Experimental and numerical studies of semi-confined heap structure after variable pouring conditions

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Keywords

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Abstract

The classic experience of filling a container with a granular medium poured from a source point reveals the presence of the intergranular forces network by the manifestation of the Janssen effect (Janssen, 1895). Indeed, the measurement of the stress applied at the base of the container according to the bed particle height, shows that the static mechanical state of the ensiled granular medium is not comparable to a hydrostatic one which is characteristic of a fluid. The lateral deflection of gravity forces to the walls via the network of intergranular contacts, allows to explain the lowering of vertical stress (σzz) in relation to hydrostatic pressure. Moreover, the sliding threshold condition must be established at the walls to explain the "saturant" shape of the σzz profile (Ovarlez and Clément, 2005). If mechanical properties are involved to explain this apparent phenomenon understanding as a static equilibrium, the analyze of the free surface during pouring correlated to the local mechanical state allow to indicate that kinetic energy had an influence on the Janssen effect (Mandato et al. 2012; Duri et al. 2018). In order to revisit the Janssen effect, experiments and Discrete Element Method (DEM) simulations are compared to investigate the structure of an ensiled granular medium poured in a cell by a single point at different initial drop heights and flow rate (parameters which allow to control kinetic energy).

Experimental device. The granular medium consists of a population of glass beads of 1 to 2 mm diameter with a small span value (50/50 in volume). The experimental set-up, developed in Mandato et al. (2012), consists of an open glass cell container (51 x 100 x 160 mm) made of transparent glass walls. A flat and rectangular steel probe is especially designed to fit into the glass container. A small probe allows local measurements of the vertical stress in the powder bed. A large probe is used to simulate the bottom of the cell and allows a global measurement of the vertical stress, as in Janssen's experiment (Janssen, 1895). Whatever its width, the probe is screwed on a rod that is linked to a load cell of a texture analyser (TA.XT2, Table Micro System), which is used as a force sensor. The filling is provided by a funnel and the flow rate is modulated by the output diameter. After pouring, the slope angle and the arrow of the free surface are measured by image analysis.

Numerical simulation. We develop our own homemade code in c^{++}using the DEM. Then we decide to develop also a code using the coarse-graining method (Weinhart and Luding, 2016) to highlight on the different fields. This last method which doesn't give access to the compactness near the wall, is replaced by a new method using two grids in order to increase the accurate. With these three codes

we can now explore all the contacts between the particles by the calculus of (i) normal and tangential forces, (ii) moment, (iii) mobility, of each particle.

Results. The variation of the initial drop height and the flow rate impacts the slope of the free surface: crater form in high kinetic energy conditions, heap form in lowest conditions and intermediary slopes between these conditions (from plate to "camel-like" form). The measured and calculated values of the arrow and of the angle of repose are in very good agreement in each case. Experiments and numerical simulation highlight the same layout of the vertical stress field (Fig. 1). In the upper part of the particle bed, there is a layer in which the stress is generally assimilated to a "quasi-hydrostatic" state. It can be seen that under this first layer, Janssen's hypothesis that stresses are lateral uniformity is not valid: there is a strong local heterogeneity of the stress within the granular medium. It can be seen that the redirection coefficient defined by Janssen (Janssen, 1985) ratio between lateral stress and vertical stress, is not constant. The study of thickness and mean stress in each different zone of the bed versus kinetic energy during the filling stage had been realized. The static mechanical state of the particle bed is also due to this dynamical parameter and this point is usually not taking into account.

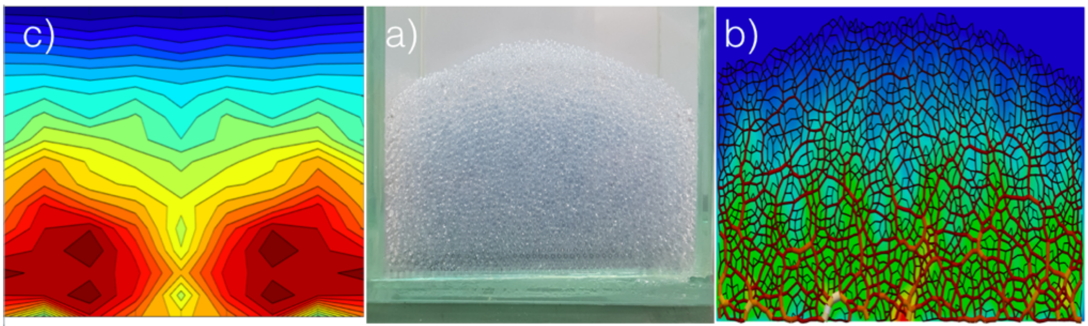

Figure 1. Illustration of the semi-confined heap: experiments and simulations a) experimental device, b) stress field obtained by coarse graining superposed on the force network, c) vertical stress field measured by a local probe.