [4]

For simplicity, the simulations assume that the bucket has a constant diameter and that the container is filled with either 5 mm or 10 mm diameter glass beads (Fig 2). In order to investigate the influence of the container size on the collision behavior of the projectile, the diameter and fill height of the bucket are varied from 31.5 and 40 cm and from 2 to 18 cm respectively. Though experimental data for this set-up only exists for the 1g case (g = 9.81 m/s^2), simulations are conducted for gravity levels ranging from 0.2 to 9.81 m/s^2.

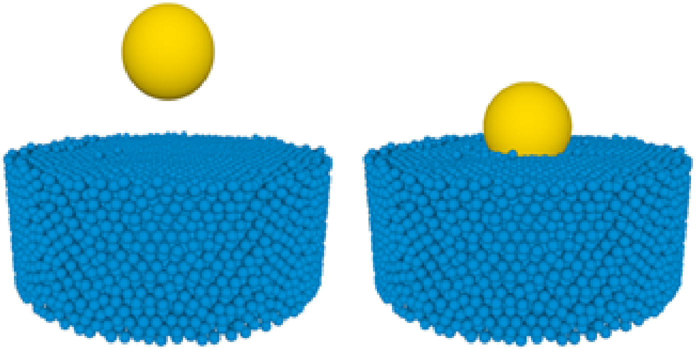

Fig. 2 – Snapshots from the beginning and end of a Chrono impact simulation

Results

The simulations are in general agreement with trends observed in the 1g impact experiments from [4]. The results are discussed within the context of existing collision models and theories and are used to identify the optimal material properties for the simulated glass beads. The coefficients of friction differ between pkdgrav and Chrono. This is to be expected, since the two codes implement different friction models. Similarly, the computation times vary due to differences in the codes' architectures and parallelization methods.

Both the experiments and simulations show that the container fill height does not influence collision behavior as long as the particle bed is at least 8 cm deep, at least for the test cases where g = 9.81 m/s^2. Chrono is used to determine if the same conclusion applies for test cases where g = 0.2 m/s^2, or the lowest gravity-level obtained by the drop-tower set-up.

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