TRANSVERSE MOTION, SEGREGATION AND ROTATIONS IN 2D GRANULAR FLOWS

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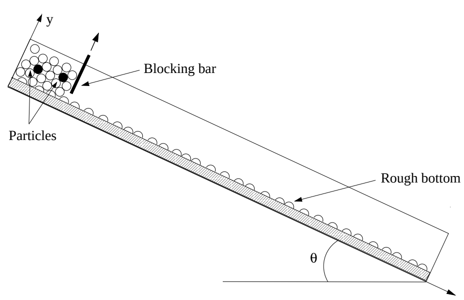
Summary We present an experimental study of 2D dense flows consisting of both monodisperse and bidisperse disks. We have analyzed the trajectories of the particles within the flow in a steady regime. In monodisperse flows, particles are arranged in layers that are in motion relative to one another. The particle transfer between layers can be interpreted as a transverse motion of diffusive nature. The diffusion coefficient associated to each layer increases linearly with the layer height. In polydisperse flows consisting of a few percentage of small disks among large ones, the small particles have a net downward motion on which a fluctuating behavior is superimposed. At short time, the small particle motion can be described as a biased Brownian motion. The ratio of the characteristic time of diffusion to that of convection is found to increase with the layer height, indicating that the segregation process is more efficient in the upper layers of the flow. At longer time, the transverse motion of the small particles seems to differ greatly from a classical biased Brownian motion.

INTRODUCTION

It is crucial to better understand the physical mechanisms which drive granular flows especially since they occur in geophysical context (rock avalanches, landslides) and in industrial applications. Granular flows generally belong to a regime where both friction between particles and collision play important roles. In this regime, no sound convincing constitutive law has been proposed despite the numerous experimental [1, 2, 3, 4, 5, 6], numerical [7] and theoretical [9, 10, 11] works devoted to granular flows. To avoid the experimental difficulties encountered in the case of 3D flows, Drake [3] proposed to use a two-dimensional geometry where particles are confined between two glass walls. This geometry is well suited to a detailed analysis of the micro-structure and the kinematics of the flow via a high speed camera. The purpose of the present work is to analyze in a 2D inclined granular chute flow the process of particle layer transfer. This study is motivated by the understanding and modeling of the segregation phenomenon in granular chute flows.

Experimental Set-up

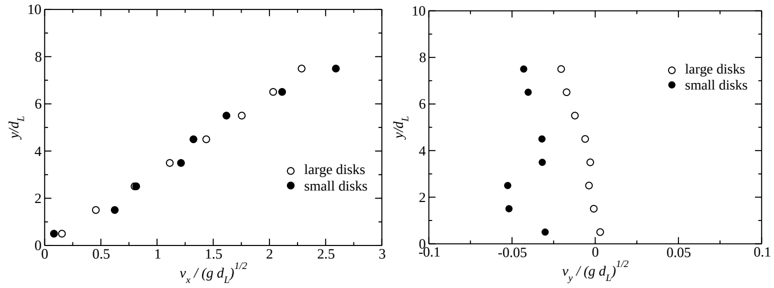
The chute flow experiments have been performed using the set-up sketched in the Figure. The flowing particles are confined between two smooth glass side walls. Unlike most granular chute experiments, particles used here are not spheres but disks. Although the use of disks instead spheres enhance the friction with the side wall, it allows to work with mono-sized assemblies as well as with binary mixtures.



Flow experiments are recorded by a high speed video camera at a frequency high enough to track the motion of each grain of the flow. An image processing software computes the position of the center of mass of the disks on each image, therefore allowing one to extract the trajectories and calculate the kinematic properties of the particles. The binary mixtures were made of large and small polystyrene disks giving a diameter ratio of 2. We worked only with very dilute mixtures (e.g. less than 1% of fine particles). Strictly speaking, the flow is not fully developed since during the chute the segregation process occurs: the small disks migrate progressively towards the lower layer of the flow. However, as the mixture is dilute, the flow of large disks remains stationary and homogeneous along the longitudinal direction. The flow, characterized by a constant height, is dense : the packing fraction is rather constant in the bulk flow and is about 0.7. Within the flow, a stratification develops: layers of one particle width are built up and slide over each other. Close to the top free surface, the layers are less structured, the medium is more fluidized and therefore the packing fraction is lower.

Some results

We have measured the mean velocity of the small particles in the flow and compared it to the mean velocity of large disks. We have plotted the mean longitudinal velocity V_x of each species as a function of the height measured from the bottom. There exists no difference between small and large disks concerning the mean longitudinal velocities. In contrast, the mean transverse velocity profile is different, whereas the mean transverse velocity of large particles is almost equal to zero, small particles have a significant downward velocity. The examination of the transverse displacements of the small particles allows us to bring some insights about the segregation process. The mean displacements of the small disks are shown in Figure 1.a.



One can note again that the small disks have a net downward motion, except for those which are located in the bottom layer. The mean displacement of the particles varies roughly linearly with time. Furthermore, the particles from the upper layers exhibit a greater downward displacement than those from the lower layers.

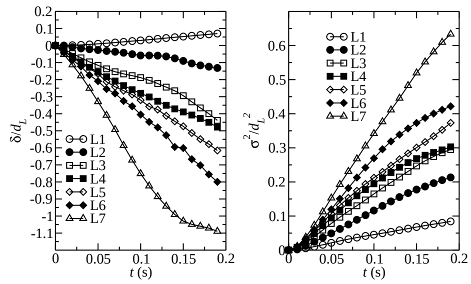


Figure 1. (a) mean transverse displacements and (b) displacement fluctuations as a function of time according the particle position.

We have also calculated the fluctuations of the transverse particle displacements according to their initial position in the flow (see Figure 1.b). The variance of the particle displacement increases linearly with time. The small particles have therefore a diffusive motion superimposed on a net downward motion. We have compared the diffusion coefficient associated to the small particles to that associated to the large ones. The diffusion behavior seems independent of the particle size. For both particle sizes, the diffusion coefficient is of the same order of magnitude and is an increasing function of the layer height.

CONCLUSION

At short time scale, we have put to the fore the existence of two competing processes driving the motion of the small particles diluted among large particles: a transverse downward convective motion which is a gravity-induced, size dependent, void-filling mechanism as described by Savage and Lun [12] and a diffusive process which is not size preferential and has no preferential direction for the layer transfer. The segregation process in dense flows is far from being comprehensively understood and we are performing additional experimental (on air table and chute flows)and theoretical efforts. Our next objective is to fully characterize the particle motion, including rotations of particles.

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