D210

Insight Into Granular Flow Dynamics and Its Generated Seismic Signals: An Experimental Study

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1. Introduction

Landslides, debris flows and snow or rock avalanches are examples of geophysical granular flows that commonly occur on steep terrain where they represent significant natural hazards to life and property. Better monitoring of hazard-prone areas and better understanding the dynamic processes involved and predicting their characteristics are key to the reduction of natural hazards, and the use of seismic signals is a promising tool toward these aims. The characterization of granular flows from the seismic signals generated by their movements remains an open question, despite the increasing number of experimental, field and numerical studies of granular flow dynamics. Here, a series of laboratory flume experiments designed with different conditions were conducted to investigate the granular flow dynamics. Basal force characteristics and seismic signal signatures are analyzed, and the relationship between them and the bulk and basal flow properties are discussed.

2. Methodology

The experimental device consisted of a 300 cm long, 30 cm wide and 40 cm high chute whose upper part was a reservoir from which particles were released to generate granular flows. The particles were glass beads of diameter d = 2, 4 or 6 mm, density ρ = 2500 kg/m^3 with mass of 5, 10, 20 or 40 kg. The slope angle of the channel θ that varied between 18° and 22°. A high-speed camera, two laser displacement sensors, two three-component force sensors and three three-component accelerometers were utilized to monitor the flow's dynamic characteristics, e.g., flow depths, flow velocities, basal forces and acceleration signals.

The images recorded by high-speed cameras were preprocessed using PIV to obtain flow velocity (Fig. 1). The average values of the basal force and flow depth were obtained by moving average filtering (Fig. 2). The fluctuating force was obtained by subtracting the mean value of the basal force. We calculated the root-mean-squares (RMSs) of fluctuating force and acceleration for each time window (t_{win} = 0.1 s, no overlaps), and treat them as the typical magnitude of basal fluctuating forces and seismic signals (Fig. 3).

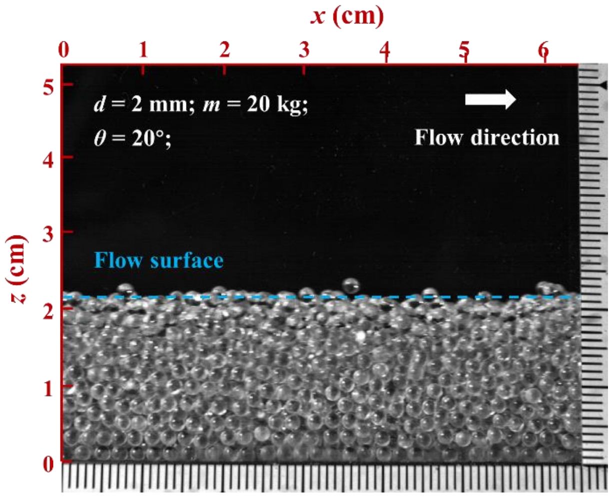

Fig. 1 PIV analysis for the granular flow velocity.

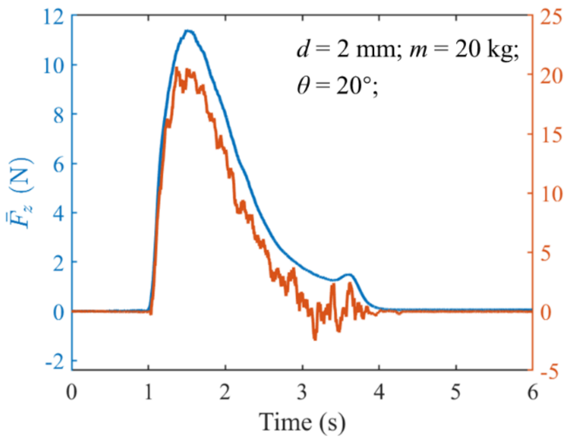

Fig. 2 Mean values of basal force and flow depth.

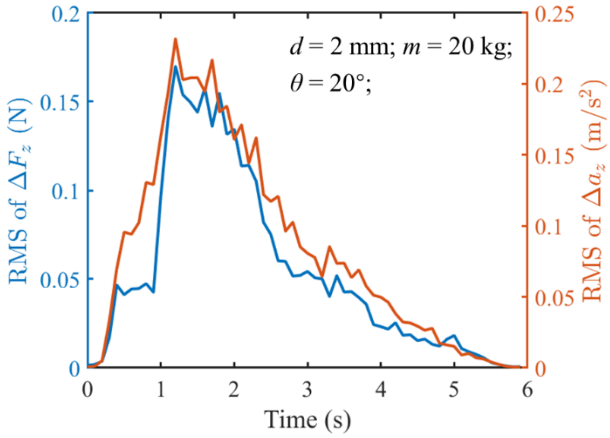

Fig. 3 RMSs of fluctuating force and seismic signal.

3. Results and discussion

The experimental results show that the flow mass has a great influence on the dynamic characteristics. With the increase of flow mass, the average flow depth, mean basal force, the RMSs of basal force fluctuation and acceleration signal increase continuously. This shows that the flow mass is an important factor that causes the change of the overall and local flow characteristics. In addition, the results show that the variation of particle size has little effect on the overall flow properties, but significantly affects local instantaneous characteristics of the flow. The variation of slope angle has little effect on the above dynamic characteristics, but the larger the angle, the faster the flow velocity.

After understanding the dynamic characteristics of granular flow under different experiment conditions, we further explored the relationships between the basal fluctuating force and seismic signatures and bulk flow properties. Fig. 4 shows the relationships under typical experiment condition (d = 2 mm, m = 20 kg, θ = 20°).

The results show that there is a strong correlation between them. It seems that there is a positive linear correlation between the basal fluctuating force and the average values of basal force and flow depth (Fig. 4(a)), and the same is true for the RMS of seismic signals (Fig. 4(c)). RMSs of fluctuating force and seismic signals also show a positive correlation with surface velocity and flow rate (Fig. 4(b) and (d)), but different from the former, it seems that the power law can better fit this relationship. N_{sav} is considered to be a key parameter to characterize the bulk flow regimes. It was believed that inertial stresses associated with grain collision prevail over the frictional stresses associated with persistent contacts in granular flows when N_{sav} > 0.1. Figure 4(e) shows that the inertial stress dominates the analyzed flow. There is also a strong positive linear correlation between the RMS of ΔF_z and Δa_z (Fig. 4(f)), which indicates that it is promising to analyze the dynamic characteristics based on seismic signals.

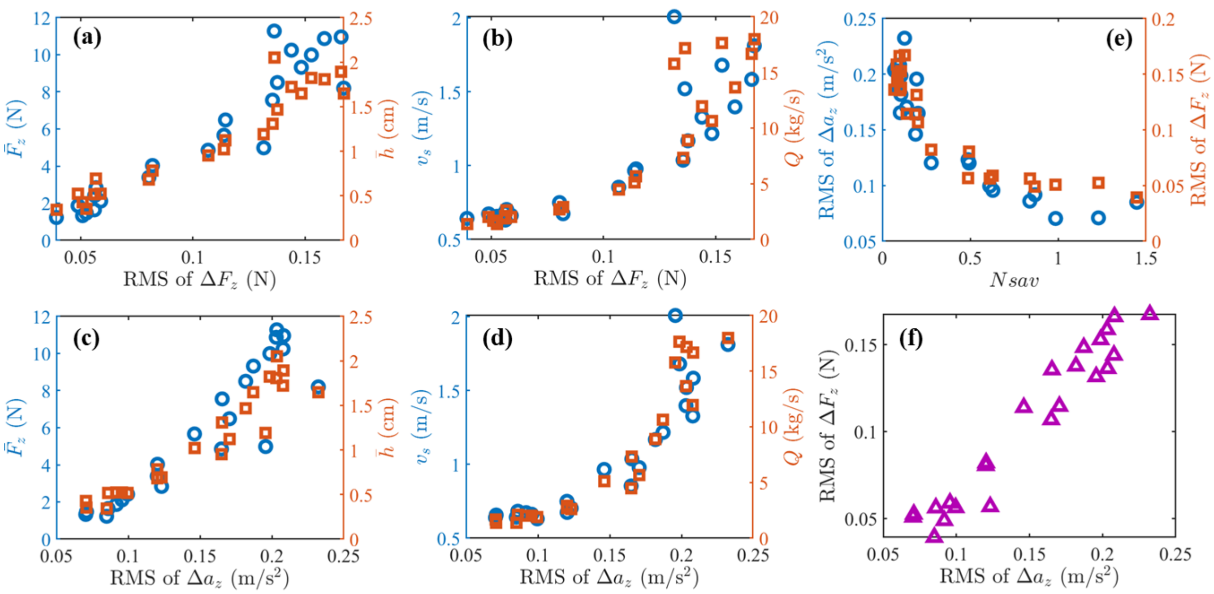

Fig. 4 Relationship between normal fluctuating forces (ΔF_z) and accelerations (Δa_z) and flow properties (mean basal force $\bar{F}_z$, flow depth $\bar{h}$, surface velocity v_s, flow rate Q and Savage number N_{sav}) under the typical condition.