BASAL FRICTION OF A DRY AND A SATURATED GRANULAR MASS IN UNSTEADY AVALANCHE VIA HIGH-SPEED IMAGING AND CONTROL VOLUME ANALYSIS

Yung-ta Huang & Fuling yang[a)]

Department of Mechanical Engineering, National Taiwan University, Taipei, Taiwan 10617, R.O.C

Summary Temporal evolution of basal friction of a dry and a saturated granular material in unsteady avalanche is investigated via systematic experiments. High-speed imaging technique with post processing is employed to achieve particle tracking velocimetry to estimate bulk instantaneous motion which is further employed in a control volume analysis to evaluate bulk basal friction. Effective friction coefficient is evaluated and its streamwise distribution and temporal evolution is reported for both the dry and the saturated mixture. This information is integrated with the corresponding bulk internal structure and velocity and solid volume fraction to discuss liquid effects.

INTRODUCTION

The rheology of solid-liquid two-phase flows has drawn growing attention in the past few decades for its occurrence in many natural hazards. The flowing mixture is composed of discrete solid objects and interstitial viscous fluid with comparable inertia and hence the strong interaction between the heterogeneous constituents can result in different transport mechanism. Theoretical modelling on such flow is challenging since both its constitutive relation and flow boundary condition can evolve with the flow. The few existing models are developed for steady flow with one of the two phases possessing negligible inertia—like for a suspension or rapid granular flow. Simulation of such a flow can be either expensive or inaccurate with its bottleneck resulting from frequent flow-body and inter-objects interaction within a mixture. Thus, this work employs systematic experiments with high-speed imaging technique to investigate the dynamics of a dry and a saturated granular mixture of finite mass from the onset of avalanche to the downstream propagation. We compare the internal structure, the solid volume fraction, and the mixture velocity to reveal the interstitial liquid effects and these measured bulk properties are employed to estimate its internal friction via control volume analysis. Temporal evolution of the mixture basal friction coefficient when undergoing unsteady avalanche is reported and discussed.

EXPERIMENT SETUP

As depicted in Fig.1, a laboratory flume has been developed consisting of a reservoir and a straight flume. The reservoir has glass sidewalls allowing high-speed imaging of 45 cm-length, 15cm-width, and 15cm-depth. The reservoir steel gate is held fixed by two strong compression springs and it be released abruptly to release the stacked material. Connection to the reservoir is a straight flume made of the same glass into 200cm length and 15cm width and depth. Both the reservoir and the flume bases are made of aluminium. A pulley system is equipped to elevate the flume to a specific angle, $\theta=19°$, from the horizontal which is the minimum inclination for one layer of experimental spheres to move freely down the whole flume. The experimental particles are identical glass spheres of diameter 16±0.03mm and density $2.54\pm0.04\mathrm{g/cm^3}$. A dry of 16 kilograms total weight was poured into the reservoir before each experiment and a saturated mixture of the same weight was prepared by immersed fewer spheres in water. The sphere collective motion was recorded by a side high-speed digital camera at 500 frames per second.

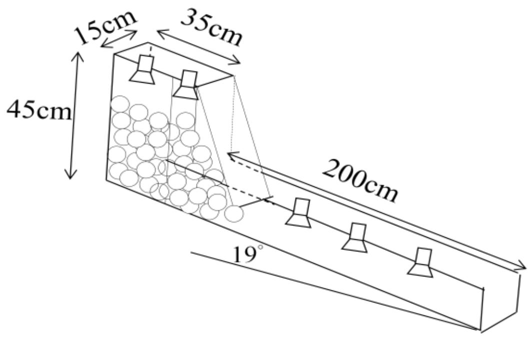

Figure 1: The experimental facility: reservoir, flume, and particles

METHODOLOGY AND RESULTS

An image analysis routine has been developed using Circular Hough transformation method to locate each sphere (see Figure 2) and the method of nearest neighbor to achieve Particle Tracking Velocimetry (PTV). An area-weighted average scheme was employed to obtain a two-dimensional estimation of bulk properties, including its solid volume

a) Corresponding author. Email: fulingyang@ntu.edu.tw

fraction, Φ, and velocity components parallel or perpendicular to the chute base, U and V as illustrated in Fig.3. By shifting the averaging box along the flow depth, we could obtain the instantaneous depth profiles for Φ, U, and V as shown in Fig.4.

This information is integrated into a two-dimensional control volume analysis to estimate the bulk basal friction under the assumption of uniform normal stress and zero surface stress. The discrete forms of the employed formulae are provided in Fig.5. Note that the required momentum flux at the left and right boundary of control volume n is estimated by the Φ and U depth profiles evaluated in the n-1 and the n+1 control volume (box) overlapped by half box width as indicated in Fig. 5. The estimated friction is then divided by the instantaneous normal loads to calculate the so-called *effective friction coefficient, f*. In present study, we divide the reservoir into 13 control volumes with each spanning 5-diameter width. Thus, the streamwise distribution of *f* can be obtained and its evolution in time could be extrapolated as shown in Figure 6.

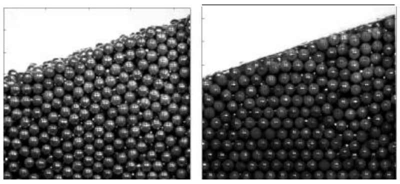

Figure 2: Sphere location (left: dry, right: immersed)

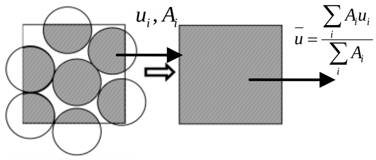

Figure 3: Average scheme

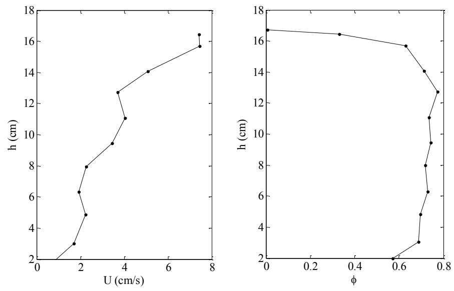

Figure 4: Depth profiles for bulk streamwise velocity and solid volume frction

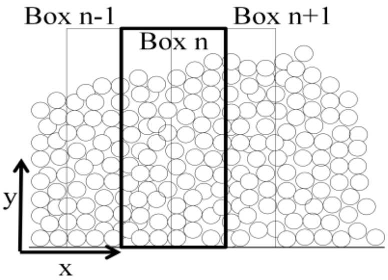

Figure 5: The sketch of control volume analysis with the employed formula (eq.(1)& eq.(2))

Continuity equation: $$\frac{(\rho_{B_n} w h_{B_n})_{t+\Delta t} - (\rho_{B_n} w h_{B_n})_t}{\Delta t} - \rho_{B_{n-1}} u_{B_{n-1}} h_{B_{n-1}} + \rho_{B_n} V w + \rho_{B_{n+1}} u_{B_{n+1}} h_{B_{n+1}} = 0 \quad (1)$$

Momentum equation: $$\frac{\left(u_{B_n}\rho_{B_n} w h_{B_n}\right)_{t+\Delta t} - \left(u_{B_n}\rho_{B_n} w h_{B_n}\right)_t}{\Delta t} + u_{B_{n-1}}\left(-\rho_{B_{n-1}} u_{B_{n-1}}\right) h_{B_{n-1}} + u_{B_{n+1}}\left(\rho_{B_{n+1}} u_{B_{n+1}}\right) h_{B_{n+1}} + u_{B_n}\left(\rho_{B_n} V\right) w = F_{B_n} + \rho_{B_n} h_{B_n} w g \sin\theta \quad (2)$$

RESULTS& CONCLUSIONS

For the dry mixture, the magnitude of *f* grows monotonically in time, from a distribution with strong streamwise degradation to a rather uniform profile. Similar trend is found for the saturated mixture but with milder variation in time and in space possibly due to liquid unifying effect. Further discussions on flow rheology and internal friction property will be presented at the conference.

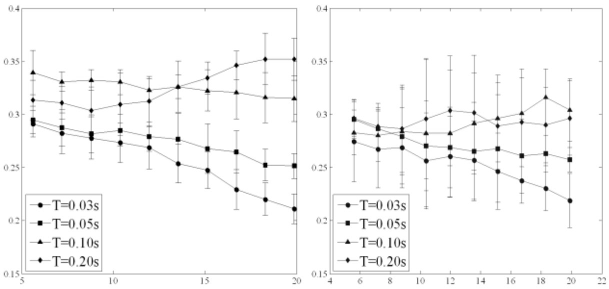

Figure 6: The temporal evolution of effective friction coefficient (left: dry, right: immersed)

References

[1] Hough, P. V. C.: Methods and Means for Recognizing Complex Patterns. *US Patent 3069654*, 1962.
[2] Richard M. Iverson: The Physics of Debris Flows. *Reviews of Geophysics*. p. 245-296, 1997.