STRUCTURE AND KINEMATICS IN DENSE FREE-SURFACE GRANULAR FLOW

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We show that the structure of a dense, free-surface boundary layer granular flow is similar to the structure of a laminar

liquid Flow: there is a strong component of order (stratification parallel to the mean flow) superposed with a mild component of disorder
(self-diffusion perpendicular to the mean flow) We also show that the self-diffusion coefficient scales with the mean velocity and propose a model that relates this scaling to the ordered structure of the flow. Last, we show that the structure of the flow imprints an oscillatory signature (similar to that found in confined granular flow) on the mean velocity profile.

When a bed of sand is tipped to an angle of about 30 degrees, the sand in a thin free surface boundary layer start to flow down the surface of the bed. This type of granular flow occurs in many industrial processes and natural phenomena.

(1) debris flows, for example, are vast free surface boundary layer granular flows; in California they post they formidable threat to urban areas at the foot of the san Gabriel mountains, whose” loose inimical slopes flout the tolerance of the angle of repose

(2) ever since the pioneering work of bagnold (3),most experimentalists researching granular flow have adopted the Eulerian view points.(in the eulerian view points, the measurements pertain to fields defined in a fixed control volume (4). Although the study of eulerian fields, especially the mean velocity field, has led to many insights into the physics of free surface granular flow (5) (and also of confined granular flow (6), much remains to be elucidated. To identify a different path of inquiry into free surface granular flow, we note that the alternative, langarian view point, is often advantageous, especially when seeking to elucidate the structure of the flow (7) (in the lagrangian view point, the measurements pertain to individual flowing particles(4) here we start by adopting the lagrangian view point. In particular, we focus on the particles trajectories and study what may reveal about the structure of dense, steady, free surface boundary layer granular flow. Then, we ascertain how the structure of the flow is manifested in aspects of the kinematics other than the particles trajectories. To that end, we study the mean velocity field and the coefficient of self-diffusion perpendicular to the mean flow.

In our experiment we fill a shallow, transparent drum(of diameter 30 cm and depth 8 mm) half way with spherical beads(of diameter d=2 or 3 mm). We rotate the drum about its axis with angular velocities between 1 and 5 rpm. (For this angular velocities, the boundary layer remains steady and its surface flat).then, we focus a digital camera on the centre of the boundary layer(where the flow is uniform in the direction of the mean flow, and collect a set of 1024 images at the rate of 500 images per second. Subsequently
We use a computer a program(8) to trace the trajectory of each bead through out the experiment with a resolution of 1/ 100 of a bead diameter.

To investigate the structure of the flow, we super pose all the trajectories in a single plot. The result shows that the trajectories are grouped in bundles aligned with the direction of the mean (in the x-direction). These bundles define a set of mutually parallel strata in which the probability of finding a bead centre is high . (we have marked three of these strata with the labels S1, S2 and S3). The distance between adjacent strata remain closed to one bead diameter as each stratum slips over the one below it.

To verify that the strata are not ephemeral features of the flow, we have performed additional experiment separated by large interval of time from one another and found the same strata

The stratified structure of the flow is similar to the structure of simple laminar liquid flow (e.g. the poiseuille flow). Bagnold envisioned a flow with the same stratified structure (3) in his classical model of the granular flow in a couette apparatus. In discussing his model, bagnold noted that the motions of the grains consist, in addition to a drift in the x direction, of oscillation in all three directions, involving approaches to , and recession from , neighbouring grains . this is a fitting description of the motion of the beads within a single stratum as they slip over the bead in the stratum below. However, each bead does not persist indefinitely within a single stratum. Instead , the bead will occasionally jumped between adjacent .to investigate the excursions of the bead in the direction perpendicular to the strata (z-direction), we perform a statistical analysis of the trajectories . we identify a trajectory by its coordinates pairs (xi ,zi,) measured in the successive images I=1,2 etc. we consider three sets of trajectory. Each set comprises a number of trajectories T=1,2…n for which the starting point (X T/L, Z T/L), falls within one of the strata marked S1, S2, and S3. for each set trajectories we compute the quantities △X t/i = X t/I-X t/Ii △Z t/I=Z t/I-Z t/I, and (△Z t/ I)