Grain-resolving simulations of submerged cohesive granular collapse

Rui Zhu[1,2], Zhiguo He[1], Kunpeng Zhao[3], Bernhard Vowinckel[4], Eckart Meiburg[2]

[1] Zhejiang University, China
[2] University of California at Santa Barbara, USA
[3] Xi'an Jiaotong University, China
[4] Technische Universität Braunschweig, Germany

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Contents

Introduction——background

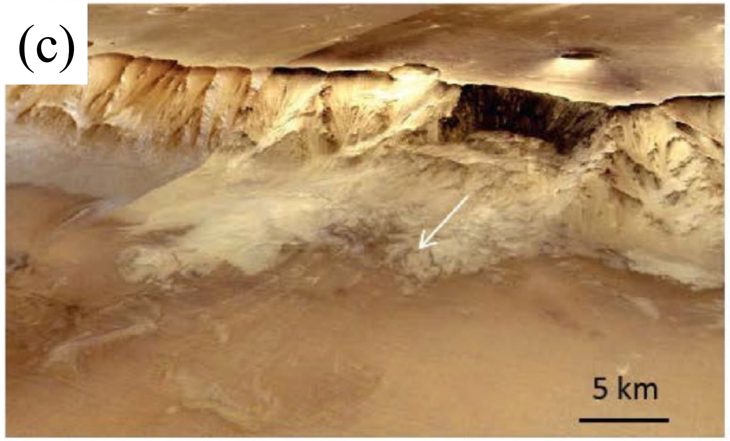
Granular collapse means a granular column is suddenly put into motion.

It is a kind of unsteady granular flow.

Pyroclastic flows

Landslides

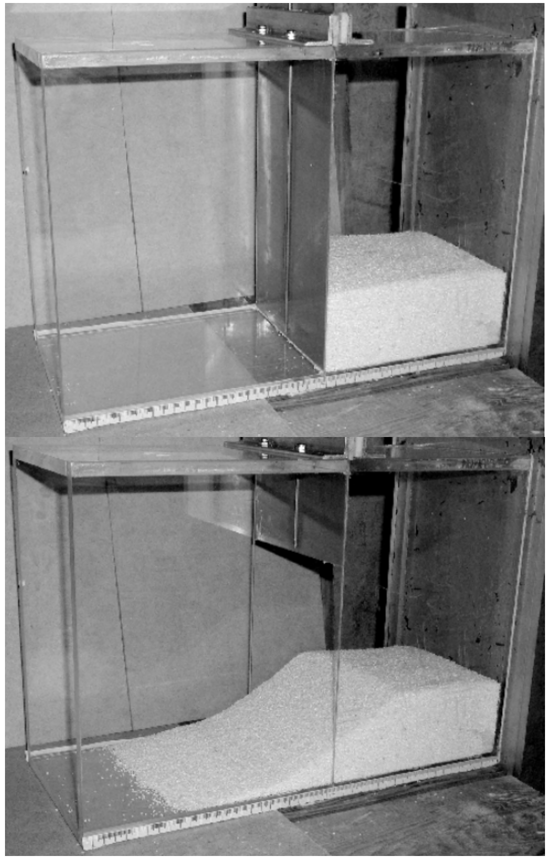
(Delannay et al. 2017)



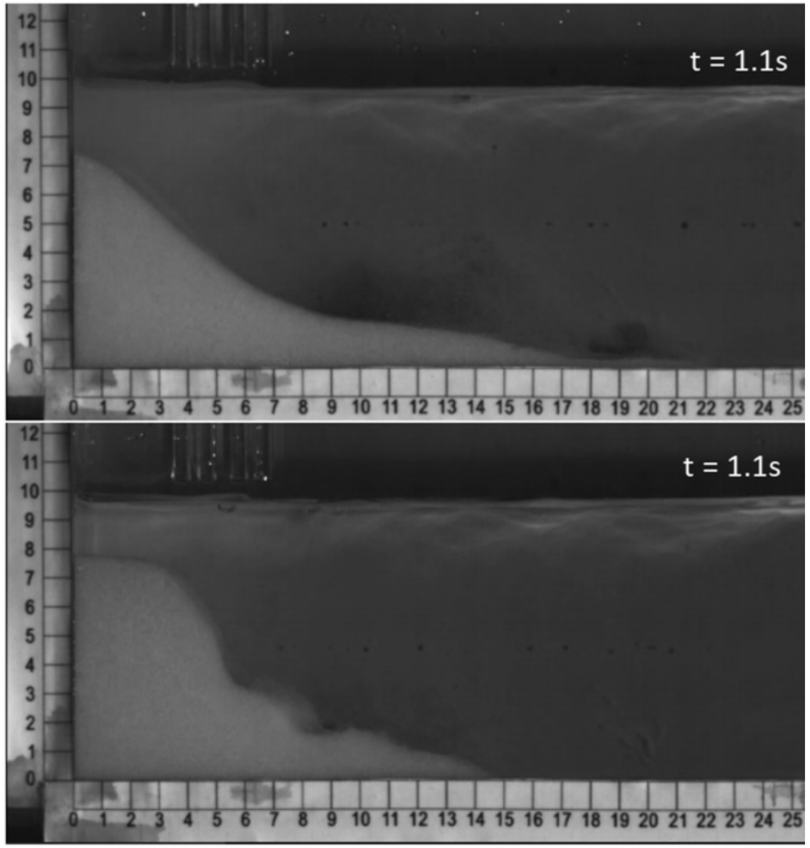
Submarine avalanches

Introduction——previous research

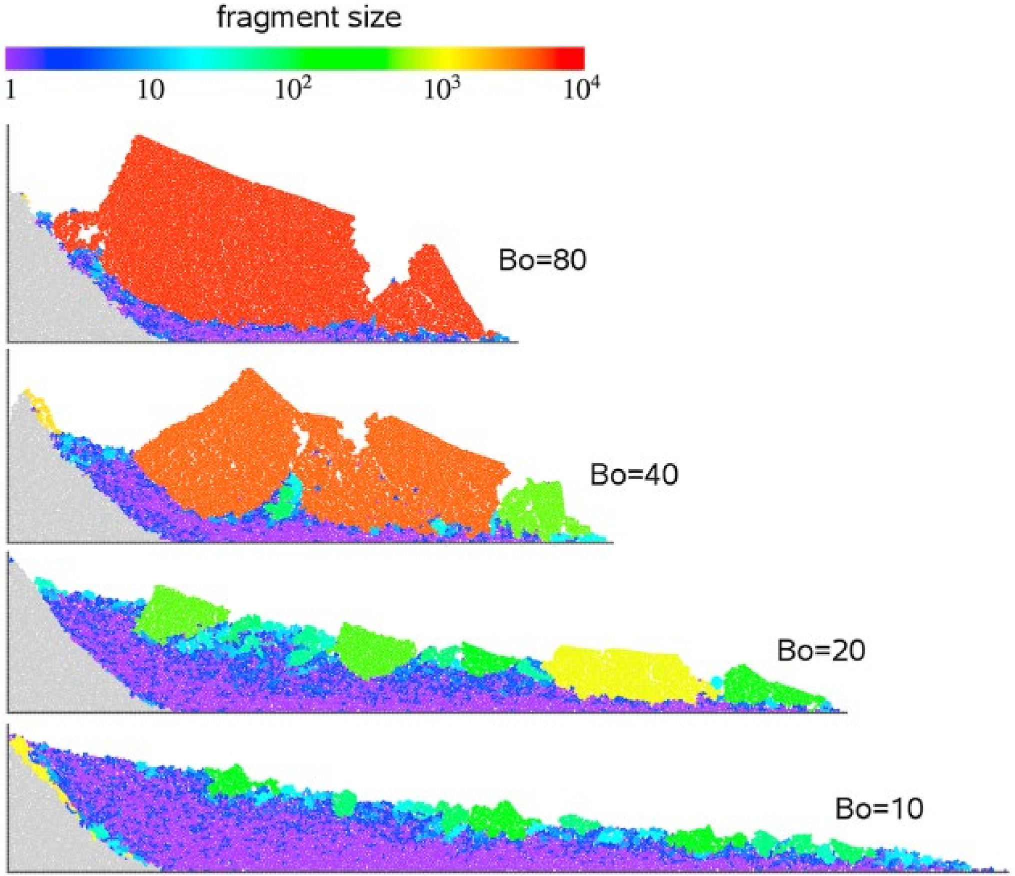
- Dry noncohesive granular collapse
- Submerged noncohesive granular collapse
- Dry cohesive granular collapse
- Submerged cohesive granular collapse ?



Balmforth & Kerswell 2005

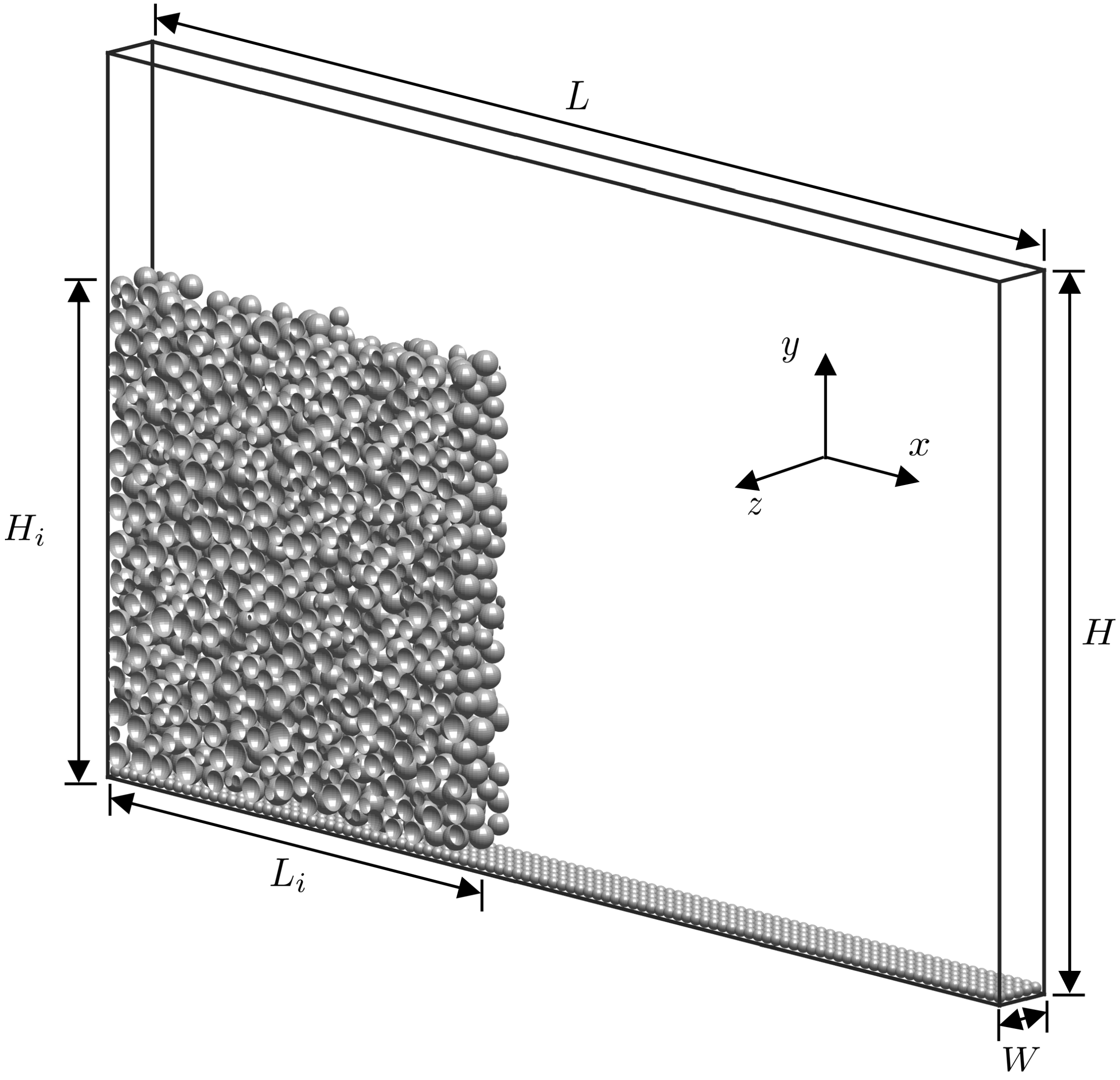


Wang et al. 2017



Langlois et al. 2015

Computational model——initial set-up



1. Aspect ratios of the initial column:

$$a = \frac{H_i}{L_i}$$

2. Cohesive numbers:

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

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:**

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

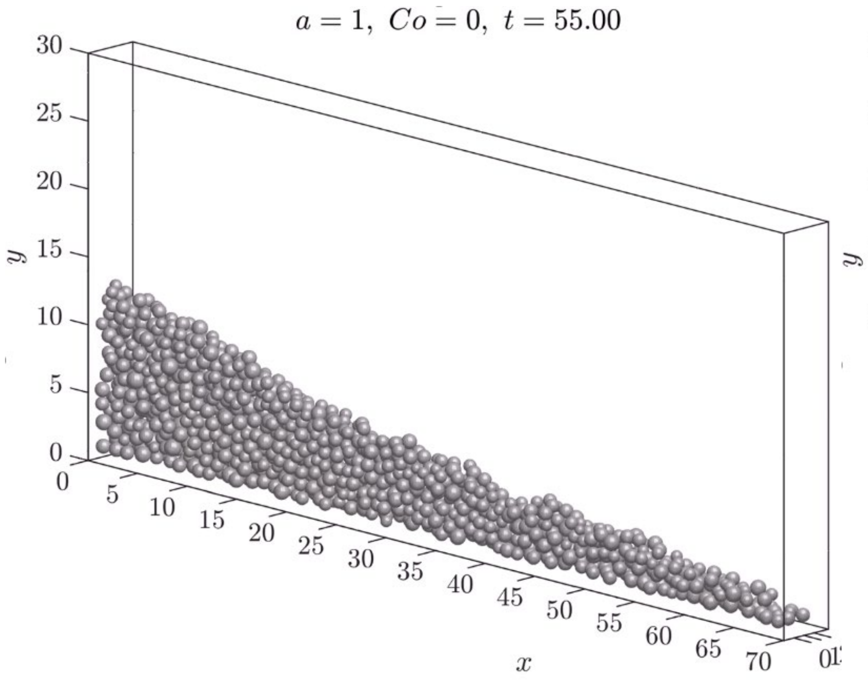
- **Angular velocity:**

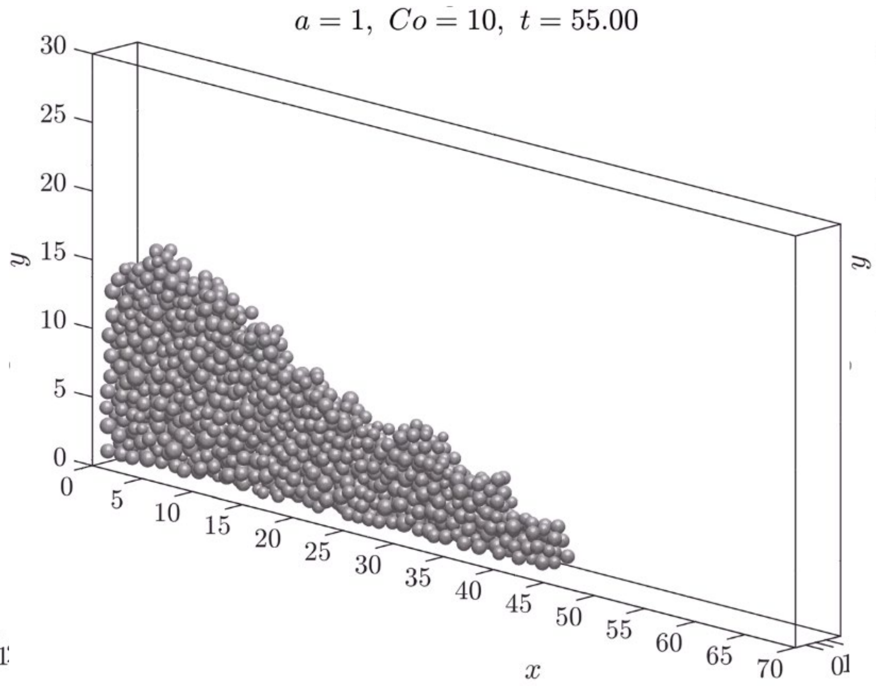
$$I_p \frac{\mathrm{d}\boldsymbol{\omega}_p}{\mathrm{d}t} = \boldsymbol{T}_{h,p} + \boldsymbol{T}_{c,p},$$

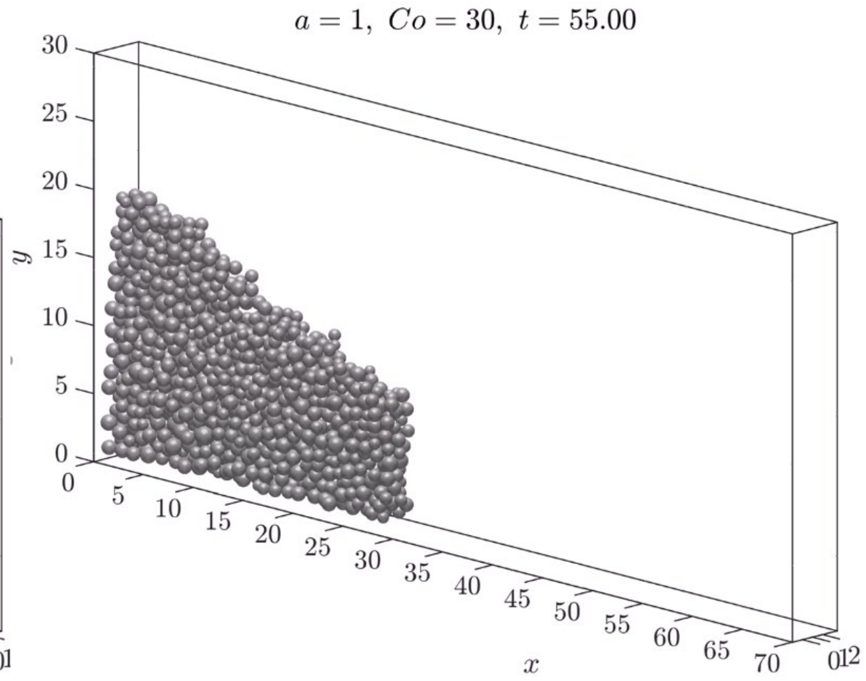
- **$F_{c,p}$: the force due to particle collisions:**

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

Observations —— shallow columns







For *Co*=0:

1. The particles near the upper right part slide down along an inclined shear surface.

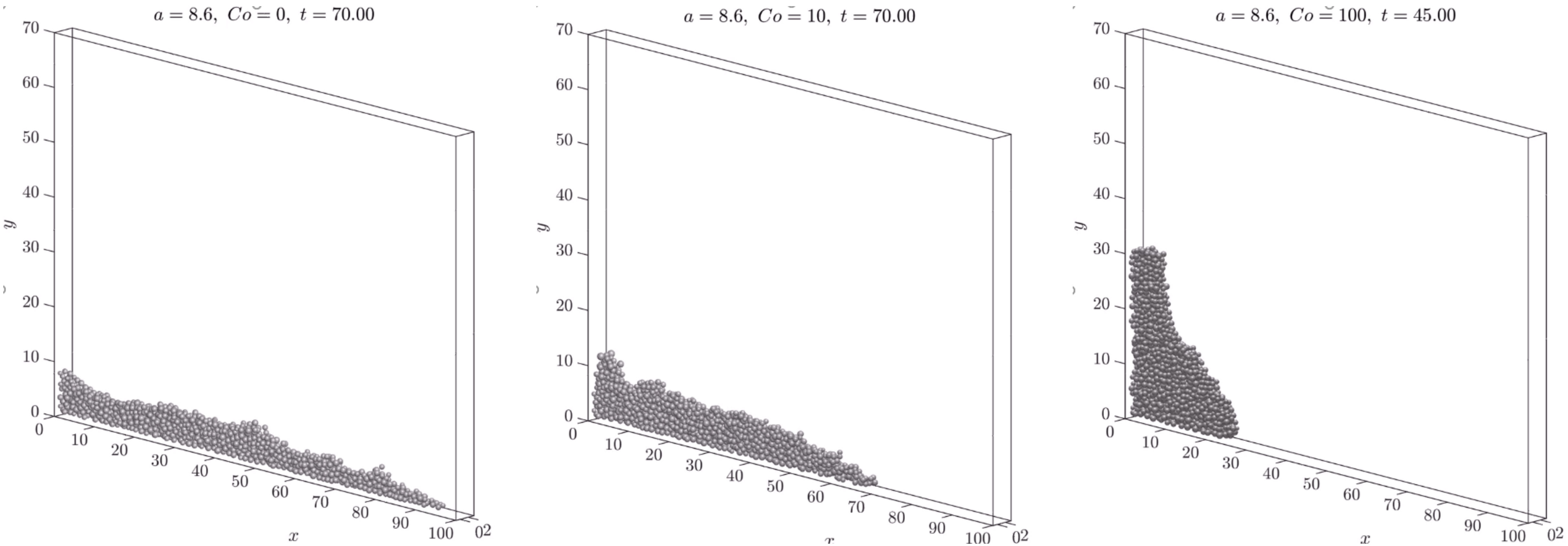
2. The counterflow detaches some particles from the main body.

3. The final deposit exhibits a triangular shape.

For *Co*=10 and 30:

Particles spread slower. No particles are detached. The final deposit is shorter and thicker.

Observations —— tall columns



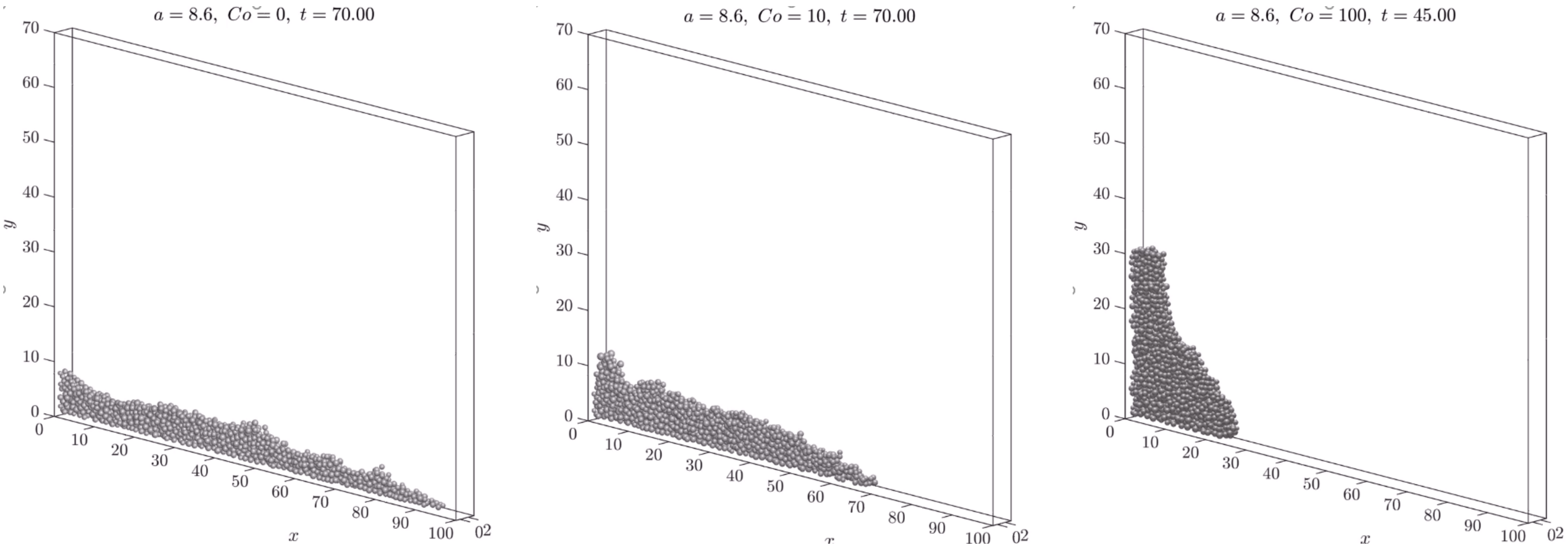
For *Co*=0:

1. The upper section freely falls in the early stage.

2. Most of the lower section moves to the right and forms a flow head.

3. Many particles are detached from the collapsing column. They settle more slowly.

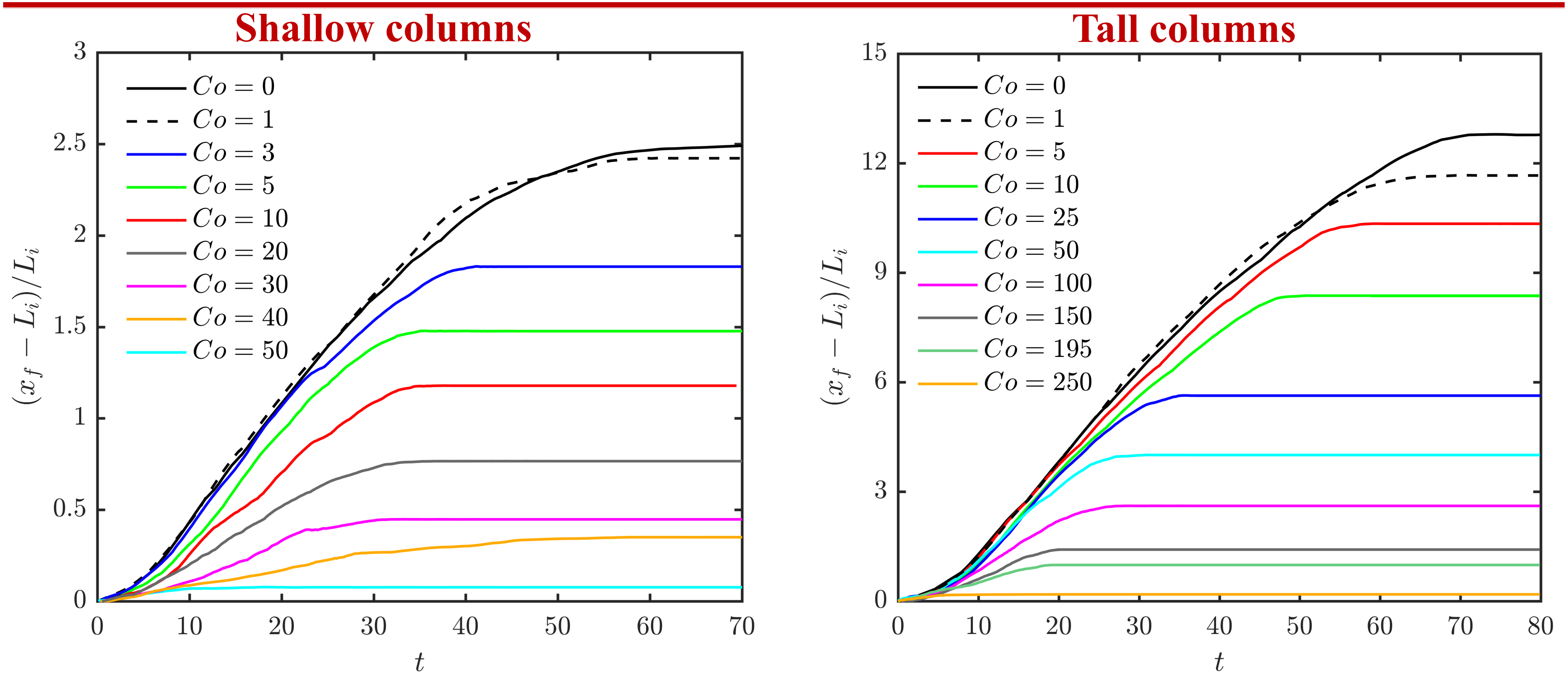
Observations —— tall columns



For *Co*=10 and 100:

1. Spreading slower and shorter runout distance.
2. The cohesive force prevents the detachment of individual particles from the collapsing column.
3. When *Co*=100 the cohesive force slows down the horizontal spreading of the particles near the bottom.

Front location

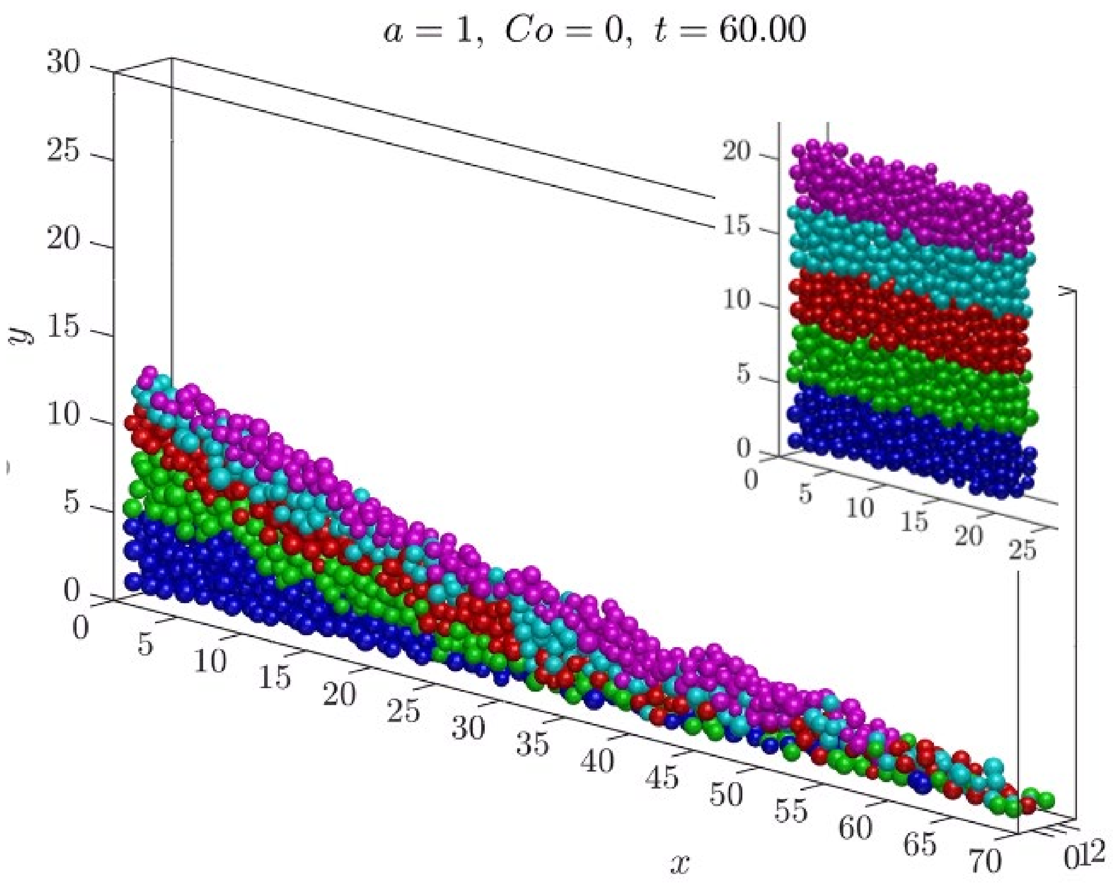


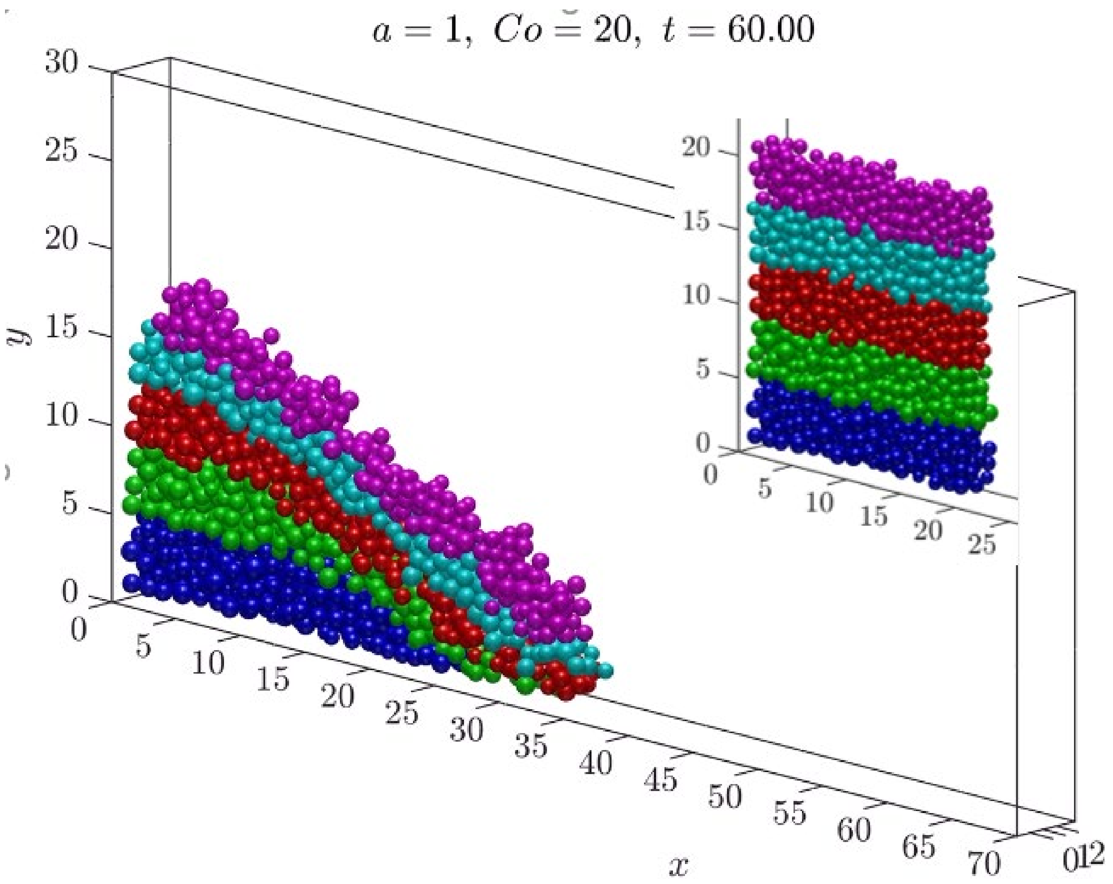
Acceleration stage → **Constant front velocity stage** → **Deceleration stage** (Meruane et al. 2010; Lee et al. 2018)

1. The **front location** decreases with increasing the ***cohesive numbers Co***.

2. The **shallow and tall columns** no longer collapse for **Co=50** and **250**, respectively.

Internal structure of the deposit





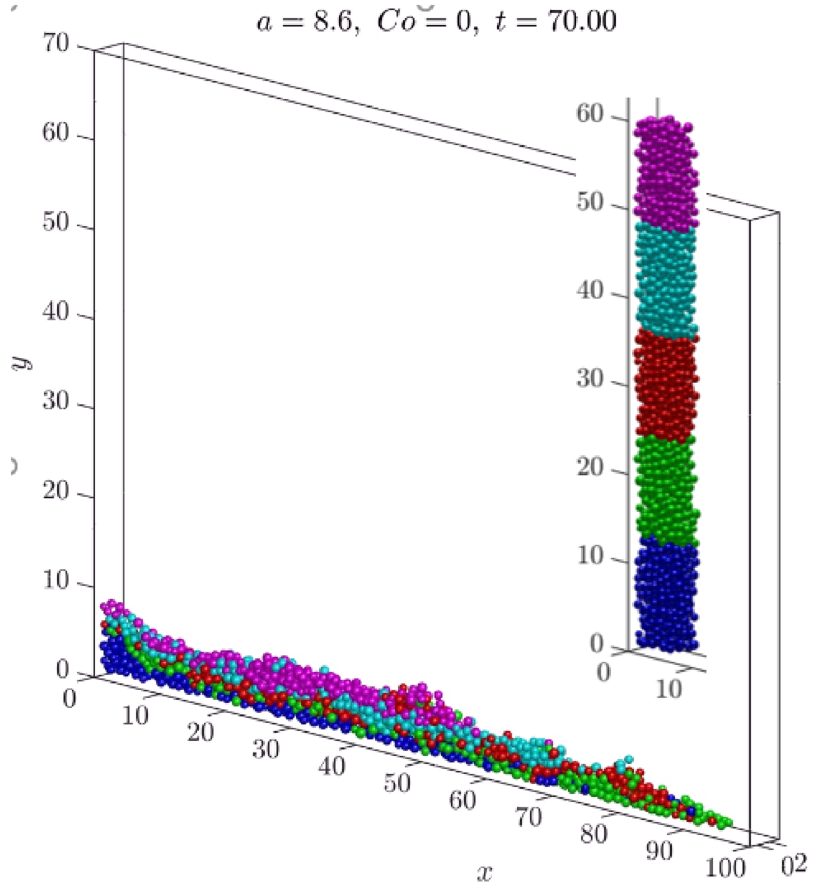
For *Co*=0 and 20:

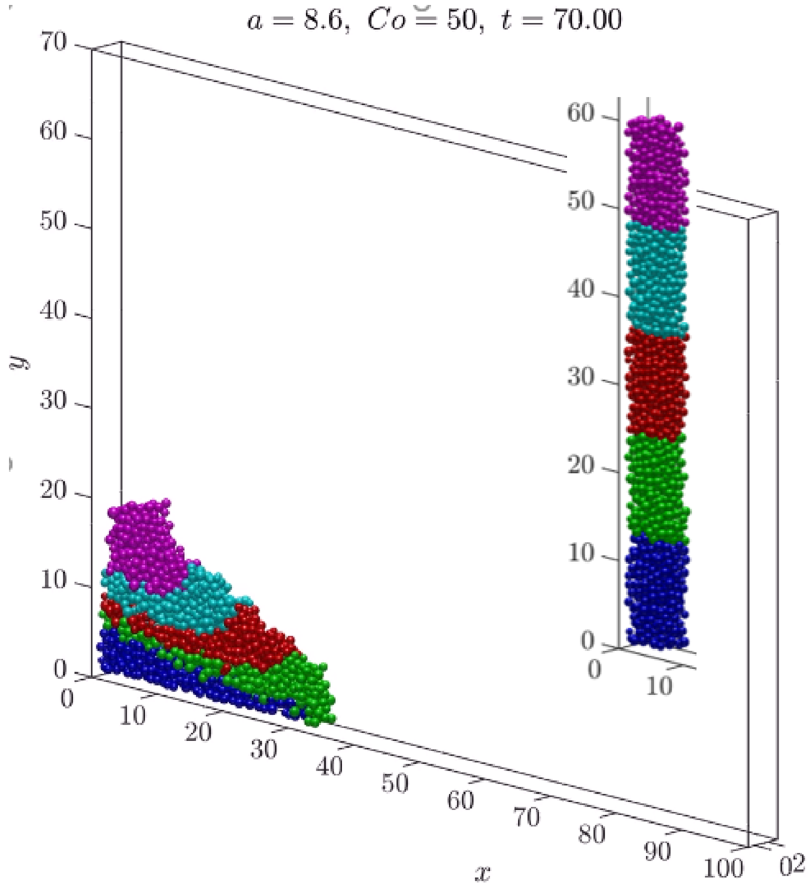
1.The layers stay mostly intact towards the left of the final deposit.

2. There tends to be more mixing towards the tip of the deposit on the right.

3. The particles that travel the farthest are mostly from the second and third-highest layers.

Internal structure of the deposit





The particles that travel the farthest now originate in the second layer from the bottom.

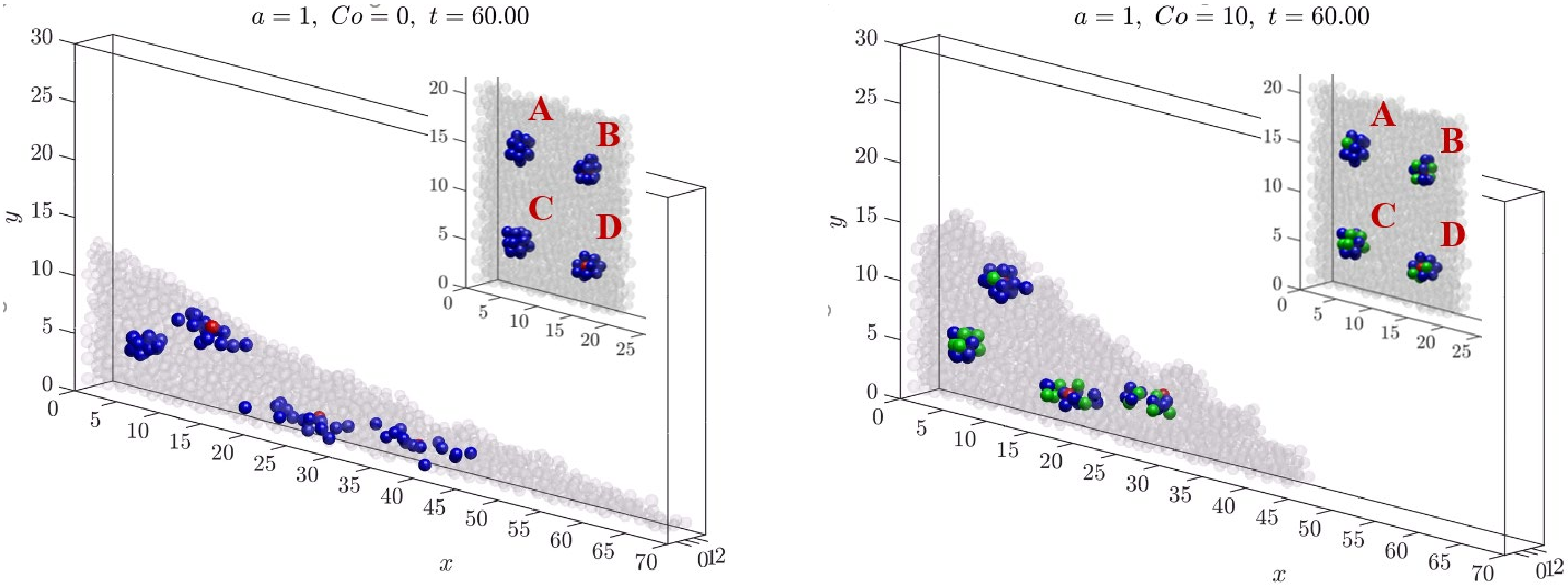
For $Co = 0$:

There is more pronounced mixing between the layers.

For Co = 50:

The layers tend to retain their identities.

Formation and persistence of flocs in the interior of the granular collapse



For *Co*=0 and 20:

Particles **A** and **C** and their neighbors travel a relatively **short distance**.

Particles **A** and **C** **remain close** to their initial neighbors.

Particles **B** and **D** travel much **larger distances**.

The **neighbors** of particles **B** and **D** become much **more separated** from each other for Co = 0 as compared to Co = 10.

Conclusions

1. The **cohesive force** acts to **prevent the detachment** of individual particles from the main body of the collapsing column, **reduce** its **front velocity**, and yield a **shorter** and **thicker** **final deposit**.

2. Computational particle tracking indicates that the **cohesive force reduces** the **mixing** of particles within the collapsing column, and it results in the **formation** and **persistence** of **flocs**

Thanks!