STEADY CHANNELS AND AVALANCHES OF DENSE GRANULAR FLOW DOWN A SLOPE

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Summary The flow of granular materials arises in many geophysical processes including debris flows, rockfalls, and snow avalanches. A quantitative understanding of the motion is useful for predicting such natural flows and conducting hazard analysis on mountainous terrain. However, the motion is not well understood, particularly in shallow layers where flowing and static regions can simultaneously exist.

To gain more insight, we examined a dense layer of dry grains flowing down a rough inclined plane both experimentally and theoretically. The experiments were initiated by releasing sand at a steady rate from a localized source (Figure 1). The resultant motion varied from a steady flow channeled by levees (Figure 2) to a series of avalanches triggered periodically, depending on the controlled flow rate and inclination angle of the slope. The avalanches are triggered either on a sufficiently gentle slope or when the flow rate is below a critical value, which is predicted by scaling arguments. Above the critical value, the grains form their own channel and flow steadily down the inclined plane. Our experimental data indicate that the characteristic width of the flowing channel increases linearly with the flow rate, while the speed and depth of the flow are almost independent of the flow rate (Figure 2).

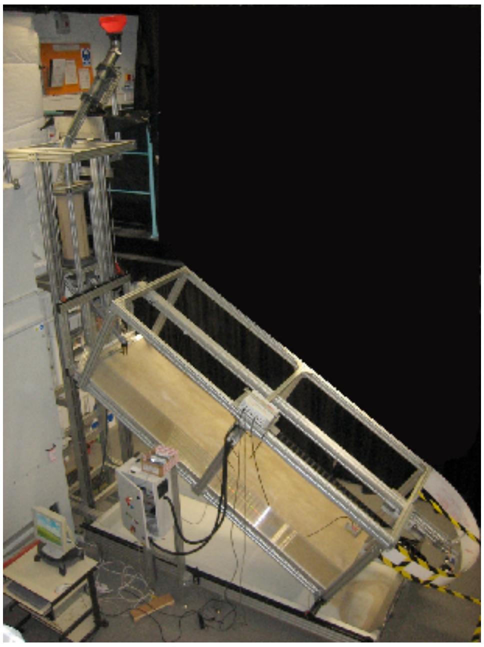

Figure 1: Photograph of the experimental set up (left) and steady channel of flowing sand confined by levees (right).

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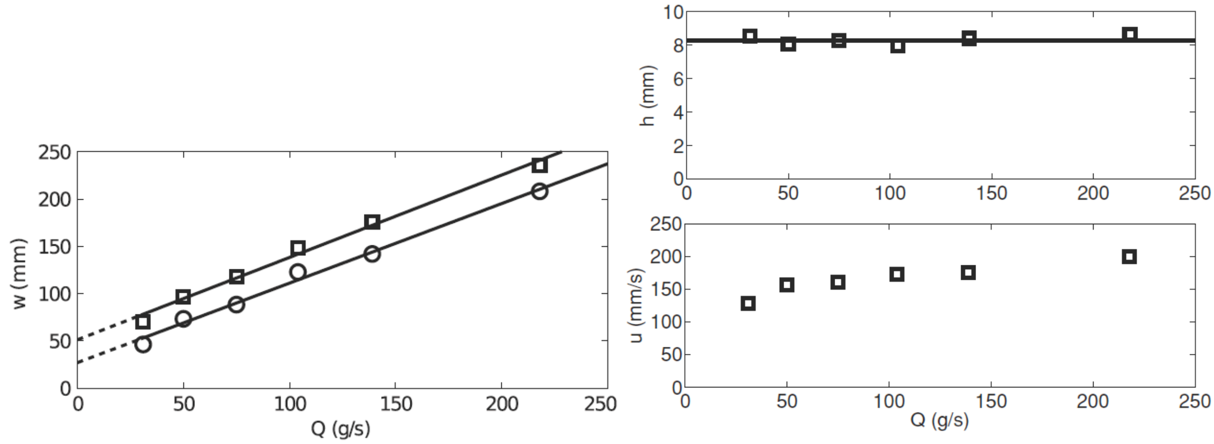

Figure 2: The characteristic width (left), depth (top right), and speed (bottom right) of steady flow plotted against the controlled volumetric flow rate on a 32 degree slope.

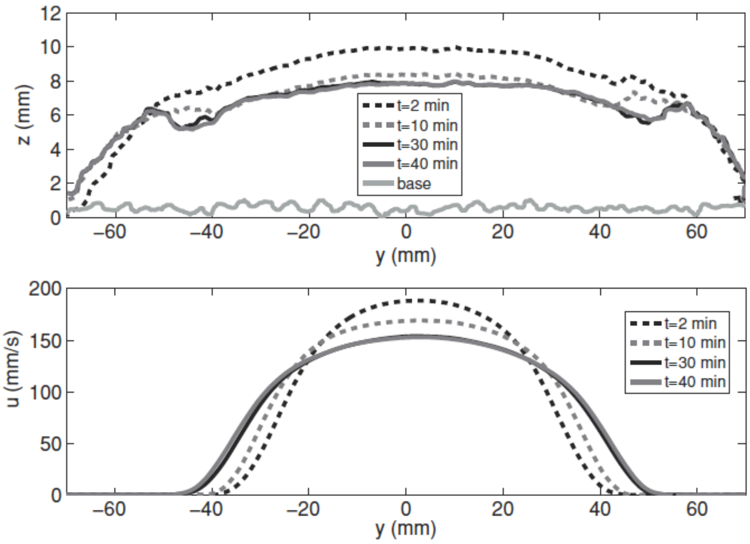

Figure 3: Depth (top) and surface speed (bottom) of sand across the flow down a 32 degree slope.

The steady surface of the bulk flowing region is almost parallel to the inclined substrate but varies in depth across the flowing direction, particularly near the margins of the flow (Figure 3). This experimental observations are studied theoretically by postulating a new granular rheology, similar to that of a second order fluid. The rheology generalizes a widely used model of dense granular flow and incorporates normal stress differences. Our model predicts that a second normal stress difference allows cross-flow variations in height in regions with considerable cross-flow shear, consistent with experiments.