Instrumented Impactors and Probing Bed Depth with Impact Penetrometry

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Motivation:

Before touching the surface of an exploration target (e.g. small rubble pile asteroid) with a *very* expensive spacecraft what tools could be used to constrain its surface properties?

-This research program aims to understand what surface properties can be identified as a function of granular materials, impact speeds and surface gravity levels through the use of small, instrument-laden, impactors.

Scientific Question:

What are the signatures of a stratified regolith bed (or target surface) in the measured accelerations of a low-speed impactor?

-This experiment seeks to characterize the change in acceleration signal as a function of a stratified impact surface. This is simply done here by decreasing the depth of the granular material, so the stratification is solid floor of the experiment.

Experiment:

We utilize only the force profiles measured from a low-speed impact into granular material and compare outcomes against universal force laws from the literature. Here, we vary: 1.)Granular bed depth, 2.)Impact speed, to measure and characterize an impactors divergence from expected force profiles (Universal force laws) as a way to detect stratified regolith on a target body.

Experiments are done with two IMUs: one is low noise, higher frequency, but lower maximum *g* capapbilities. This is used for timing of the event – determining the length of the event (Figure 3). The other is higher noise but higher *g* capability. It is used to measure the peak acceleration experienced (Figure 4).

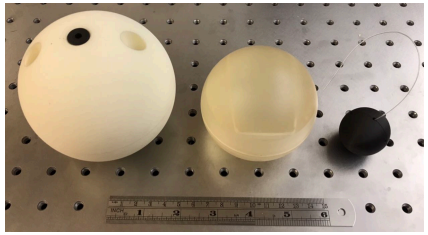

Figure 1: the three generations spherical impactors. The first two were instrumented with YOST 3-space IMUs, and the 3rd, (smaller than a ping pong ball) is instrumented with a tinycircuits IMU.

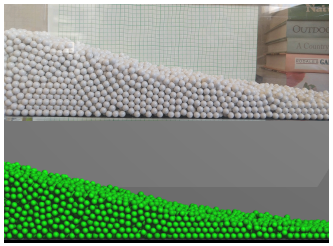

Figure 2: Airsoft pellets are a simple and very large (diam=5.95mm) granular media that is ideal for calibrating numerical modeling. Here, we performed one-to-one tests of avalanches to establish parameters for numerical modedling.

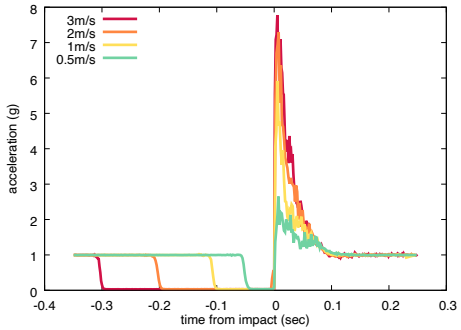

Figure 3: averaged acceleration profiles for four different impact speeds into a 8cm depth bed of Airsoft pellets. The key quantitative measures are the peak acceleration, the time until acceleration stops and the size or existence of any overshoot that leads to a reverse in velocity (or a rebound). The max accelerations here are: 2.65g, 5.9g, 7.29g and 7.78g respectively for increasing impact speed.

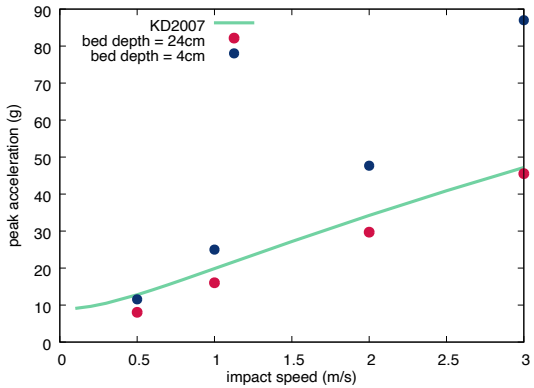

Figure 4: Peak accelerations as determined from >10 drops each with the high-g capability IMU. The green line is the Katsuragi and Durian 2007 universal law prediction, with the deeper bed depth (24cm) results showing a good match. The shallow bed (4cm) shows higher values and a divergence at higher impact speeds. The force law predicts a ~4cm and 6cm penetration at 0.5m/s, and 1m/s respectively, but results in modest increase in peak acceleration

Results:

For deep bed depth (24cm) and varying only impact speeds (Figure 3 and 4) the quantitative outcomes match formulations for stopping time and peak accelerations (Fig 4, red dots).

For constant impact speeds and bed depth of 1/2 impactor diameter (4cm) vs 3 impactor diameter (24cm) a divergence in peak acceleration becomes very clear (Fig 4 - blue dots). All impact speeds are predicted to penetrate deeper then the entire bed depth, making a large peak acceleration an obvious outcome. The surprise is that it is not larger, and was not obvious in a few tests at mildly deeper bed depths (8cm or 1 impactor diameter).

Conclusions:

- For impact speeds in the range tested here stratified layers larger than an impactor diameter width would not be simply or unambiguously detectable. Coarse granular material (relative to impactor size) increases graininess of acceleration profiles. While easily averaged in lab experiments (as done here), this could pose challenges for operations at an exploration target with a small number of impactors and a coarse/rocky target body (think Bennu).