

Avalanches of Granular Materials

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1. Introduction

The phenomenon of granular matter flowing down an inclined plane, with interactions between the air, the bed surface, and the particles themselves, is called a “granular avalanche”. Most catastrophic geophysical flows, such as turbidity currents (a rapid, downhill flow of water caused by increased density due to high amounts of sediment), debris flows, rock avalanches, pyroclastic flows (a fluidized mixture of solid to semi-solid fragments and hot, expanding gases that flows down the flank of a volcanic edifice) and snow avalanches, are examples of granular avalanches. Although the phenomenon appears rather simple, its physical aspects are not fully understood.

2. Ping-pong Ball Avalanche

Figure 1 shows the release of 300,000 ping-pong balls at the Miyanomori ski jump in Sapporo, Japan, which is used for ski jump competitions. The ping-pong balls used in this study were 3.8 cm in diameter, weighed 2.5 g, and had a density of 0.087 g/cm³. As the effect of air drag on such light balls is fairly large, the flow velocities were expected to arrive at a steady or quasi-steady state within a short distance (Nishimura *et al.*, 1998).

In the front view of avalanche, a clear head with a long tail is obvious (Fig. 1). The driving force causing the flow (i.e., gravity) is proportional to the cube of the length of the flow, while the resistance is proportional to the square of the length. Thus, a larger group of particles flows faster when the terminal velocity is reached. A larger group with higher velocity will overtake smaller groups until, eventually, the largest group arrives at the front and creates a distinct head structure. The distance between the smaller groups and the main body increases with time, so the particles spread out and form a long tail in the rear of the flow.

A similar pattern has been recognized in laboratory granular flow experiments with light particles, such as styrene foam particles. However, this has not been observed with flows of heavy balls, such as golf balls on a ski jump or glass beads on an inclined table. Flows of heavy particles do not adapt well to air drag within a short distance.

3. Head and Tail Structure

In nature, an impressive feature of large-scale geophysical flows is a clear head with a long tail; e.g., large snow avalanches, pyroclastic flows, and rock avalanches. Thus, reproducibility of the macroscopic features of the head and tail structures is critical in investigations of this phenomenon using reduced scale experiments.

The motion of a mass of granular material that accelerates to reach a steady state is generally characterized by the terminal velocity of the flow V_e , the acceleration due to gravity g , and the system size, such as the slope length L . Using these parameters, the dimensionless number V_e^2/Lg can be derived, corresponding to the Froude number when the velocity and the length scale are set as the terminal velocity and the slope length, respectively (Nishimura *et al.*, 1998). It should be noted that the dimensionless number V_e^2/Lg designates whether the flow arrives at a steady state and whether a head and tail structure is formed. From the above discussion, it is possible to deduce that a ping-pong ball flow at 8 m/s on the ski jump corresponds to a natural powder snow avalanche moving at 50 m/s for several kilometres.

The flow velocities and the run-out distance are strongly dependent on the number of balls released. When two balls were released the velocity attained was only 2.8 m/s, which was much less than the free-fall velocity of the ping-pong ball. However, the free-fall velocity was reached and exceeded when a larger numbers of balls was released. The highest front velocity of 15 m/s (nearly 55 km/h) is 1.5 times higher than the free-fall velocity (Fig. 2). Similarity analysis shows that the flow speed V_e increases by the 1/6th power of the particle number N for three-dimensional systems, and by the 1/4th power of N for two-dimensional systems.

4. Drag Force and Head Structure

The resistance force acting on the granular avalanche is greatest at the head of the flow. Thus, the particles at the leading edge and the following particles change positions. In a two-dimensional system, one of the flow patterns shown in Fig. 3 will develop, depending on the magnitude of the basal friction and the air drag. In a three-dimensional flow without side walls, individual balls also



Fig. 1. Front view of an avalanche of 300,000 ping-pong balls at the Miyanomori ski jump.

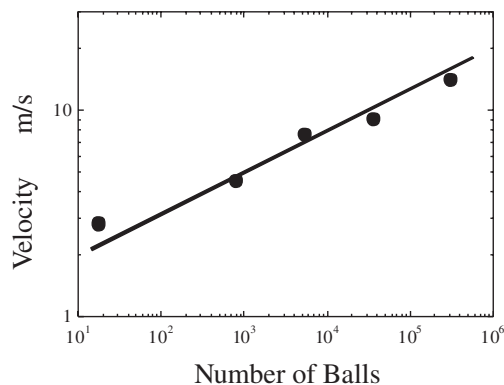


Fig. 2. Front velocities as a function of the number of balls released. The solid line shows the relation derived theoretically.

change their positions laterally. Two small regions of reduced flow height, located symmetrically about the centre line of the flow, are present a little behind the head in Fig. 1. These regions are termed “eyes”, and probably correspond to the centre of the vortex formed by lateral flow of particles.

As shown above, ordered structures such as the head and tail are formed when the resistance forces, such as air drag, act on the flow and the flow arrives at a steady state. In

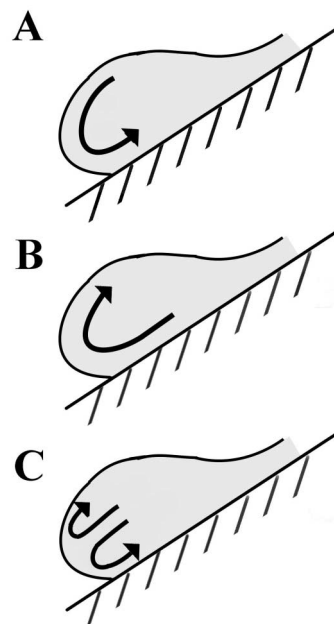


Fig. 3. Internal structure of a two-dimensional granular avalanche head. Arrows indicate particle movement. A: Basal friction is dominant; B: air drag is dominant; C: basal friction and air drag are of similar magnitude.

a real flow, the difference in flow speed between the head and the tail, in addition to the dropping out of particles from the head, causes the entire flow to become longer with time. The descriptions given above are limited to a certain period of time of the flow. However, most natural snow avalanches entrain snow particles from the snow cover and thus compensate for particle loss. This process assists in maintaining the ordered structure of the flow for a longer period.

Three-dimensional granular flow experiments with polystyrene foam particles have shown that the front tend to bifurcate into a train of vortices after the head and tail structures are formed (Nohguchi and Ozawa, 2009).

References

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