Submerged Granular Collapse: Different Cohesion Strength and Initial Packing Densities

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Contents

1 Introduction

2 Computational model

3 Results

4 Conclusions

Introduction——background

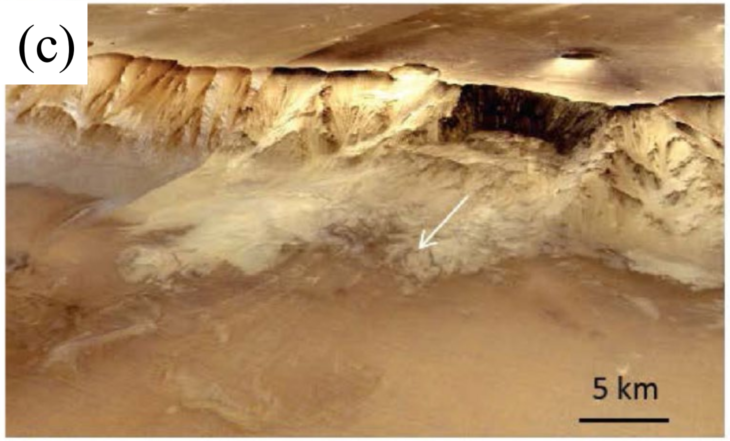
Granular collapse means a granular column is suddenly put into motion.

It is a kind of unsteady granular flow.

Pyroclastic flows

Landslides

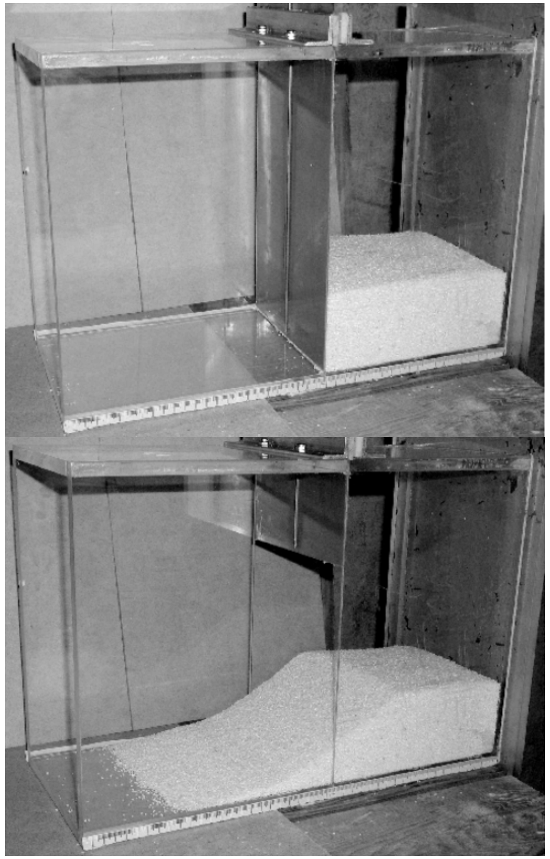
(Delannay et al. 2017)



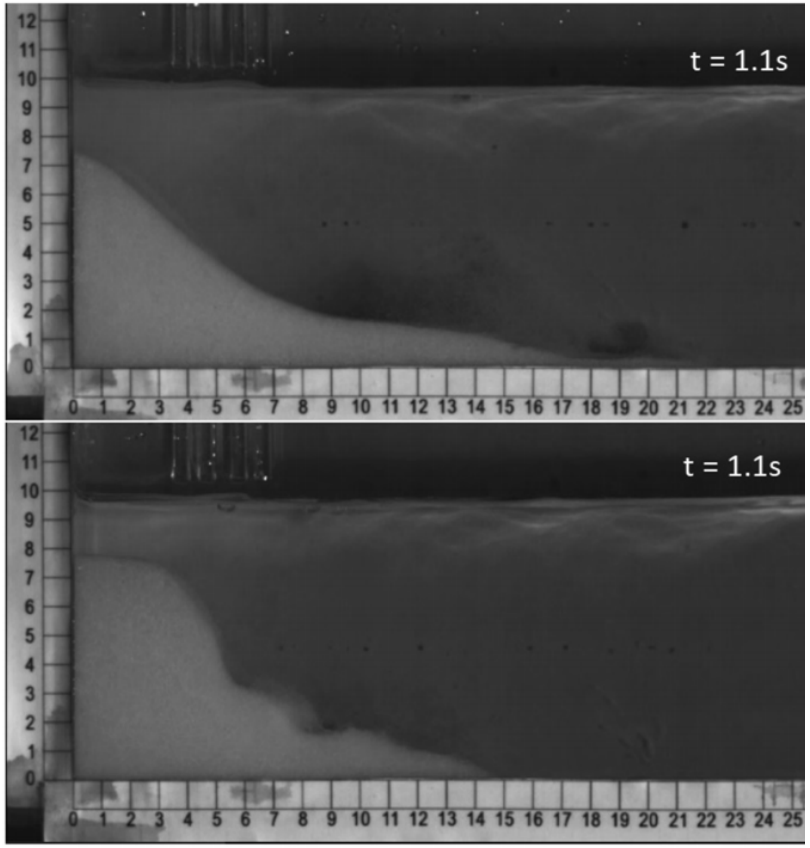
Submarine avalanches

Introduction——previous research

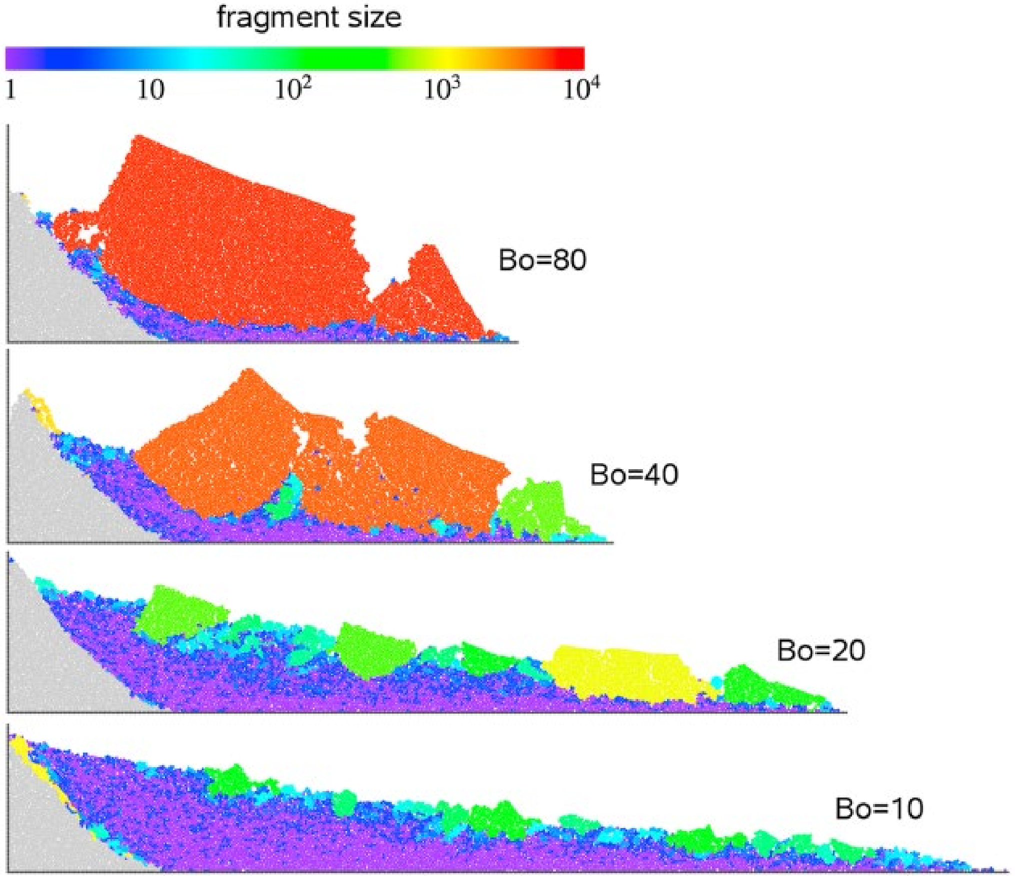
- Dry noncohesive granular collapse
- Submerged noncohesive granular collapse
- Dry cohesive granular collapse
- Submerged cohesive granular collapse ?



Balmforth & Kerswell 2005

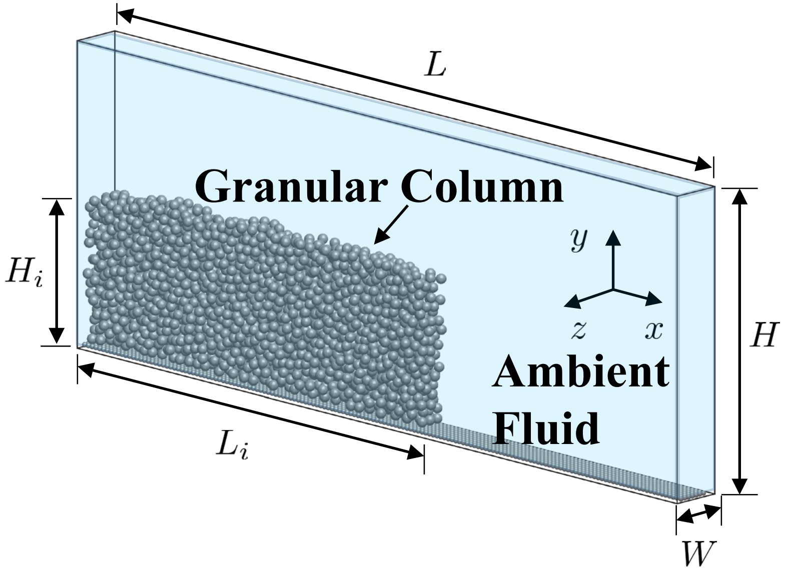


Wang et al. 2017



Langlois et al. 2015

Computational model——initial set-up



- The size of domain is $L = 100d_p$, $H = 30d_p$, and $W = 3d_p$.
- The size of the granular column is $L_i=45d_p$ and $H_i=15d_p$.
- **Periodic boundary** is set in z-direction.
- A layer of particles with diameter **0.5*dp*** are fixed at the bottom boundary.
- St=12.8, and r=1.6 ($St = \frac{\rho_p d_p^2}{18\eta_f}\sqrt{\frac{g'}{2d_p}}$ $r = \sqrt{\frac{\rho_p}{\rho_f}}$).

1. Packing density

(Volume fraction of the particles in initial columns**):**

$$\phi = \frac{V_p}{V_c} \quad (0.55\text{-}0.64)$$

2. Cohesive number:

$$Co = \frac{\max(||\boldsymbol{F}_{coh,50}||)}{m_{50}g'}$$

Computational model——governing equations

□ Fully coupled, grain-resolving direct numerical simulations.

□ Fluid:

The unsteady Navier-Stokes equations:

$$\frac{\partial \boldsymbol{u}}{\partial t} + \nabla \cdot (\boldsymbol{u}\boldsymbol{u}) = -\frac{1}{\rho_f}\nabla p + \nu_f \nabla^2 \boldsymbol{u} + \boldsymbol{f}_{IBM},$$

The continuity equation:

$$\nabla \cdot \boldsymbol{u} = 0,$$

□ Particle:

Within the framework of the IBM, we calculate the motion of each individual spherical particle.

- **Translational velocity:**

$$m_p \frac{\mathrm{d}\boldsymbol{u}_p}{\mathrm{d}t} = \boldsymbol{F}_{h,p} + \boldsymbol{F}_{g,p} + \boldsymbol{F}_{c,p},$$

- **Angular velocity:**

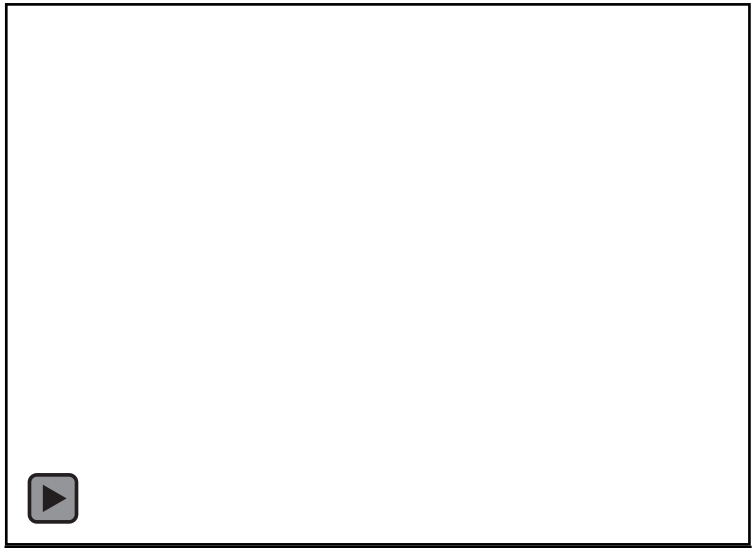
$$I_p \frac{\mathrm{d}\boldsymbol{\omega}_p}{\mathrm{d}t} = \boldsymbol{T}_{h,p} + \boldsymbol{T}_{c,p},$$

- **$F_{c,p}$: the force due to particle collisions:**

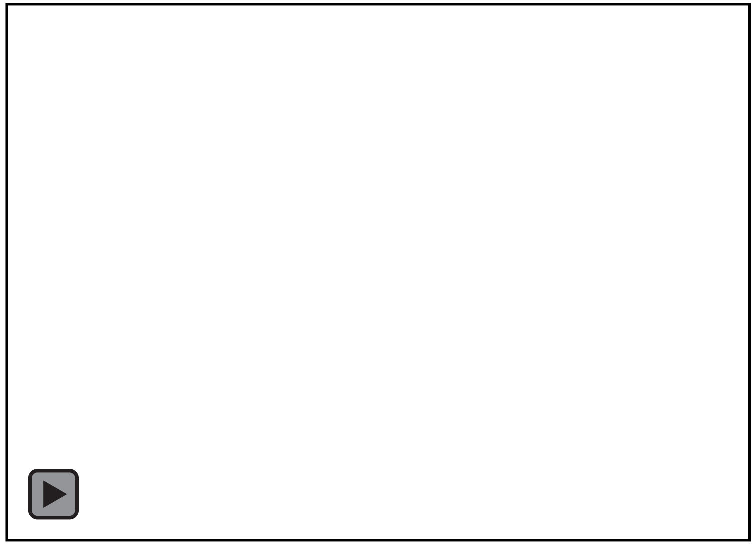
$$\boldsymbol{F}_{c,p} = \begin{cases} \boldsymbol{F}_l & \text{Lubrication force} \\ \boldsymbol{F}_n & \text{Normal contact force} \\ \boldsymbol{F}_t & \text{Tangential contact force} \\ \boldsymbol{F}_{coh} & \text{Cohesive force} \end{cases}$$

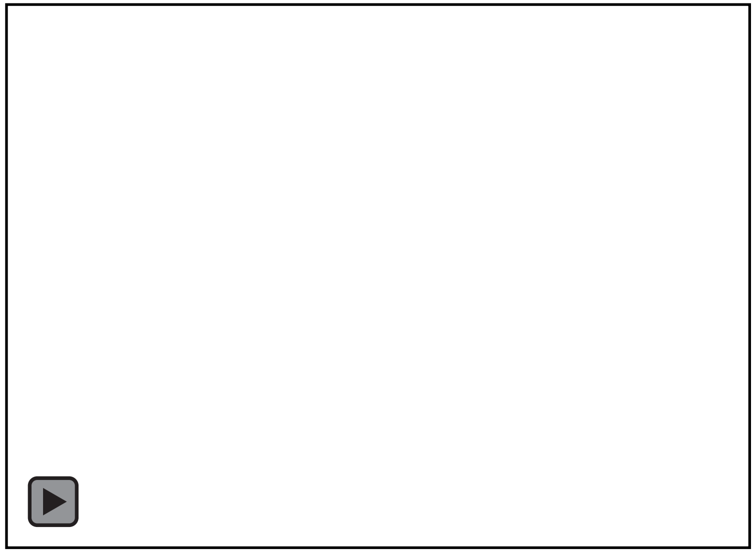
Observations

Loosely packed Columns

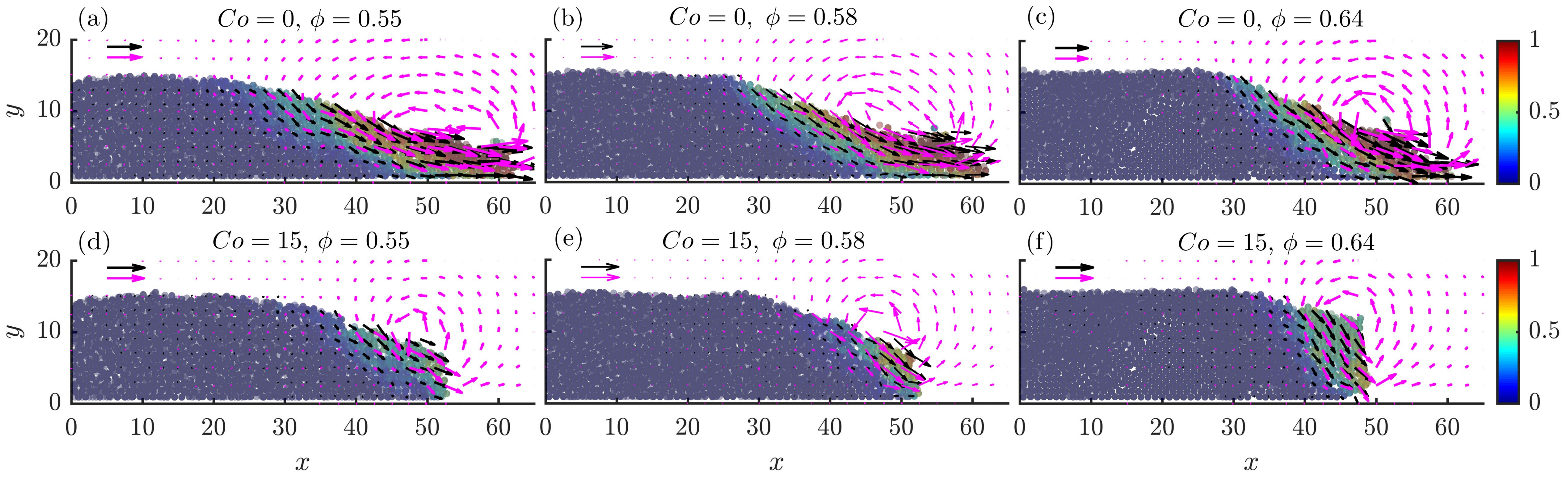


Densely packed Columns



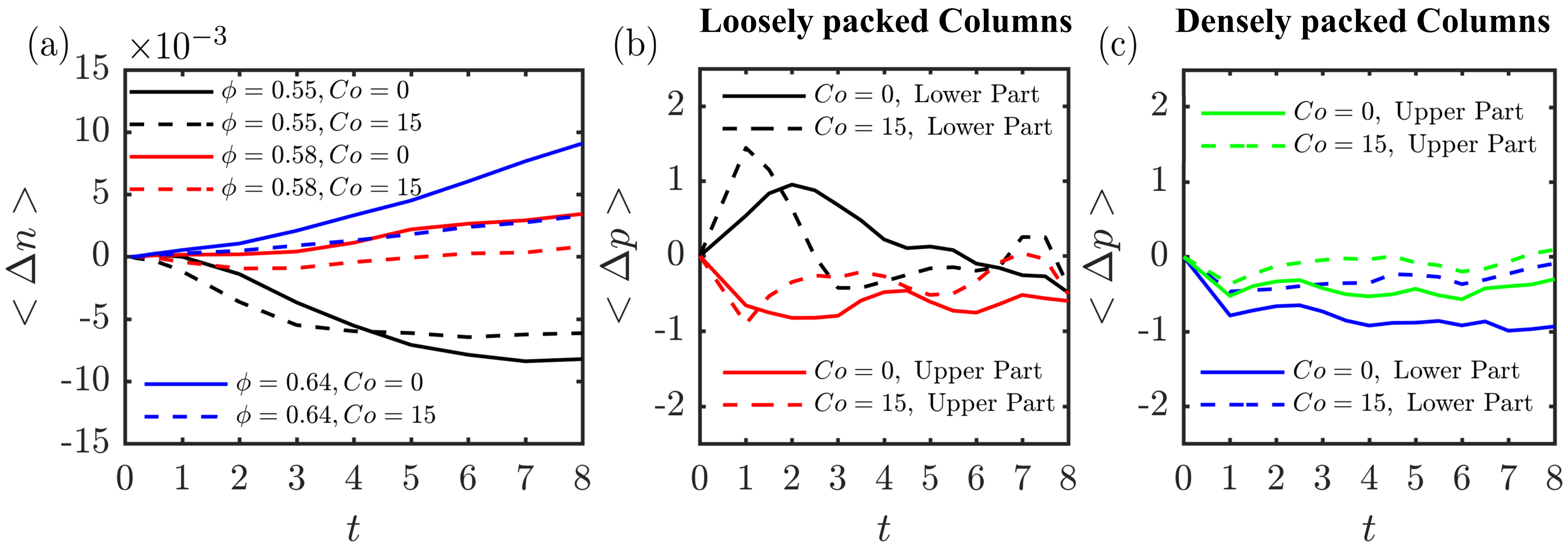


Velocity Field



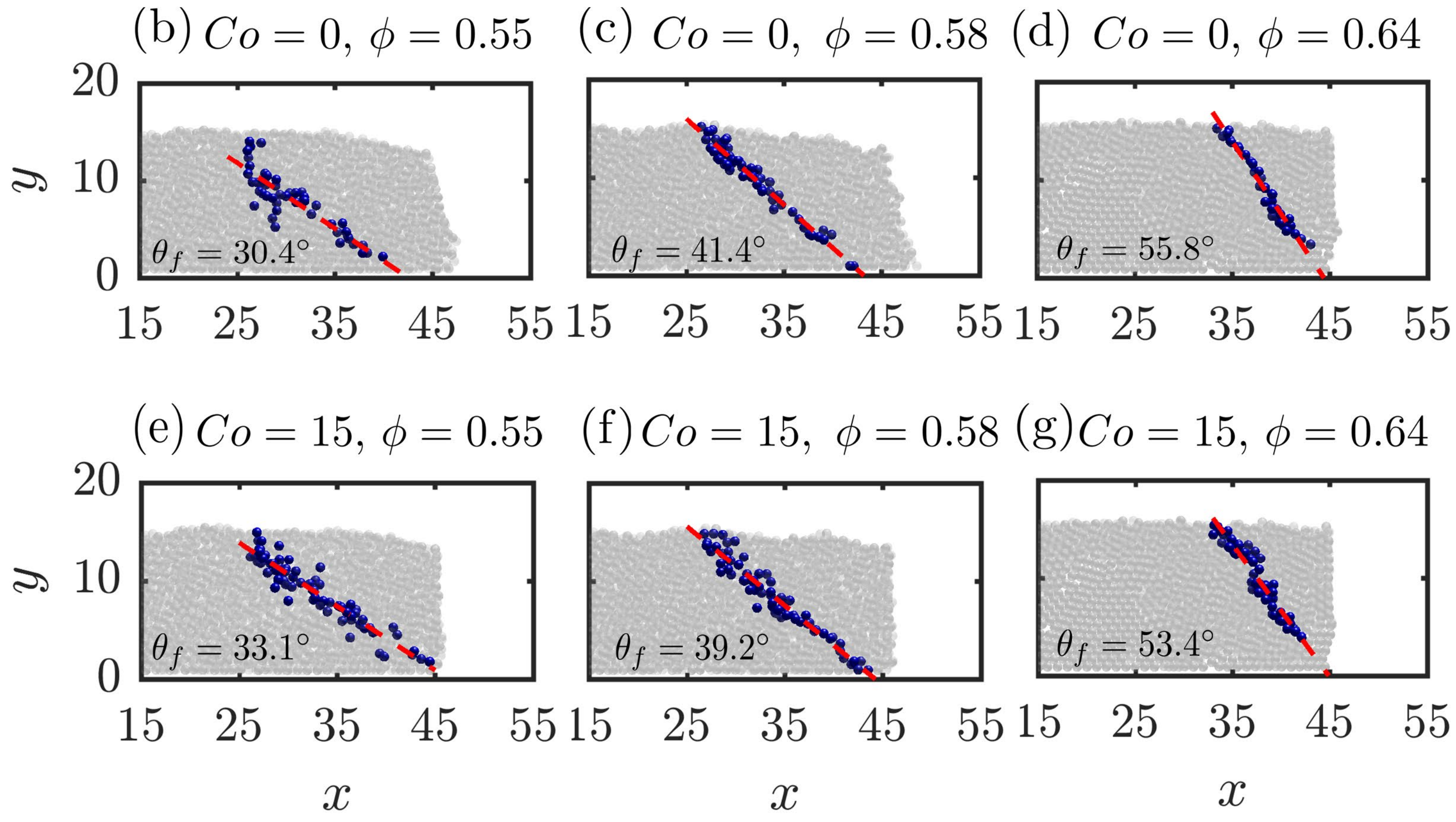
- The black and red arrows represent vectors of the **particle velocity** and the **fluid velocity**.
- With **increasing packing density**, fewer particles participate in the collapse process and they spread more slowly.
- **Cohesion** leads to a greater decrease in particle velocity for more densely packed columns.

Porosity and Pore Pressure



- The cohesion **accelerates the initial contraction** for loosely packed columns and **decelerates the dilation** for densely packed columns.
- The cohesion leads to a **larger** or **smaller** excess pore pressure.

Onset of the Failure



- The collapsing column exhibits **planar failure surfaces**
- The **failure angle increases** with the packing density

Cohesive Aggregates

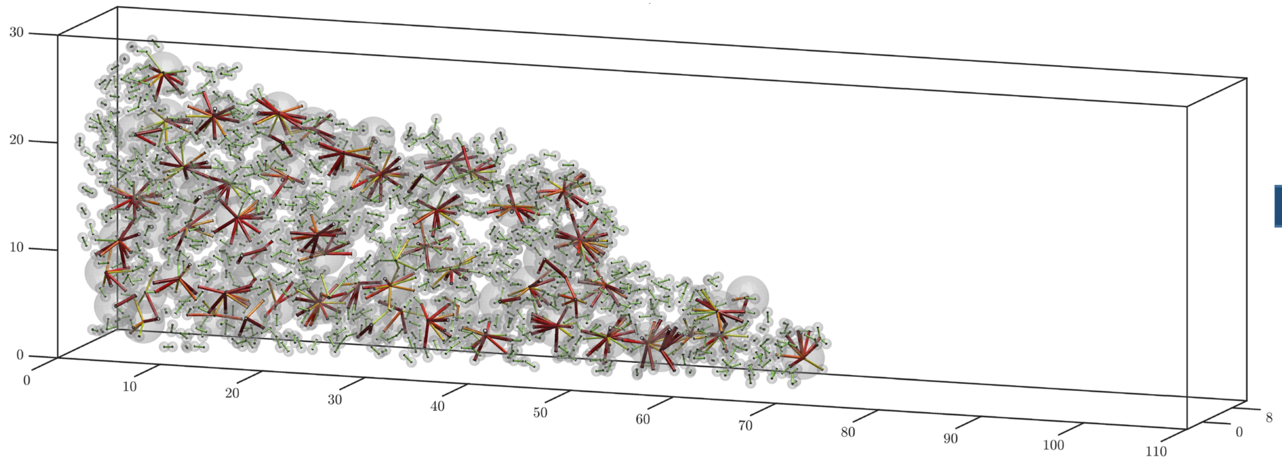
- **Construct a force-weighted particle network W in our granular columns**

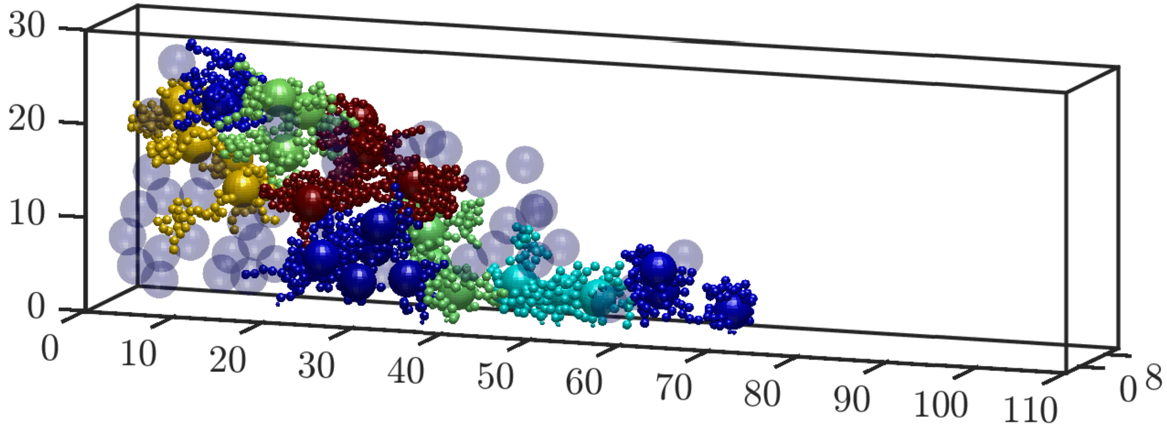
$$W_{pq} = \begin{cases} ||\boldsymbol{F}_{pq}|| / < ||\boldsymbol{F}|| >_b, & \text{Particle } p \text{ and } q \text{ have cohesive force} \\ 0. & \text{Particle } p \text{ and } q \text{ do not have cohesive force} \end{cases}$$

- **To extract cohesive aggregates from W, we use a community detection approach**

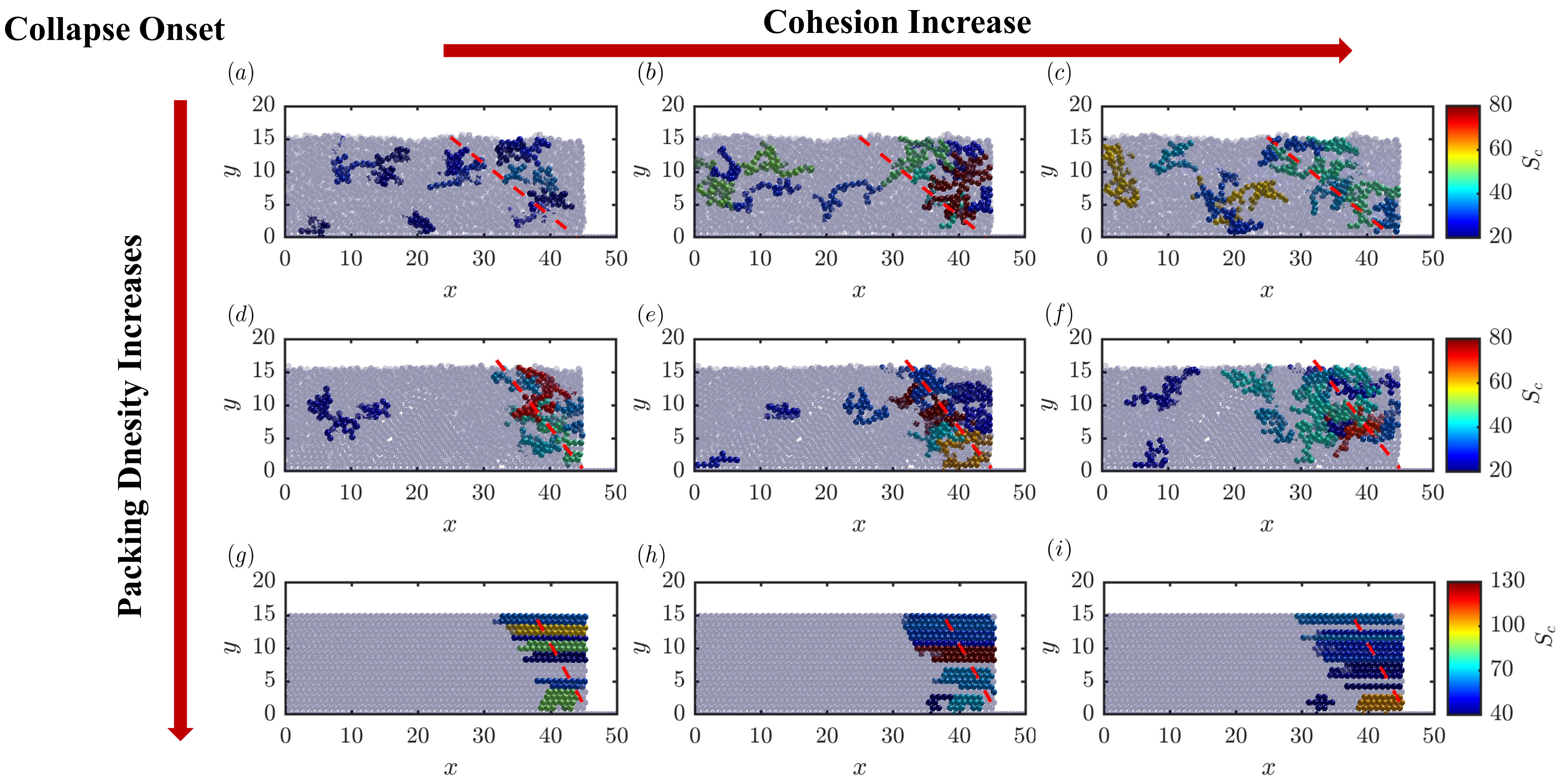
$$Q = \sum_{p,q}[W_{pq} - \gamma P_{pq}]\delta(c_p, c_q) \qquad \delta(c_p, c_q) = \begin{cases} 1 & c_p = c_q, \\ 0 & c_p \neq c_q. \end{cases} \qquad P_{pq} = \begin{cases} 1 & W_{pq} \neq 0, \\ 0 & W_{pq} = 0. \end{cases}$$

- **This approach calculate the maximum value of the quality function *Q* to identify sets of particles with strong cohesive force bond**





Cohesive Aggregates



Conclusions

1. The cohesion accelerates the initial contraction for loosely packed columns and decelerates the dilation for densely packed columns, leading to a larger or smaller excess pore pressure.

2. The collapsing column exhibits planar failure surfaces and failure angle increases with the packing density

3. Force-chain network structures form preferentially in the failure region. They tend to be larger for higher packing density, which induces a larger macroscopic cohesive resistance.

Thanks!