ALERT GEOMATERIALS

Microstructural interpretation of instabilities in granular media

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Motivation and context

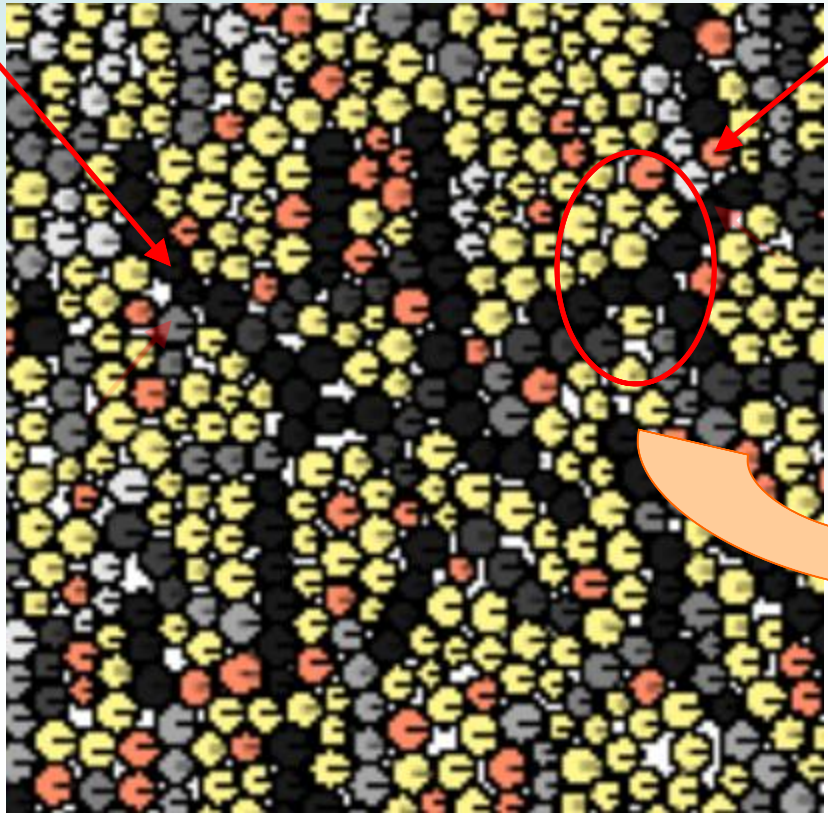
- What is the microstructural origin(s) of mechanical strength / instability in granular materials?
- Could we identify elementary bodies (on a relevant scale) which control the macroscopic behavior?
- This relevant scale should be intermediate between the micro scale (contact scale) and the macro scale (specimen scale)
- The following investigation is carried out in 2D

Force chains – Grain cycles

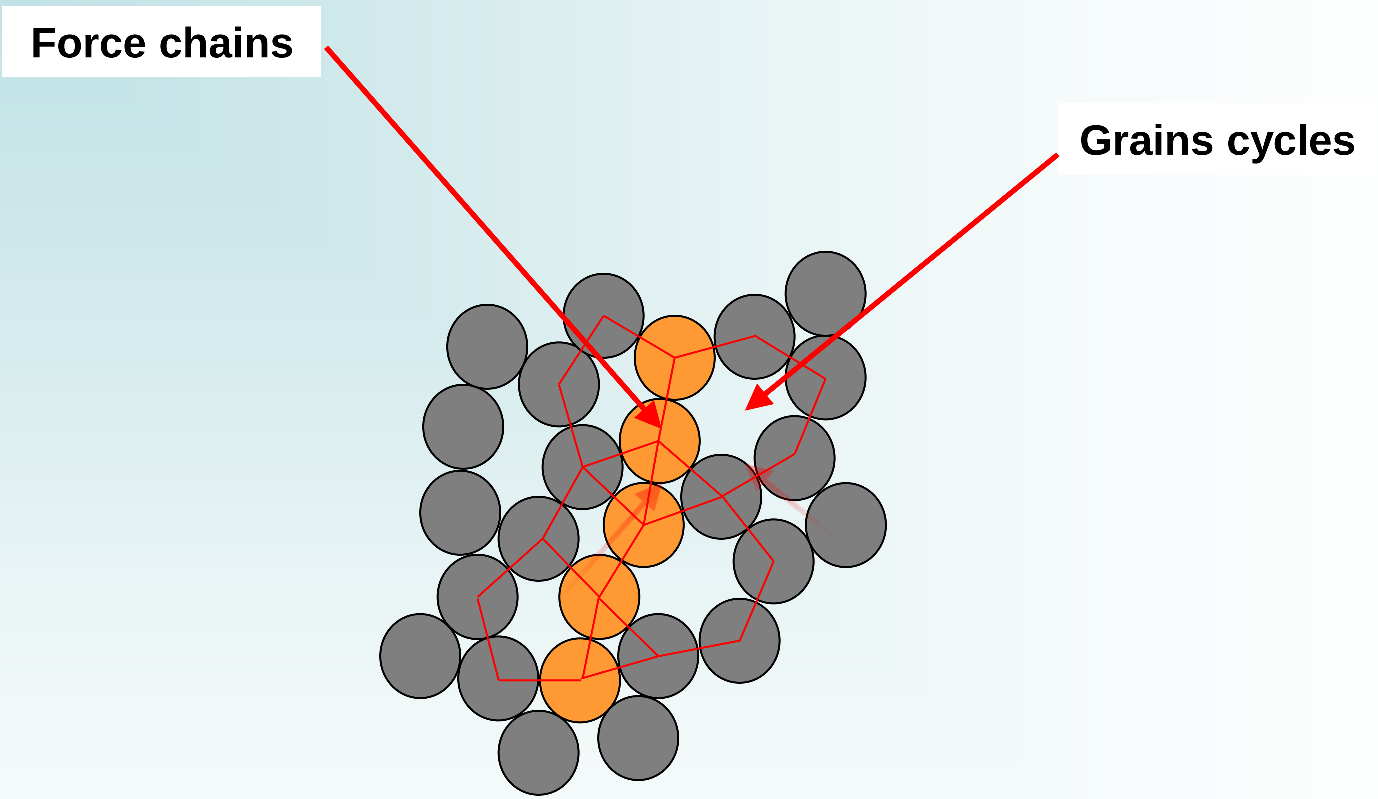
Static - Kinematic duality

Force chains

Grains cycles



Force chains – Grain cycles



Objectives

1. DEM (YADE code) simulation of a drained biaxial test, using dense to loose specimens

2. Trying to track the different sides of cycles (Loop-n) and force chains evolution along the loading path

3. Finding the link between the change in Loop-n and other mechanical properties

Cycles ⟺ force-chain

Cycles ⟺ localization

Cycles ⟺ volumetric behavior

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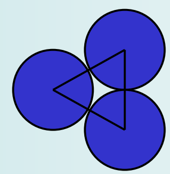
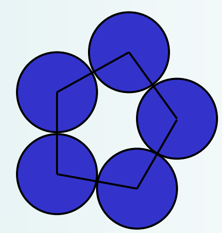
Definition

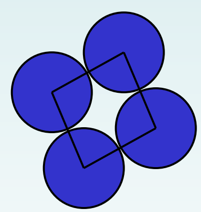
Cycle (or Loop) = A group of particles being closed to form a polygon by contacts with each other



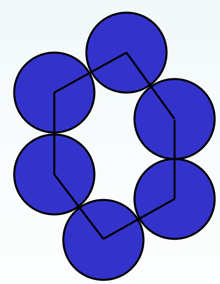
Loop-3



Loop-5



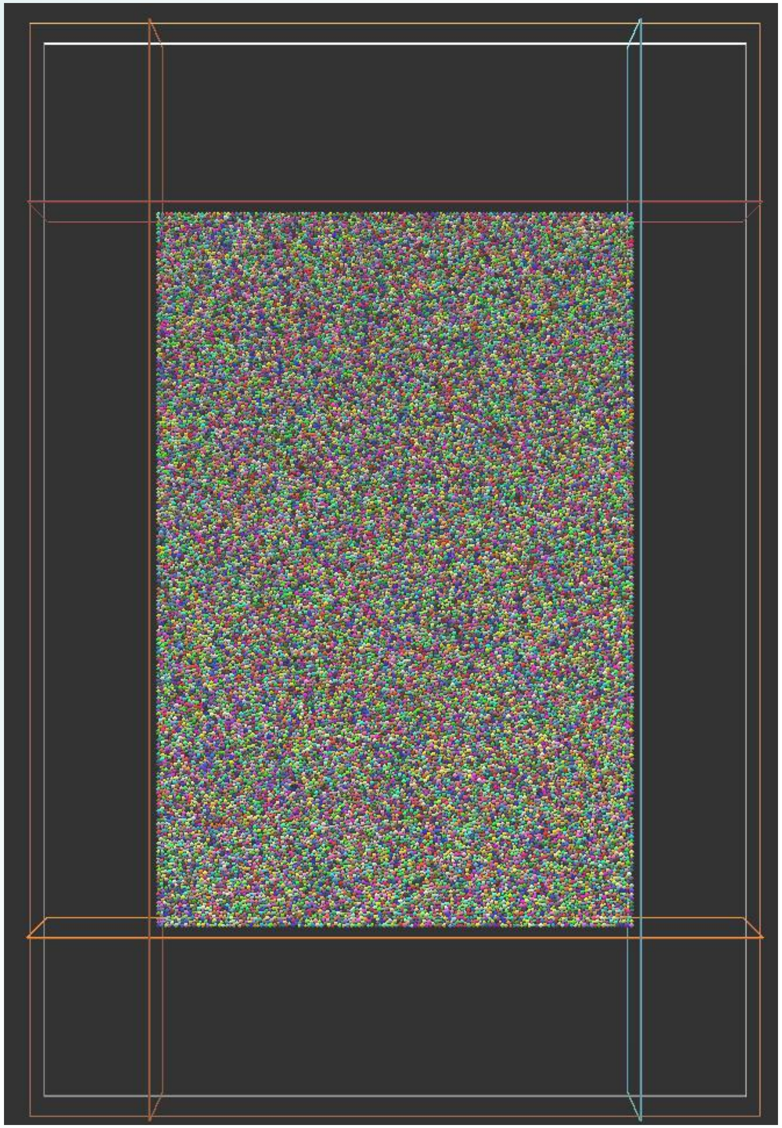
Loop-4



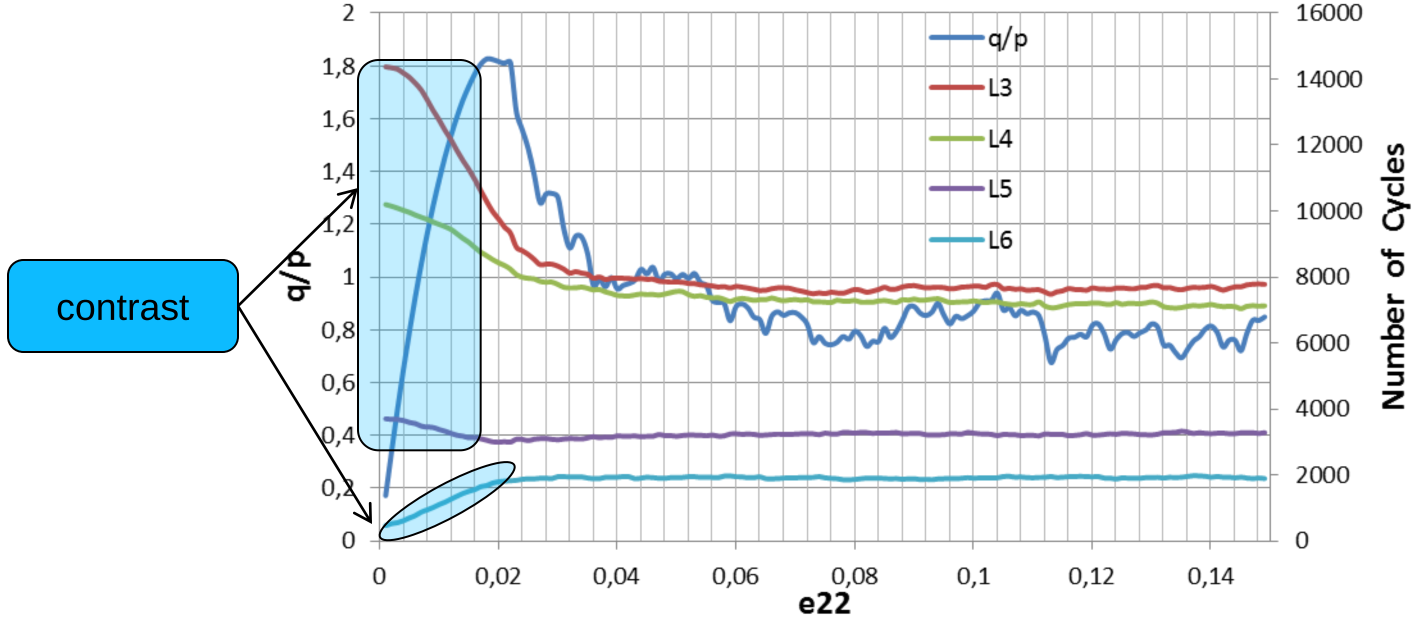
Loop-6

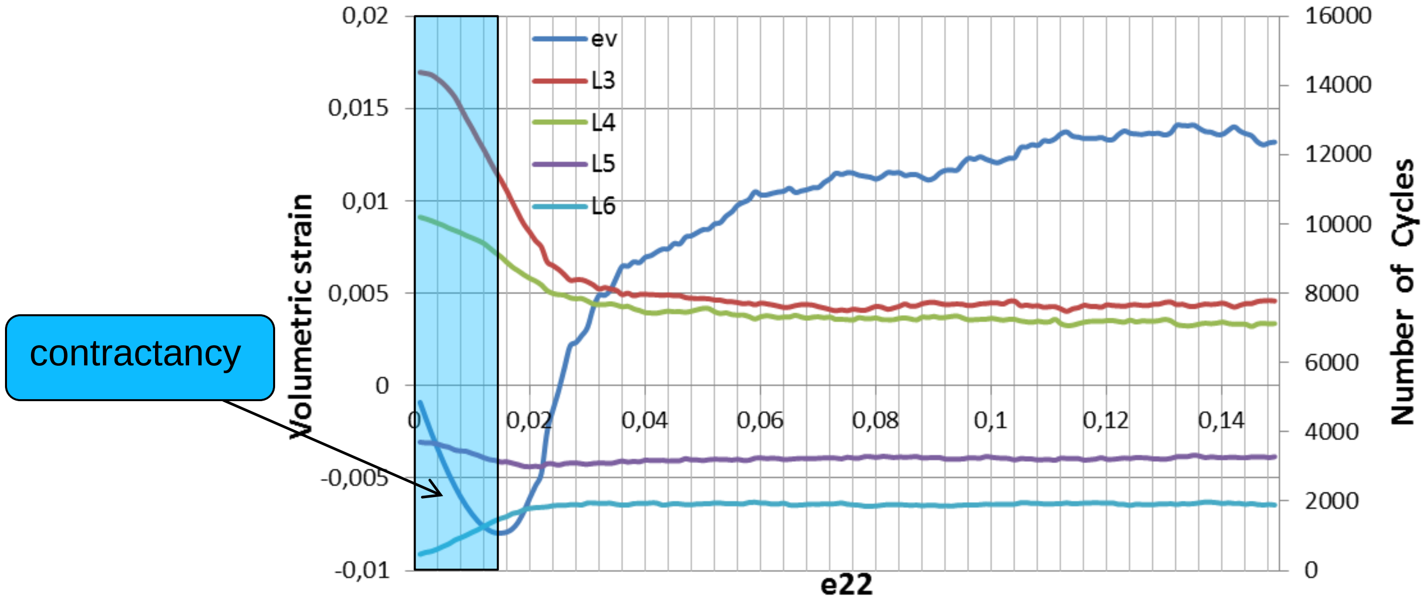
Model and parameters

Parameter	Value
Model size	0.90 m x 1.35 m
kn	5.0e9 N/m
kt/kn	1.0
Number of particles	25 000
Particle density	2 600.0 kg/m^3
Particle radius	2.70e-3 m - 4.49e-3 m
Inter particle friction	30.0°
Particle-wall friction	0.0°
Damping coefficient	0.1



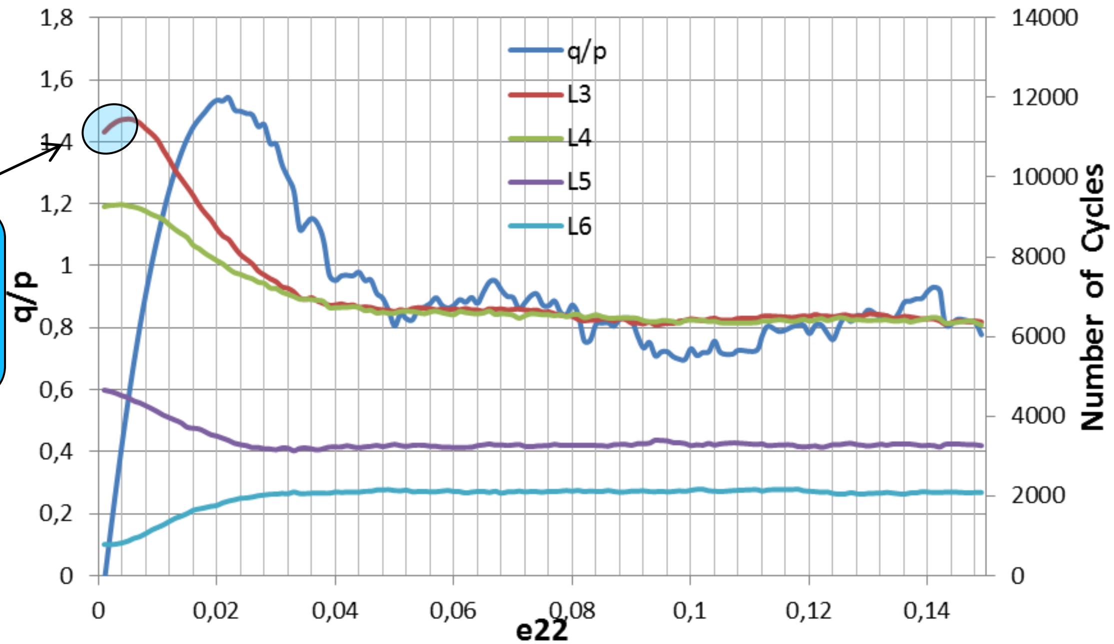
Initial porosity = 0.148 (densest specimen)   confining pressure = 100kPa

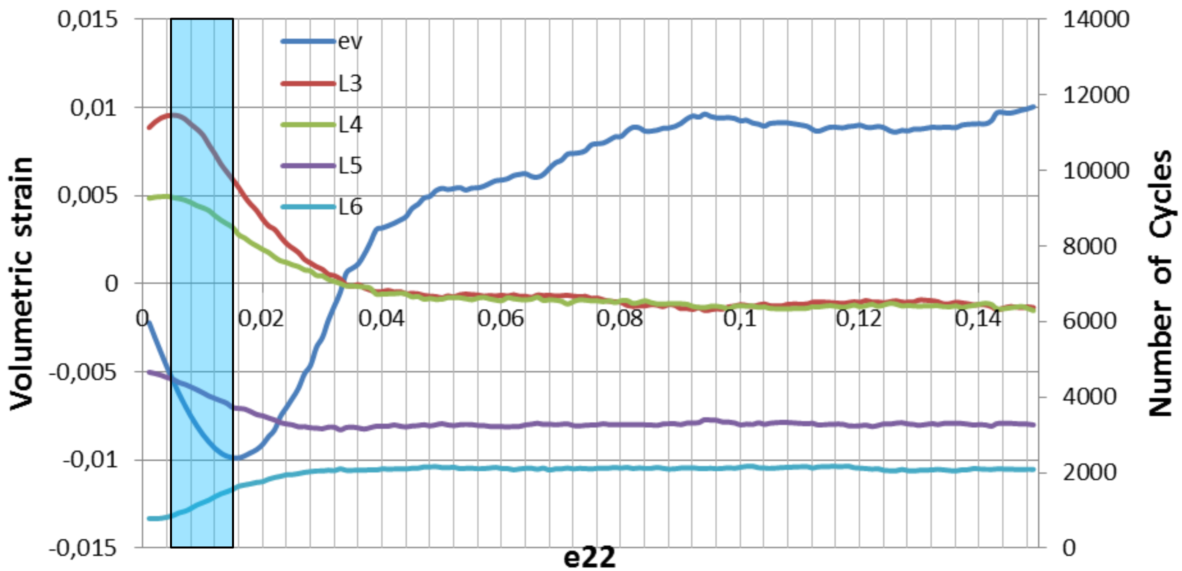




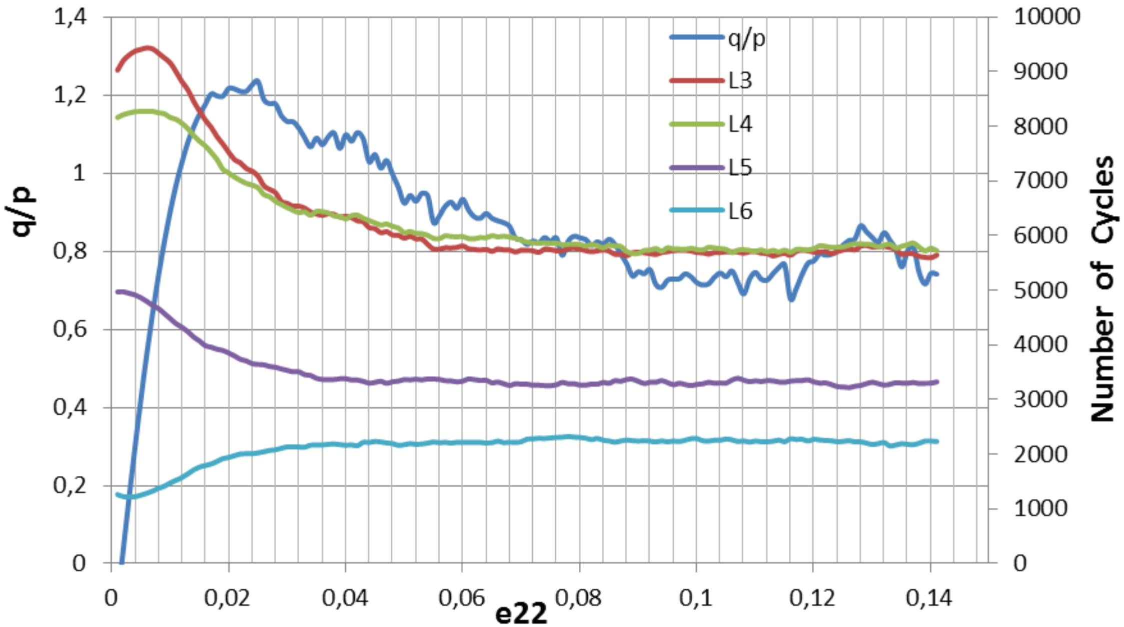
Initial porosity = 0.161 confining pressure = 100kPa

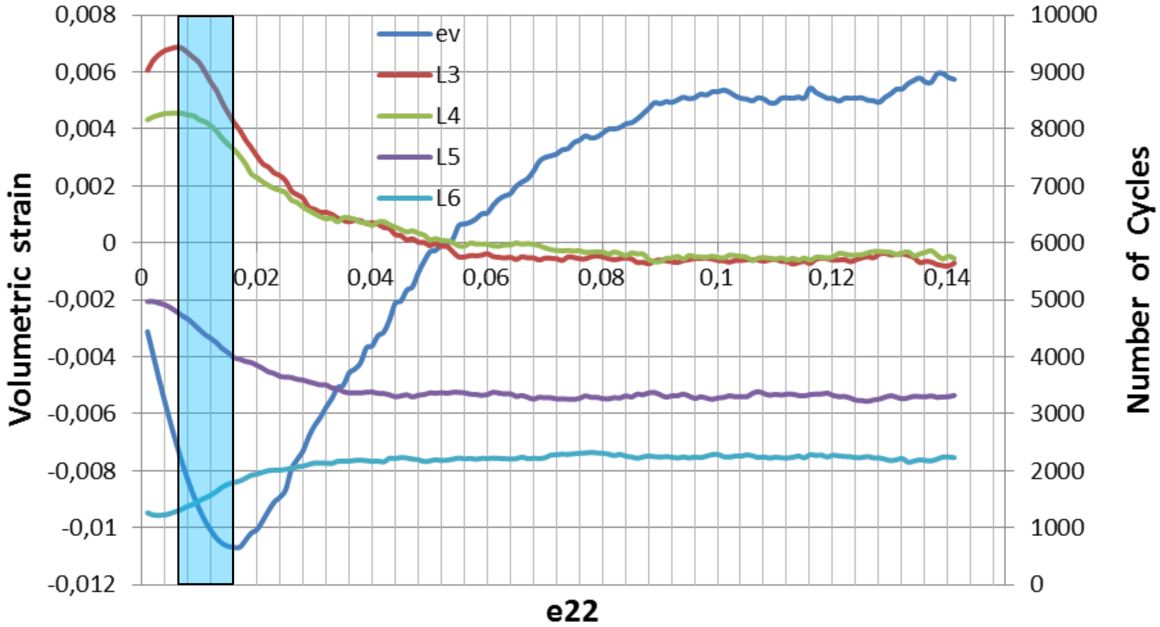
As initial density drops, the Loop-3 sees a slight rise at the beginning



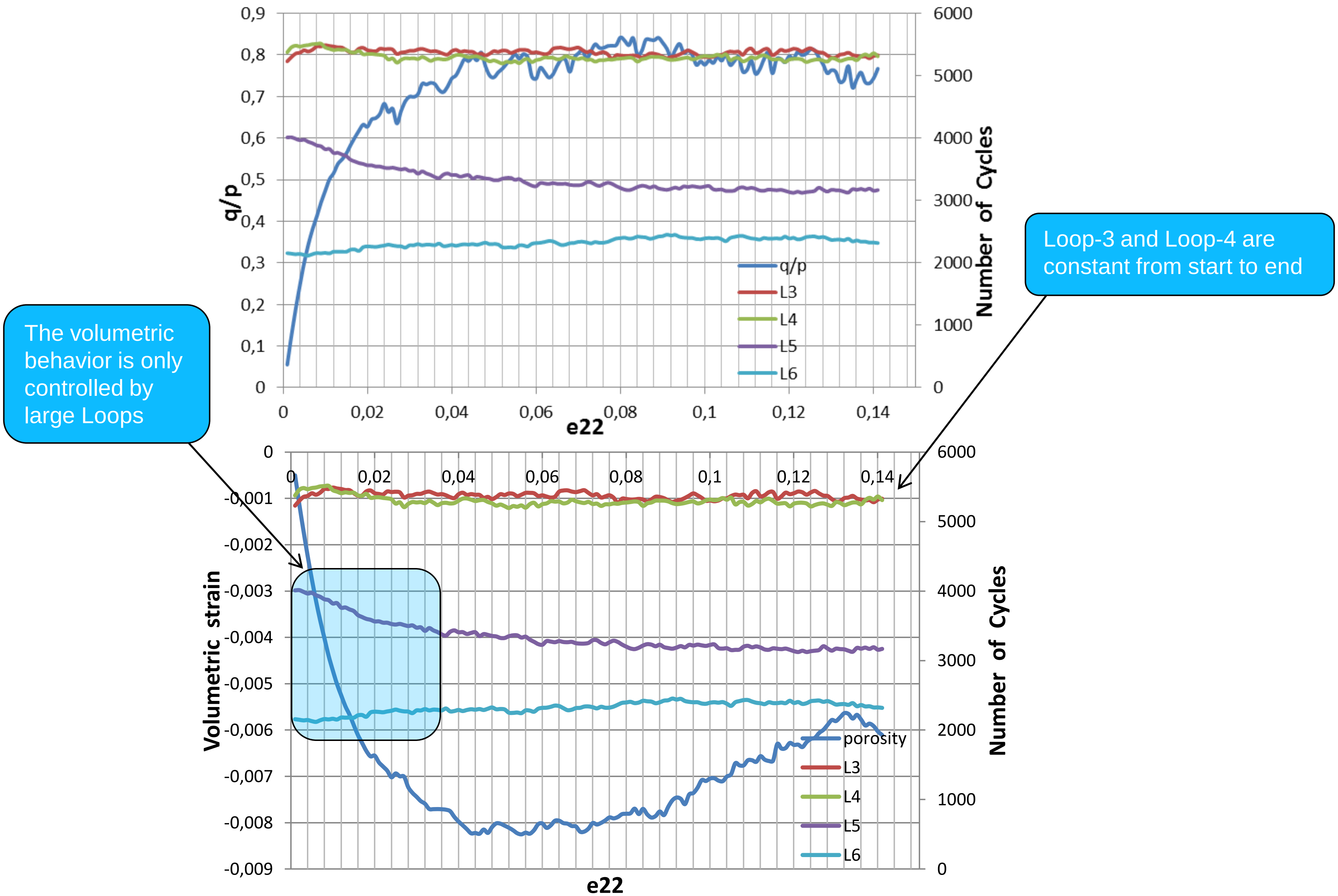


Initial porosity = 0.171 confining pressure = 100kPa





Initial porosity = 0.187 confining pressure = 100kPa



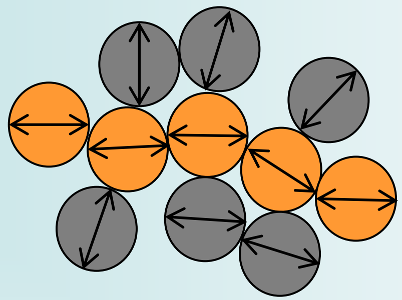
Intermediate conclusion

1. In not loose specimens, number of Loop-3, Loop-4, Loop-5 develop oppositely to Loop-6.

2. In the dense specimen, as the micro-structure indicates the dilatancy from the beginning, the initial contractancy derives from the penetration between particles, controlled by elastic parameters.

3. In loose specimen, Loop-3 and Loop-4 are constant from start to end. The volumetric behavior is only controlled by large Loops.

Force-chain concept



Definition:

- A cluster of particles (at least three particles)
- The geometrical line joining the centers is quasi a line,
- Particles main force directions should define a quasi linear line
- The maximal normal force is larger than the average normal force in the specimen

(Tordesillas *et a*l., JMPS, 2013)

Determining of the major force direction

Particle average stress:

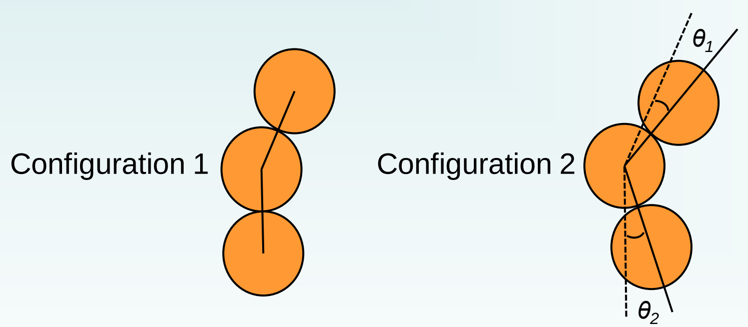
$$\sigma_{ij}^{(p)} = \sum_{c=1}^{N_c} F_i \, l_j$$

Major force direction is the major principal of particle average stress

Force-chain buckling

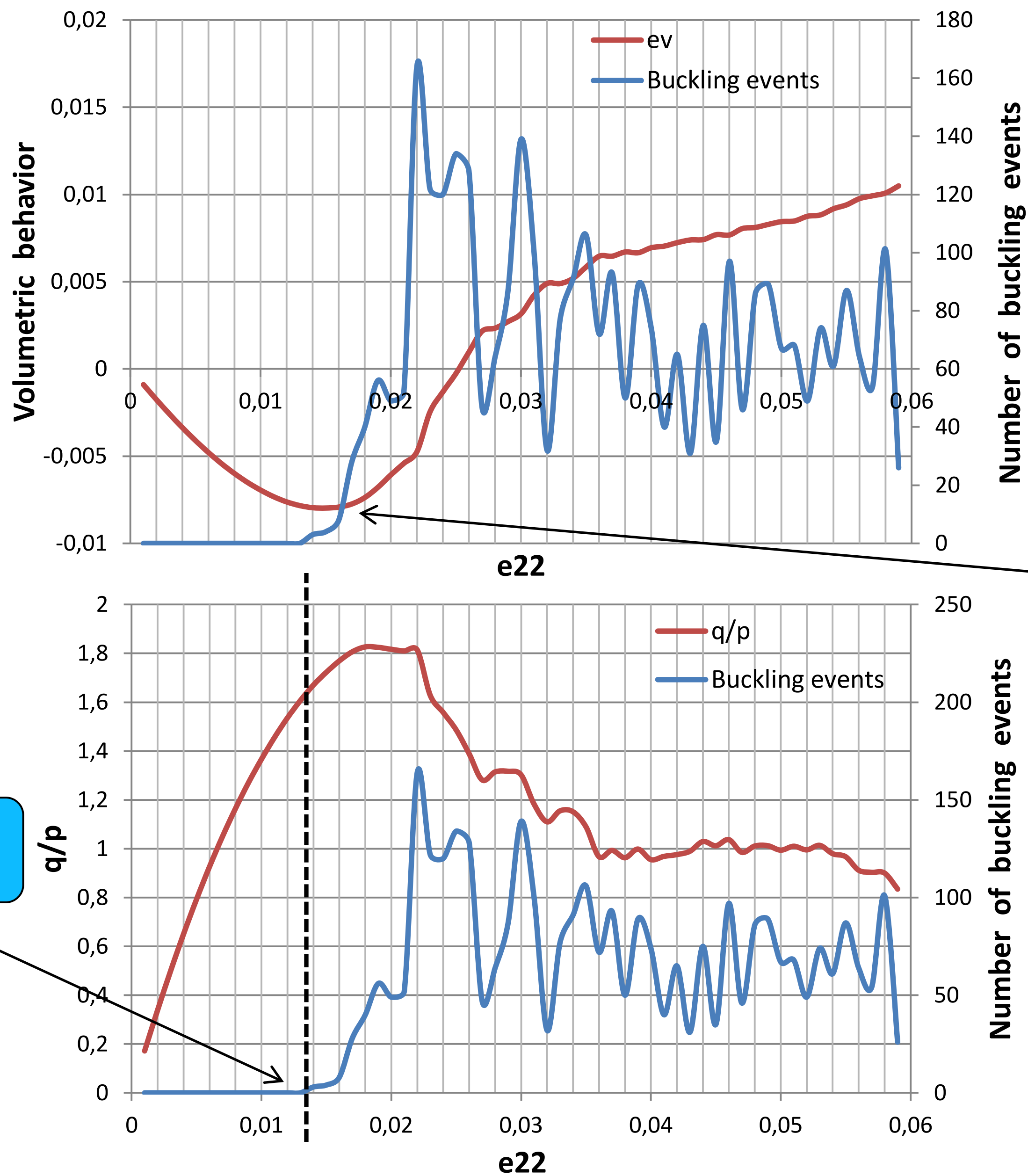
Deflection angle $\theta_d = \theta_1 + \theta_2$

Critical buckling angle θ_b



If $\boldsymbol{\theta_d > \theta_b}$, the group of three particles is buckling

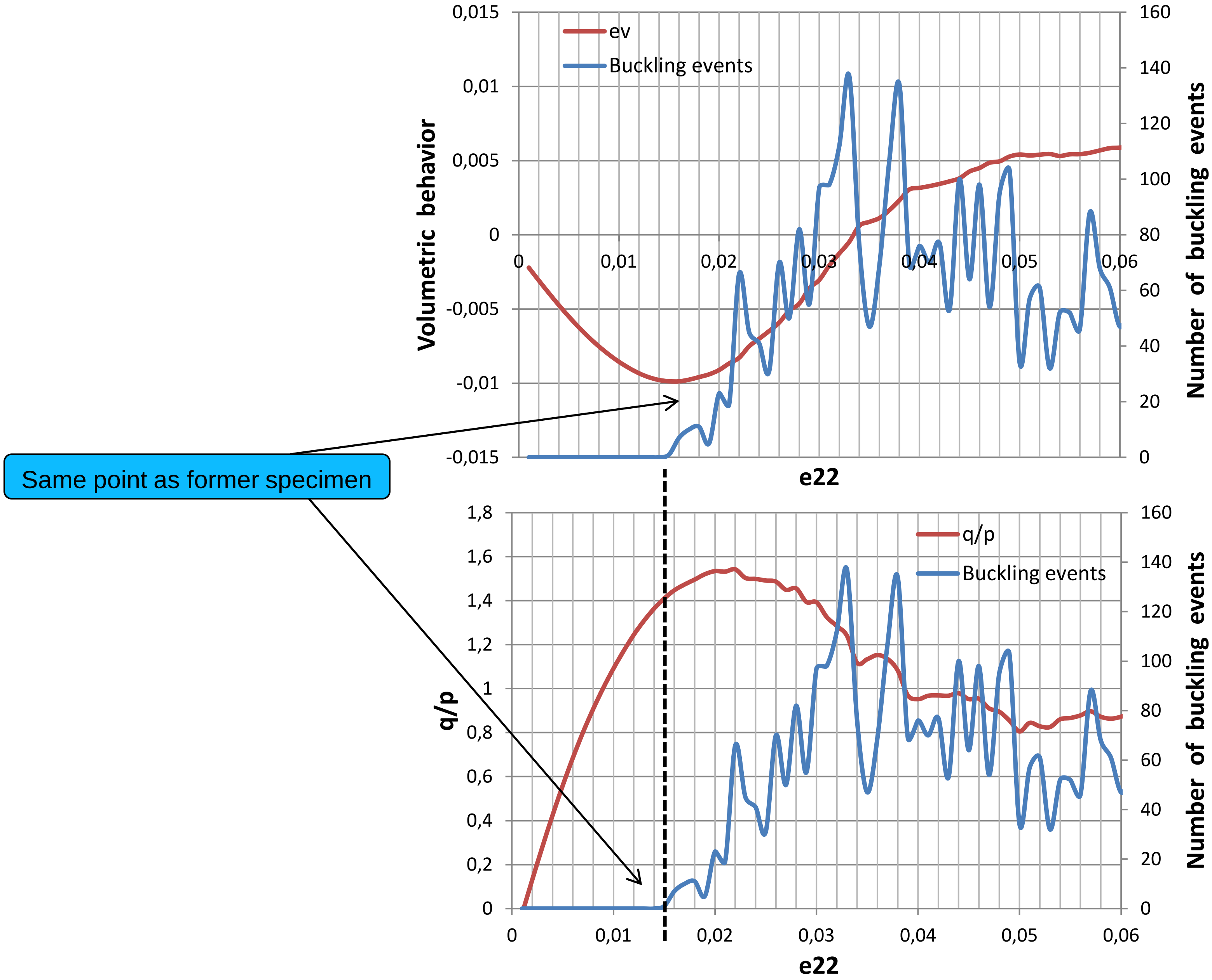
Initial porosity = 0.148(densest specimen)   confining pressure = 100kPa



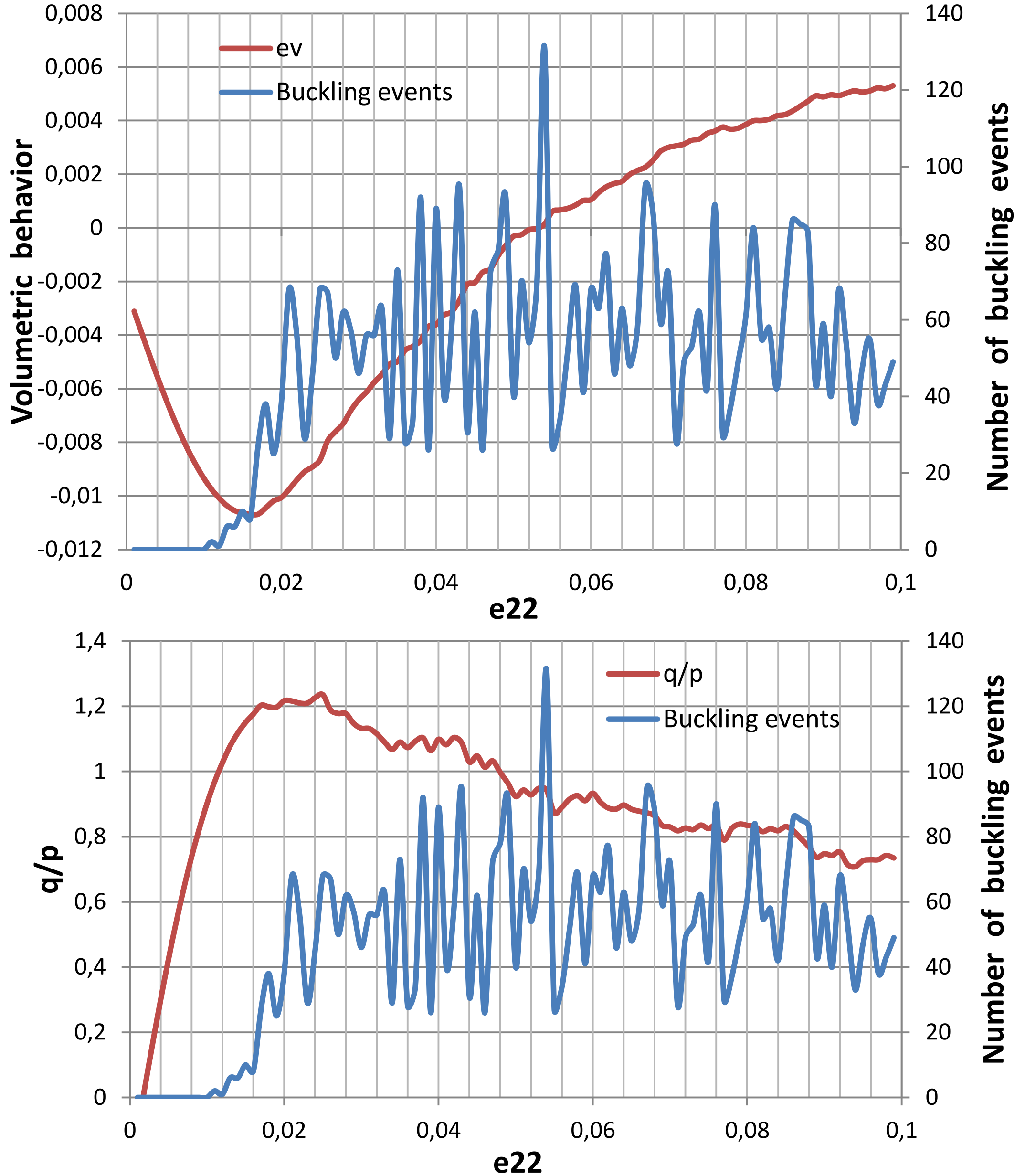
In dense specimen, the buckling start-up point coincides with the volume turning point to dilatancy

Force-chain buckling starts before stress peak

Initial porosity = 0.161   confining pressure = 100kPa



Initial porosity = 0.171   confining pressure = 100kPa



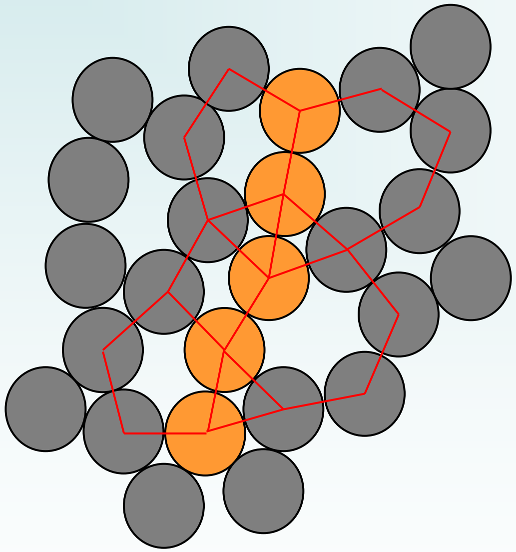
Intermediate conclusion

1. Force-chains start buckling before the stress peak.
2. In dense specimens, the buckling start-up point coincides with the volume turning point from contractancy to dilatancy
3. The stress peak seems to coincide with the maximum of force-chain buckling

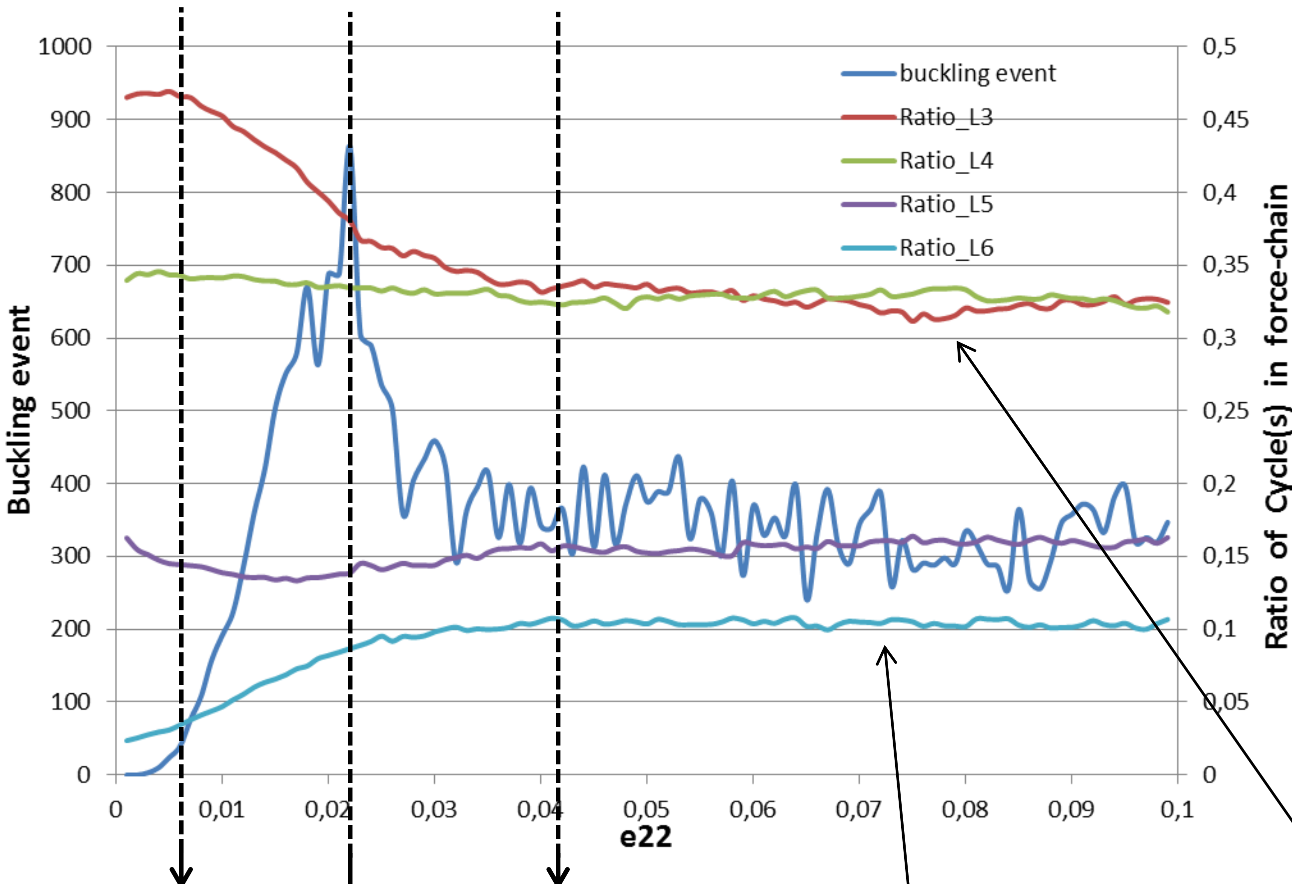
Cycles / force-chains correlation in dense specimen

Confining Cycles

This research only involves Loops having at least one particle belonging to a force-chain
They are called Confining Cycles onward



Initial porosity = 0.148 confining pressure = 100kPa



When Loop-3 start to drop, buckling accelerates

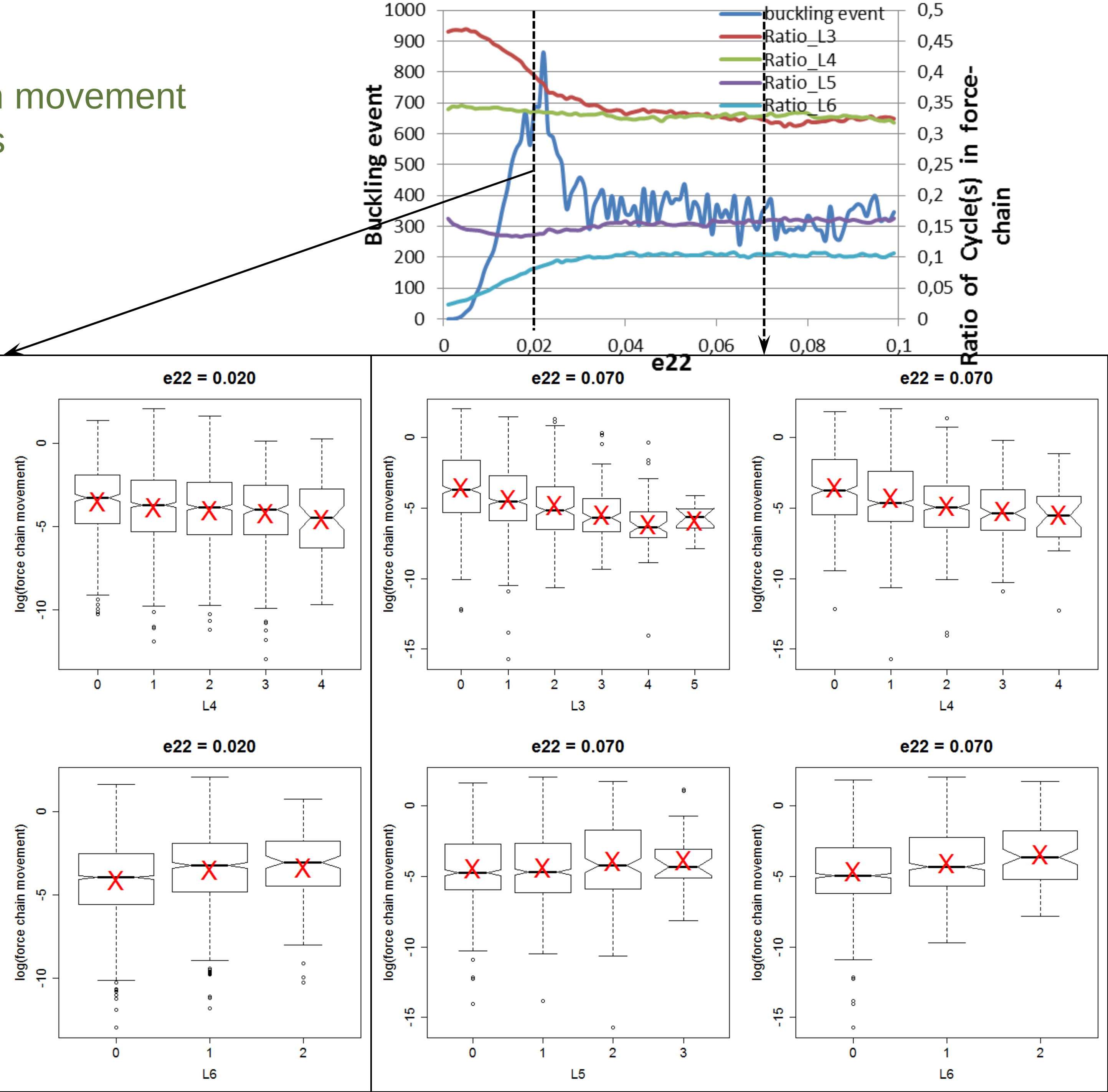
When Loop-3 inflects to slow drop, buckling starts to drop

When Buckling is steadied up, the Loop-3 also being stable

Loop-6 show more or less the same pattern like Loop-3

At critical state, Loop-3 and Loop-4 come to the same level

Cycles, force-chain movement correlation analysis



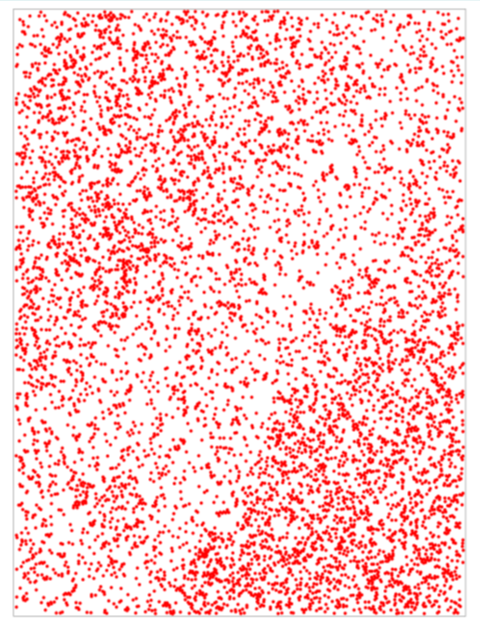
Intermediate conclusion

1. The Loop-3 is consistently dominating the Cycles near force-chain, as far as reaching the critical state.

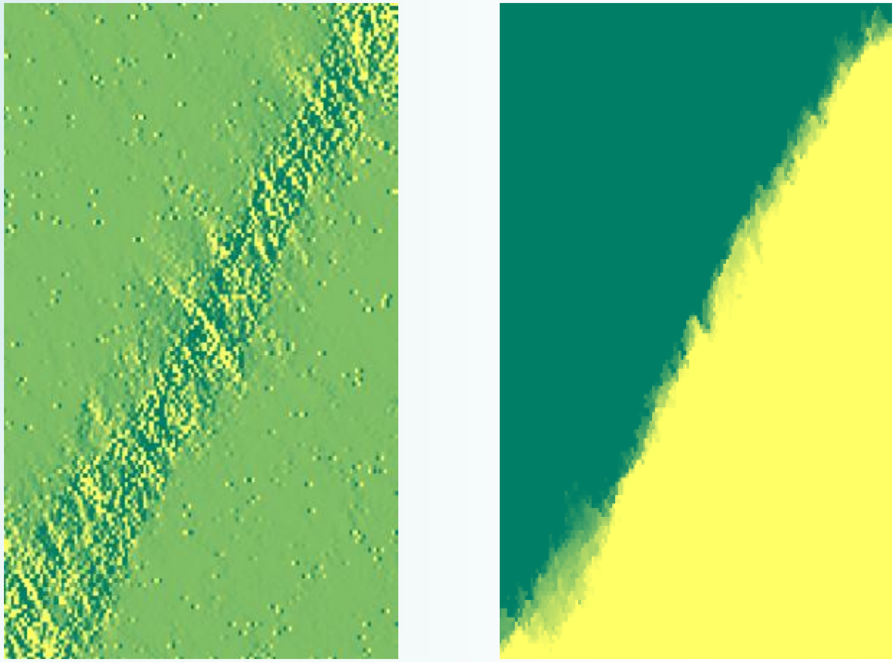
2. The proportion of the Loop-3 near force-chain is prominently related to the force-chain buckling pattern, when Loop-6 inverse the way.

3. The number of Loop-3 has significantly negative effect on the movement of the force-chain, when Loop-6 being significantly positive.

Cycles localization in dense specimen

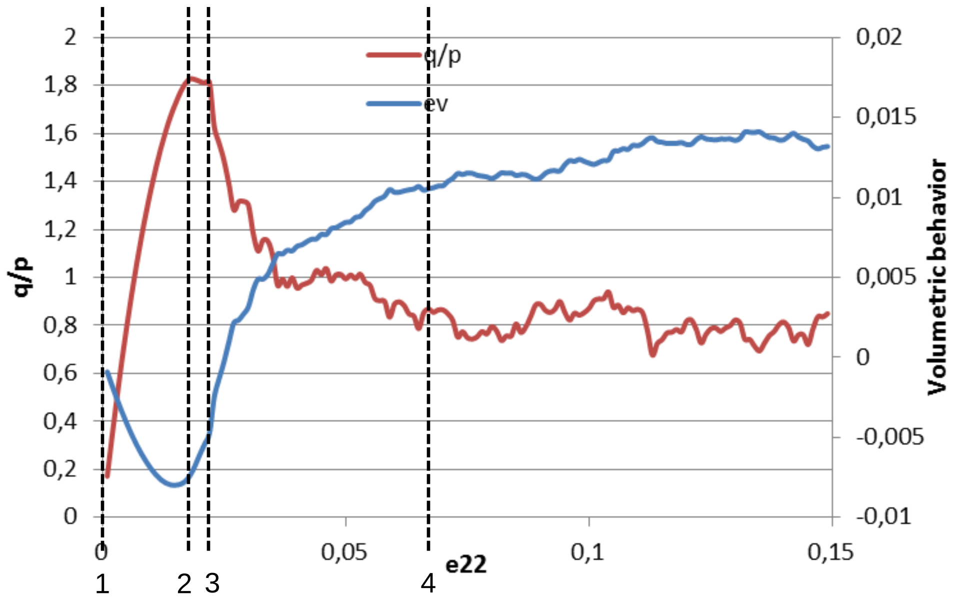


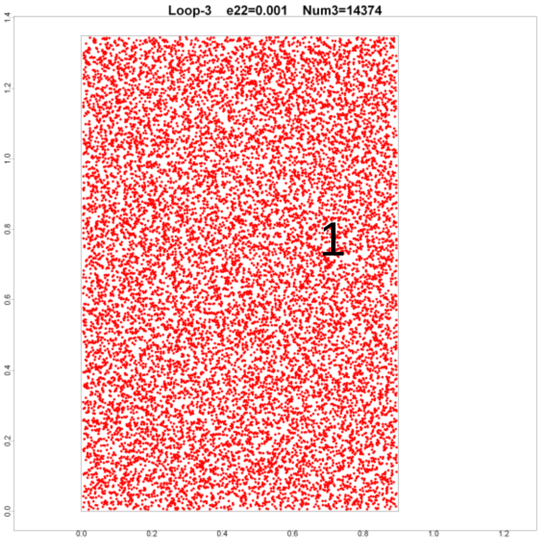
Loop-3 centroids distribution

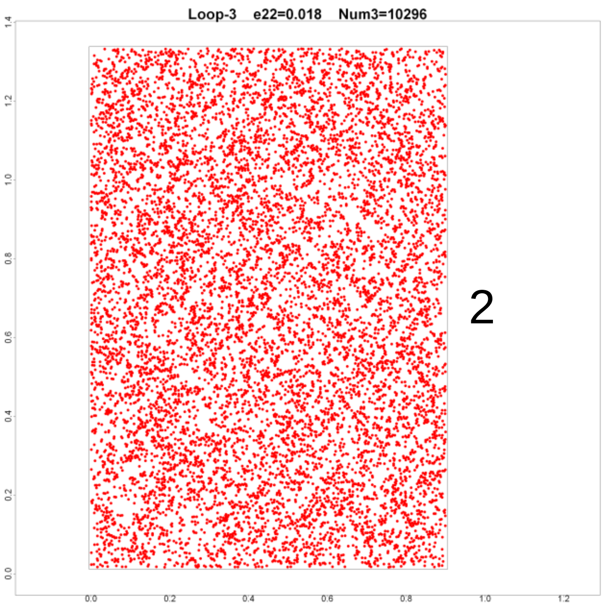


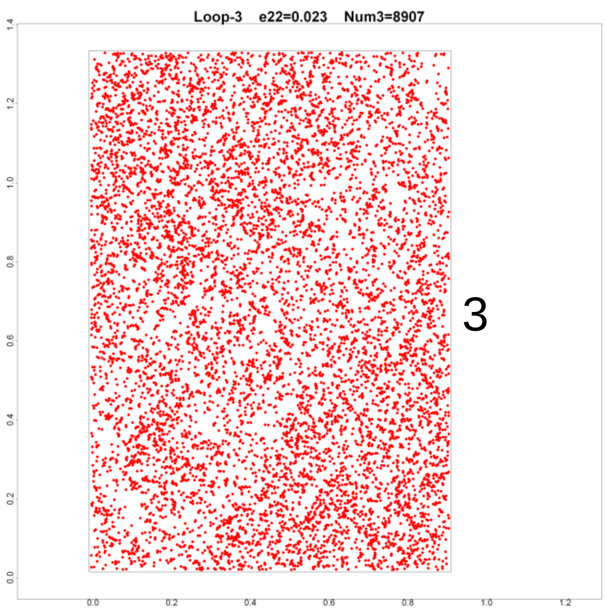
Displacement localize in a line of area
($\Delta\varepsilon_{dev}$ and $|\triangle u|$ image from Hadda's thesis)
Sibille et al,, JMPS, 2014)

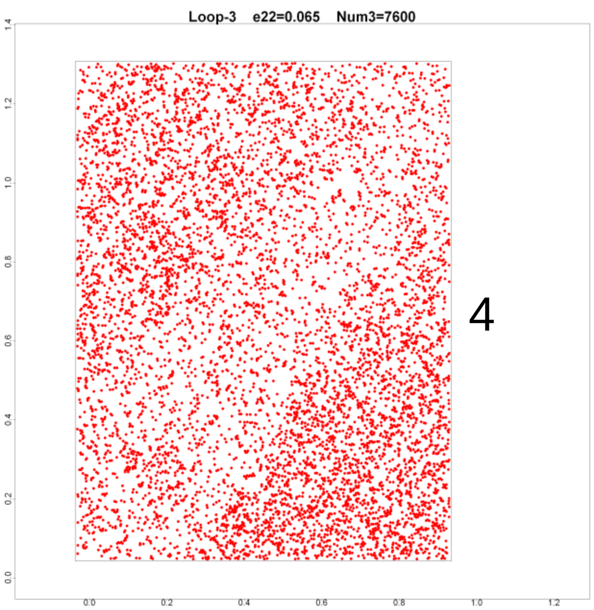
Loop-3 Initial porosity = 0.148



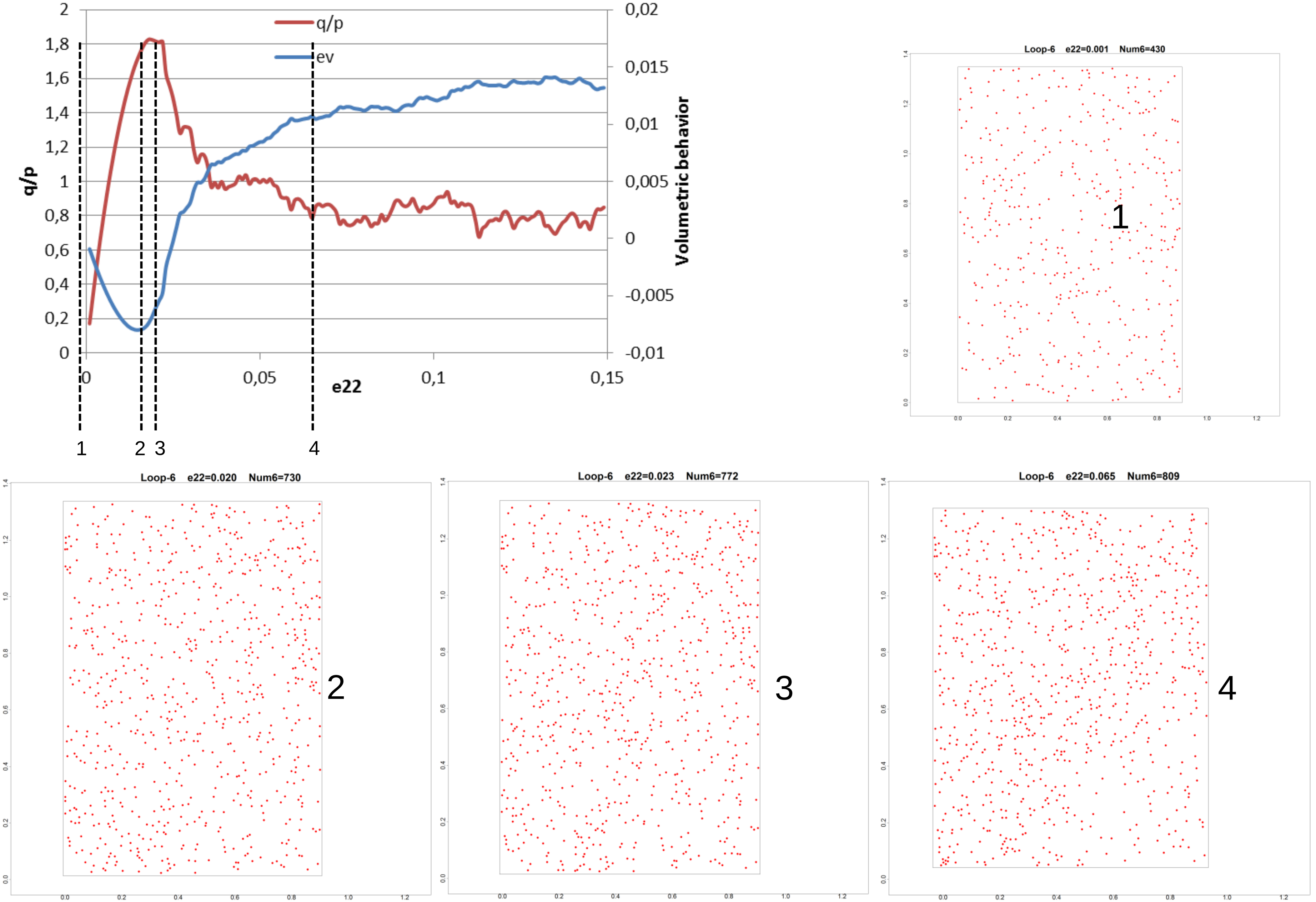








Loop-6 Initial porosity = 0.148

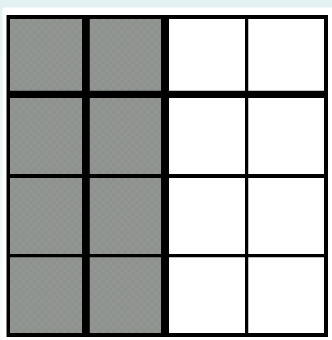


Quantitative appreciation of localization in dense specimen

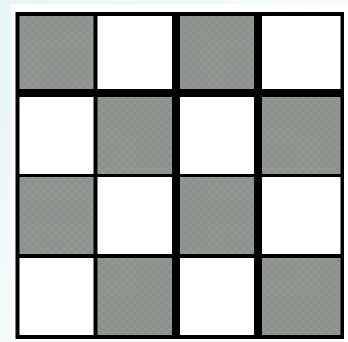
A geographic method often used in GIS and ecology to quantitatively describe the self-aggregation of a certain attribution within objective area.

Moran's quotient:

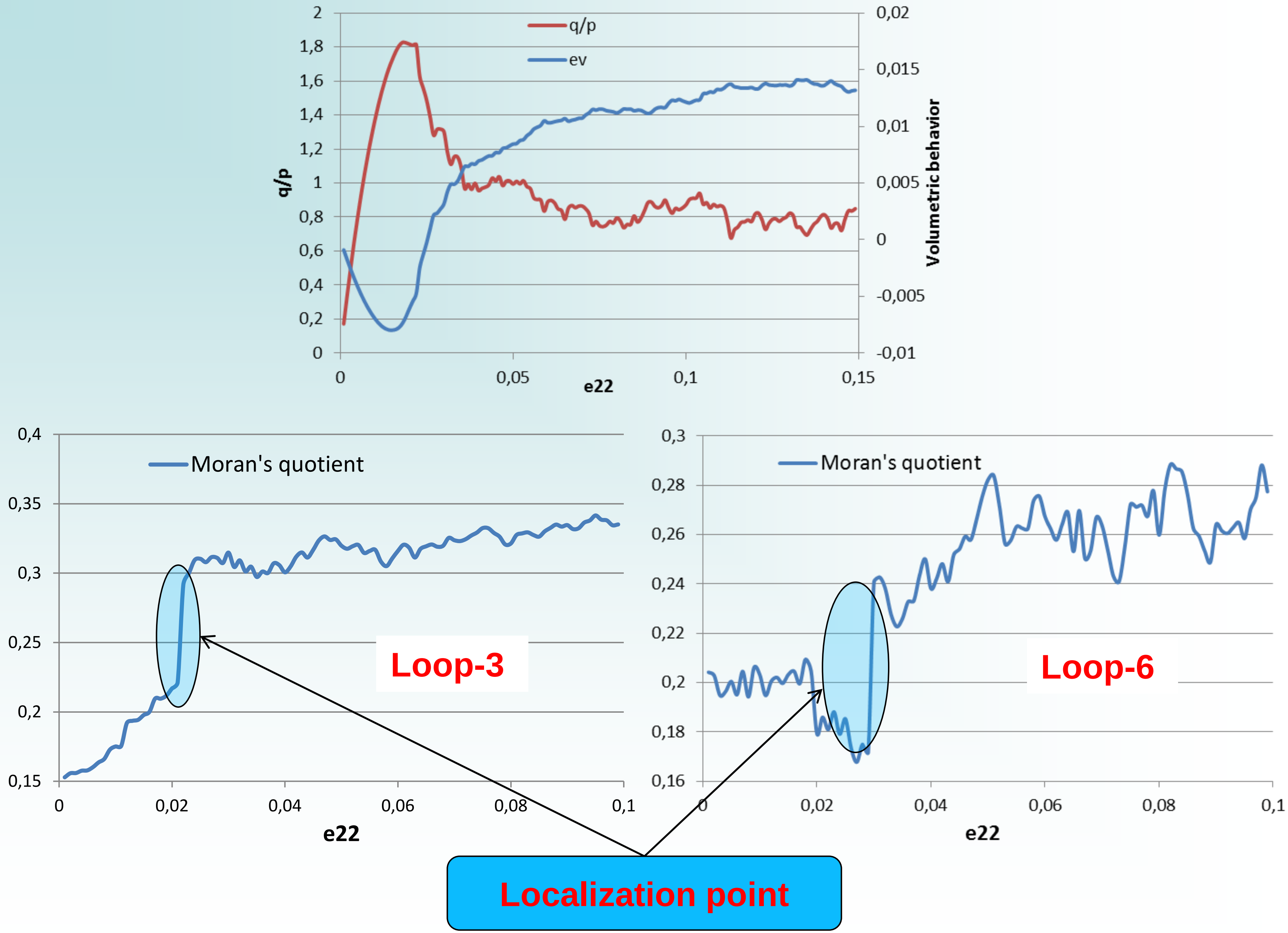
$$I = \frac{n}{\sum_{i=1}^{n}\sum_{j=1}^{n} Wji(d)} \times \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} Wij(d)(xi-\bar{x})(xj-\bar{x})}{\sum_{i=1}^{n}(xi-\bar{x})^2}$$



Moran's I>0（aggregative distribution）



Moran's I<0（lattice distribution）


q/p
ev
q/p
Volumetric behavior
e22
Moran's quotient
Loop-3
e22
Moran's quotient
Loop-6
e22
Localization point

Concluding remarks (1)

A tentative microstructural interpretation of mechanical strength in granular materials

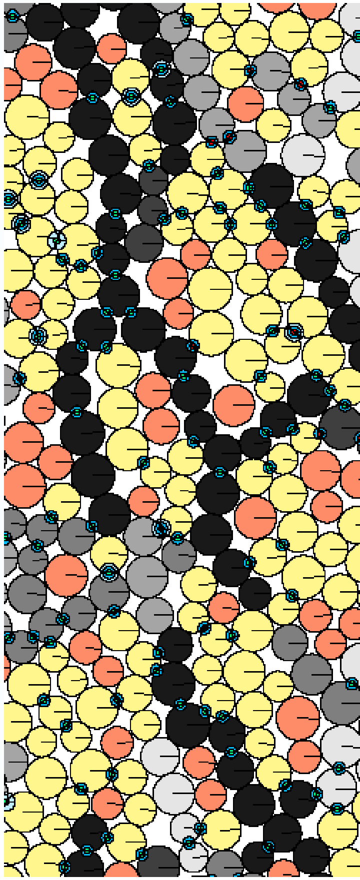
The case of the drained biaxial loading path on a dense material

1- The dense structure of the assembly (Loop-3) directs important lateral forces. To maintain a constant lateral pressure, the specimen needs to dilate

2- This dilatancy results in the increase in Loop-6, and decrease in Loop-3

3- The increase in the axial stress requires developing force chains. The stability of these force chains is ensured by lateral confining made up of loops:

Loop-3 better than Loop-6



Concluding remarks (2)

4- The stability of force chains is no longer guaranteed, and buckling dramatically increases (possibly with localization)

5- As a result, the deviatoric stress reaches a peak

6- The so-called “critical state” could correspond to the emergence of a stable/steady microstructure able to resist against an axial compression with no volume change together with constant lateral/axial stresses

7- The concept of “**critical state**” (we should say “steady state”) could be the following:

A critical state is reached along a given loading path, if the microstructure converges toward a steady pattern

Then, the volume does no longer evolve, and the lateral/axial stresses remain constant