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A multiscale approach for cohesive and unsaturated soils as a constitutive model designed for FLAC3D

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Plan

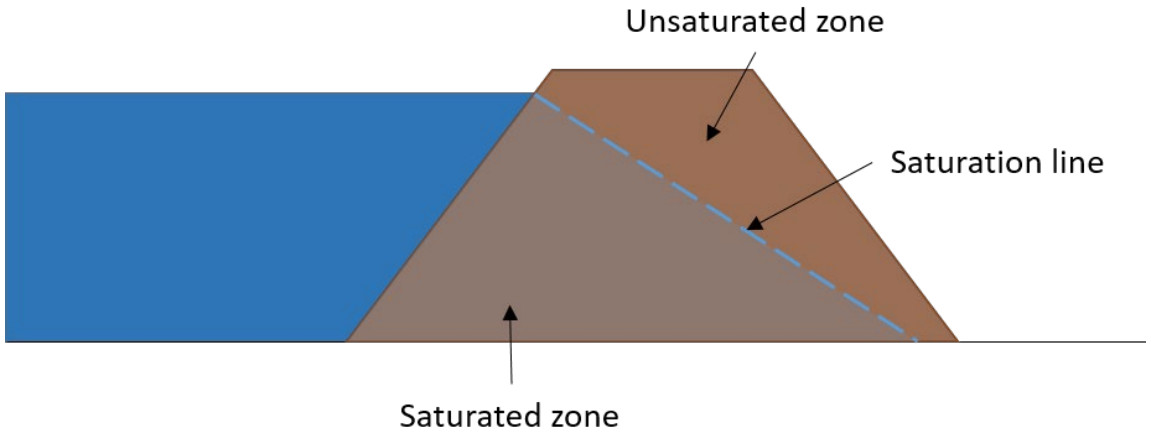
- Introduction
- H-microdirectional model
  - Principle
  - Mescoscale
  - REV scale
- Capillary forces in H-model
- Conclusion and outlooks

Introduction

Context

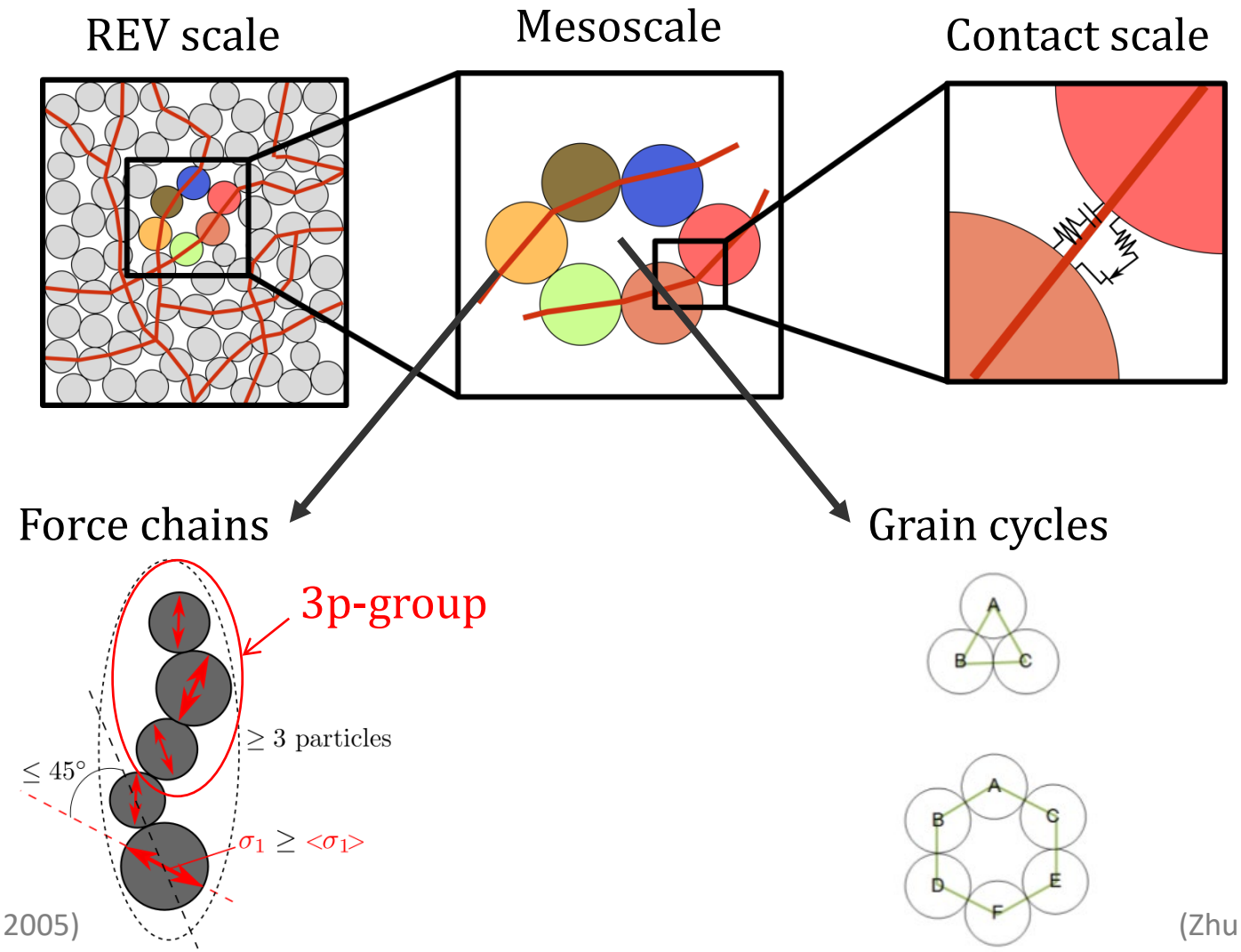
- 9000km of dykes in France
- Use of soil material present on site
- Unsaturated zones
- Hazards (earthquakes, floods)

Teton dam failure, Eunice Olson, 06/05/1976



Tailing dam failure in Brumadinho, Brazil, 25/01/2019

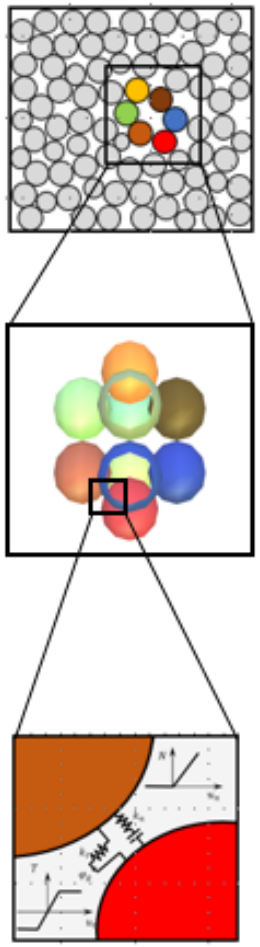
Imbricated scales in granular materials

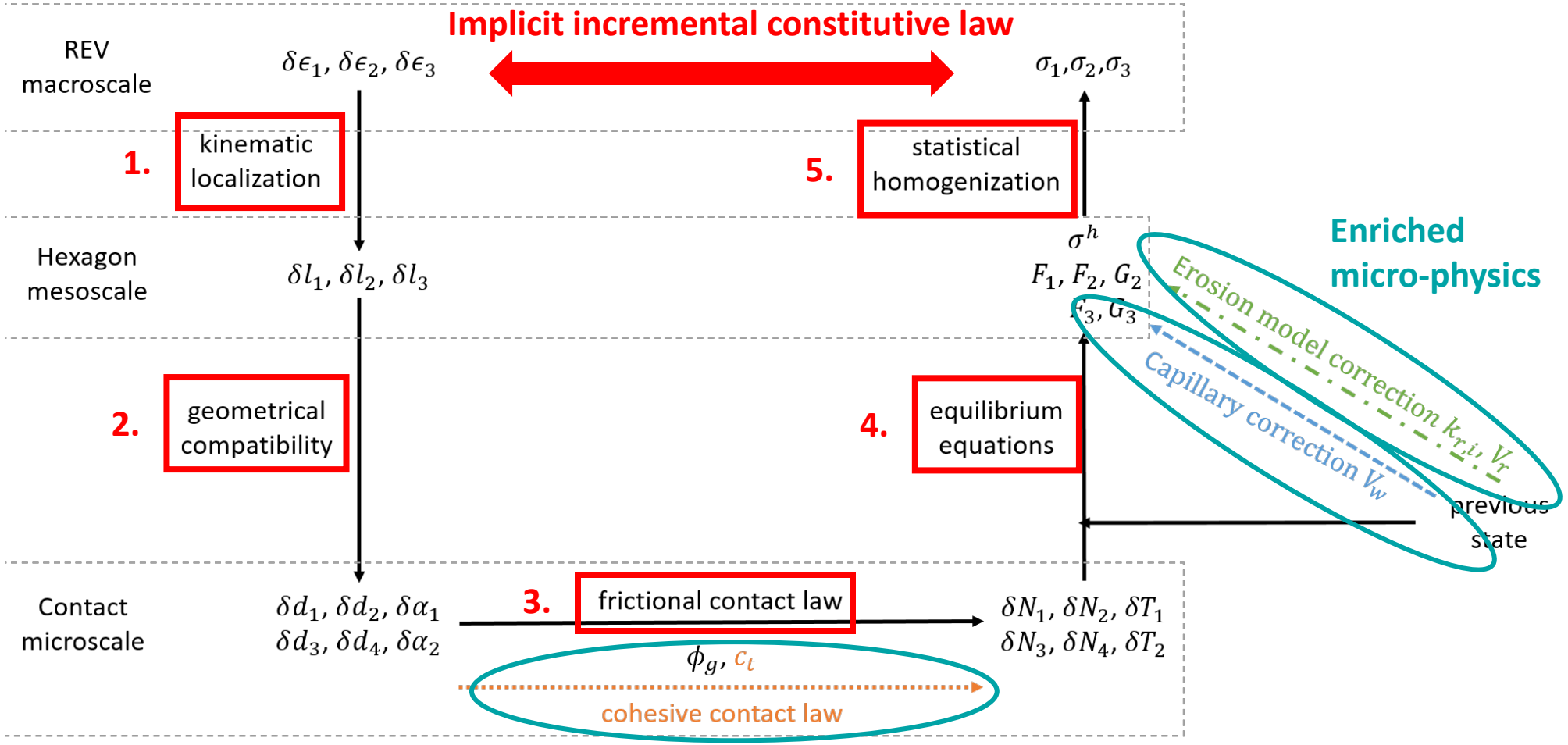


(Peters et al. 2005)

(Zhu et al. 2016)

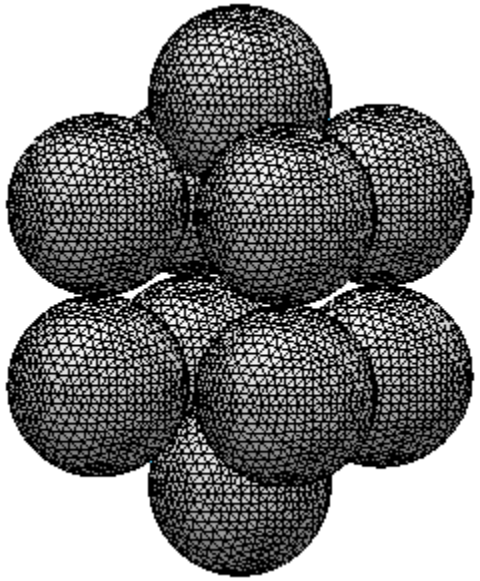
H-microdirectional model





H-microdirectional model

Hexagonal cell at mesoscale

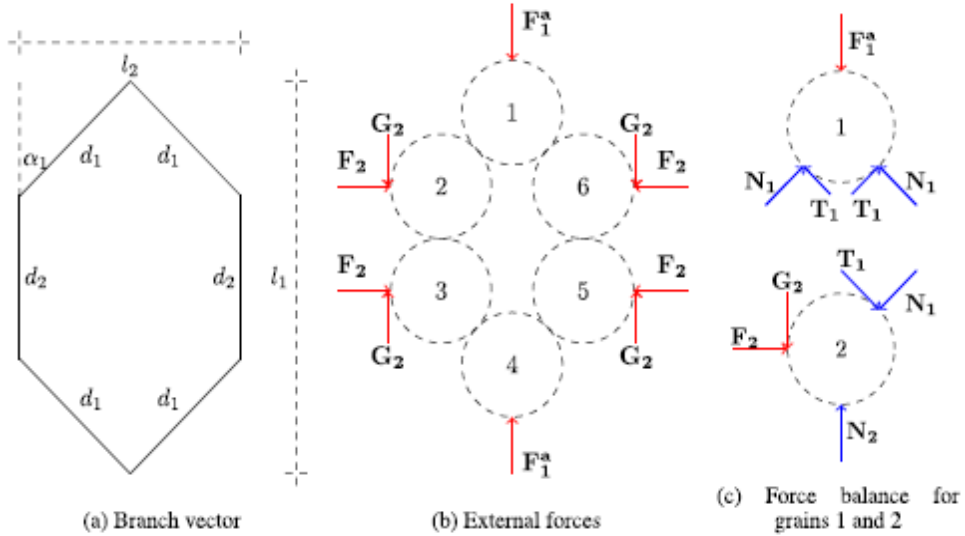


6 geometrical variables in 3D:

- 2 opening angles α_1 and α_2
- 4 intergranular distances d_i

Assumptions:

- 10 spherical grains
- Same radii
- Centres of the grains forming two orthogonal hexagons
- Three planes of symmetry for both the geometry and the external forces
- No grain rotations

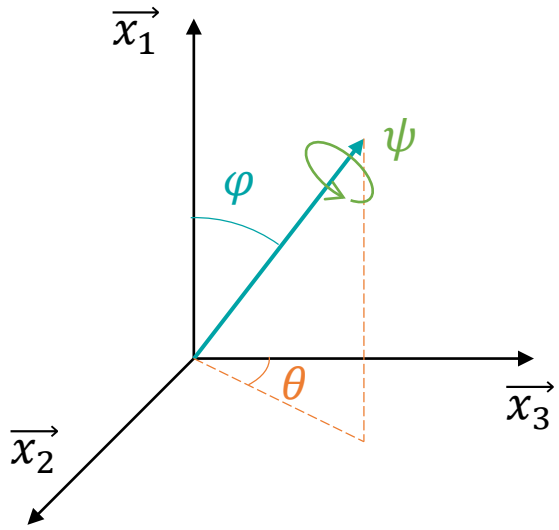


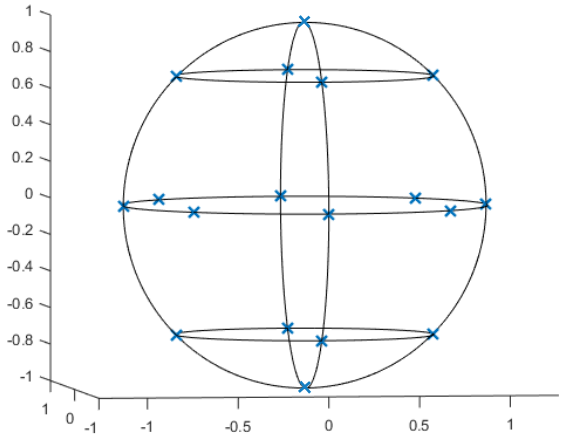
(a) Branch vector (b) External forces (c) Force balance for grains 1 and 2

[Xiong et al., 2017]

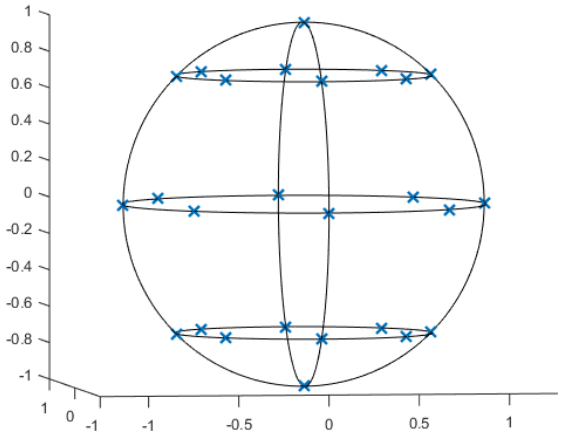
H-microdirectional model: statistical homogenization

Orientations distributions





Isotropic distribution



Anisotropic distribution

H-model advantages

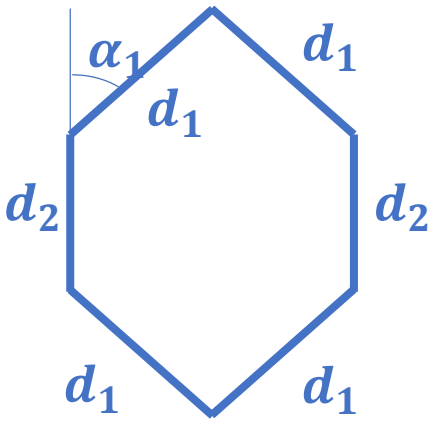
- Analytical model
- Take the microstructure into account
- Very few parameters in entry
  - k_n and k_t
  - α_0 or e_0
  - Orientation distribution (3 parameters for an isotropic distribution)
- Faster than DEM

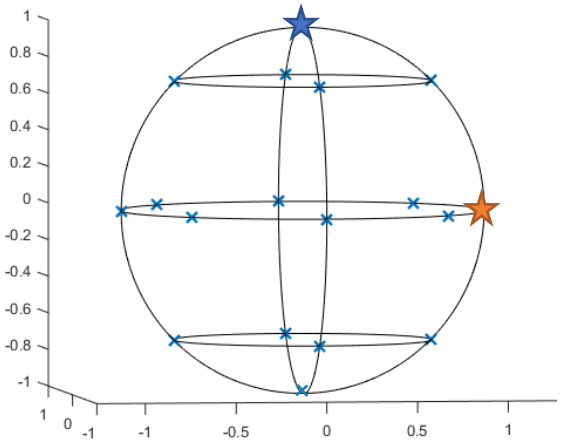
Mechanical behaviour at mesoscale

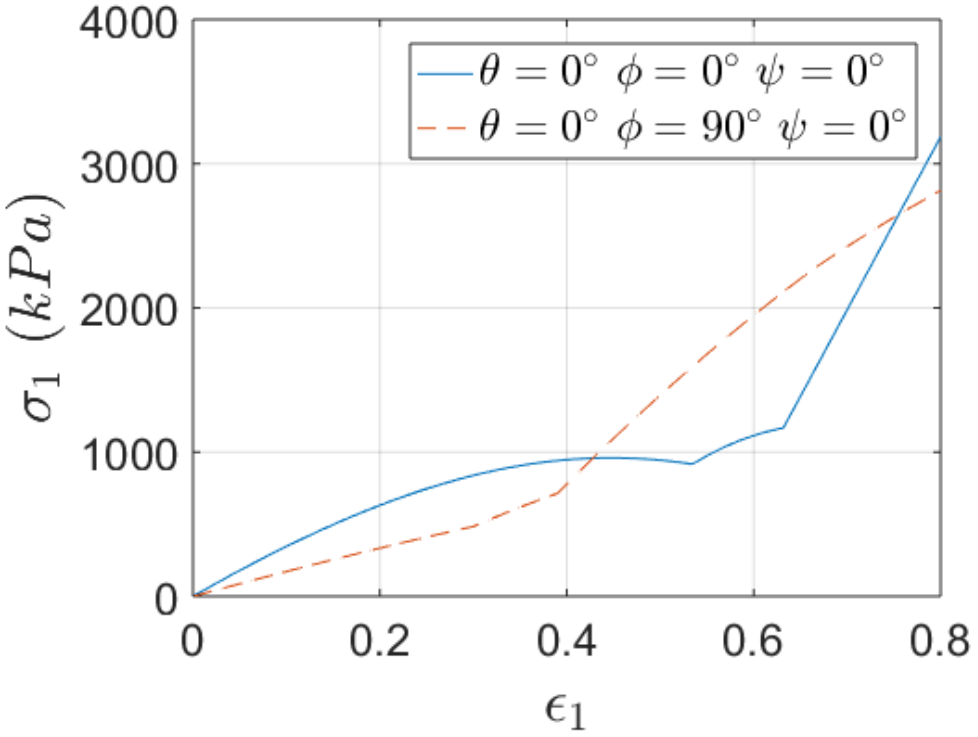
Oedometer test:

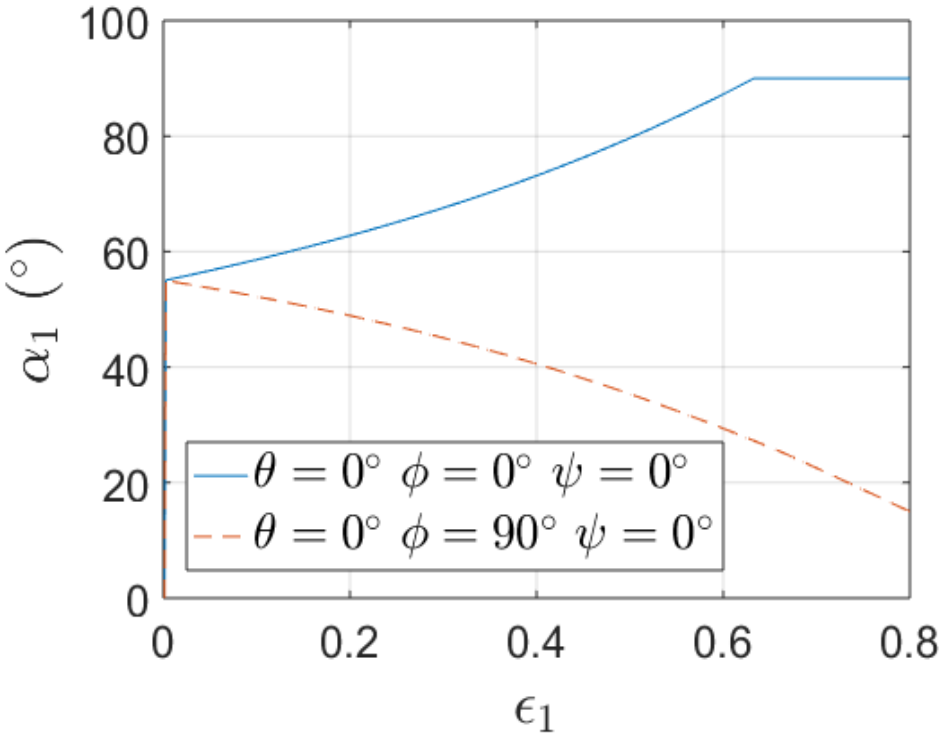
$\dot{\epsilon_1} = cst$ $\quad k_n = 5\ 10^6 N/m$

$\dot{\epsilon_2} = \dot{\epsilon_3} = 0$ $\quad k_t = 2.5\ 10^6 N/m$



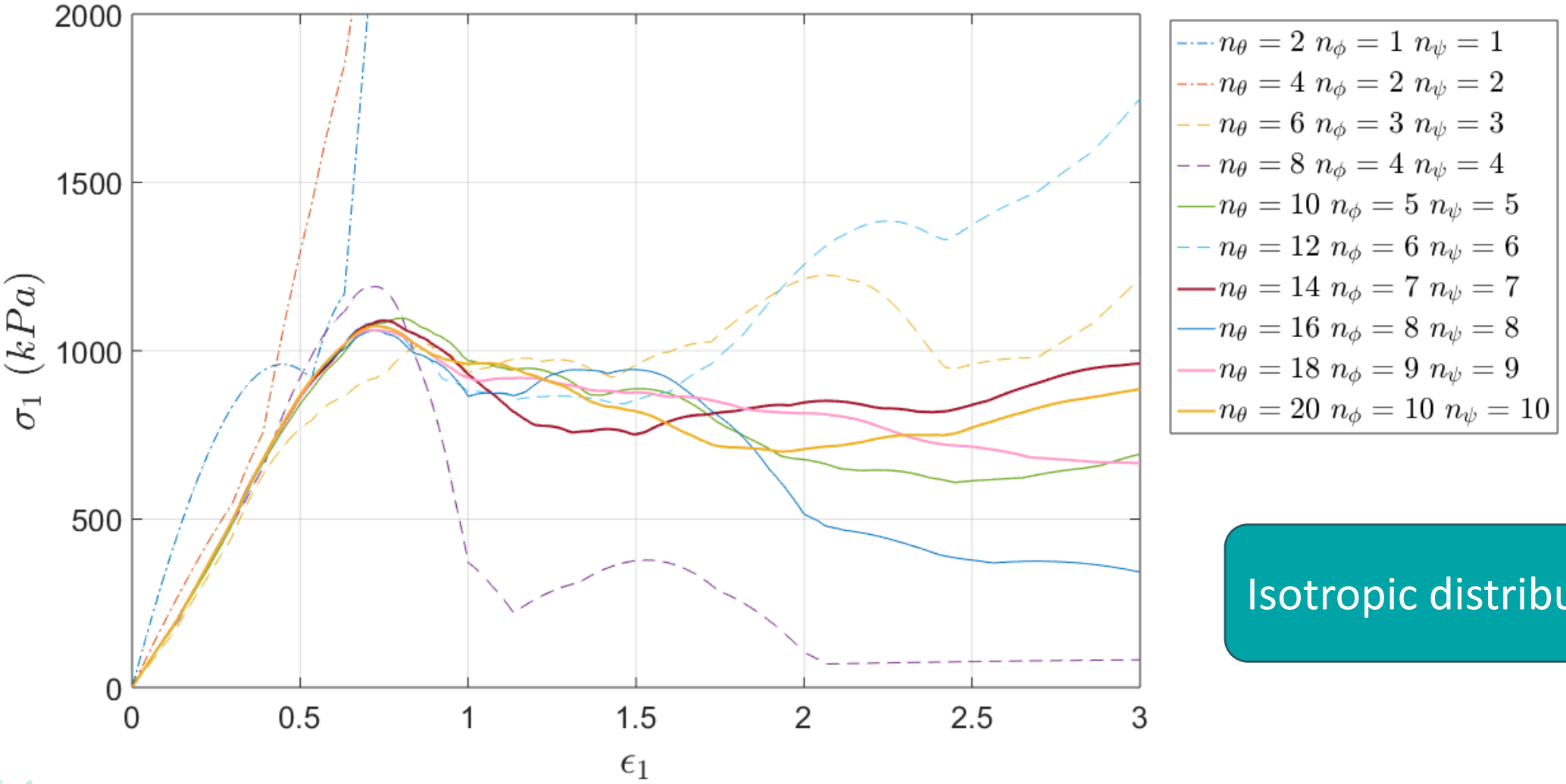






Mechanical behaviour at the REV scale

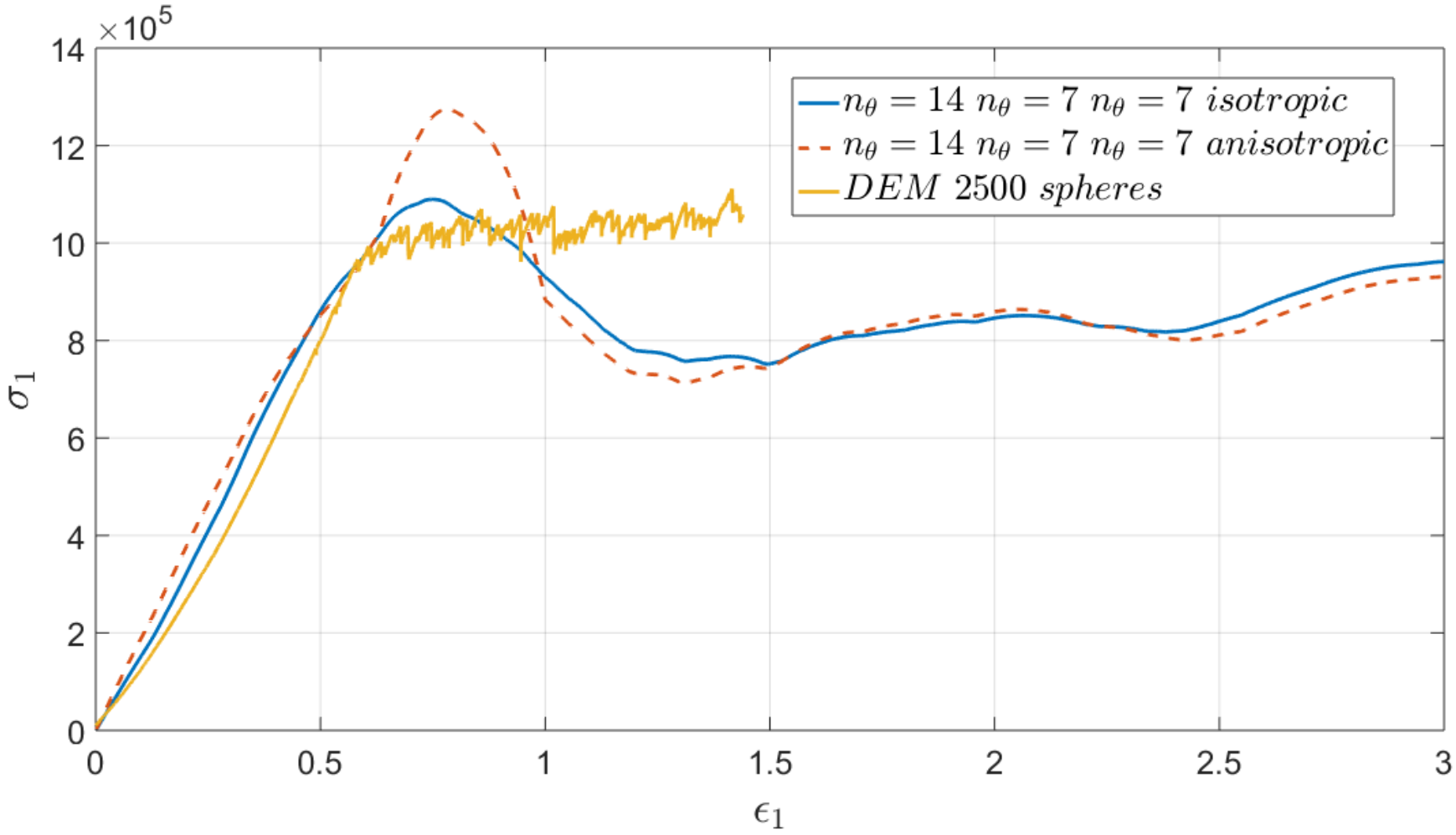
Oedometer test – Impact of the discretisation of the distribution



Isotropic distributions

Mechanical behaviour at the scale of the REV

Oedometric test – Impact of the distribution and comparison with DEM



DEM:
2500 spheres
$k_n = 5 * 10^6 N/m$
(spheres and walls)

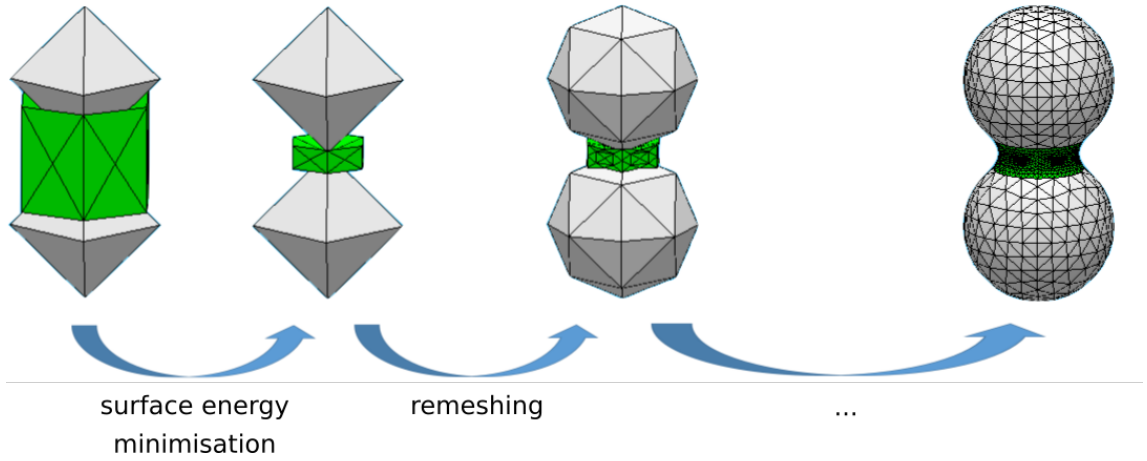
Capillary forces at mesoscale

Methodology

Objective:

Obtaining capillary forces in the cell depending on

- the opening angle of the cell
- the volume of water



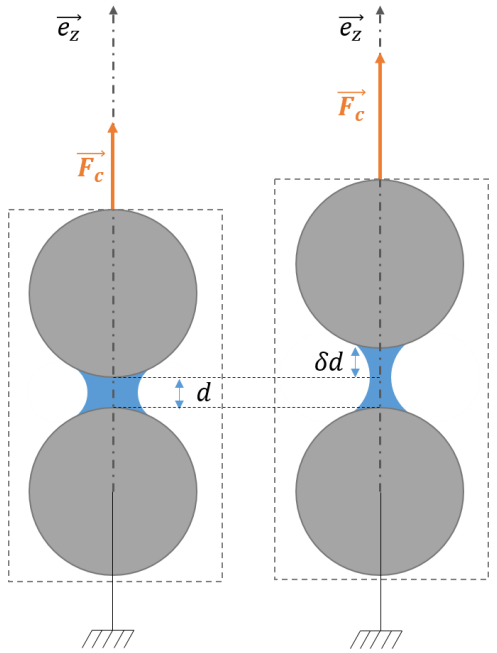
Method:

Using a surface energy minimization software:

- calculate the total energy of the water system
- deduce capillary forces from Virtual Work Principle:

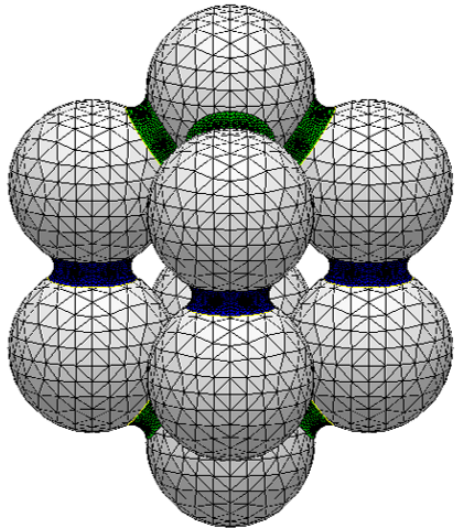
$$\delta W = \delta E_s + \delta E_{int} = \overrightarrow{F_c}.\delta\vec{d}$$

$$\overrightarrow{F_c}.\overrightarrow{e_z} = \frac{\delta E_s}{\delta\vec{d}.\overrightarrow{e_z}}$$

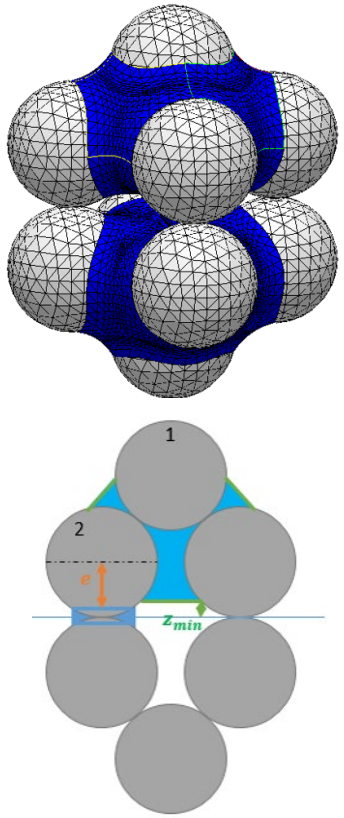


Capillary forces at mesoscale

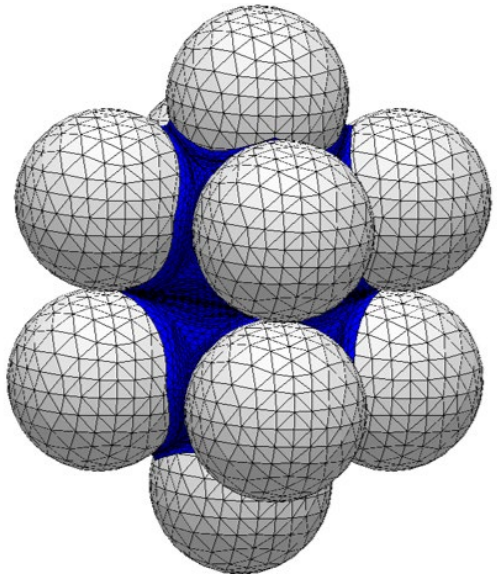
Capillary regimes



Volume ↗



Volume ↗



12 capillary bridges:

- 8 inclined bridges
- 4 vertical bridges

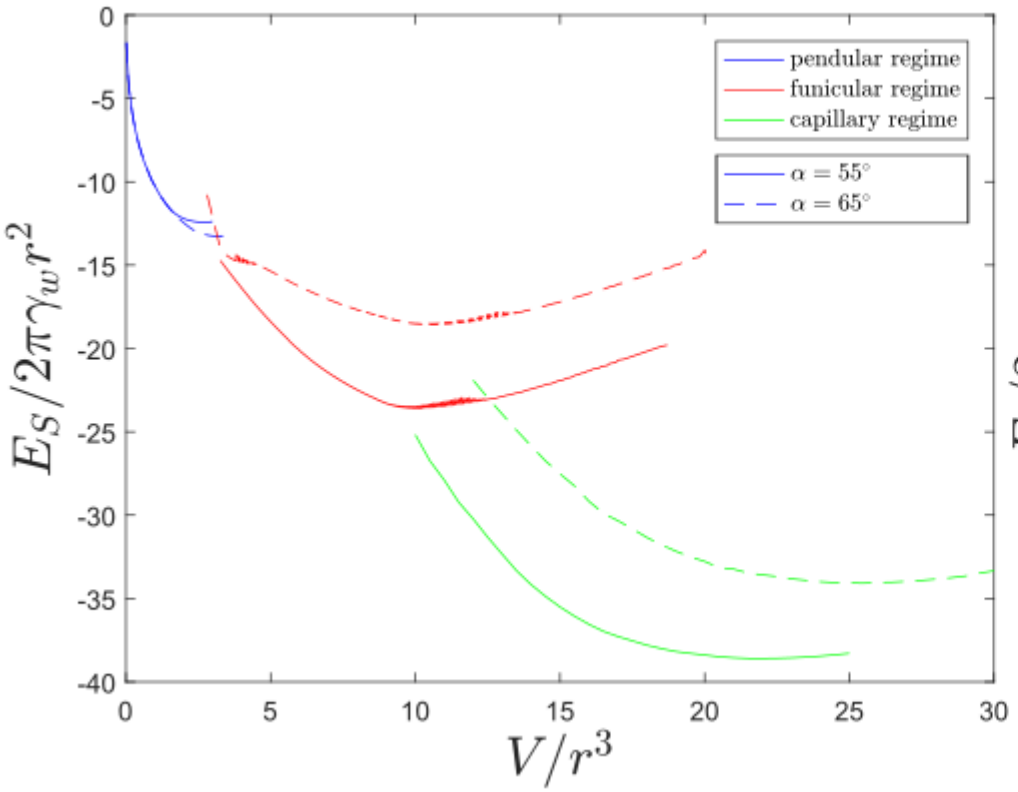
Merging of the inclined bridges:

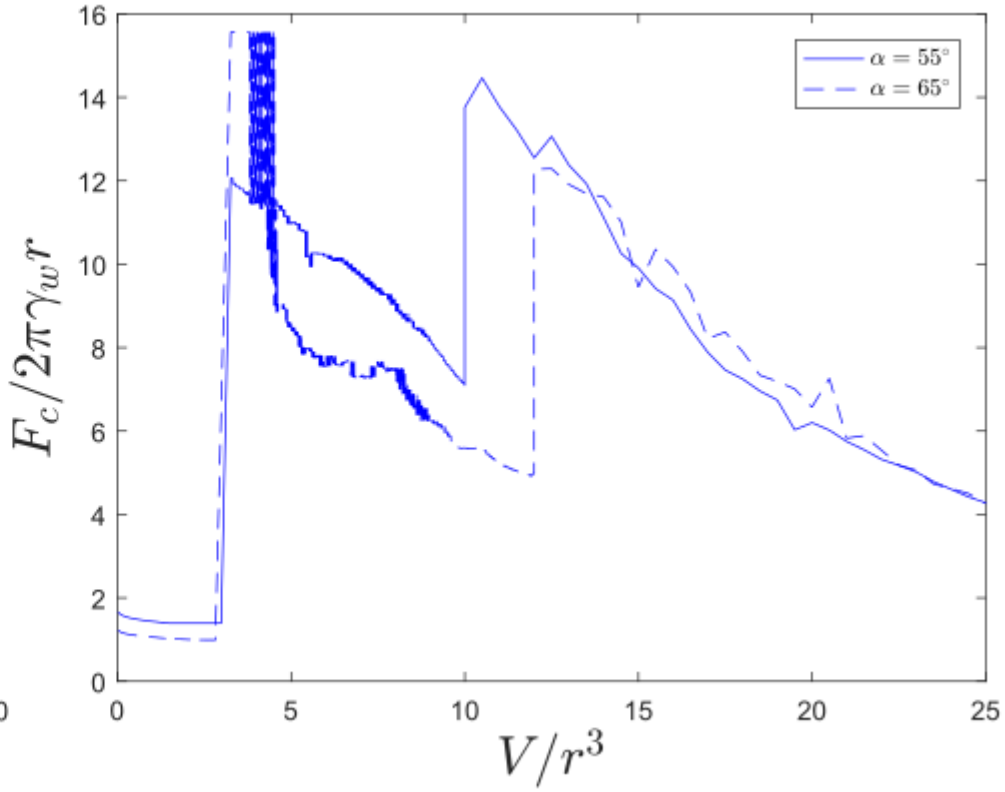
- 2 clusters in contact with 5 grains
- 4 vertical bridges

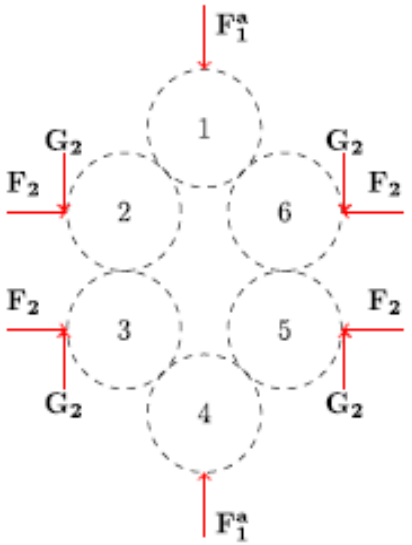
Merging of the clusters and the vertical bridges:

- 1 cluster in contact with 10 grains

Capillary forces at mesoscale







(b) External forces

Conclusions and outlooks

Conclusions

- Presentation of a multiscale constitutive model
  - At mesoscale, study of a 10 grains-hexagonal cell
  - Study of the impact of the distribution of orientations
  - Comparison with DEM
- Calculation of capillary forces at mesoscale for adding in the model

Outlooks

- Finalise the validation of the implementation of the 3D-H model under FLAC
- Implementing capillary forces into the model
- Introducing rattlers in the model in order to implement an erosion model