Evolution of water waves generated by subaerial deformable landslide

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Abstract

We consider experimentally the waves generated by subaerial granular landslide. A set of experiments are performed in a $2.20 \times 0.40 \times 0.2$m wave tank to characterize the behavior of the granular flow as well as its influence on the generated wave. A PIV method is used to capture the evolution of the velocity field in the water. From these experiments several observations are presented on both the generation of the wave and the evolution of the granular during the collapse.

1 Introduction

Predicting the dynamics of granular flow plays an important role in geophysical and industrial applications. Since the seminal work of Bagnold in 1954 [1], a huge number of studies have considered the dynamics of dry granular media in various geometry such as on an inclined plane or in a rotating drum (for a review, see e.g. [3]). Most of these studies focused on dry granular flow as the situation is already complicated to describe. In particular, there is still a lack of constitutive laws to explain and predict the experimental observations. For a dense and dry granular flow, the $\mu(I)-$rheology seems to be the only model which allows a successful continuum description of the flow [5]. This rheology is purely phenomenological but has shown good agreement with experiments and numerical simulations in various situation (see [6]).

However, the situation becomes more complicated for underwater granular flow where the presence of the surrounding fluid modifies the rheology of the flow. Recently, Cassar & al. [2] adapted the $\mu(I)-$rheology to submarine flow by replacing the inertial time scale with a viscous time scale in order to take into account the presence and influence of the surrounding fluid. Numerically, Topin & al. [8] have performed numerical simulations on submarine granular collapse by coupling a contact dynamics method and a fluid dynamics method.

Whereas this last problem is already complicated to quantify, it becomes even more challenging to predict the impact of a granular media from the air into the water and the wave generated by this impact. This situation is a model for subaerial deformable landslide and would have many important implications to forecast the subsequent generation of tsunamis. Based on numerous experiments, Mohammed & Fritz [7] have studied the generation of impulse wave by subaerial landslides with a Froude number ($V_{slide}/\sqrt{gH}$) at the impact larger than one. From these experimental studies, they provided a predictive equation on wave amplitude, period and length.

Despite these studies, the dynamics of a dry granular flow during the collapse into water remains largely unknown, especially at Froude number smaller than unity. 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 flow of the granular media after its penetration into the water. By performing systematic experimental studies and obtaining relevant scaling laws, we aim to estimate the potential tsunami which would be generated after an impact of granular flow into water in various geophysical events.

2 Experimental set-up and data acquisition

A schematic view of the experimental set-up is presented in figure 1. It consists in a wave tank of 2.20 m

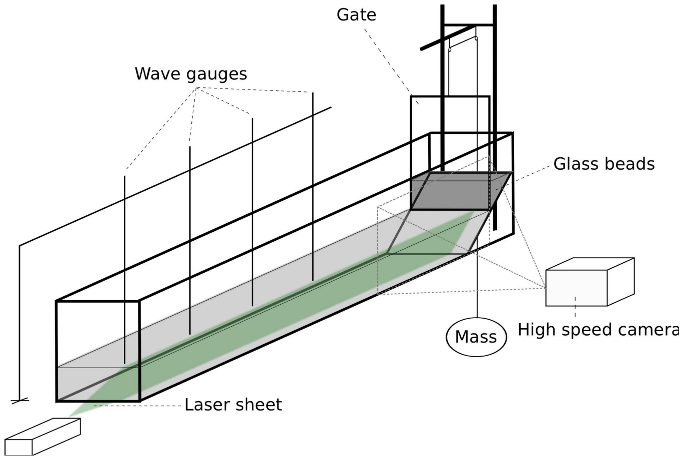


Figure 1: *Schematic view of the experimental set-up*

long, 0.40 m high and 0.195 m wide. The slope is made of a polyvinyl plate with glass beads stuck on it to take into account the friction and suppress slipping of particles on the surface. The initial water depth in the tank remains constant for all the experiments and equal to $H = 14.8$ 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 velocity of the gate reaches a value of 5 m.s^{-1} which is sufficient to ensure a granular front almost vertical at the initial time. The particles used are glass beads of diameter $d = 1.5$ mm and density $\rho_s = 2500$ kg.m^{-3}. It has been shown that the initial compaction of the material is an important parameter for the later granular flow [4]. Therefore, to ensure a good reproducibility of our experiments, the edge of the wave tank is hit a sufficient number of time with a hammer the same way for each experiment.

Then, the evolutions of the generated wave and of the granular flow are recorded with a high speed camera at 200 fps. The propagation of the generated wave is also measured with 4 resistive gauges located at 0.59 m, 1.052 m, 1.402 m and 2.019 m from the right side of the tank. (In some experiments we have also performed PIV measurement to estimate the velocity field in the water. The water was seeded with 8 μm diameter silver coated hollow glass spheres with a density of 1.1 g.cm^{-1}. Then, an intercorrelation window technique with several loops is performed to obtain the velocity field from the recorded movies.

Experiment	slope angle (°)	Initial mass (kg)
1	60	3.566
2	45	3.566
3	45	3.000
4	45	2.75
5	45	2.50
6	45	2.25
7	45	2.0

Table 1:

3 Experimental results

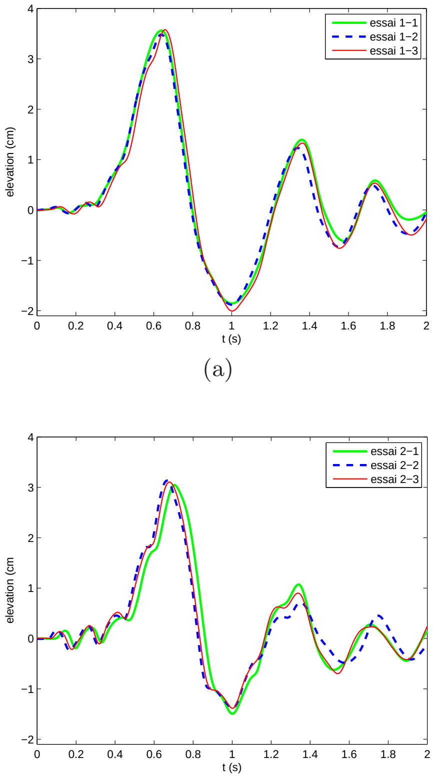
Several experiments were performed varying the initial mass of the landslide and the slope angle. This study is in progress, additional results will be presented during the conference. The range of parameters is summarized in table 1.

The first and second experiments in table 1 were both conducted three times to ensure the reproducibility of it. The evolution of the free surface at the first probe is represented in figure 2 for both configurations. The reproducibility of the experiment is excellent. We can also note that the maximum amplitude of the generated wave is larger for a higher slope angle. This observation was quite intuitive, the granular flow impact the undisturbed free surface stronger than in the case of a gentle slope.

The evolution of both the free surface and the granular media is represented on figure 3a) for a slope angle of 45°. For convenience, only 1 curve of 4 is displayed (we used more curves for the study).

The time evolution of the granular front position and its velocity are represented in figure 3b). The velocity of the granular remains constant during the collapse and is larger for a higher slope angle. This was quite unexpected, it seems that the slide reaches a terminal velocity very quickly. The evolution of the free surface during the generation is represented in figure 4.a for three differents experiments (tests 1, 2 and 5 in table 1). As expected increasing the slope angle and/or the initial mass of the granular, increase the maximum amplitude of the generated wave. Figure 4b) shows the evolution of the thickness of the granular slide during the collapse for these three experiments. Here again, the thickness increases with the slope angle but does not seems to depend of the initial mass of granular. Indeed for tests 2 and 5 the thickness is quite the same wherase the initial mass is about 30% less in one case.

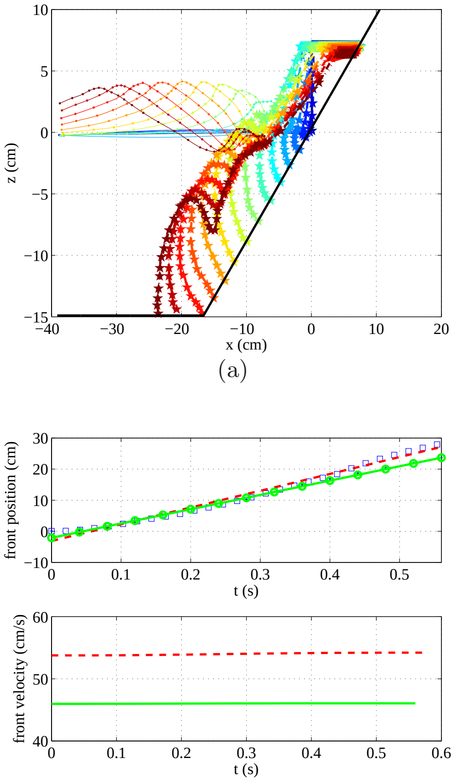
The influence of the initial mass of granular is represented on figure 5 for a slope angle of 45°. The



(a)

(b)

Figure 2: *Time evolution of the free surface at the first probe locates at* 0.59 *m from the right side of the tank. (a) slope angle of* 60°*, (b)* 45°*.*



(a)

(b)

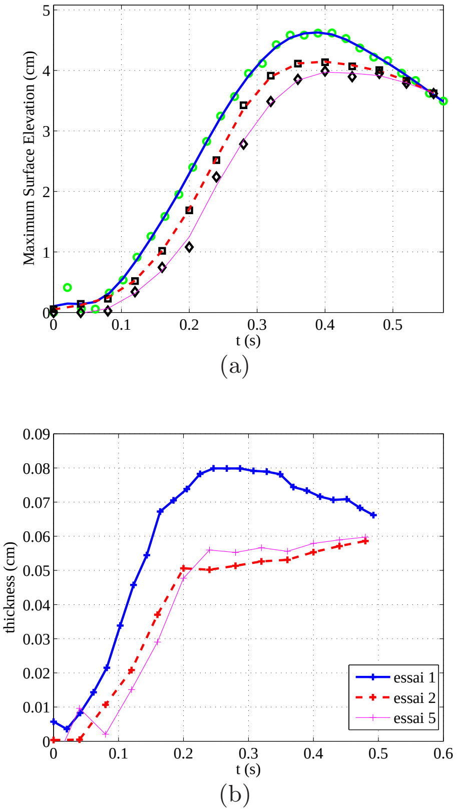
Figure 3: *(a) Evolution of the free surface and the granular media (time between two curve is* 1/50 *s. (b) Evolution of the front position and its velocity during the collpase for a slope angle of* 45° *continous line and* 60° *dashed line.*

maximum amplitude of the leading wave is represented at each gauge as a function of the initial mass of the slide. Has expected and already observed in previous figure (fig.4a) the amplitude of the generated wave increase with the mass of the slide.

The field velocity in the water during the collapse is represented in figure 6. We can observe the formation of a vortex at the head of the granular flow which may explain its constant velocity during the collpase (see fig. 6b). The leading beads reach their terminal velocity (which is about 0.20 m.s^{-1}) but the top of the intial amount of granular is still dry and pushes it. This generates an instability giving rise to the vortex. Figure 6c) shows that the vortex generated during the collapses induces a reverse current in the water, this current stops the granular flow for some instant and then finishes to slide down along the slope.

4 Discussion

From all these experiments we observed expected results on the generation of the wave. The amplitude increases with the slope angle and the initial mass of the slide. More suprising results were observed for the granular flow. One of the less intuitive is the velocity of the flow during the collpase. Indeed, the velocity increases with the slope angle but keeps a constant value during the collapse. Evaluating the terminal velocity of a single bead for a slope angle of 45° gives a value of 0.20 m.s^{-1} which is near twice less than the observed velocity. The other new observation is about the evolution of the thickness of the slide. It reaches a constant value, which can be explained by the generation of the vortex and the induced circulation but does not seem to depend on the initial mass of the slide. This study is still in progress. We are performing several experiments varying the slope angle, the water depth and the diameter of the beads to confirm these first observations and develop a scaling law on the evolution of the amplitude of the generated wave. A numerical study is also conducted using the approximation of a Bingham fluid to model the granular flow.



(a)

(b)

Figure 4: *(a) Elevation of the free surface as a function of time. (b) Evolution of the thickness of the granular flow during the collapse. Thick solid line essai 1 (see table 1), dashed line essai 2 and thin solid line essai 5. Markers represent the measurement from the camera.*

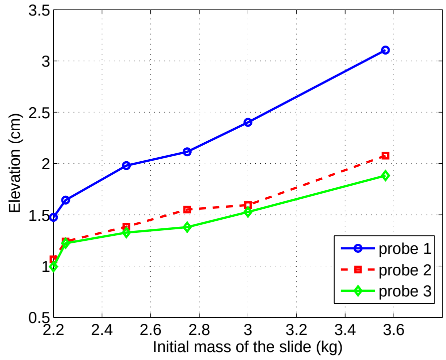


Figure 5: *Maximum elevation of the free surface at each probe as a function of the initial slide mass.*

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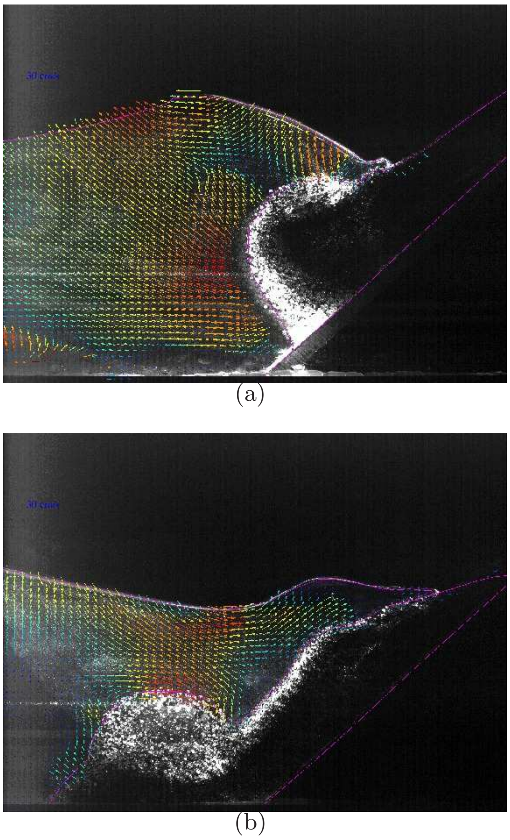

(a)

(b)

Figure 6: *PIV measurement for a slope angle of 45°.*

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