PARTICLE IMAGE VELOCIMETRY ANALYSIS OF GRANULAR MATERIAL FLOWS

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Summary: Digital Particle Image Velocimetry (DPIV) technique, well know in fluid mechanics, has been applied to evaluate main flow characteristics for granular material (amarantus seed) sliding between parallel walls of a Plexiglas model of a silo. The development and evolution of the consecutive stages of the flow will be demonstrated. The vertical velocity functions on the horizontal sections of the model are used to describe different flow regimes. Velocity fields are used to calculate particle tracks, lines representing main flow structure.

INTRODUCTION

Particle Image Velocimetry technique is a well established experimental method in fluid mechanics, allowing for quantitative measurement of two-dimensional flow structure. It enables measurement of the instantaneous in-plane velocity vector fields within a planar section of the flow field. This method is of great interest to researches and engineers allowing them the calculation of spatial gradients, dissipation of turbulent energy, spatial correlations, and the like. The typical DPIV evaluation procedure is based on the analysis of two successive images of the flow. One of the main drawbacks of classical DPIV is its inability to accurately resolve flow regions characterized by large velocity gradients. Several alternative evaluation methods have been proposed to remove the above limitation. This paper is our effort to apply the optical flow based on DPIV technique (OP-DPIV) [1] in granular material flows to measure flow boundaries, velocity fields and stresses in a model of a silo made of Plexiglas.

Early attempts to describe the plug and funnel flows in bins/hoppers and in different models of silos – plane, conical, wedge-shaped were based on assumption of plasticity, predicted the existence of stagnant zones in the flowing material. But later it was found that radial velocity field predicted theoretically in the flowing zone is far narrower than that observed in practice. Many observations of batch discharge show that the position of the stagnant zone boundary occurs during the flow changes quite slowly with time. Watson and Rotter [2] defined the stagnant zone boundary to be the position at which the velocity was equal to 1% of the centreline velocity at the same height. It is found as a satisfactory approximation for the steady state. Mathematical models of the flow assume the constancy of material density throughout the bin/hopper and describe that the velocity distribution is given by the simple differential equation:

$$\frac{\partial \upsilon}{\partial y} = B \frac{\partial^2 \upsilon}{\partial x^2} \tag{1}$$

where υ is the vertical velocity and x and y are horizontal and vertical distances and B is the kinematic constant and is often of the order of particle diameter. Modification of the kinematic model for unsteady discharge based on the assumption of incompressible radial velocity field resulting from kinematic theory was presented by Nedderman [3], Waters and Drescher [4] and others. An additional assumption that volume changes take place only across the boundary of the expanding flow region was equivalent to identifying the boundary as a dilatational wave or a propagating density shock. The predicted velocities are higher along the center line and decrease gradually towards the boundary, whose shape resembles a growing candlelight [4].

Our paper concerns semi-mass flow in a model of silo made of Plexiglas. The width of the outlet is 1 cm and the dimensions of the model are: 80 cm height, 26 cm width and 5 cm in depth, with a value of inclination of the walls to the vertical 90^{o}. The model was placed on a stand and granular material was supplied through a box suspended above the model. The box was equipped with a bottom of a wire net. Material discharged into the box scatters producing a uniform granular rain. The material develops negligible static electricity when flowing and sliding over Plexiglas. Uniform and repeatable packing of the materials with no particle segregation was obtained. The model was filled with 75 cm-high column of material. The velocity fields , the evolution of the flow region and the traces of flowing particles were measured and registered with a digital experimental setup. The pictures were registered at a time step 0.266 sec. We present experimental measurements of the stagnant boundary as a function of time, predicted positions of stagnant zone boundary as a function of time and the evolution of the flow during free gravitational discharge.

PIV technique is employed to measure two-dimensional velocity fields. The evaluated fields are used to calculate development and evolution of the flow in the model and the flow paths showing main flow structure. It was found that the mass discharge is not constant, decreasing as the material flows.

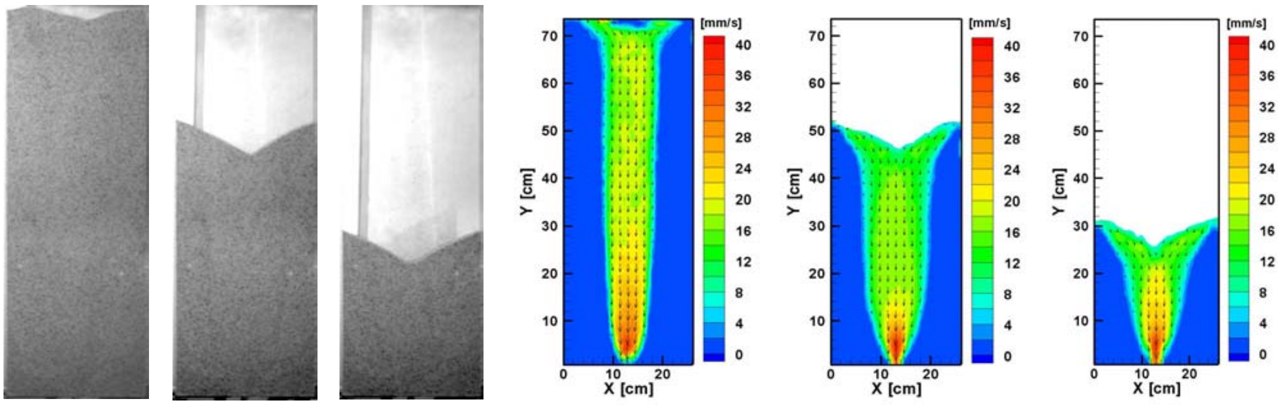

Figure 1. Example of the flow images of the amarantus and the evaluated velocity fields at time steps: 3.75 sec, 30 sec and 52.5 sec.

Figures 1 show the evolution of the flow during free gravitational discharge. The upper plane surface becomes lower and then concaves. With progressing discharge, the upper surface lowers and the flow region increases reaching the top of the material. It was observed in vector fields that the boundaries of the flow zone away from the outlet are vertical and the instantaneous velocities in this zone appear also vertical and decrease with time. Near the outlet the velocity vectors are directed towards the outlet.

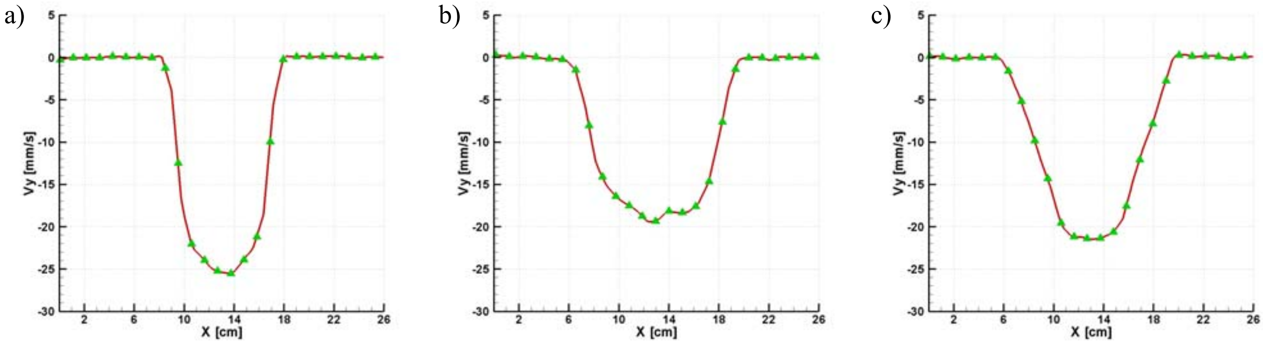

Figure 2. Profiles of the vertical velocity component across the cavity obtained at height h=15cm at time steps 3.75 sec (a), 30 sec (b) and 52.5 sec (c) after beginning of the experiment. Points of the profiles are extracted from the PIV measured velocity vector fields and smoothed with splines (solid line).

Figures 2 show examples the velocity distributions extracted from the full field measurements for a selected cross-sections in the model of silo. It is seen that a quasi-symmetrical flow structure builds up shortly after the flow starts. However, in some cases initial asymmetry was present due to non-uniform packing of the seed in the silo.

CONCLUSIONS

The PIV technique enables measurements velocity fields and the velocity distributions in the flowing granular material. The method offers unique possibility to compare instantaneous full field measurements with theoretical formulations and numerical models. Information gained can be easily converted to calculate local stresses and predict regions of non-uniformity and delayed empting of the silo.

References

[1] G. M. Quenot, J. Pakleza, T. A. Kowalewski: Particle image velocimetry with optical flow, Experiments in Fluids. Vol. 25 (1998), 177-189

[2] G.R. Watson, J. M. Rotter: A finite element kinematic analysiss of planar granular solids flow, Chemical Engineering Sciences. No 51 (1996) 3967-3978

[3] R. M. Nedderman: The use of the kinematic model to predict the development of the stagnant zone boundary in the batch discharge of a bunker, Chemical Engineering Science. Vol.50 (1995) 959-965

[4] A.J. Waters, A. Drescher: Modeling plug flow in bins/hoppers, Powder Technology. Vol. 113 (2000) 168-175