Numerical Simulations of Granular Materials Flow around Obstacles: The role of the interstitial gas

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Overview

- Two-dimensional granular flow against a flat plate.
- Single & two-phase numerical simulations of dry granular materials around plates were conducted.
- The simulations examine the role of the interstitial gas.
- Parametric study examine the role of the phases' velocities, solids volume, particle sizes and gravitation.

Introduction

- Flow patterns are influenced by bulk material properties, flow rates and geometry of both the flow channel and the obstacle.
- Many experimental studies where conducted to determine the drag force of the granular flow on immersed objects, force fluctuations, the role of obstacle shape, and the jamming potential.
- Tuzun et al. (1985) examined the 2D dense flow in a vertical bin around various inserts.
- The formation of a distinct granular shock wave in front of an obstacle observed by Buchholtz and Poschel (1998). They carried out 2D molecular dynamics simulations of an unconfined stream of particles and determined the role of the force on the obstacle, obstacle size, and upstream velocity.

Introduction

- Amarouchene et al. (2001) experiments showed that such shock waves form in front of obstacles. Their measurements provide detailed geometry of the shocks and velocity profiles for flow around cylinders, wedges, and plane obstacles.
- Rericha et al. (2002) also observed shock waves in numerical and experimental investigation of dilute granular materials with wedge-shaped obstacles.
- Wassgren et al. (2003) conducted comprehensive molecular dynamics simulations of the interaction of dilute granular flows with cylinders. They observed granular shock waves and compared to those observed in compressible gas flow.

Introduction

- For dense flows, the experiments of Chehata et al. (2003) showed that no such shock waves took place.
- The effects of the interstitial gas on the granular flow interaction with obstacles have been traditionally neglected.
- Those effects have been examined in a number of situations such as hopper discharge (e.g. Srivastava & Sundaresan, 2003).
- However, the role that the interstitial gas plays as a granular stream impacts an obstacle, and in particular on shock wave characteristics, remains poorly understood (Levy & Sayed, 2006).

Approaches for modeling granular flow

Single-Phase Granular Flow Model

The Particle-In-Cell (PIC) Approach

•An ensemble of particles represents the bulk material.
•Each particle is given attributes such as density, position, and velocity.
•Particles are advected in a Lagrangian manner.
•The momentum equations, however, are solved on a fixed Eulerian grid.
•Various variables are mapped between the particles and the grid.
•granular stress: Frictional (surface friction & interlocking) & Dynamic (collisions & momentum transfer).

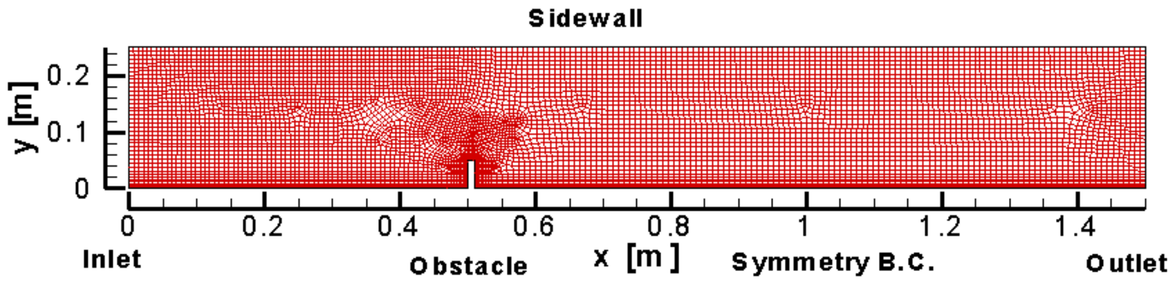
Two-Phase Gas-Solids Model

Two-Fluid Eulerian-Eulerian formulation.

•Numerical solution is obtained using the code FLUENT
•The granular phase follows the kinetic theory.
•The flow is isothermal.
•The influence of gas turbulence is neglected.
•Inter-Phase Forces: based on Ergun's equation for solids volume fraction >0.2 , otherwise the force is calculated using drag force on a single particle with Richardson-Zaki modification.

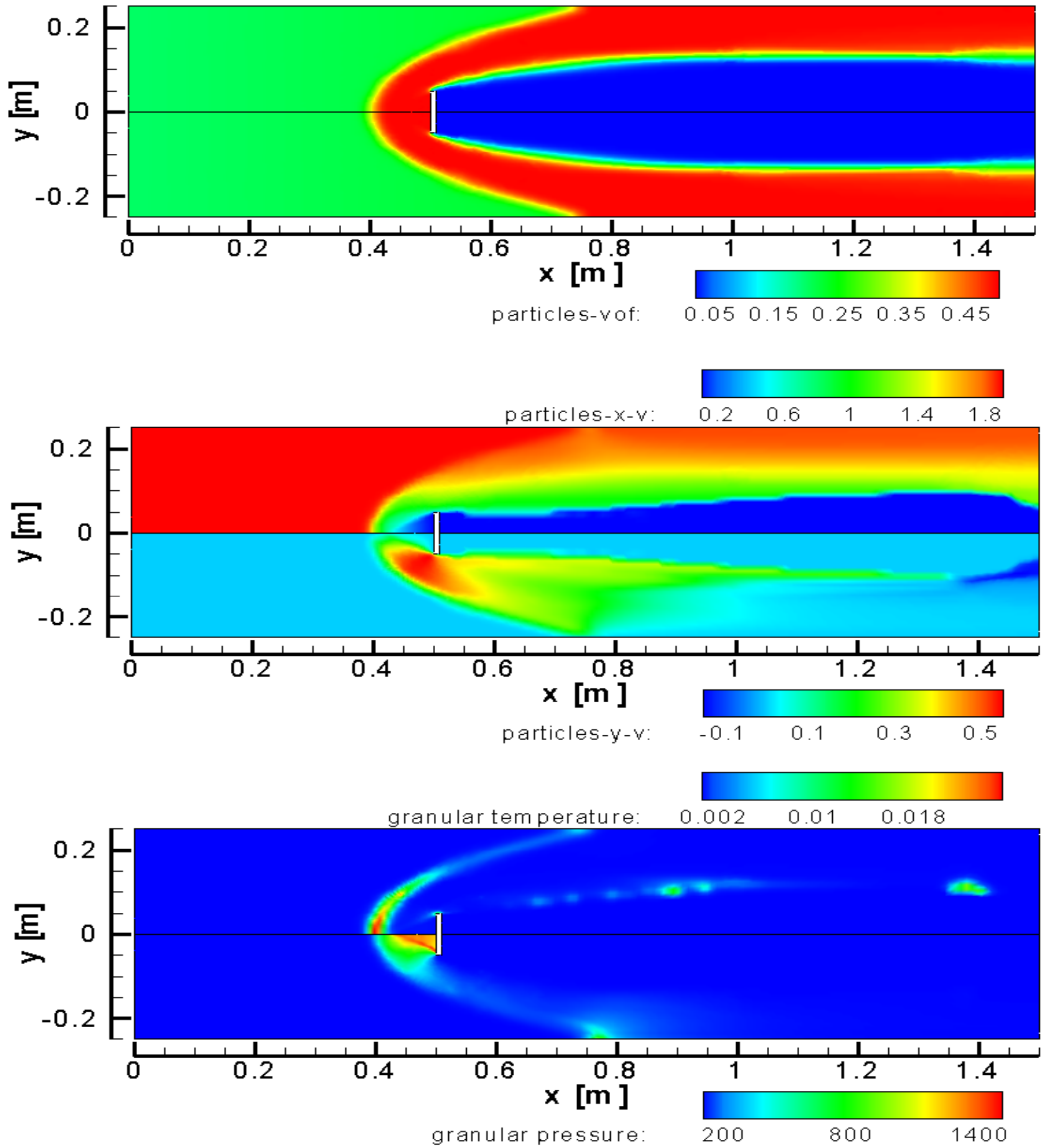
Single-Phase Granular Model

Initial and Boundary conditions

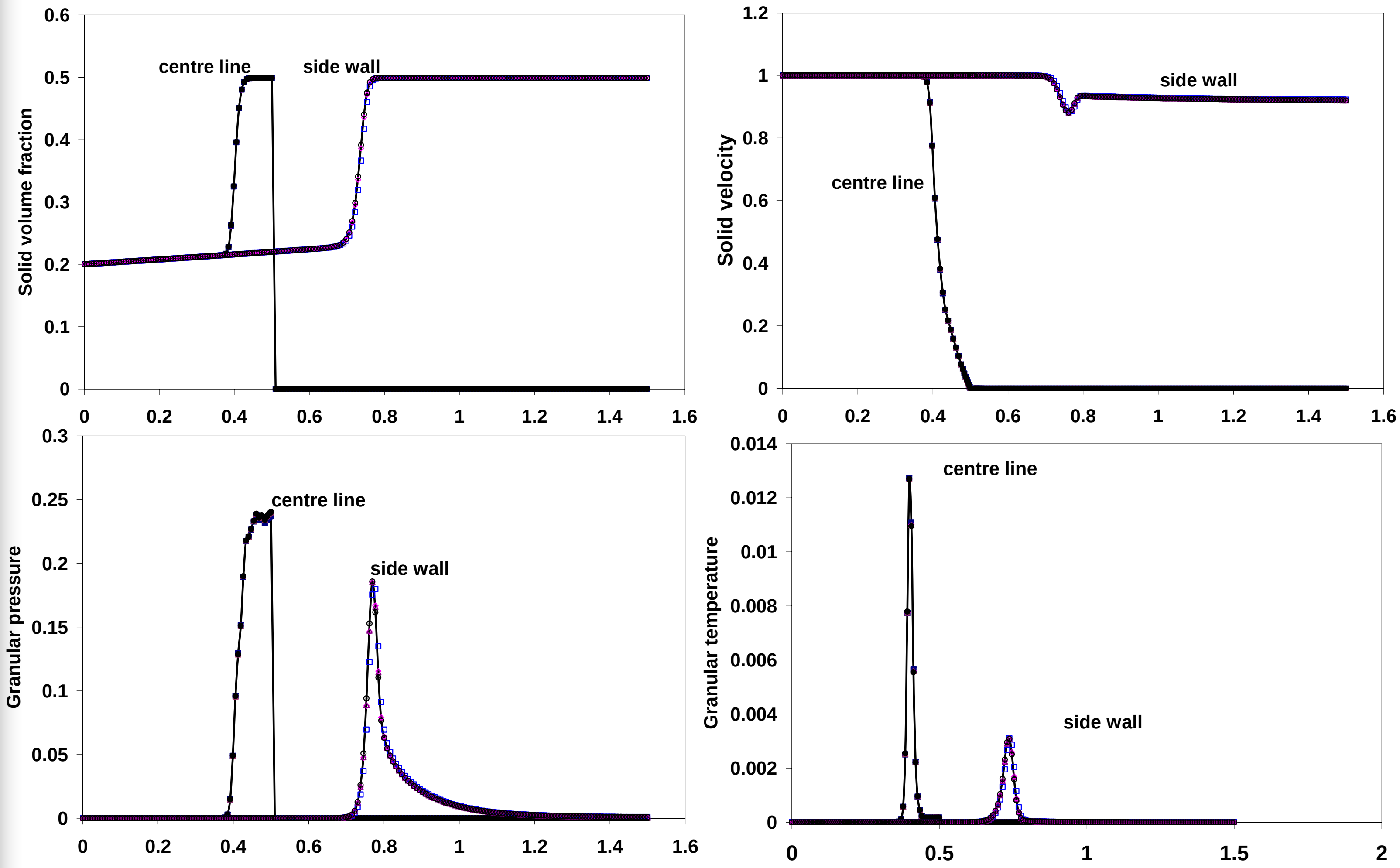


The *base* test case:
volume fraction = 0.2.
No Gravity.
No Fluid-Solid interaction.

Case No.	Inlet $\mathbf{v}_s$	Inlet $\mathbf{v}_g$
1	1.0	0.1
2	2.0	0.1
3	2.0	1.0
4	3.0	0.1



Particles flow field characteristics for case 3: a) Solid volume fraction; b) solid velocity components; and c) granular pressure and temperature.



Prediction of the numerical simulations for the solid volume fraction, normalized velocity, granular pressure and temperature, (a) to (d), respectively, along the symmetry line and the side wall for cases 1-4

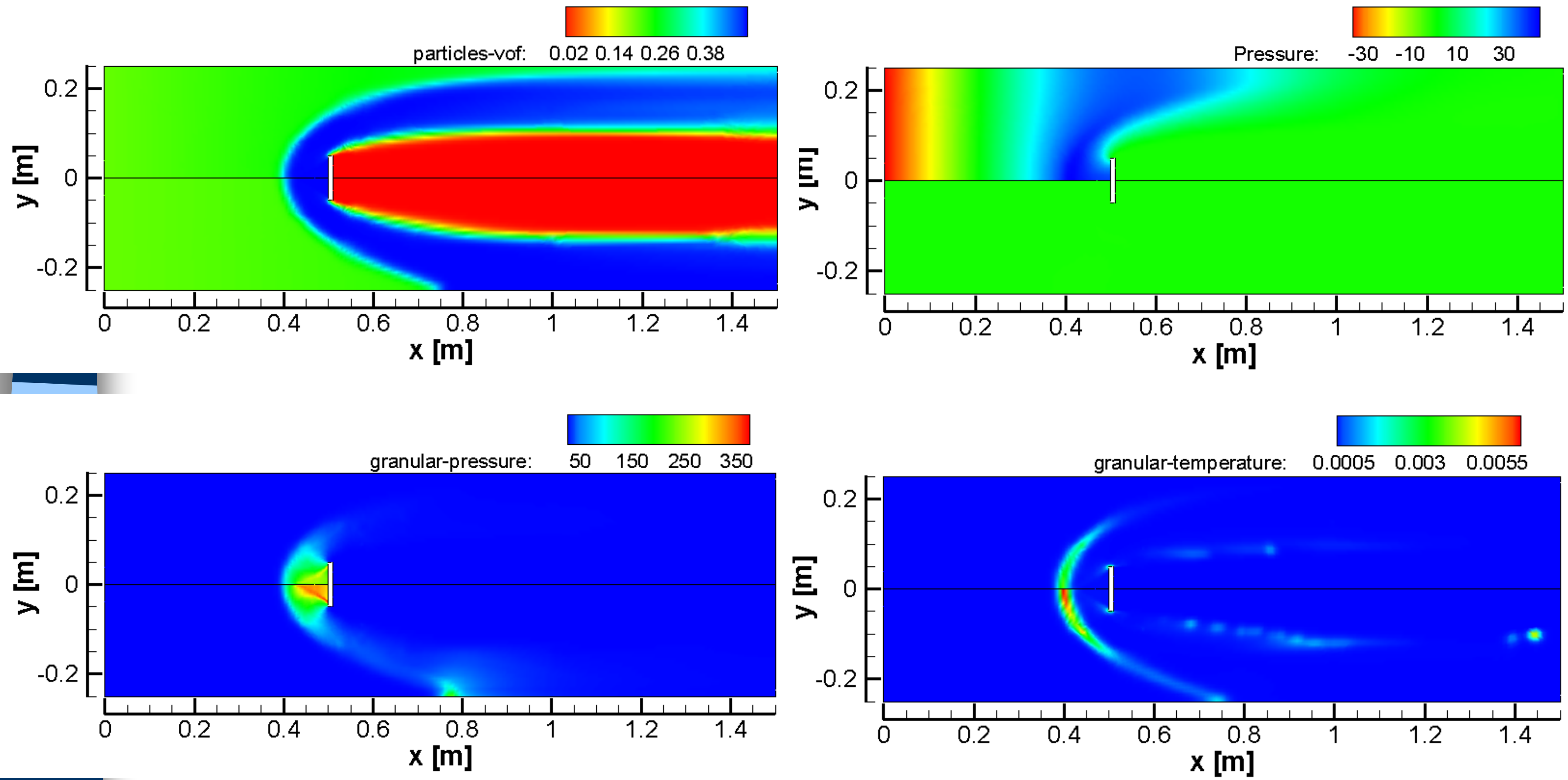
Two-Phase Granular Model

Initial and Boundary conditions

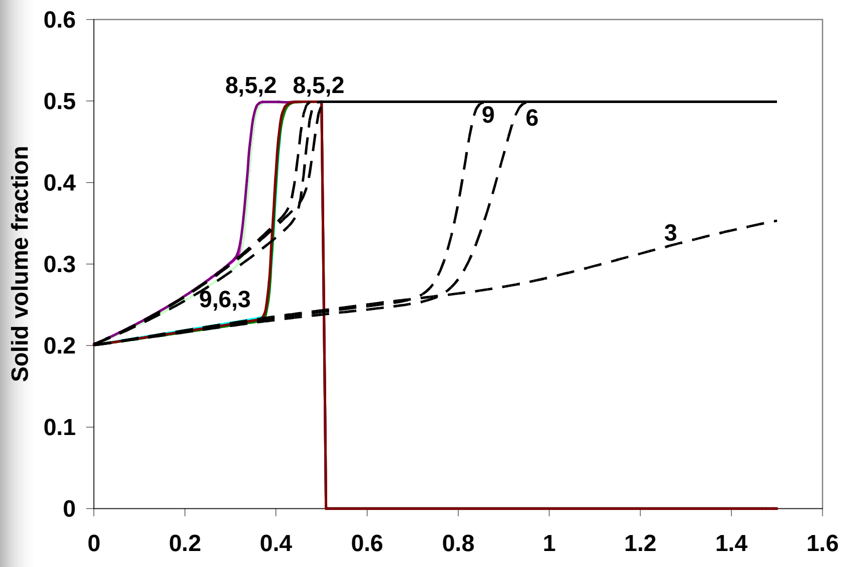
The *base* test case:

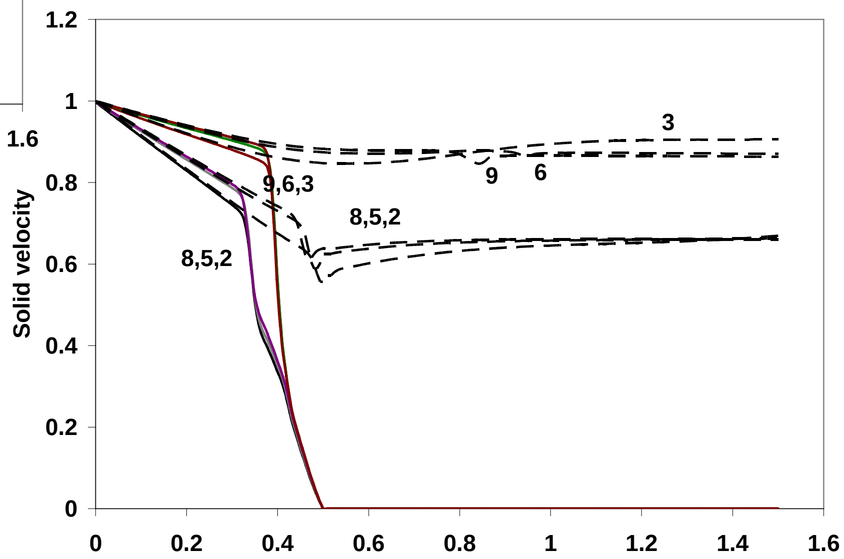
volume fraction = 0.2; No Gravity; Particle's dia. 1mm.

Case No.	Inlet $\mathbf{v}_s$	Inlet $\mathbf{v}_g$
1	1.0	0.10
2	1.0	0.25
3	1.0	0.50
4	2.0	0.20
5	2.0	0.50
6	2.0	1.00
7	3.0	0.30
8	3.0	0.75
9	3.0	1.50

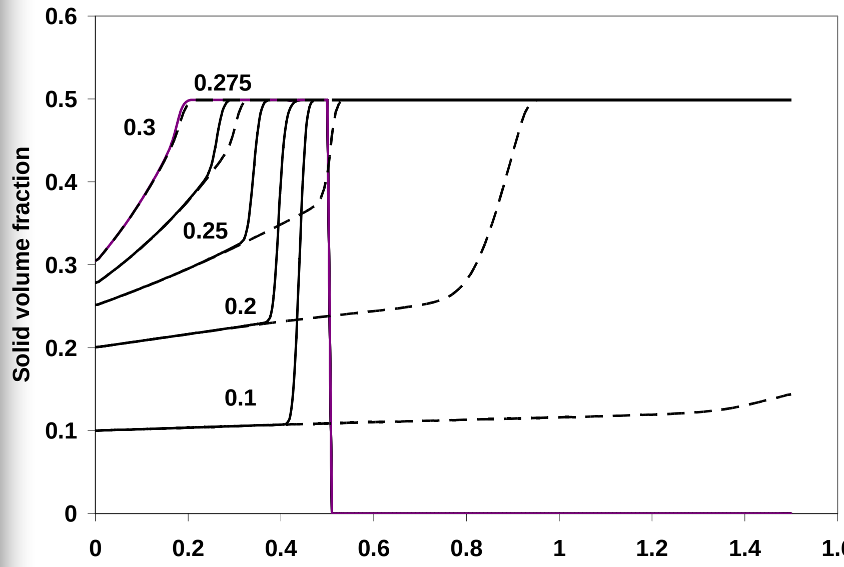


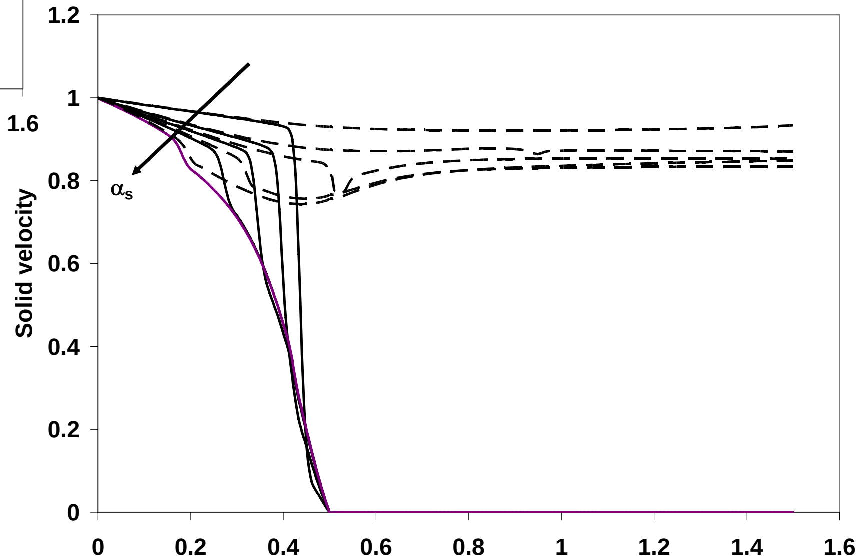
Comparison between flows with two-phase flow and single-phase granular flow, upper and bottom parts respectively, solids volume fraction, pressure and granular temperature and gas pressure for inlet solids and gas velocities of 1 and 0.5 m/s, respectively, and inlet solid volume fraction of 0.2.



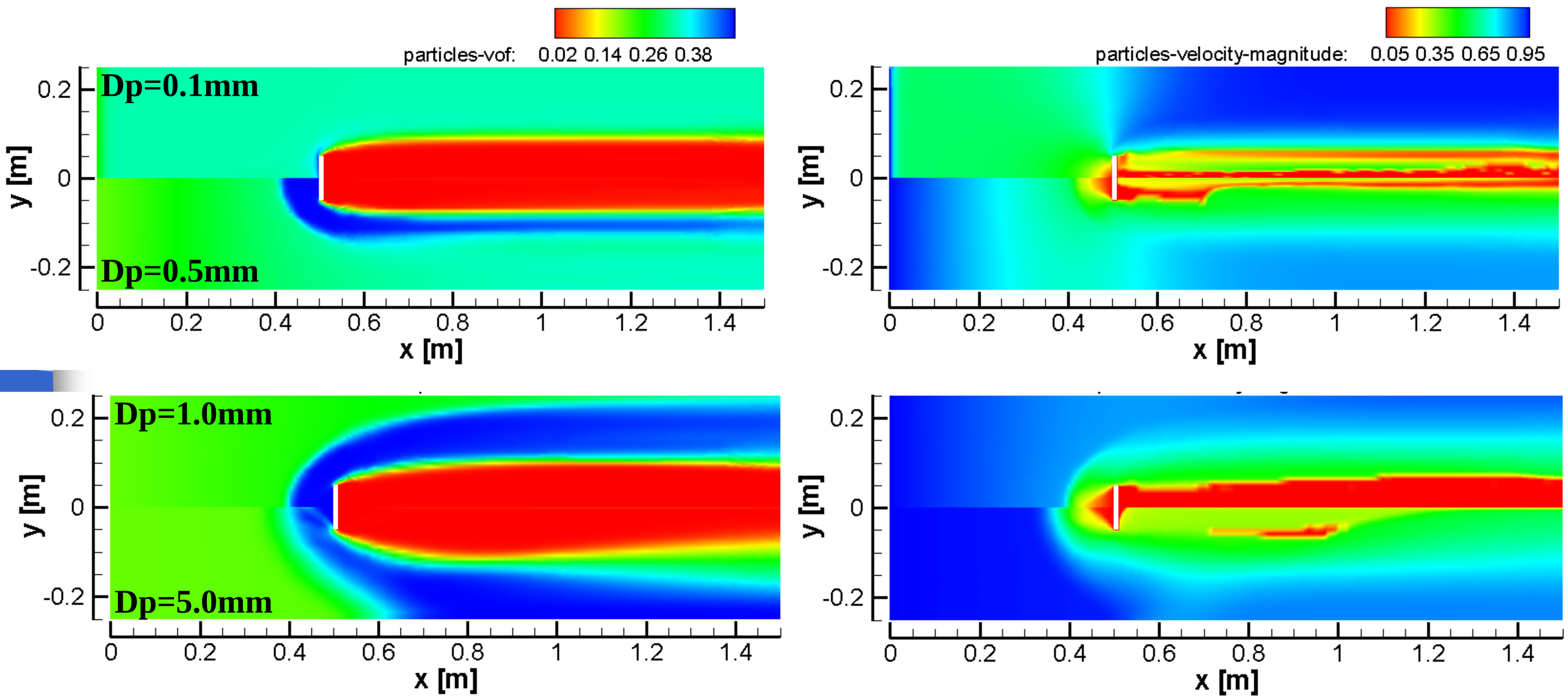


The influence of the inlet velocities (inlet α_s =0.2) on the profiles of solids volume fraction and velocity along the center line (solid lines) and the side wall (dashed lines) for cases 2, 5 and 8 (inlet vg / vs = 0.25) and 3, 6 and 9 (inlet vg / vs = 0.5)

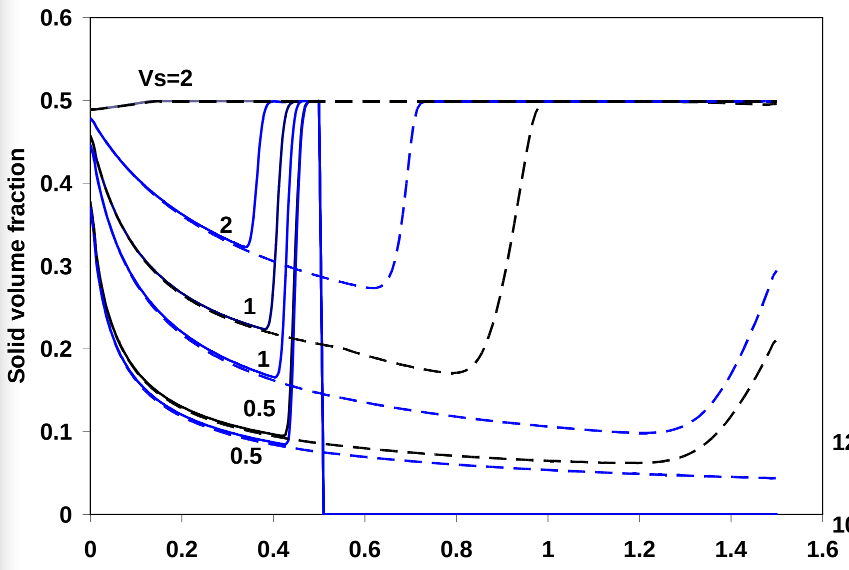


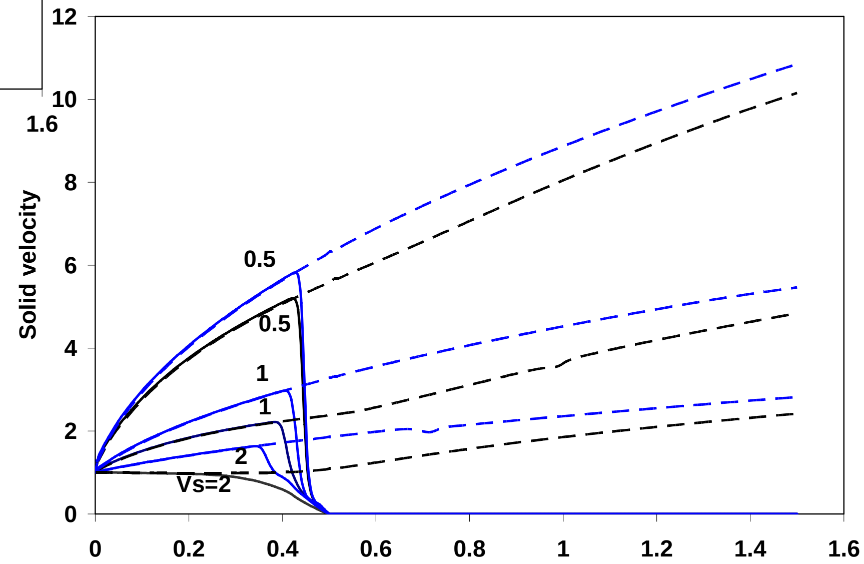


The influence of inlet solids volume fraction (inlet vg / vs = 0.5) on the profiles of solids volume fraction and velocity along the center line (solid lines) and the side wall (dashed lines) for inlet α_s =0.1, 0.2, 0.25, 0.275 and 0.3, respectively.



The influence of particle sizes on the solids volume fraction and velocity for inlet α_s =0.2, and air and solids velocities 1 & 0.5 m/s, respectively.





The influence of the inlet velocities (inlet vg /vs = 0.1 & α_s =0.49) with gravity on the profiles of solids volume fraction and velocity along the center line (solid lines) and the side wall (dashed lines) for single and two phase granular model, blue & black, respectively.

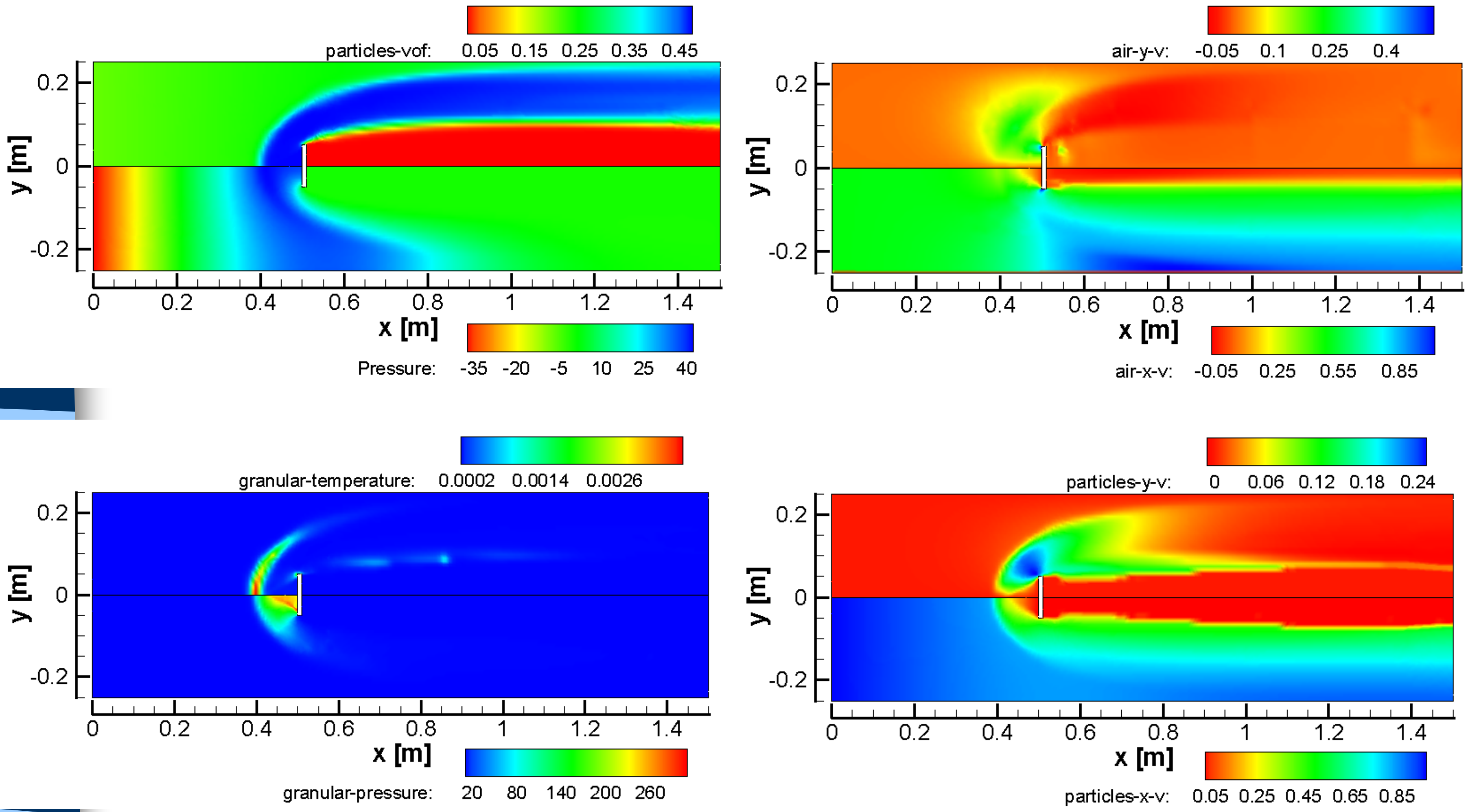
Conclusions

- The simulations based on two different rheological models and numerical methods gave very close results.
- By deducting the fluid-solid interaction term the influence of the interstitial fluid phase on the granular flow can be eliminated.
- By normalizing the properties of the granular phase, the predictions of the numerical simulations converged into the same solution for the non-interactive cases (i.e., the solution of the solid phase flow field is self-similar).
- A granular shock wave was observed in front of the obstacle, where velocities and solids volume fraction underwent a jump.
- The shock wave is forms when upstream solids fraction is relatively low, for a wide range of velocities.

Conclusions

- The shock has a parabolic-shaped front.
- A stagnant wedge forms inside the shock immediately in front of the obstacle.
- The formation and the shape of the bow granular shock wave are influenced by the presence of the gas phase, particle size, the interaction forces between the phases, and gravity.
- The role of the interstitial gas is too significant to ignore for the present problem.
- The effect of the gas flow was negligible only in the vicinity of the obstacle, where granular creeping flow is observed

Thank you for your attention!



Contour plots of solids volume fraction and gas static pressure, solids and gas velocities, and granular temperature and pressure for inlet solids and gas velocities of 1 and 0.5 m/s, respectively, and inlet solid volume fraction 0.2.