Gravitational Collapse of Rectangular Granular Piles

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Presentation Outline

- Introduction, Motivation & Background
- Constitutive Relations
- Numerical Solution
- Material Properties & Investigated Geometries
- Results
    - Evolution of Slump Shapes
    - Comparison with Experimental Data
- Summary & Conclusions

Introduction

- **Flow & collapse of granular materials:**
  - **Industry:**
    - Agriculture
    - Pharmaceuticals
    - Petroleum & Mining
  - **Geophysical processes:**
    - Landslides
    - Avalanches

Motivation & Background

- Available Literature
  - Experimental
    - Geometries (2D Symmetric, 2D dam-break, Semi-Axisymmetric, Axisymmetric)
    - Materials (sand, glass beads, rice, sugar, …)
    - Basal conditions (rough and/or smooth bottom)
  - Numerical
    - Usually depth-averaged equations, shallow-water approximation
    - Collapse of short-thick blocks; NOT tall-thin blocks

Constitutive Relations & Governing Equations

- Modified von Mises yield function
- Isotropic
- Associated flow rule
- Incompressible
- Plane strain

NRC·CNRC

- **Stress-strain rate relationship:**

$$\sigma_{ij} = \sigma_m \delta_{ij} - \left(\dot{\in}_{ij} - \dot{\in}_{kk} \ \delta_{ij} / 3 \right) \sigma_m \sin\phi / \left(I_2 \right)^{0.5}$$

- **The granular material is a fluid with the dynamic shear viscosity of:**

$$\eta = p \sin\phi / \left(2 \left(I_2 \right)^{0.5} \right) \longrightarrow \eta = \alpha + p \sin\phi / \left(2 \left(\beta + I_2 \right)^{0.5} \right)$$

Numerical Stability

Numerical Solution

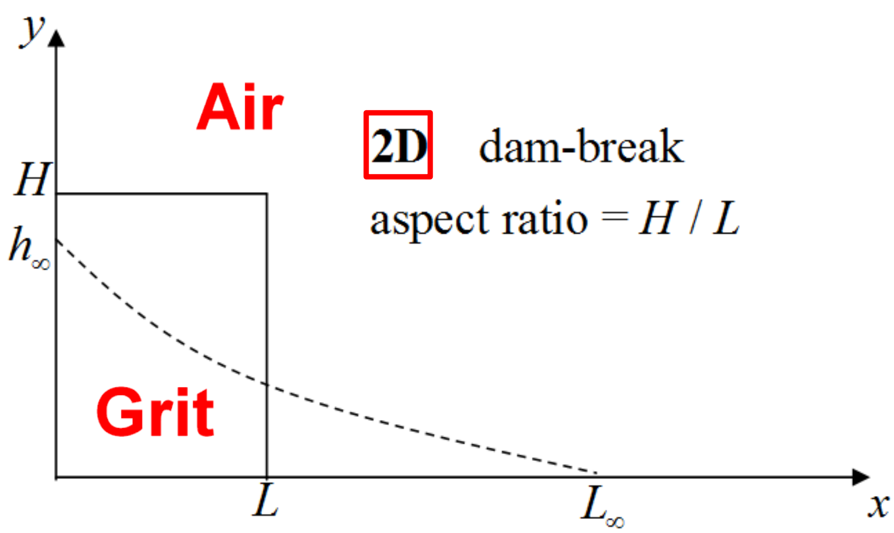
- COMSOL FE tool (version 4.2a), CFD two-phase laminar flow module

- The Level-Set method was used to track the interface between the two phases

Granular Material

- **Grit, irregular grain shapes, mean size 1 mm.**

Grit	Surrounding Air
$\phi_{grit} = 34^\circ$	$\eta_{air} = 10^{-5}\, Pa \cdot s$
$\rho_{grit} = 2600\ kg/m^3$	$\rho_{air} = 1\ kg/m^3$

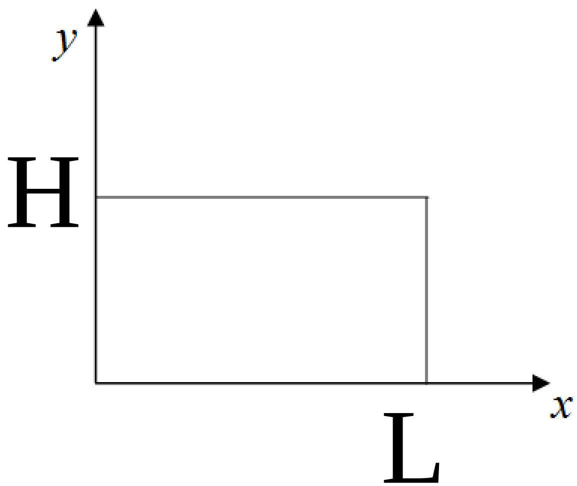


Geometries

Case I $(short - thick)$

H = 10 cm

L = 20 cm

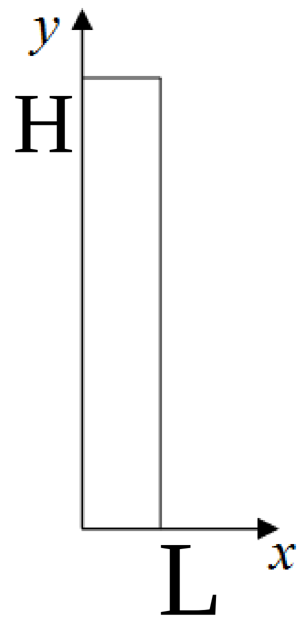


aspect ratio = 0.5

Case II $(tall - thin)$

H = 25 cm

L = 2 cm

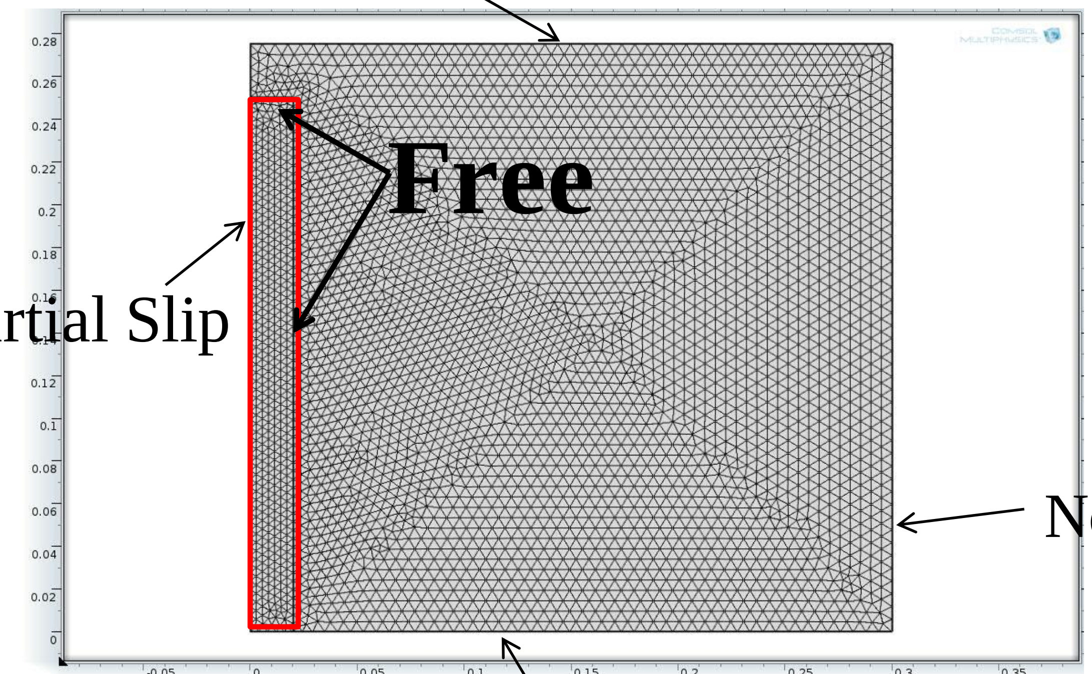


aspect ratio = 12.**5**

Results

- **Triangular mesh, element size is approximately 4 mm**

Slip



$$\eta = \alpha + p\sin\phi / \left(2\left(\beta + I_2\right)^{0.5}\right)$$

$$\alpha = 1\ Pa \cdot s$$

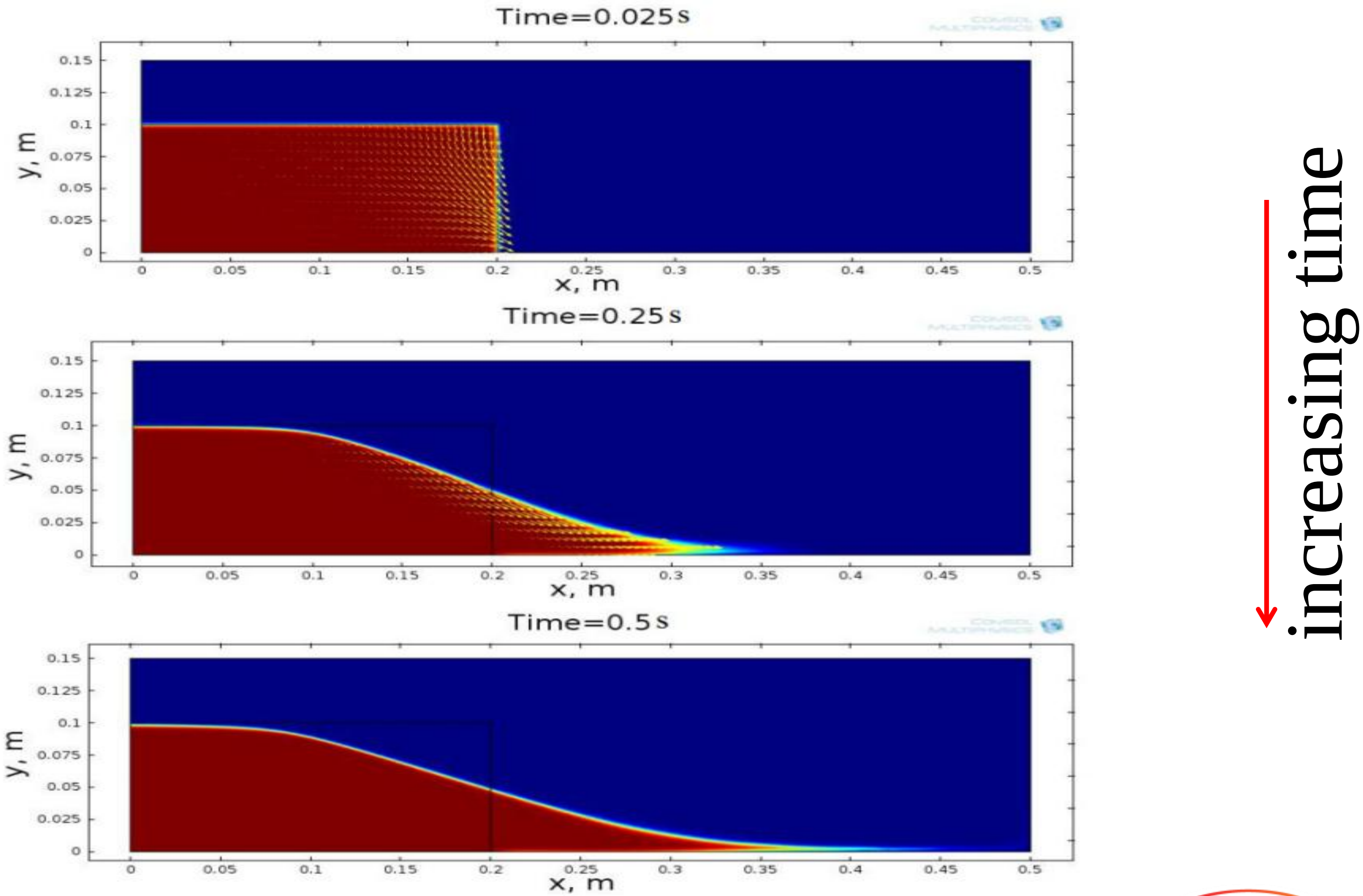
$$\beta = 0.075\ s^{-2}$$

Slip length = 2 mm

Partial Slip

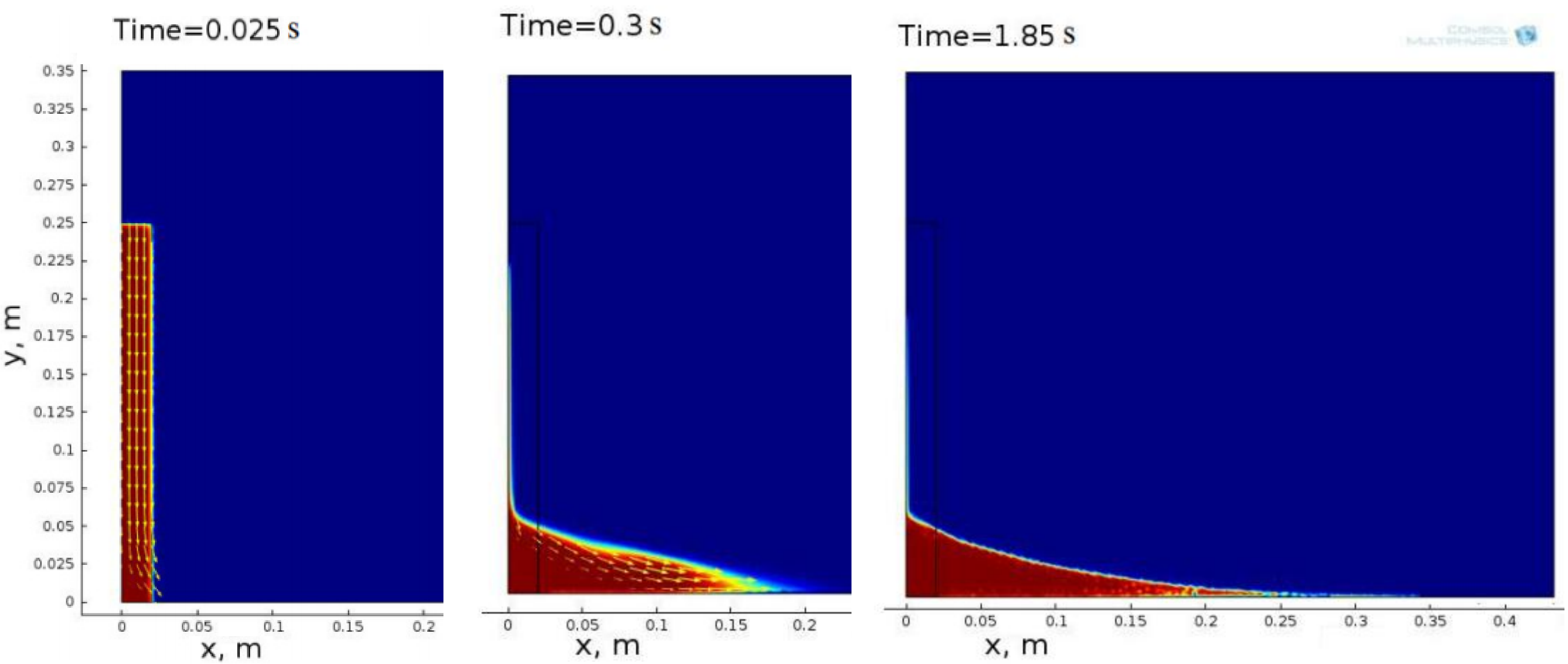
Evolution of Slump Shapes

- **CASE I, Low Aspect Ratio Pile**

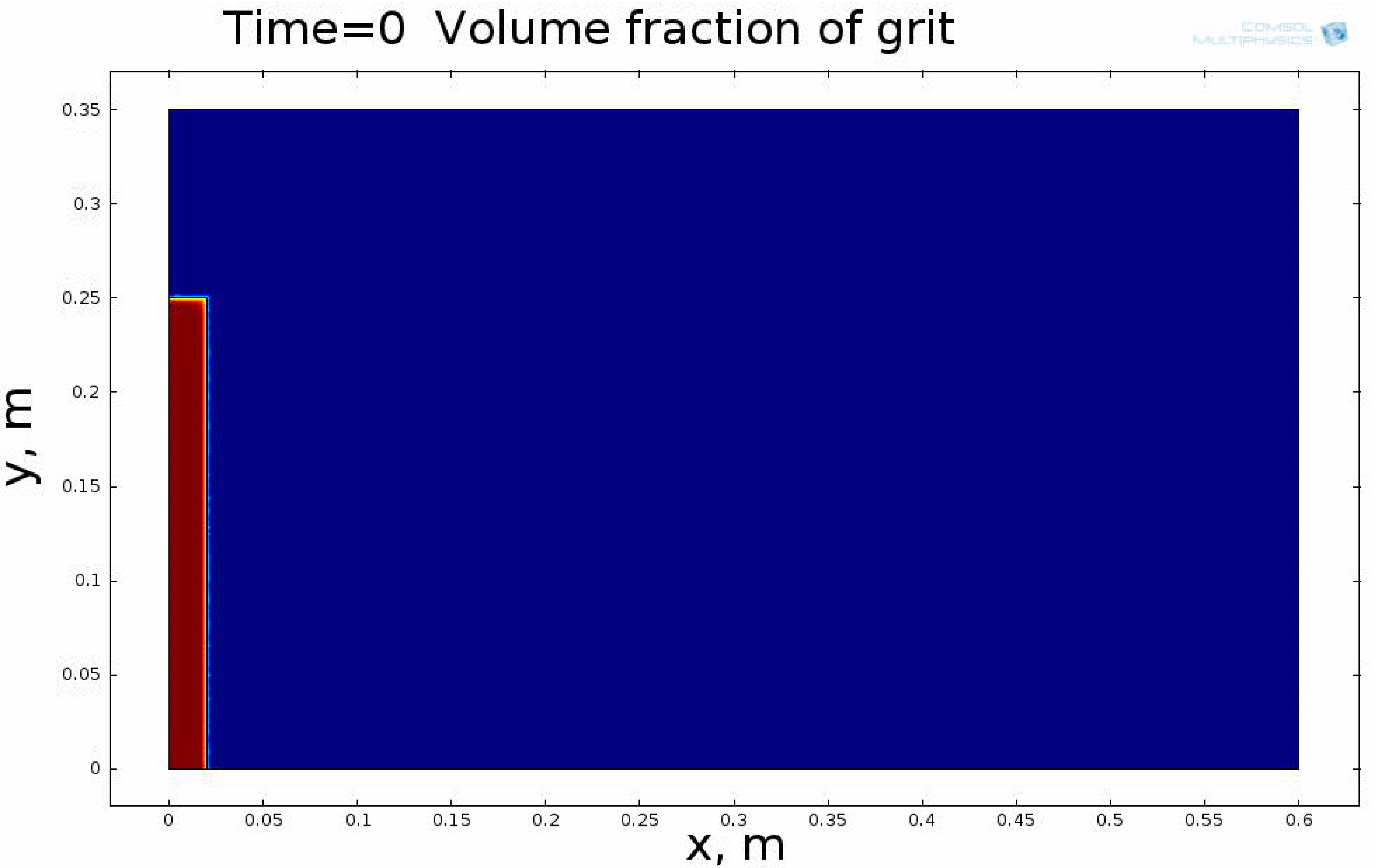


Evolution of Slump Shapes

- **CASE II, High Aspect Ratio Pile**

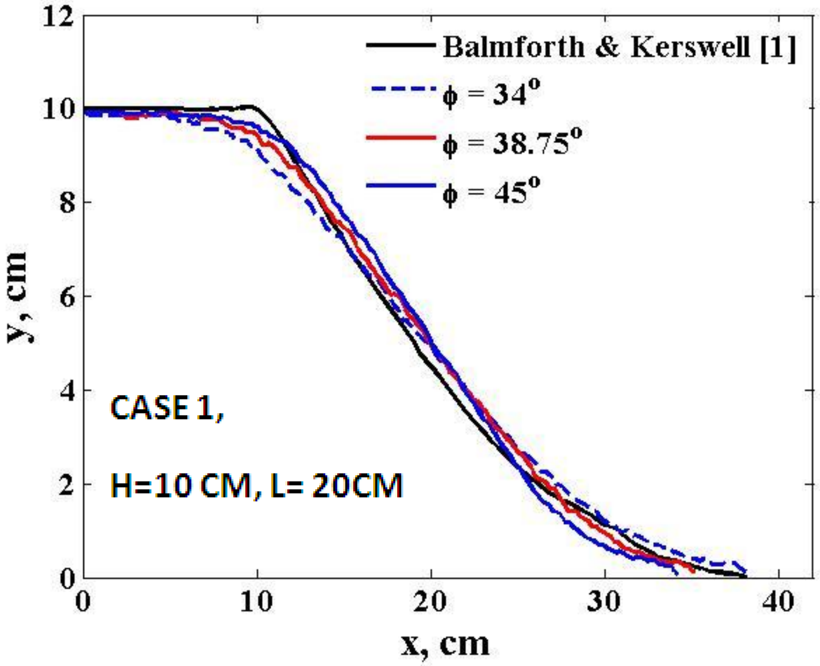


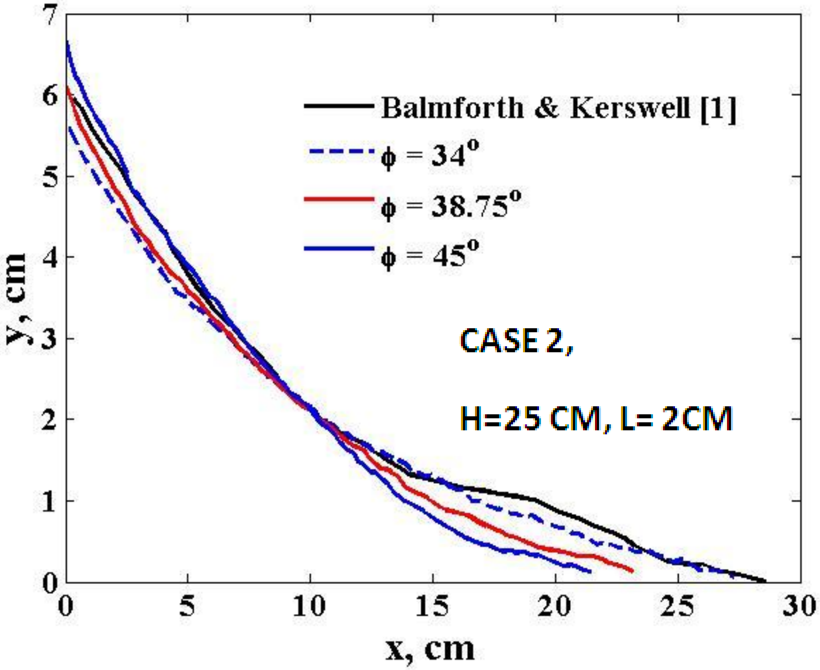
increasing time


Time=0 Volume fraction of grit
COMSOL MULTIPHYSICS
y, m
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5 0.55 0.6
x, m

Comparison with Available Experiments

- Close prediction of the final runout, final height, and the final free surface profile
- An increase in the internal angle of friction reduces the runout





Final profiles

Summary & Conclusions

- Mohr-Coulomb based constitutive relations
- Strain-rate and pressure dependent shear viscosity
- Two-phase flow problem

- Partial slip at boundaries in contact with the granular material

- Stable heaps are captured
- Final free-surface profiles agree with experiments

Thank you!