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GRANULAR FLOWS ON A HEAP

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Summary Flows of granular material on a heap is experimentally investigated. A layer of granular material is flowing from a hopper on top of a static pile in a channel. We study the role of the side walls and show that it has a dramatic influence on the dynamics of the flow. The angle of the free surface increases with flow rate for narrow channels but remains constant when the side walls are far enough. The systematic study of the flowing thickness for different flow rates and different widths of the channel is also investigated.

INTRODUCTION

The flow of granular matters is often encountered in engineering applications involving the transport of materials such as minerals, cereals, but also in geophysical situations. One of the difficulties in describing such complex flows lies in the uncertainty in the constitutive equations. An important effort has been made in the last few years to study steady uniform flows in various configurations in order to understand the main ingredients necessary for the rheology of granular material [1]. In the case of free surface flows (flow on a pile or flow in a rotating drum) the difficulty is the coexistence of both a liquid and solid behavior of the material: a thin layer of granular material is flowing on top of a static pile. An important question is the selection of the flowing thickness. Previous studies in both rotating drums and flows on piles have shown that the velocity profile in the flowing layer is linear with an exponential tail [2]. The interesting result is that the shear rate seems to be constant independent of the flow rate, implying that the thickness of the flow increases like the square root of the flow rate. However, most of the studies reported in the literature are carried out in narrow channels for which the distance between side walls is less than 50 particles diameters. In this paper we present results about the influence of the width of the channel up to very wide channels and show that side walls dramatically change the dynamics of the flow.

EXPERIMENTAL SET-UP

The set-up is a long channel (1.5 m) with two smooth side walls made of glass and a rough bottom (Fig. 1a). We can change the width of the channel (W) from 10 particle diameters to 600. The channel is partially closed at the bottom end by a 10 cm plate. The whole channel is inclined at an angle less than the angle of repose of the material, such that a static pile can be trapped in the box. The flow is obtained by injecting the granular material (0.53 mm glass beads) from a hopper at the top of the box (Fig. 1a). When starting the experiment, the box is initially empty. When the hopper gate is opened, the material first fills the box, before flowing over the end plate. A steady regime is then reached with a layer flowing on top of a static pile. In this regime, the injected flow rate is exactly equal to the outlet flow rate. It should be noticed that once the width (W) is fixed, the flow rate is the only control parameter. The inclination of the free surfacec and the flow depth are not prescribed *a priori* but selected by the system.

Once the steady regime is obtained, we perform measurements of the free surface inclination and of the velocity profile at the side wall using PIV method. In order to get information of the flowing thickness far from the wall we have developed a weakly intrusive method based on the erosion of a thin powder deposed on a thin obstacle.

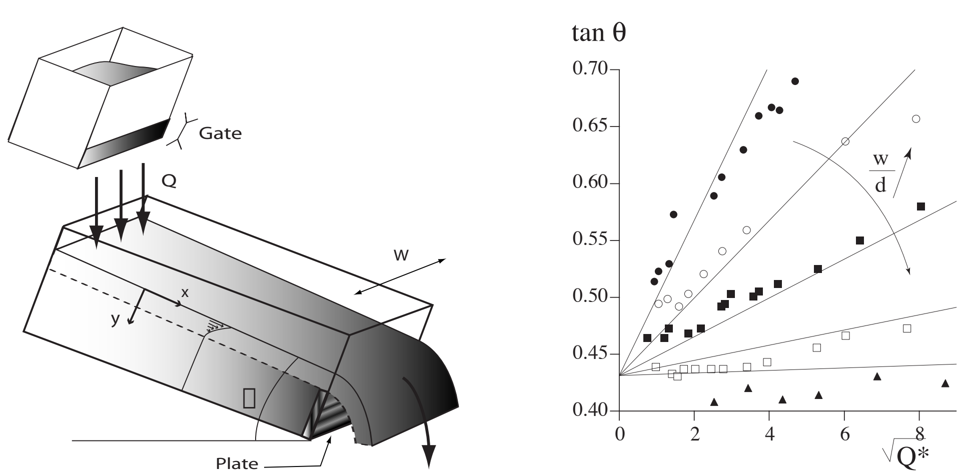

Figure 1. (a) Sketch of the experimental set-up. **(b)** Surface slope as a function of the square root of the dimensionless flow rate for different channel widths (W/d from 10 to 600)

RESULTS

Slope of the free surface

The first result concerns the free surface inclination (Fig 1b). For narrow channels, the inclination increases when increasing the flow rate as reported in the literature [3, 4]. However, when the width of the channel is larger than 500 particle diameters, this effect vanishes and the slope of the flow remains constant independent of the flow rate. These measurements show that the increases of the slope is linked to the additional friction induced by the walls and can be easily understood in the framework of a Coulomb model. This result is compatible with recent measurements carried out on avalanche angles in rotating drum of various widths [5] and on inclined rough plane for high flow rates [6].

Flowing thickness

The measurement of the flowing thickness h in the middle of the channel using the erosion method shows a dramatic influence of the channel width. For example, at a fixed flow rate per unit of width, the thickness h is found to be twice larger for wide channel ($W/d > 500$) than for thin channel ($W/d = 20$). This result raises the question of the role of the boundary in the selection of the boundary between flowing and static region.

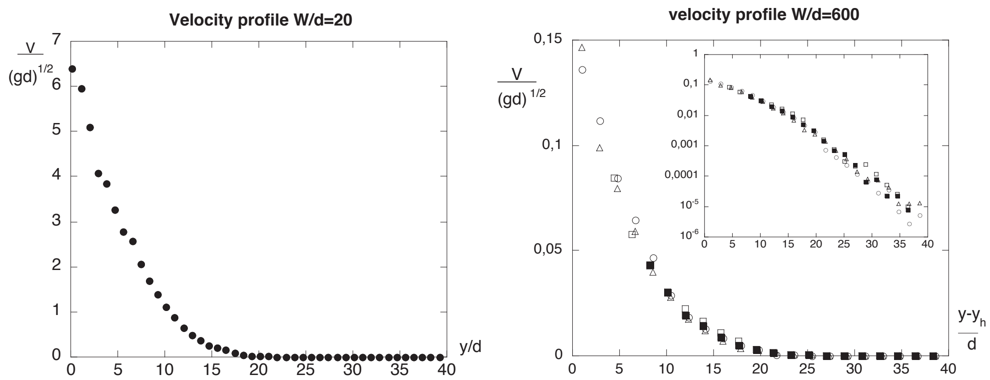

Figure 2. (a) Velocity profile for W/d=20 (Q=30 g/s/cm). **(b)** Velocity profile for $W/d = 600$ and different flow rates plotted to follow the fastest profile. Q=2.9 (black square), 5.4 (white square), 12.8 (triangle) and 25.5 (circle) g/s/cm. Inset : same as b in log-lin

Velocity profiles

Unfortunately we are unable to measure velocity profile in the bulk to get ride of wall effect. The only profile accessible with classical imaging method are at the side wall. A typical velocity profile obtained for thin channels is plotted in Fig. 2a. We can see the linear part at the surface followed by a cut-off. For large width (Fig. 2b) the shape of profiles seems to change. The convex part is larger. An interesting result is that the different profiles obtained for different flow rates can be collapse when shifted along the y direction.

CONCLUSIONS

By studying the flow of granular material on a pile in channel of different widths, we have been able to show that side wall friction has a great influence. One important result is that for wide channel, when side wall effect are negligible, the surface slope is constant, showing that the material choose a single critical inclination. Moreover, the flowing thickness in this case is larger than what has been observed before in narrow channel.

References

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