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# Granular collapse into water: toward tsunami landslides

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## 1 Introduction

Modeling of granular flow is a key issue in many geophysical and industrial applications. Since the seminal work of Bagnold [1], a huge number of studies have considered the dynamics of dry granular flow in various situations [2–4]. Underwater granular events are more complicated to describe as the presence and the influence of the surrounding fluid modifies the rheology of the flow [5,6]. It becomes even more challenging, but also important, to predict the impact of a granular media from the air into a fluid and the subsequent wave generated by the impact. This situation constitutes a model for subaerial deformable landslide and have many implications to forecast the generation of tsunamis. Recent experimental studies considered the generation of impulse wave, in water of depth $H$, by subaerial landslides [7]. However, these experiments focused on a Froude number at the impact $Fr = v_s/\sqrt{g\,H}$, i.e. the ratio of the slide velocity $v_s$ to the gravitational wave velocity, larger than one. Therefore, the dynamic of a dry granular flow during the collapse into water remains largely unknown, especially at Froude number smaller than unity which would be of crucial importance for cliffs failure into water. In this work, we study such a situation in an experimental setup designed to characterize both the wave generated by the impact but also the granular flow after its penetration into the water.

## 2 Experimental set-up

The experimental set-up is shown in Fig. 1. It consists of a wave tank of 2.20 m long, 0.40 m high and 0.20 m wide and a slope with glass beads stuck on it to suppress slipping of particles on the surface. The initial water depth is $H = 14.8$ cm. A vertical gate is used to delimitate the initial reservoir of granular materials located just above the undisturbed free surface. The gate is opened vertically using a 20 kg mass and pulley. The particles used are glass beads of diameter $d = 1.5$ mm and density $\rho_s = 2500$ kg.m$^{-3}$. The evolution of the generated wave and of the granular flow are recorded with a high speed camera (Phantom Cinemag II). The amplitude and the propagation of the generated wave are also measured with 4 resistive gauges located at 0.45 m, 0.75 m, 1.05 m and 1.35 m from the lifting gate. In addition, a PIV measurement system is used to estimate the velocity field in the water.

## 3 Results and perspectives

Experiments were performed varying the initial mass of the granular media in the range $m \in [0.5; 4]$ kg and the slope angle $\theta \in [35^\circ\,; 60^\circ]$. Fig. 2 shows a sequence of snapshots of the granular collapse process and the generation of the wave. The shape of the granular front just after the opening of the gate remains vertical.

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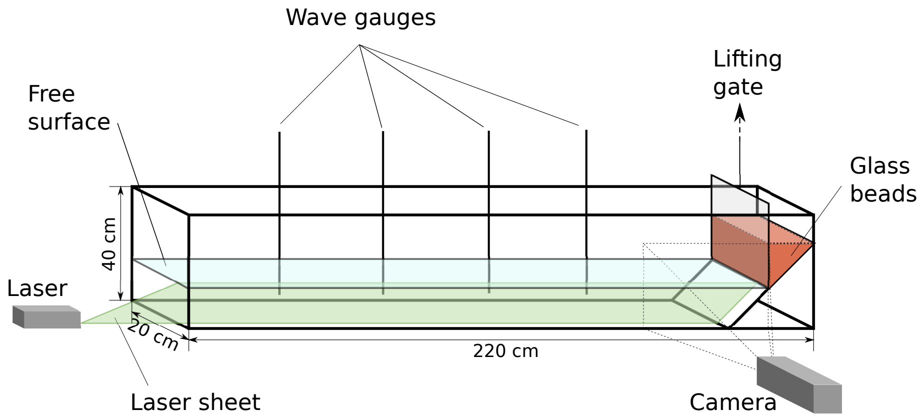
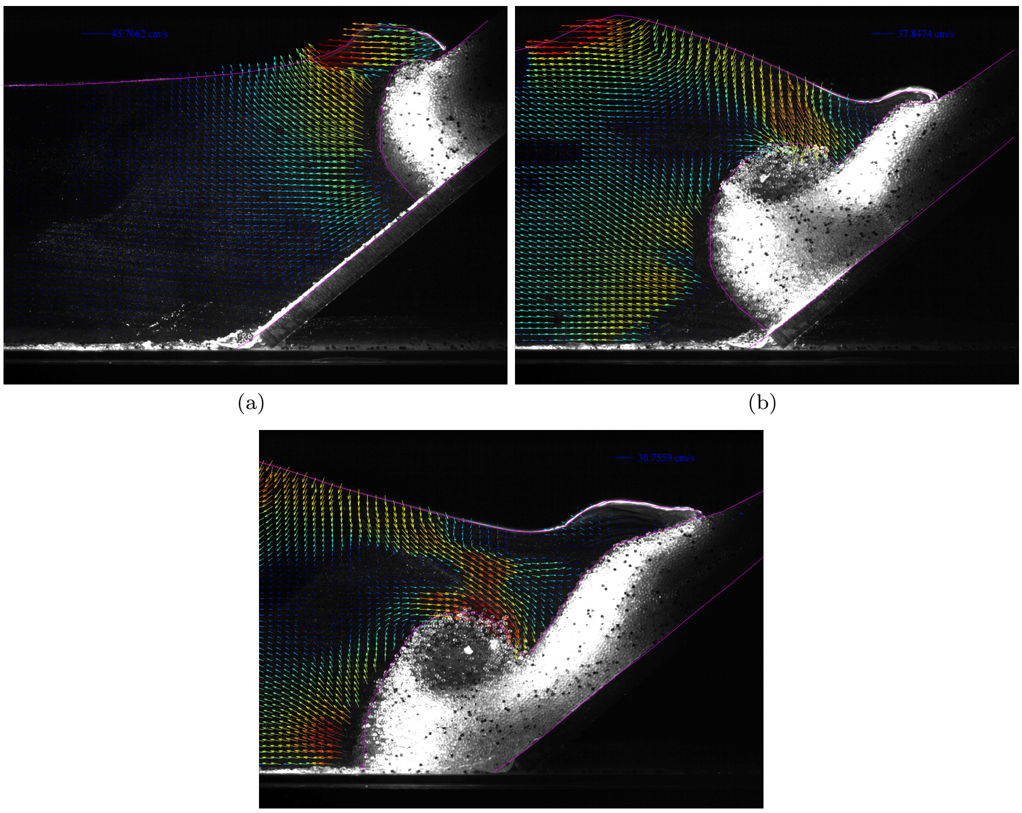



(a)

**Fig. 1** *Schematic view of the experimental set-up*

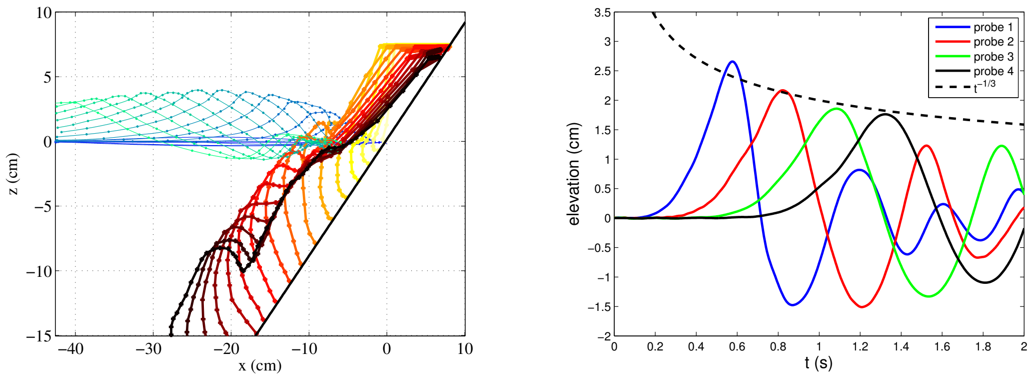
During the collapse, a vortex is generated at the interface of the granular flow and the water which may be induced by a shear instability. The time evolution of the free surface and the granular flow are represented in Fig. 3(a), every 1/50 s. The free surface evolution at each probe is represented in Fig. 3(b). Sufficiently far from the collapse, i.e. in far field, the leading wave amplitude decreases as $t^{-1/3}$ during the propagation (see ref. [8]).



(a) (b)

(c)

**Fig. 2** *Sequence of snapshots showing the granular collapse and the generated wave for a slope angle of* $45°$ *and* $3.00$ *kg of beads. At time (a)* $t = 230$ *ms, (b)* $t = 410$ *ms and (c)* $t = 520$ *ms. PIV field are also represented.*




(a) (b)

**Fig. 3** *(a) Evolution of the free surface and the granular flow during the collapse and (b) elevation of the free surface at each probe for the parameters used in Fig. 2.*

Despite the complexity of this phenomenon, the experiments reported in this article provide first insights into the collapse of a dry granular flow into water and the generated wave. A more detailed analysis is in progress to quantify and model the interactions between the landslide and the wave. fThe derivation of scaling laws to relate the experimental parameters such as size or density of the granular media to real landslides would be of crucial importance to forecast tsunami generated by cliffs failure.

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