Dynamics of penetration into a granular medium by successive impacts

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Probing the ground to analyse its properties or extract samples is at the heart of many civil engineering activities and exploration missions. Among the techniques used to drive a probe into the ground, the hammering method consists of transferring kinetic energy to the intruder through a series of percussions. The hammering mechanism is the basis of the operation of space probes, which are designed to dive beneath the sandy surface of other planets and inspect their physical properties [1] [2]. From a fundamental point of view, many studies have focused on the single impact of an object in a granular medium and the resulting granular flow [3]. However, the case of penetration by a series of impacts remains much less explored. The aim of this study is to fill this gap and realize model experiments to understand the penetration dynamics of an intruder in a dry granular medium when it undergoes a series of impacts.

We realize experiments with a vertical cylinder partially immersed in a dry granular medium and subjected to a series of impacts generated by the movement of an internal mass (top left inset in Fig. 1). We measure the depth of a cylindrical object below the grain surface as a function of the number of impacts, their energy, the geometry of the object and the properties of the granular material. These experiments reveal two distinct intrusion regimes, one at shallow depth and the other at great depth [4]. The depth of the impactor below the free surface z_N first evolves linearly with the impact number N and then follows a power-law evolution $z_N \propto N^{1/3}$ (see Fig. 1). The depth reached by the cylinder after a given number of impacts is observed to increase with the impact energy but to decrease with its diameter and the density of the granular medium. In order to rationalise these observations, we consider the forces applied to the cylinder, which result from the flow of grains induced by its penetration. This approach allows to predict the two intrusion regimes observed experimentally and their dependence on the experimental parameters. In addition, we extend the study to the effect of sidewalls on the dynamics of the impactor. We show that lateral confinement changes the dependence of the impactor depth on the impact number, $z_N(N)$, towards a logarithmic trend. This effect is taken into account by considering the increase in granular drag with lateral confinement.

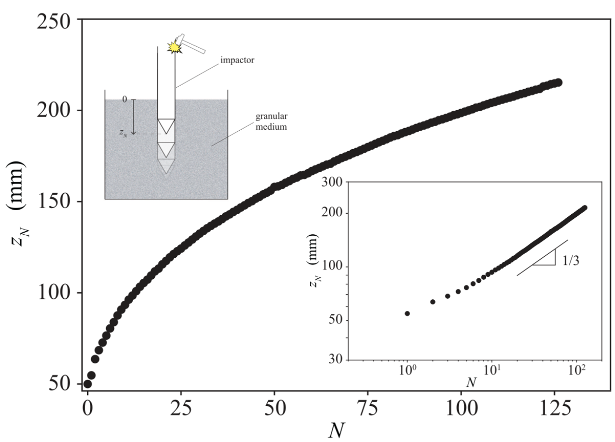

Figure 1: Intrusion depth z of a cylindrical intruder into a granular medium as a function of the number of impacts N. Top inset: sketch of the experimental setup. Bottom inset: logarithmic plot of the data.

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[1]Spohn et al. *Space Science Reviews* **214** (2018).
[2]Olaf et al. *Acta Astronautica* **164** (2019).
[3]Van Der Meer *Annual review of fluid mechanics* **49** (2017).
[4]Seguin et al. *Physical Review E* **106.5** (2022).