Aalto University
School of Engineering

Continuum modelling of the granular flows in gaseous states using material point method

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Introduction

Research

Results

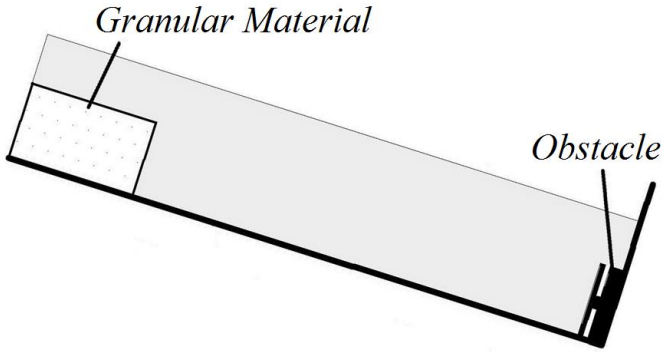
Introduction

Different stages of granular flow

Previous investigations

This study

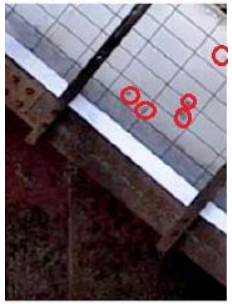
Different stages of granular flow



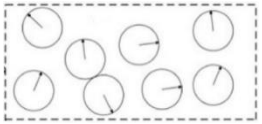
1- Small strain: High shear stress for initiation

2- Flow-like: Shear and volumetric strains
Continue to critical state

At critical state and depending on rate of flow $\begin{cases} \text{moderate} \rightarrow \text{critical state} \\ \text{high} \rightarrow \text{gaseous state} \end{cases}$



3- Gaseous state: Density reduction



Very fast deformations
Interact mainly through collusions

(based on Jiang & Towhata, 2013)

Previous investigations

- Stage 1 and 2: Many researches investigated using MPM

- Gaseous state: Very few researches used MPM
  - Constitutive model for gaseous state
    Dunatunga & Kamrin, 2015 } Derive an equation of state
    Dunatunga & Kamrin, 2017 } Approximate gaseous flow as stress free
  - Switching the stress behaviour at a volume related state
    Dunatunga & Kamrin, 2015
    Dunatunga & Kamrin, 2017 } ρ_{cr}
  - No investigation on replication of gaseous state
  - Problem using cpGIMP and CPDI

This study

- Assumption:
  - Stress free approximation of Dunatunga & Kamrin, 2015, 2017
  - Neglecting the collisional contribution
- Investigated:
  - Stress free approximation in MPM
  - Replication of gaseous state
- Goal:
  - A solution viable for all versions of MPM

Research

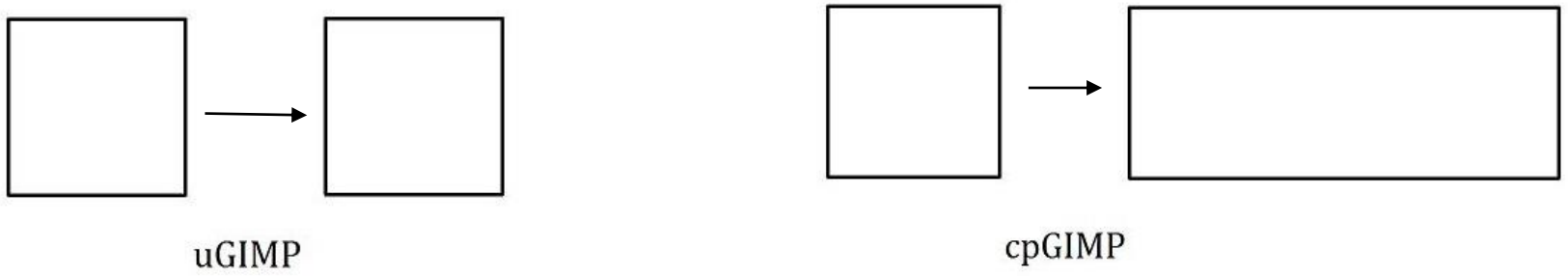
MPM versions

Replication of gaseous state

A solution for all versions of MPM

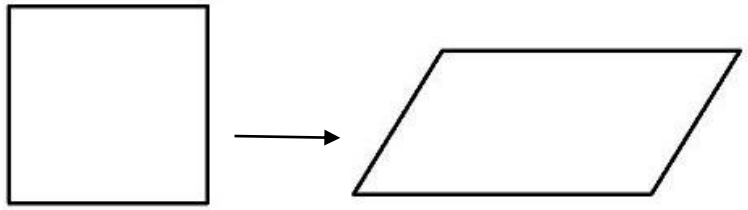
MPM versions

- Original MPM:
  - Introduced by Sulsky et al. ,1994
  - Approximates the continuum with material points
  - Employs a background grid for calculation
  - Defines material points merely as points
- GIMP:
  - Introduced by Bardenhagen and Kober, 2004b
  - Define space occupied by a material point
  - Two commonly used variants : uGIMP & cpGIMP
    - uGIMP: particle domain is constant
    - cpGIMP: particle size changes & particle shape remains constant



MPM versions

- CPDI:
  - Introduced by Sadeghirad et al., 2013
  - Tracks variations of particle domain size and shape

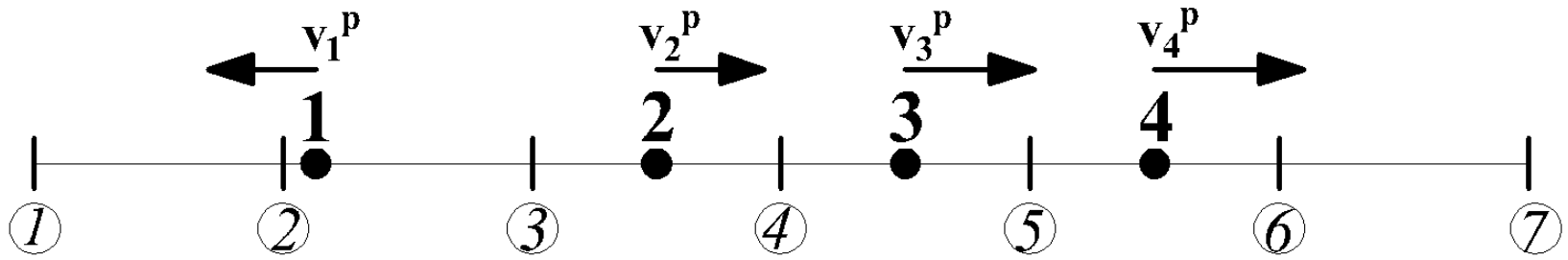


CPDI

Replication of gaseous state

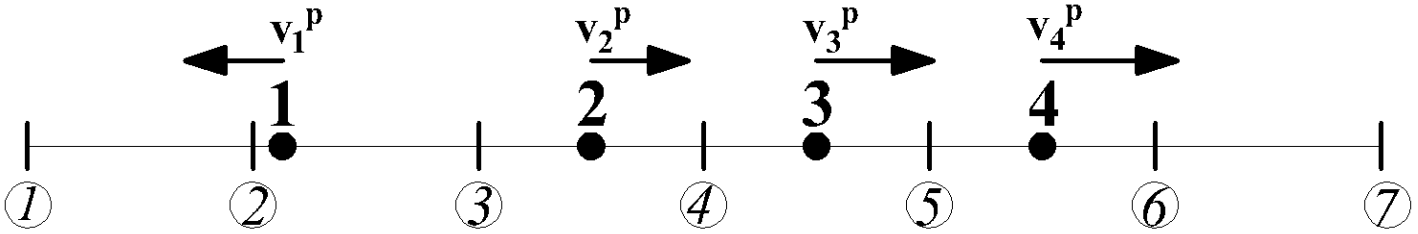
- Gaseous material points :

lost frictional contacts
stress free approximation → disregarding collisions
No interaction with other material points



Material point 1 in the gaseous state
Others in the solid state
$|v_2{}^p| \neq |v_3{}^p| \neq |v_4{}^p|$

Replication of gaseous state



- In original MPM :

$Node\ 3 \rightarrow \quad m_3{}^N \& p_3{}^N \propto$ material point 1

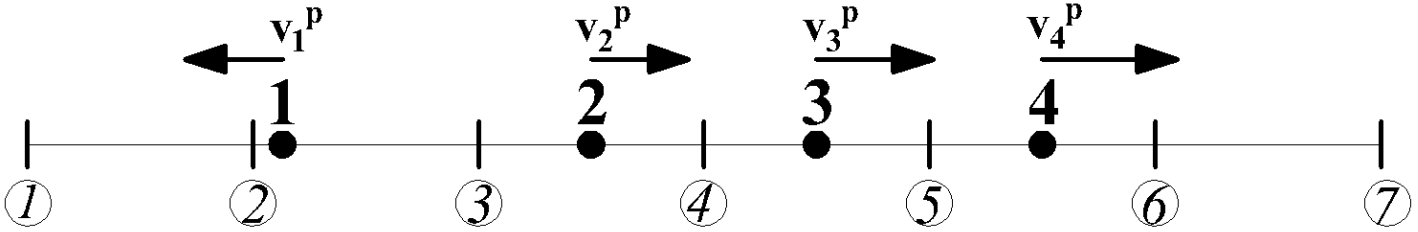
$Node\ 3 \rightarrow \quad m_3{}^N \& p_3{}^N \& f_3{}^{int} \propto$ material point 2

Updating material points $\rightarrow v_1{}^p$

Material point 1 interacts with material point 2

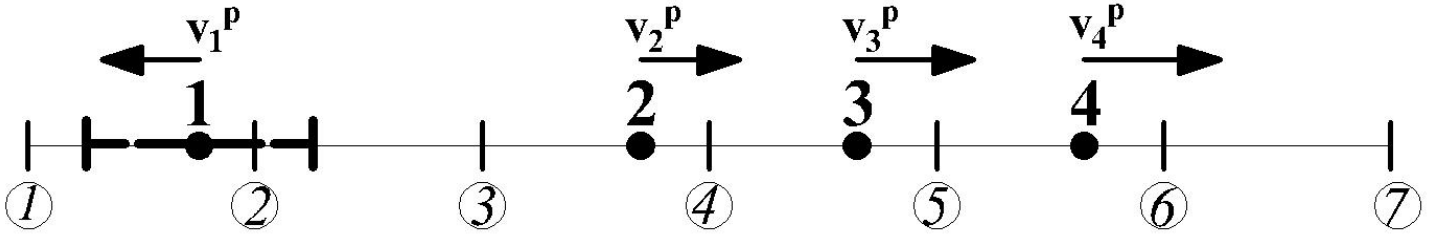
Material points 1 and 2 stop interacting after one moves to another cell

Replication of gaseous state

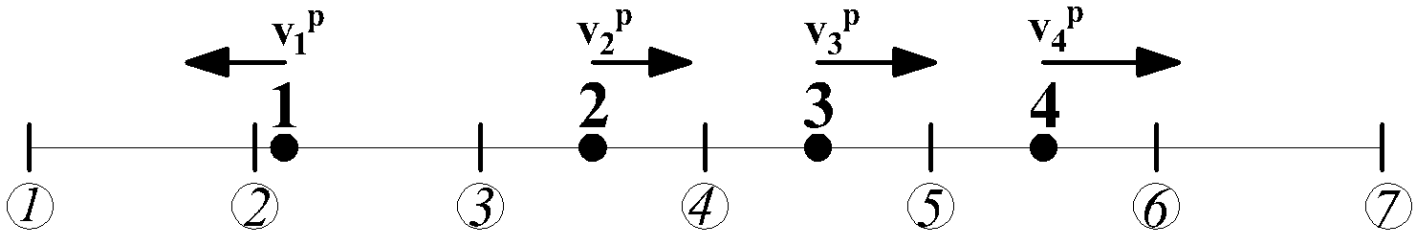


- In uGIMP :

Material points may contribute to the nodes of the neighbouring cells
Material points 1 and 2 *can* interact *even* after one moves to another cell
Ultimately, Material points 1 and 2 stop interacting



Replication of gaseous state



- In cpGIMP and CPDI:

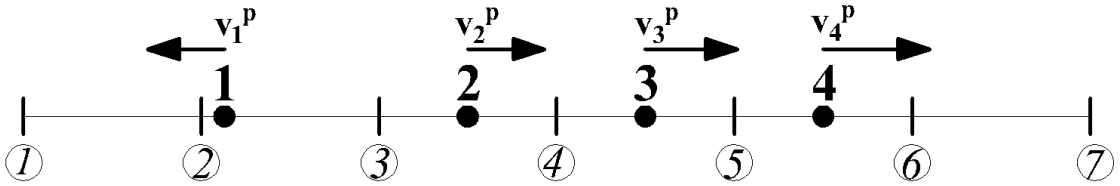
Size of particle domain change
Material points contribute to increasing number of nodes
Material points keep interacting and never fully disconnect

A solution for all versions of MPM

- Narin, 2003:

  Introduction of discontinuity into MPM and modelling explicit cracks
  Material points on the opposite side of a crack → seperate grid
  Prevents material points from interacting

- Proposed solution:



  Material points interacting with each other → same grid
  Material points in gaseous state → seperate grid
  Material points start interacting → grid merging

- Domain of interaction for material point

A solution for all versions of MPM

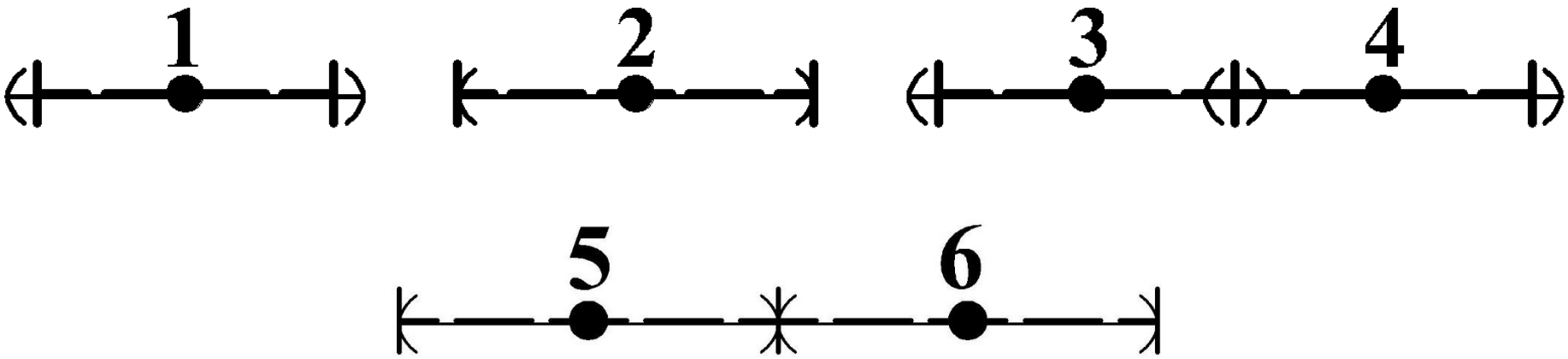
- Domain of interaction :

$\rho_{cr} = \frac{m}{V_{cr}} \rightarrow V_{cr}$: the highest volume of particle in solid state

Domain of interaction → particle domain scaled to V_{cr}

Particle volume $< V_{cr}$ → domain of interactions intersect

Particle volume $= V_{cr}$ → No intersection

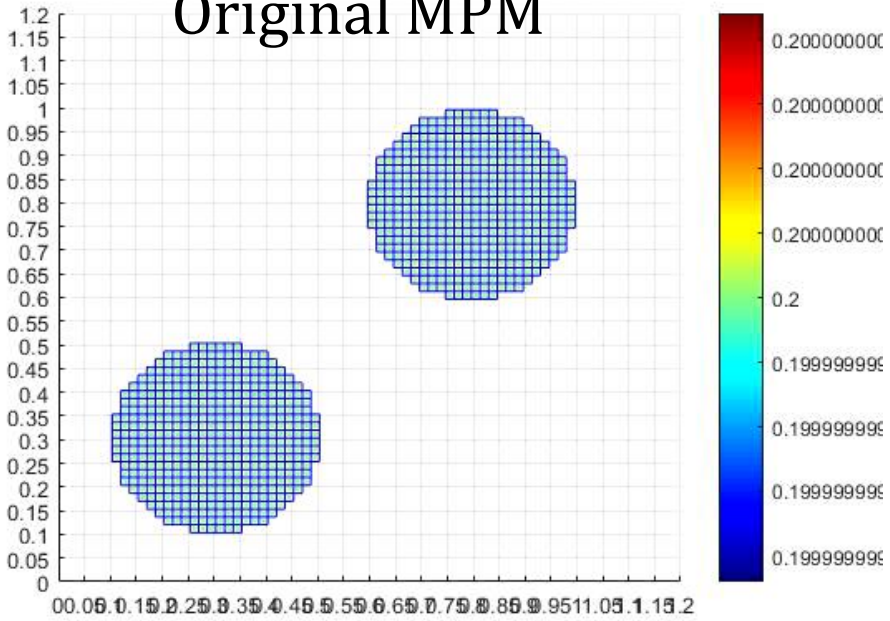


A solution for all versions of MPM

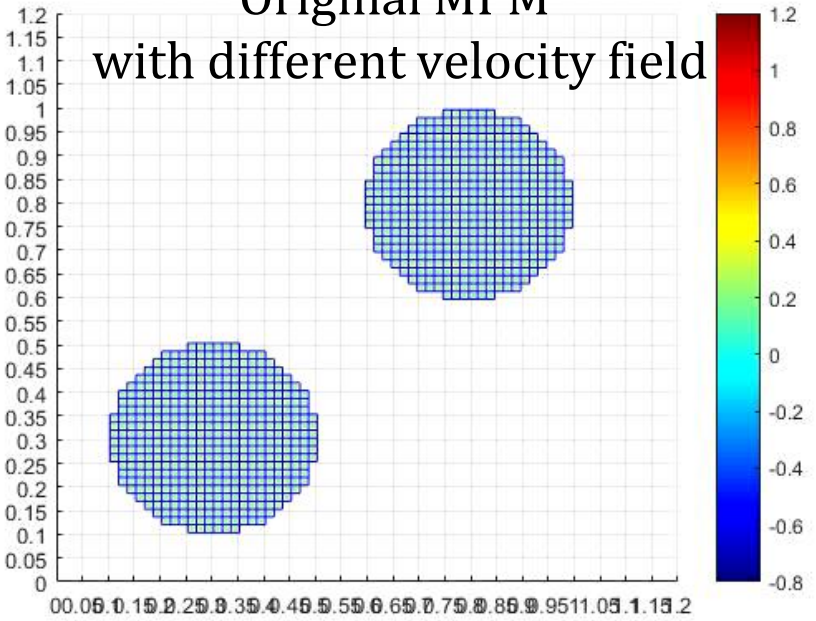
- Algorithm for designating velocity field :

At the beginning of an MPM step and based on particle domains of interaction
1- designates velocity filed 1 particle 1 to
2- checks if domain of interaction of particle 1 intersects with any particle.
3- Those interacting particles will also have their velocity field set to 1
4- All particles intersecting with step 3 particles will also have their velocity field set to 1
5- If any material points remain not assigned, the process repeated, but with velocity field 2, 3 and so on

Original MPM



Original MPM
with different velocity field



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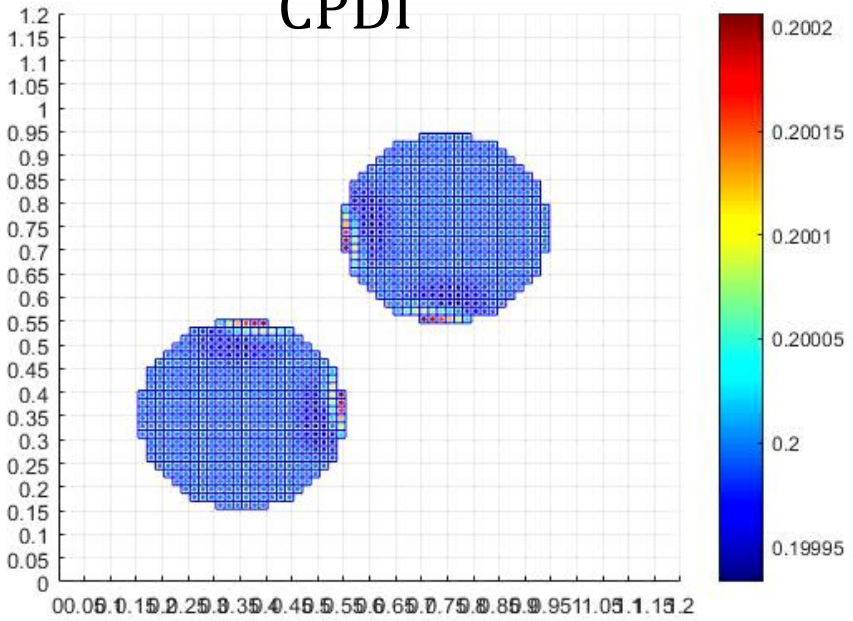
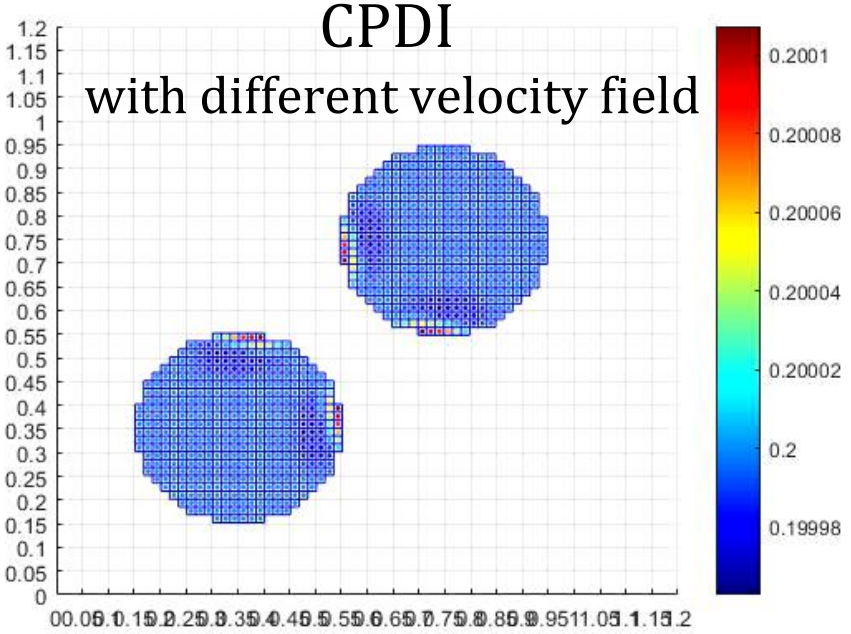
CPDI

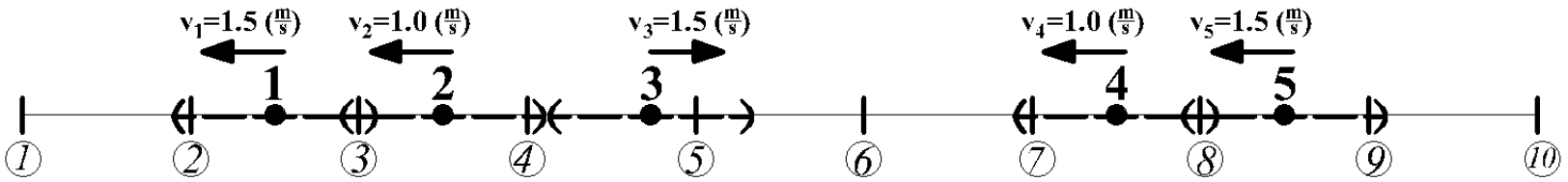


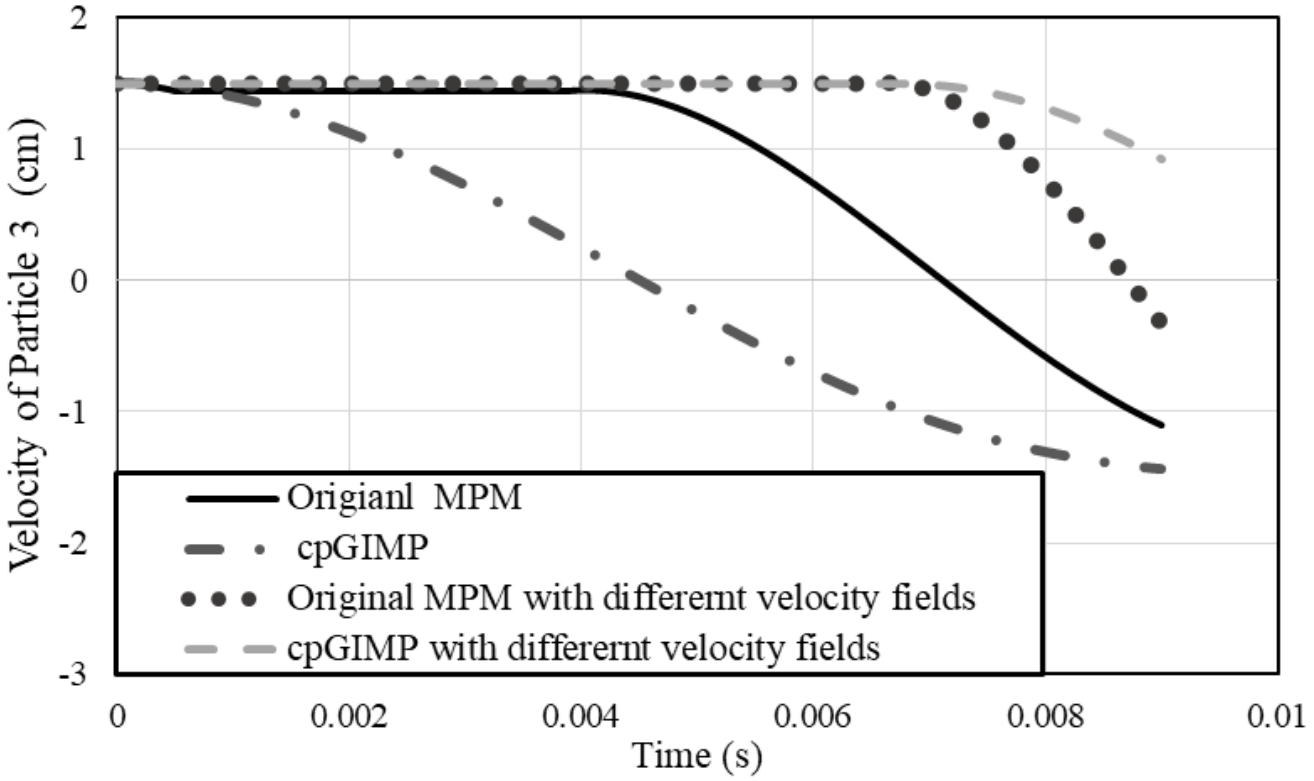
CPDI
with different velocity field



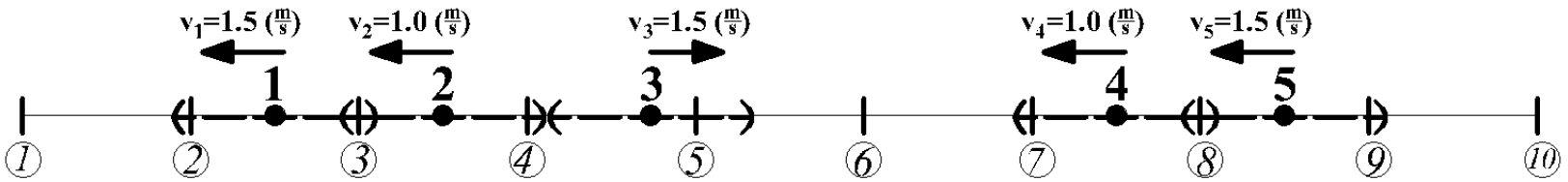
Result

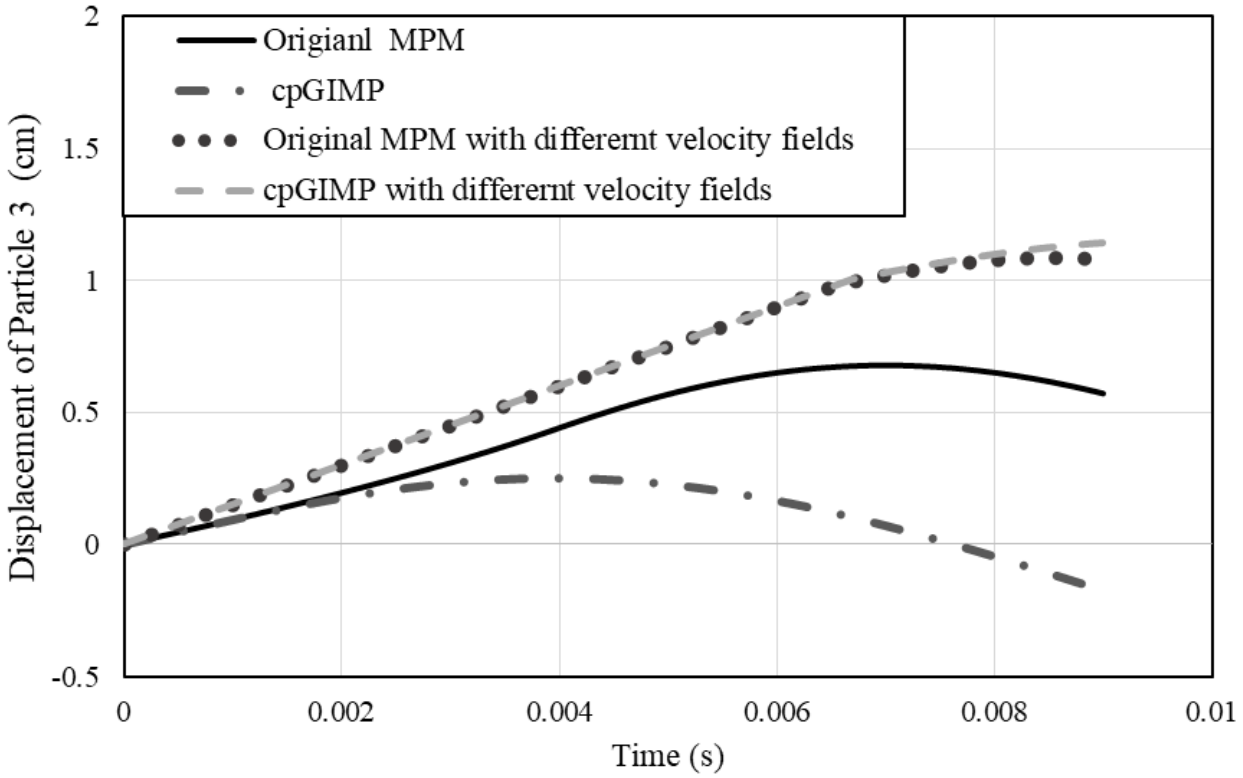
Result


v1=1.5 (m/s)
v2=1.0 (m/s)
v3=1.5 (m/s)
v4=1.0 (m/s)
v5=1.5 (m/s)
1
2
3
4
5
1
2
3
4
5
6
7
8
9
10

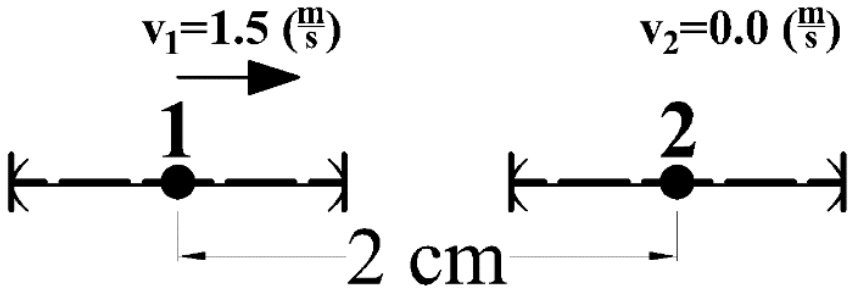

Velocity of Particle 3 (cm)
2
1
0
-1
-2
-3
0
0.002
0.004
0.006
0.008
0.01
Time (s)
Origianl MPM
cpGIMP
Original MPM with differemt velocity fields
cpGIMP with differemt velocity fields

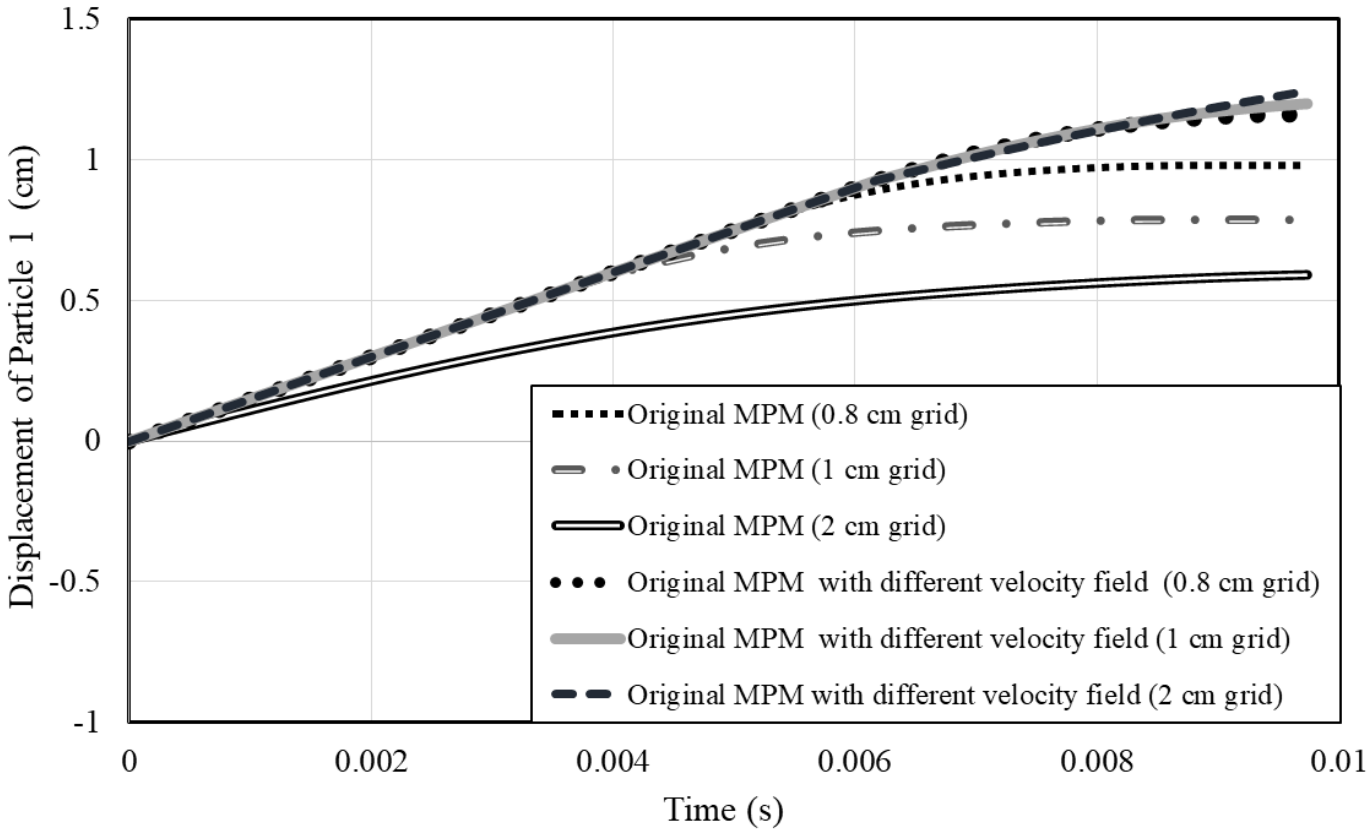
Result


v1=1.5 (m/s)
v2=1.0 (m/s)
v3=1.5 (m/s)
v4=1.0 (m/s)
v5=1.5 (m/s)
1
2
3
4
5
1
2
3
4
5
6
7
8
9
10


Origianl MPM
cpGIMP
Original MPM with differemt velocity fields
cpGIMP with differemt velocity fields
Displacement of Particle 3 (cm)
Time (s)
2
1.5
1
0.5
0
-0.5
0
0.002
0.004
0.006
0.008
0.01

Result


v_1=1.5 ($\frac{m}{s}$)
v_2=0.0 ($\frac{m}{s}$)
1
2
2 cm


Displacement of Particle 1 (cm)
Time (s)
1.5
1
0.5
0
-0.5
-1
0
0.002
0.004
0.006
0.008
0.01
Original MPM (0.8 cm grid)
Original MPM (1 cm grid)
Original MPM (2 cm grid)
Original MPM with different velocity field (0.8 cm grid)
Original MPM with different velocity field (1 cm grid)
Original MPM with different velocity field (2 cm grid)

Conclusion

- This research investigated MPM replication of granular flow gaseous state.
- Original MPM and uGIMP face problem modelling gaseous state & are grid dependent.
- cpGIMP and CPDI can not model gaseous state of granular flow.
- This research suggests a solution allowing for replicating of gaseous state in different versions of MPM.
- The procedure leads to mesh independent simulations of gaseous state in Original MPM and uGIMP .

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Thank you for your attention