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Numerical simulations of granular material dynamics: Comparison with shaking experiments

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Abstract

We demonstrate that a new adaptation of the parallel *N*-body code `pkdgrav` has the capability to accurately model the collective motion of granular materials in a dense regime as a result of shaking. Our numerical results correctly reproduce both the occurrence of granular strings in a vibrated granular medium and also demonstrate that, as experimentally observed, the scale of the collective motion depends on the small-particle additive concentration. As the frequency of the vibrations in these experiments is similar to what is predicted for seismic shaking on an asteroid, we will also be able to relate this work to asteroid surfaces.

1. Introduction

Surfaces of planets and small bodies in our Solar System are often covered by a layer of granular material that can range from a fine regolith to a gravel-like structure of varying depths. Therefore, the dynamics of granular materials is involved in many events occurring during planetary and small-body evolution and contributes to their geological properties.

Seismic shaking is expected to occur when small projectiles impact the surface of small bodies. The gravity on small bodies is low enough for this process to potentially lead to various kinds of surface motion, such as down-slope migration and degradation, or erasure of small craters. Regolith motion resulting from seismic shaking of asteroids has been addressed in several papers, but without simulating explicitly the dynamics of the granular material [1] [2].

Recent experiments investigating the nature of particle motion in a vibrated layer of densely packed hard spheres have demonstrated that the hard spheres spontaneously form crystallized regions known as grains. These grains are separated by relatively disordered grain boundary (GB) regions. Within these GB regions highly cooperative string-like motion has been observed [3]. The addition of small particles to the ensemble further increases the scale of the collective motion. In this work we attempt to use numerical simulations to reproduce the experimental results.

2. Numerical Code

The code used for our experiments is a modified version of the *N*-body code `pkdgrav` [4] that was adapted to handle hard-body collisions [5]. The granular dynamics modifications consist primarily of providing wall "primitives" to simulate the boundaries of the experimental apparatus [6].

Currently four wall primitives are supported that can be combined in arbitrary ways: infinite plane, finite disk, infinite cylinder, and finite cylinder (the finite primitives consist of a surface combined with one or two thin rings). Certain primitives can have limited translational or rotational motion. The experiments described here use combinations of infinite planes to simulate the apparatus; one of the planes is a vibrating base plate.

3. Seismic Shaking Simulations

The following method was used to reach a similar total surface area coverage (~85%) as in experiments [3]. First, a box of 12 cm × 12 cm is constructed using the infinite plane geometries now available in `pkdgrav`. Several layers of particles with radius (R_p) 1.5 mm are dropped into the box under gravity (1 g = 9.8 m s^{-2}). Then, a fraction of the large particles is replaced with smaller ones (radius 1 mm). The fraction replaced depends on the desired final small-particle concentration. A sixth infinite plane is then introduced into the simulation to provide confinement in the vertical *z* direction at a height of 1 mm above the top surface of the largest particles. The four walls in the *x* and *y* directions are then moved inwards gradually until the box reaches a size of 10 cm × 10 cm (see Figure 1). Finally, we start the base wall vibrating. Just as in the real experiments [3], the maximum acceleration of the vibration is 4.5 g and the frequency is 125 Hz. The amplitude of the oscillations is thus 7.15×10^{-2} mm. During the vibrations, the downward acceleration due to gravity remains constant at 1 g and there is no inter-particle gravity.

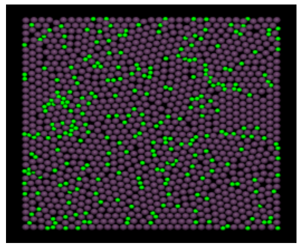

Figure 1: Ray-traced image of a simulation during the plate vibration phase as seen from above. The total surface area coverage is 84.97%. The small particles (green) cover 10 % of this total covered surface area. All walls are transparent.

4. Results

The GB regions in the numerical simulations were determined with the algorithm of [7] using exactly the same method as the analysis of the experimental results. The numerical simulations correctly reproduced the experimentally observed regions of crystallization (grains) and regions of disorder (GB regions). Figures 2 and 3 give the results for two numerical simulations with a surface area of 100 cm^2. The results of 3% small-particle concentration and 10% small-particle concentration are shown respectively.

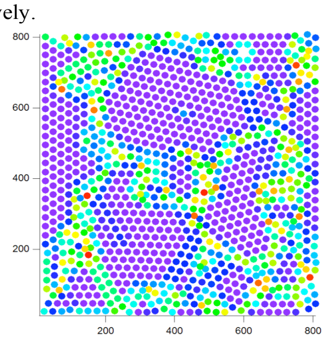

Figure 2: Results of numerical simulations with surface area 100 cm^2 and 3% small-particle concentration. Purple signifies near-hexagonal particle packing. Red corresponds to more disordered packing (i.e. GB regions).

The total area of crystallization clearly decreases as the small-particle concentration increases while the GB regions greatly increase in size. In line with the experimental results, the mean mobility of particles in the GB area in our simulations also increases as a function of small-particle concentration.
On further examination it was found that, in further agreement with the experimental results, almost all of the small particles are located in the GB regions (see Figure 3).

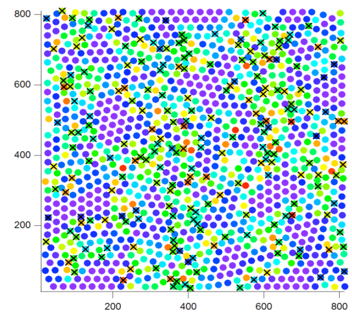

Figure 3: Results of numerical simulations with surface area 100 cm^2 and 10% small-particle concentration. This time the small particles are all marked with an X.

5. Summary and Conclusions

We have shown that our simulations using the new adaptation of the *N*-body code `pkdgrav` are capable of accurately modeling the collective motion of granular materials in a dense regime as a result of shaking. As the vibration frequency considered is similar to the predicted seismic shaking frequencies of asteroids, this work may have important implications for the mobility of granular material on the surfaces of small bodies. Further work is in progress to investigate the effect of varying the gravity field over 5 orders of magnitude from 10 g to 10^{-3} g. This will also be presented at the conference.

References

[1] Michel, P. *et al*., Icarus 200 (2009), 503-513.
[2] Richardson, J.E. *et al*., Icarus (2005) 179, 325-349.
[3] Berardi, C.R. *et al.*, Phys. Rev. E 81, 041301 (2010).
[4] Stadel, J, 2001, PhDT.
[5] Richardson, D.C. *et al.*, Icarus 143 (2000), pp. 45–59.
[6] Richardson, D.C. *et al*. 2010, in preparation.
[7] Hamanaka, T. and A. Onuki, Phys. Rev. E, 75, 041503 (2007).