CEMENTED GRANULAR SOILS FOR ROAD AND RAIL INFRASTRUCTURE

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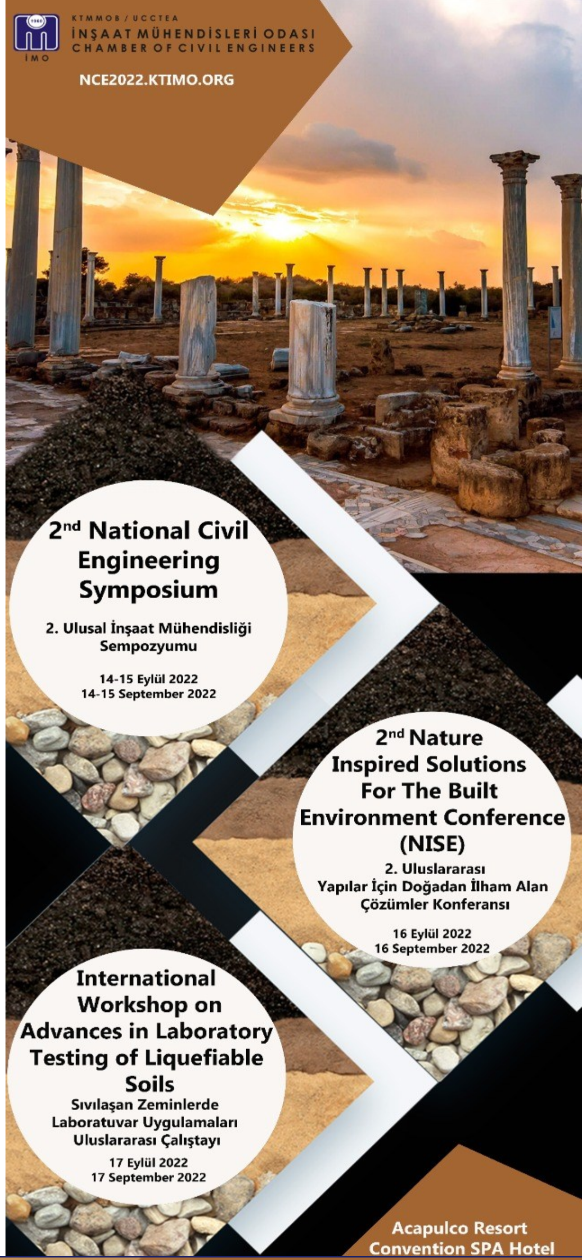


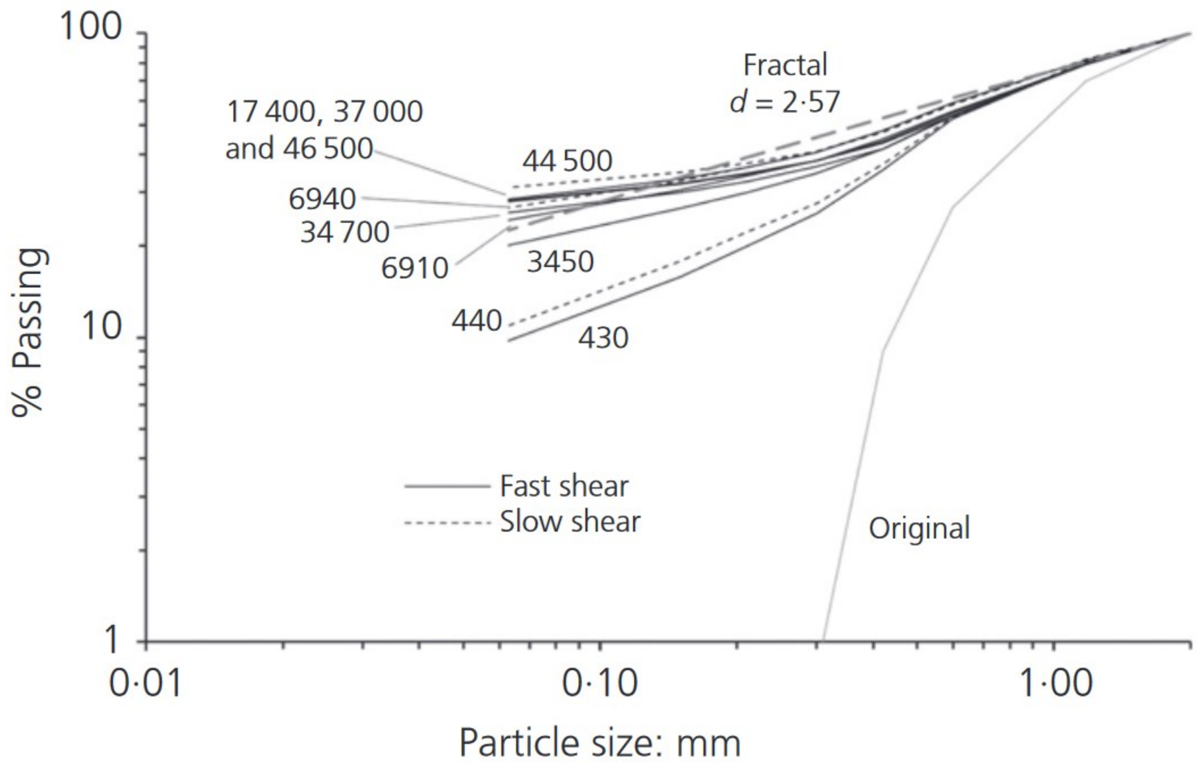
Content

- Small introduction
- Materials and sample preparation
- Triaxial test results and analysis
  - Granular material for base- roads
    - Monotonic
    - Cyclic + monotonic
  - Preliminary results from Ballast
    - Cyclic
- Conclusions

Introduction

- Granular materials:
  - Critical State Soil Mechanics concepts can be applied
  - Breakage is important in shearing – fractal grading

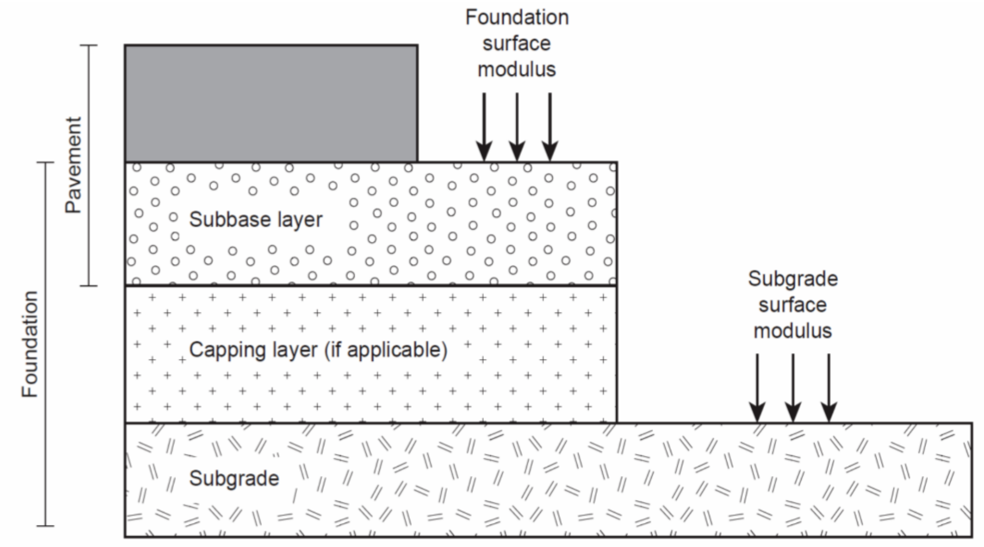
- Cemented soils:
  - Increase in strength
  - Increase in stiffness
  - Addition of tensile strength



Ferreira & Coop (2020)

Introduction

- Base and subbase of roads
  - Foundation of a road, a drainage layer and has a significant structural capacity in flexible pavements
  - Design based on stiffness and class requirement.

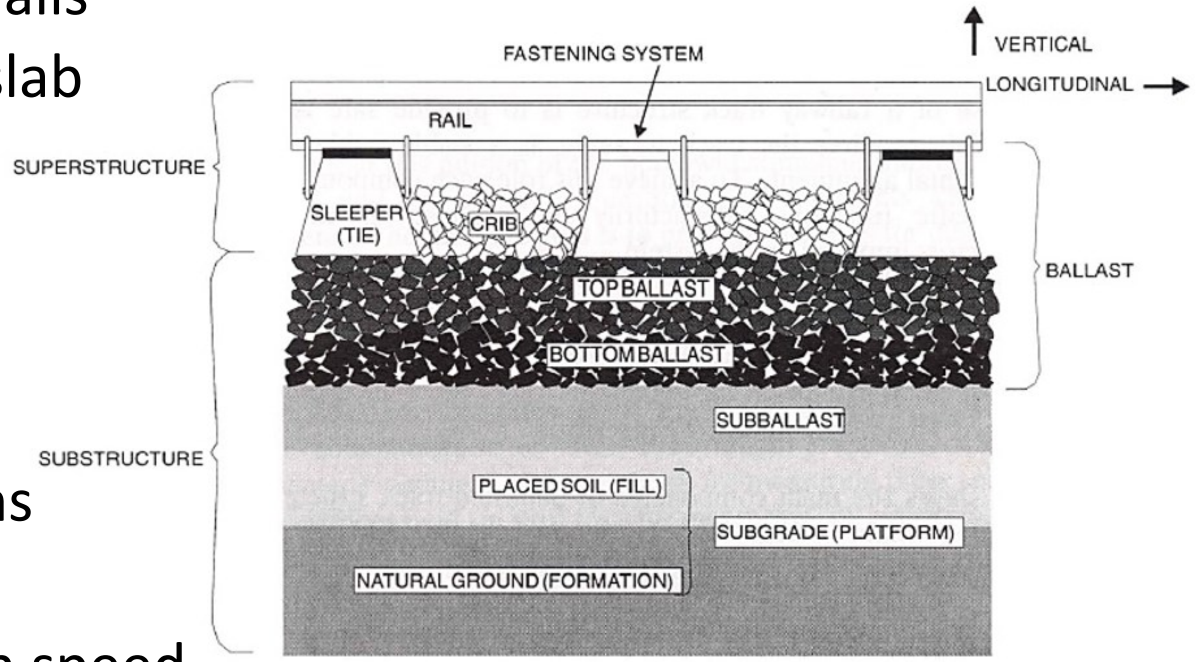


DMRB CD 225 (2009)

- Maintenance problems:
  - Excessive deformation – rutting
  - Fines pumped into the pores – lack of drainage
  - Fatigue – cyclic traffic load
  - 70 – 80% of the life cost is maintenance (Frangopol & Furuta 2001)

Introduction

- Rail - ballast:
  - Stabilise the position of the sleepers/rails
  - Structural layer – replaced by a track slab
  - Resistance to crushing, attrition and weathering
  - Drainage
- Maintenance problems
  - Rail deformation – several mechanisms
  - Ballast fouling – attrition, pumping
  - Ballast flying – sleeper vibration + high speed



Selig and Waters (1994)

Aims of this work:

1. Understand if the addition of small percentages of a binder to a base and subbase soils can increase maintenance intervals and reduce costs.

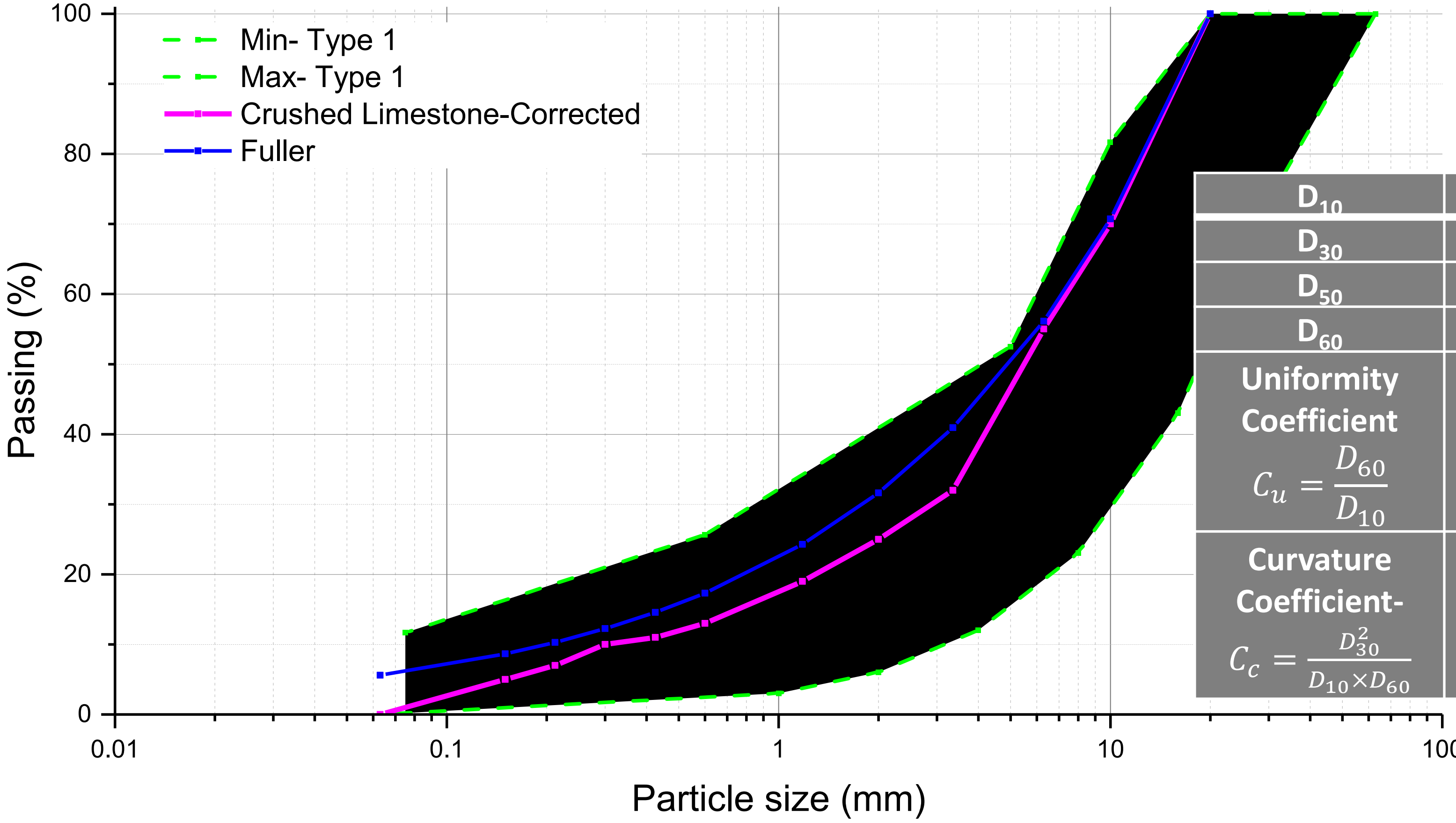
2. Understand if the addition of bonding to ballast can improve the cyclic behaviour of ballast and consequently reduce deformations and maintenance costs.

Material

- Crushed Limestone
  - Commonly used for base and subbase in UK
  - Used as Ballast in some minor rail lines
  - Material was sieved and bagged by sieve range
  - >20mm discarded
  - Samples created by mixing different percentages.

Material – base and subbase

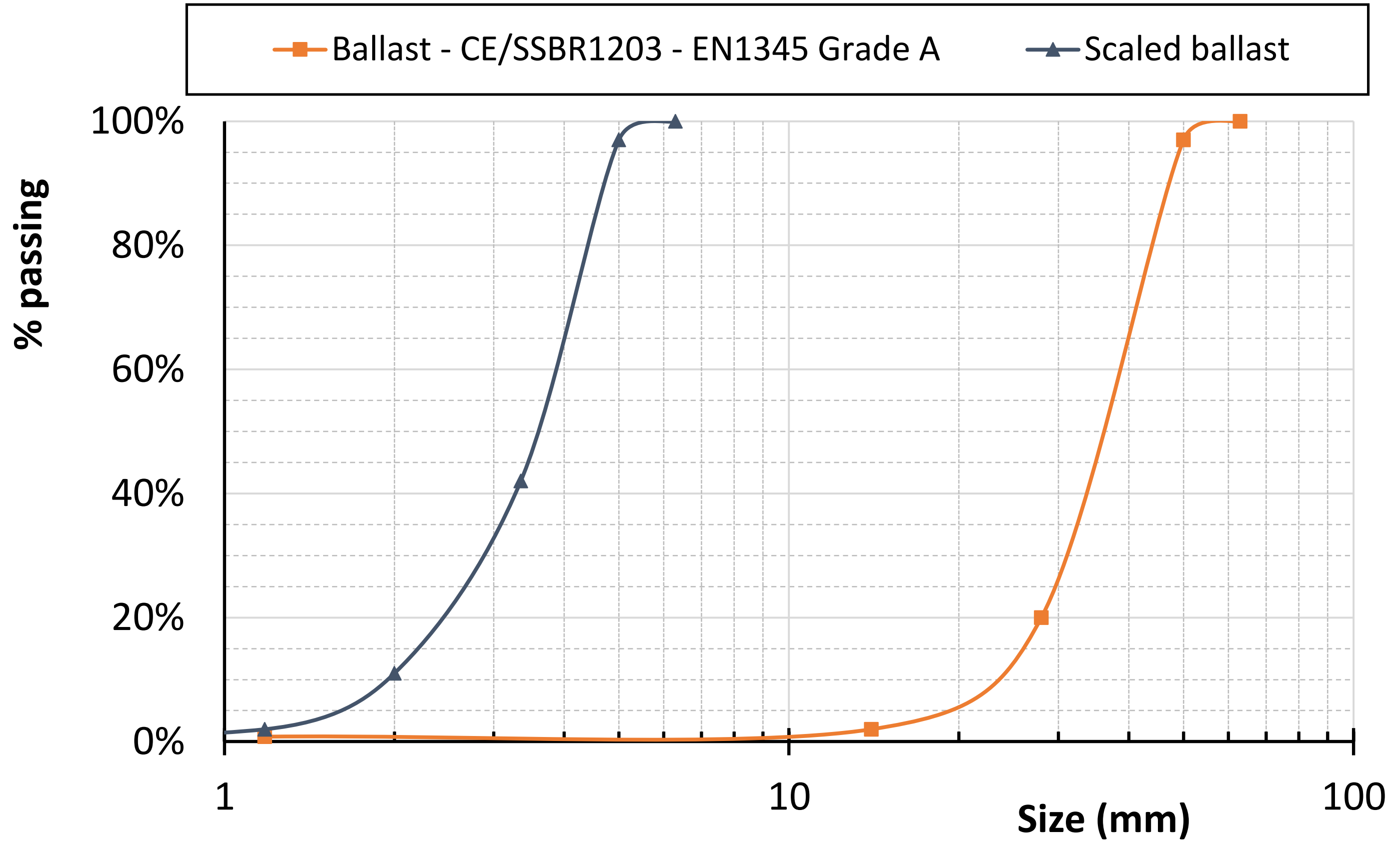
- Gray band – Type 1, Highways agency to MCHM, volume 1- clause 803.
- Fuller and Thompson (1907) – optimum size for a dense fabric.



D_{10}	0.3
D_{30}	3.3
D_{50}	5.5
D_{60}	7
Uniformity Coefficient $C_u = \frac{D_{60}}{D_{10}}$	21
Curvature Coefficient- $C_c = \frac{D_{30}^2}{D_{10} \times D_{60}}$	5.2

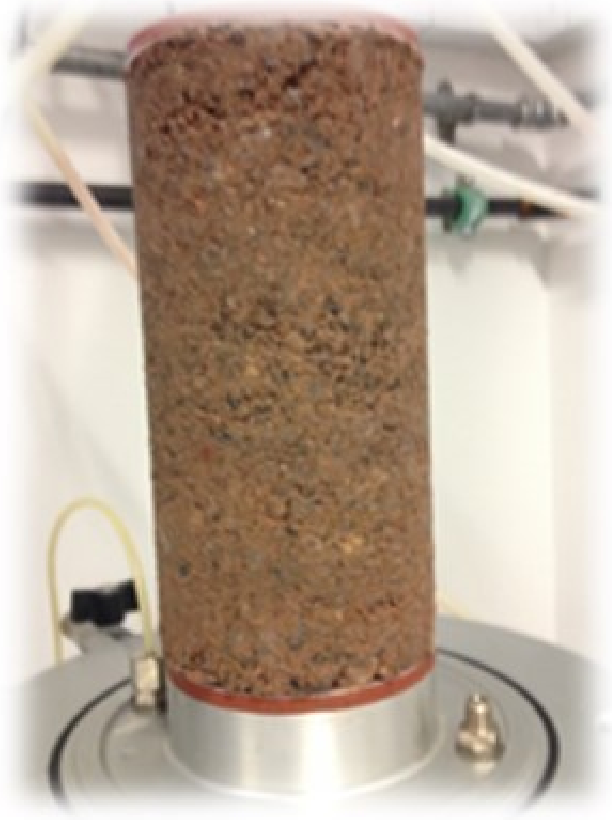
Material – scaled ballast

- Ballast Grade A – EN 13450 Aggregate for Railway ballast
- Scaled ballast – Parallel Gradation Technique or scale down of the grade A by 10x –



Methodology – sample prep. – Base

- Uncemented samples:
  - Compacted on a mould (100mmΦx200mm)
  - At the optimum moisture content (6%)
- Cemented samples (1 and 2% Portland cement):
  - Fines were replaced by cement
  - Compacted on the same mould
  - Optimum moisture content
  - Cured for 1 day in the mould and 4 under water.
  - Sheared on the 7th day



Methodology – sample prep. - Ballast

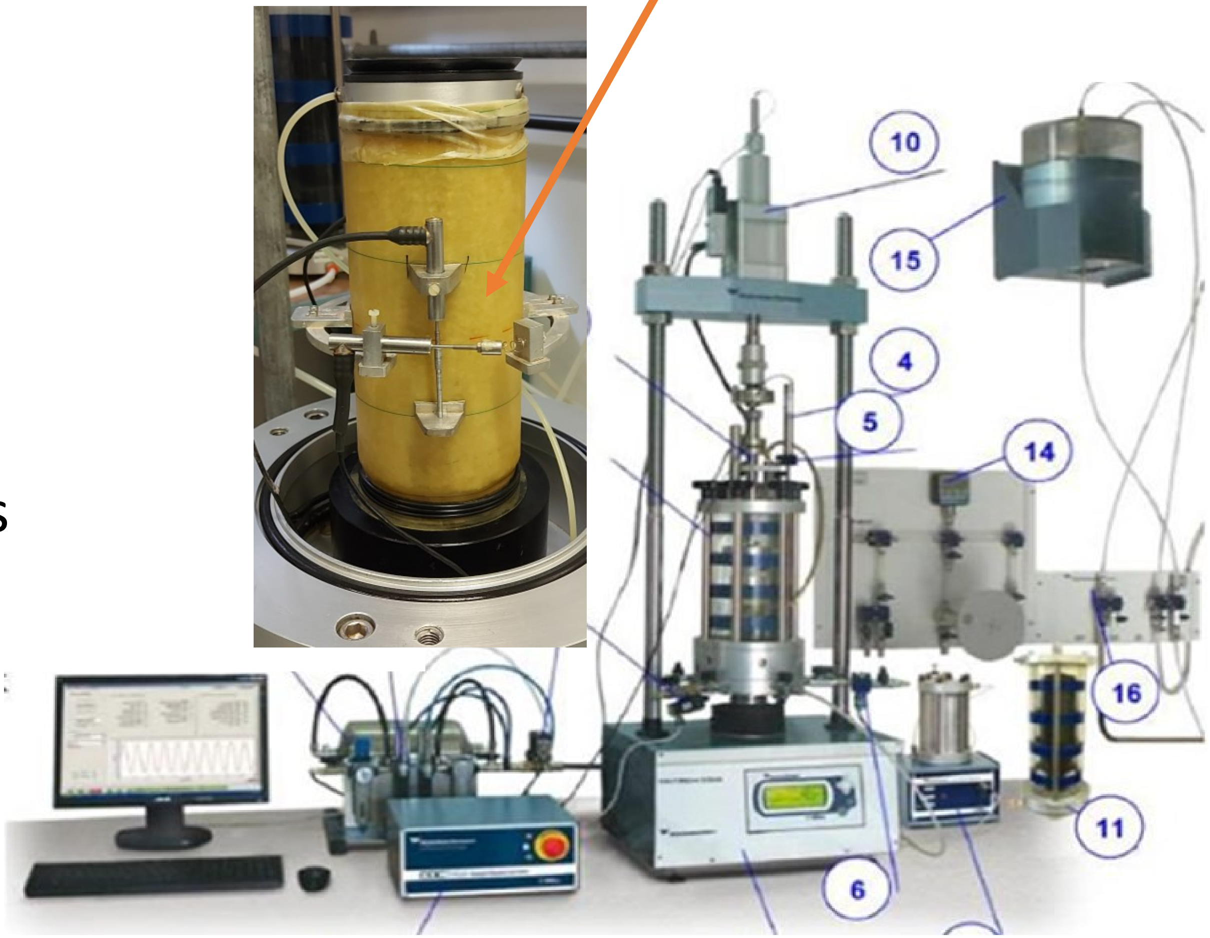
- Uncemented samples:
  - Tamping and vibrated on a moould on the triaxial pedestal (100mmΦx200mm)
  - Moisture content around 6%

- Cemented samples (5% Portland cement):
  - Cement added to the sample
  - Vibrated in 3 layers on the mould.
  - Moisture content of 8%
  - Curing: 1 day in the mould and 4 days inside a sealed bag.
  - Sheared on the 7th day

Testing Methodology

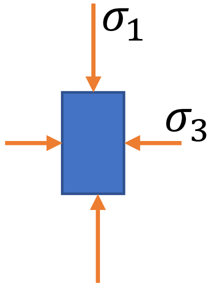
LVDT – local instrumentation
Cuccovillo & Coop (1997)

- Monotonic triaxial tests:
  - Isotropic Consolidated Drained tests
- Cyclic triaxial tests
  - Isotropic consolidation
  - Cyclic loading up to a 1million cycles
  - Different stress ratios
  - Drained monotonic shearing afterwards

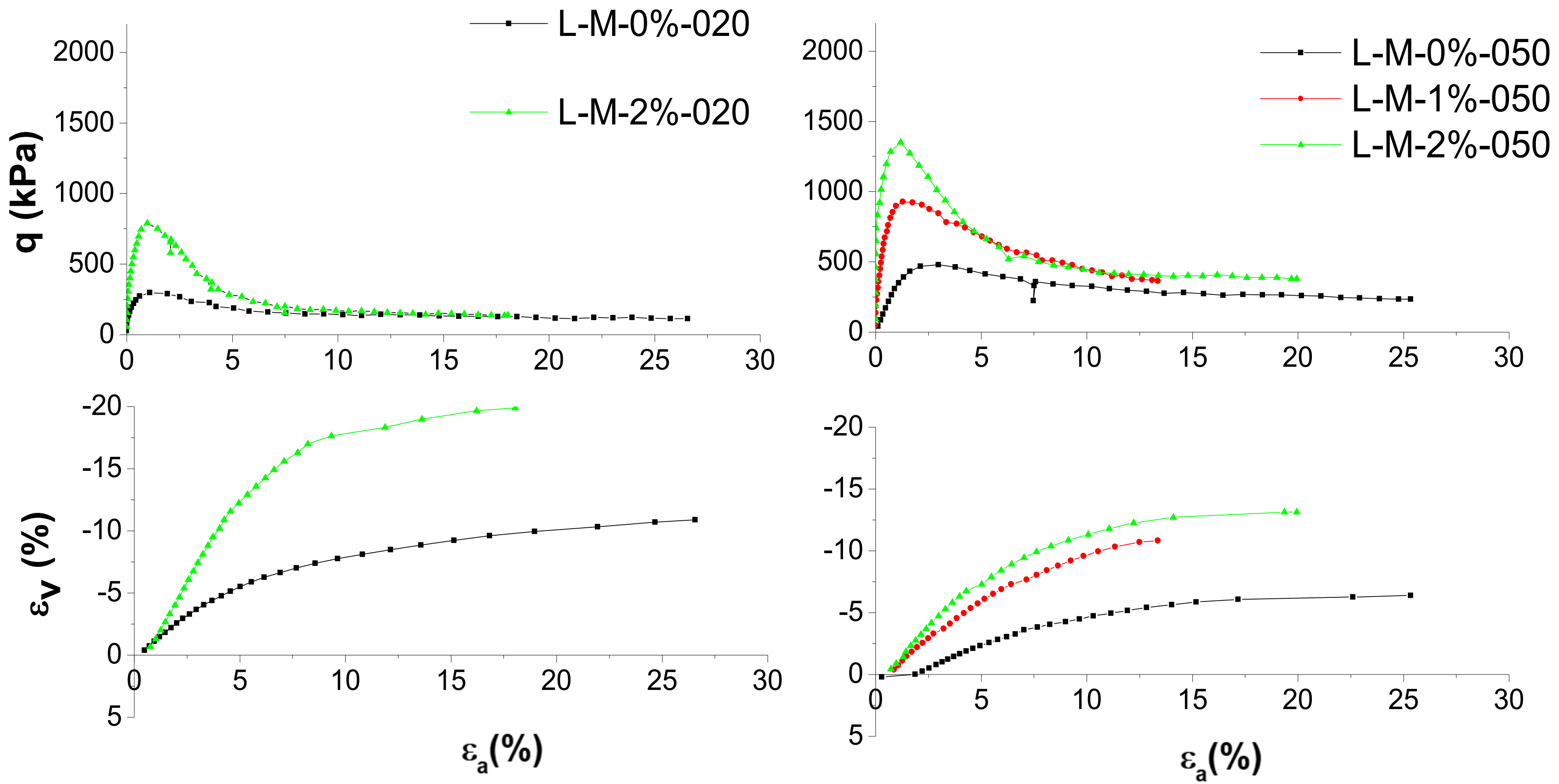


Monotonic triaxial test results - comparison

$q = \sigma_1 - \sigma_3$

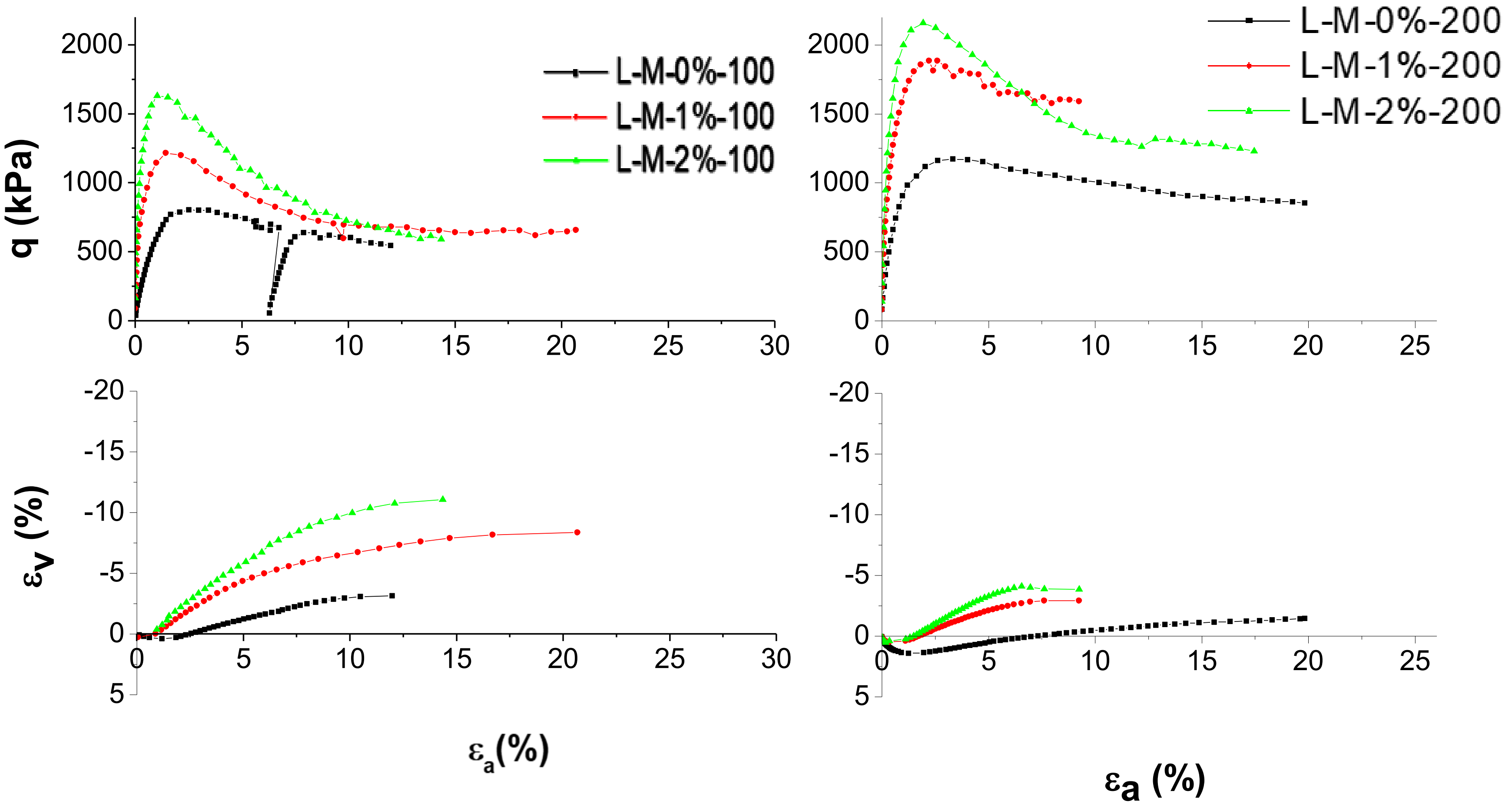


- Cemented samples:
  - Have higher strength (~ 3x)
  - Have much larger volumetric strains
  - Bonded particles acting like larger aggregates



Monotonic triaxial test results - comparison

- Cemented samples:
  - Higher strength (~2x)
  - Increasing confining stress reduces the effectiveness of the cement.
  - Larger volumetric strains

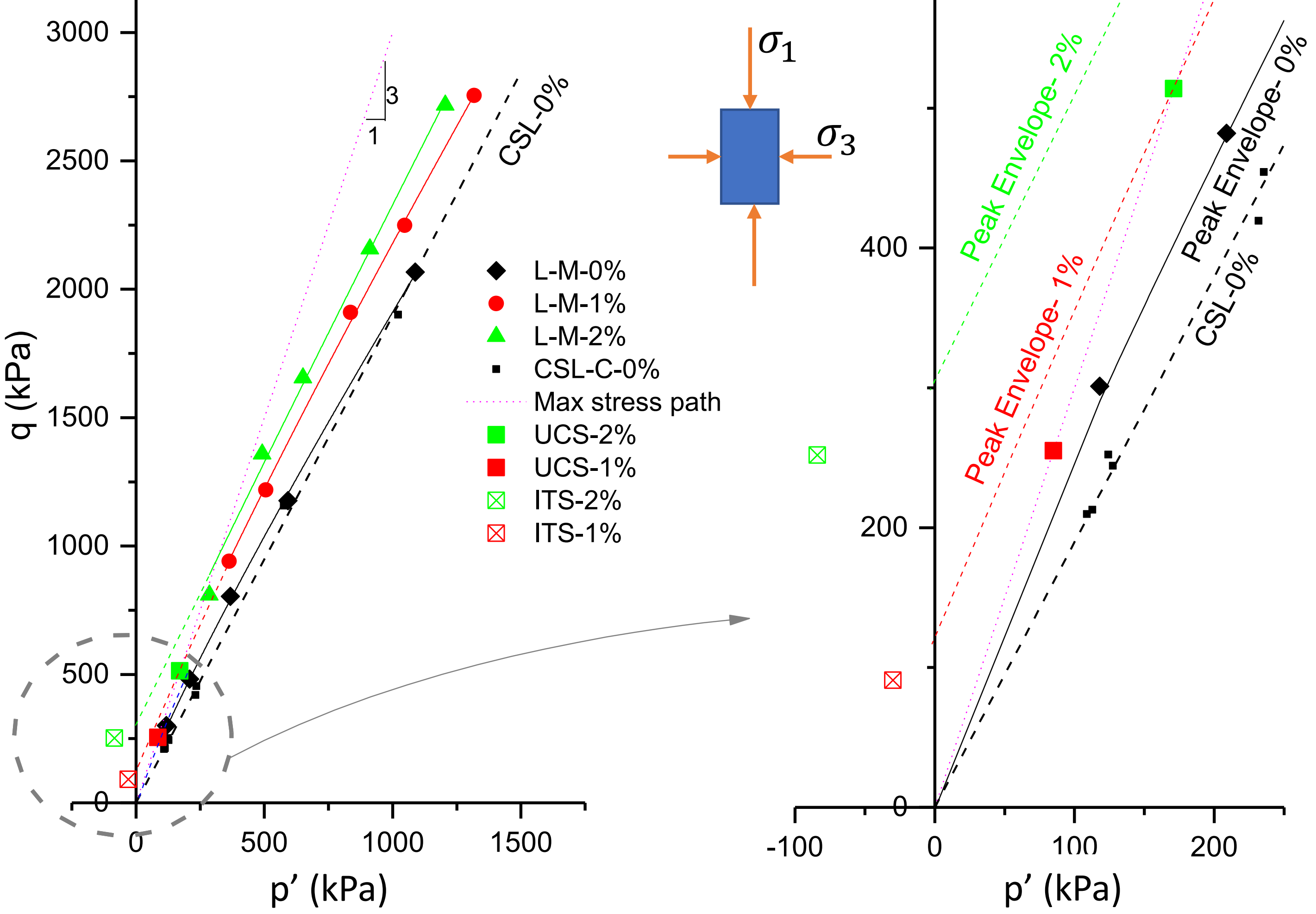


Failure envelopes

- Uncemented samples
  - Not much difference between peak and large deformations
- Cemented samples
  - Identical friction angle
  - Cohesion intercept

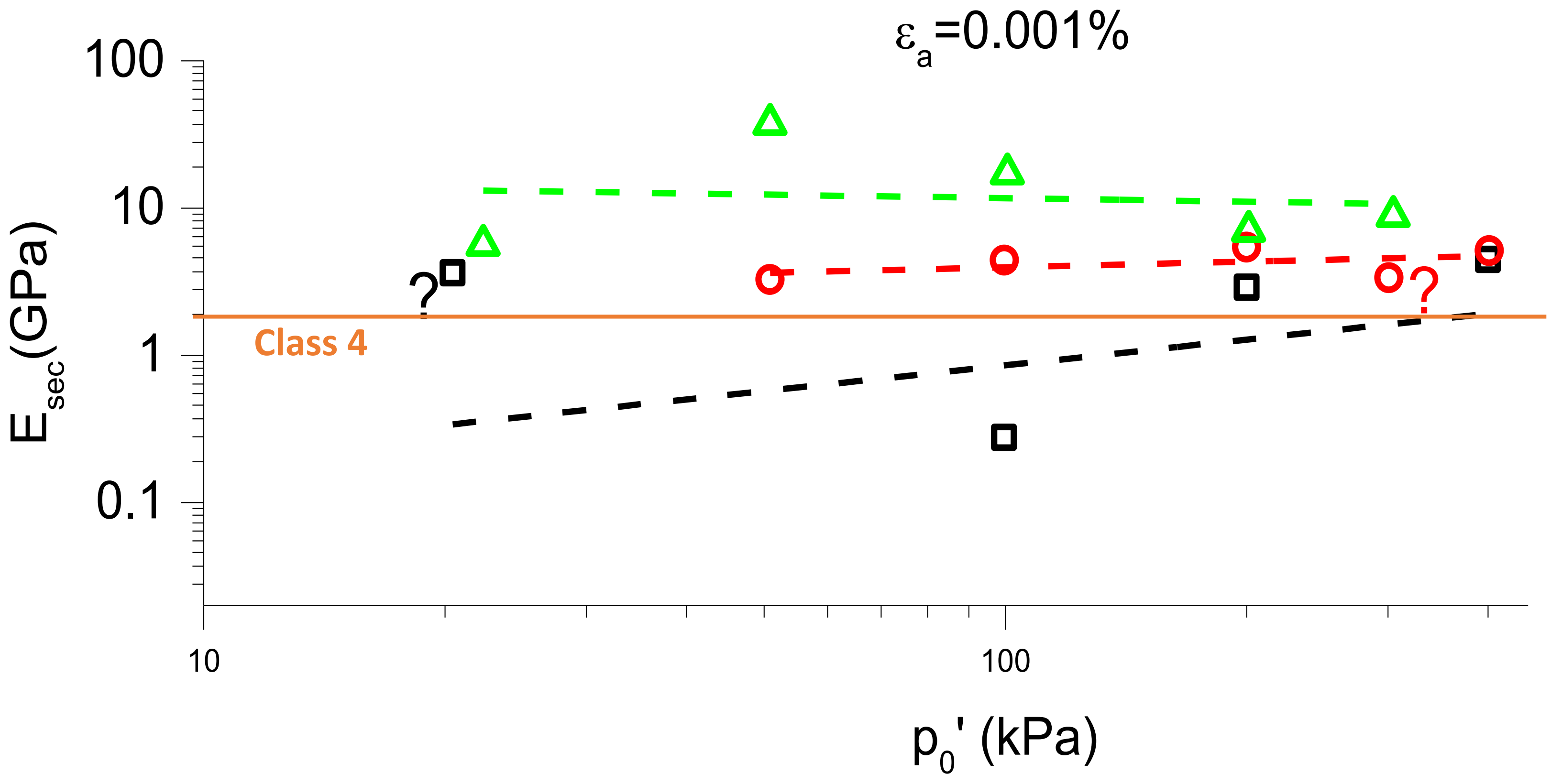
Soil	0	1%	2%
ϕ_{peak}	46.6	46	46.7
$q_{intercept}$	0	136	299

$$q = \sigma_1 - \sigma_3 \qquad p' = \frac{\sigma_1' + 2\sigma_3'}{3}$$



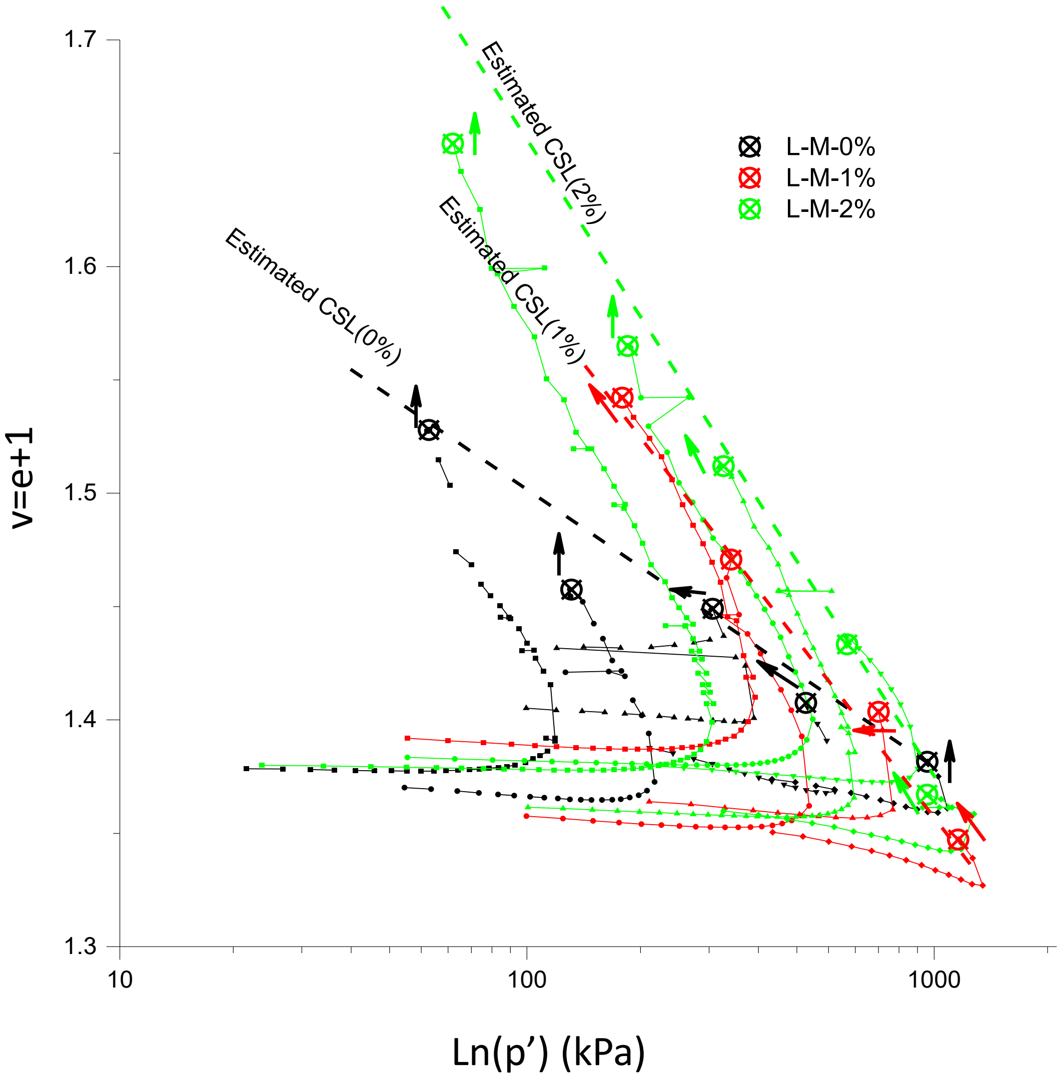
Secant Stiffness

- Class 4 – most onerous requirement for a base – determined using CBR
- Without cement stiffness is lower than Class 4 requirement
- With cement the stiffness is higher than Class 4



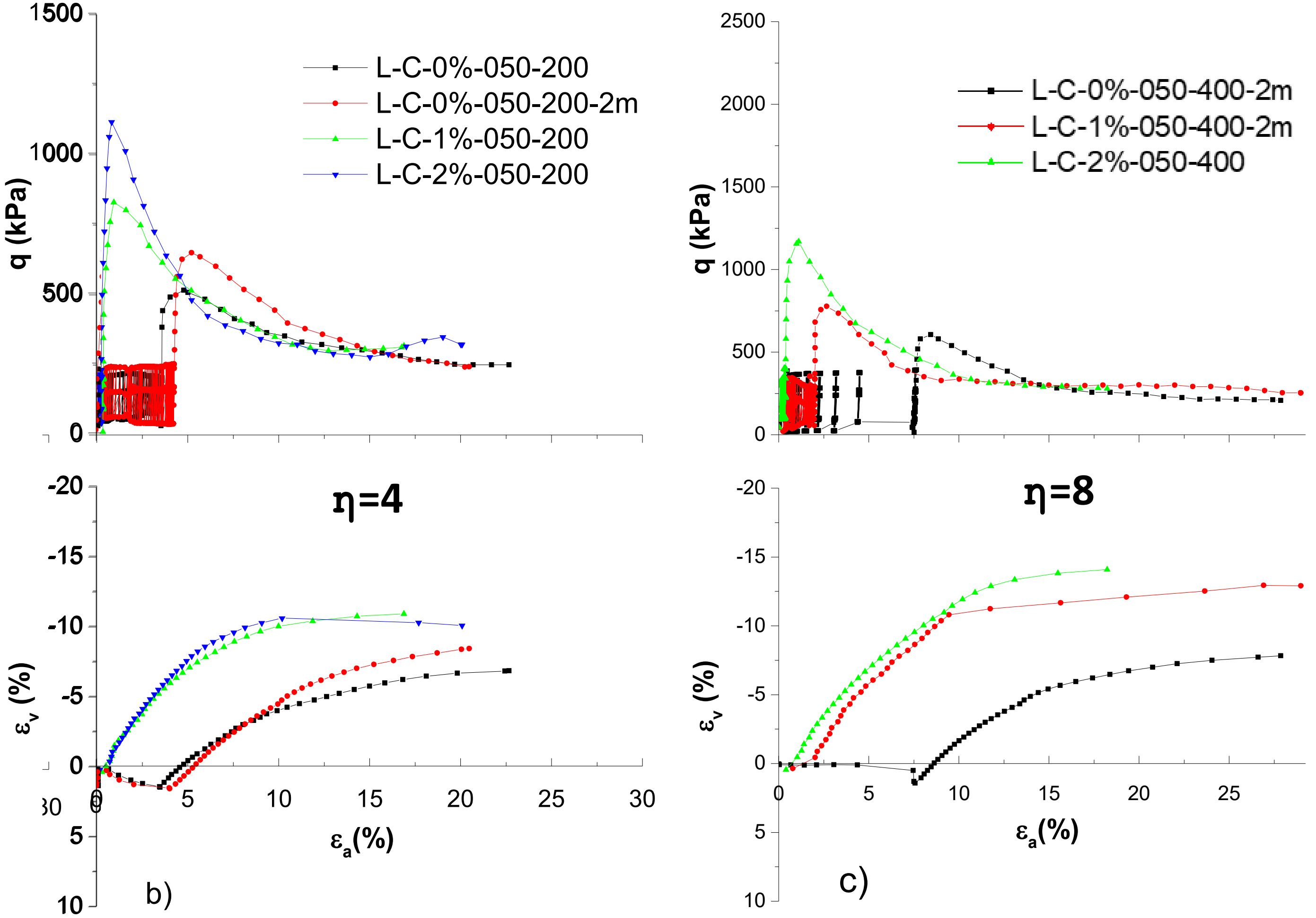
Critical State Line

- Localisation occurred in some of the low stress tests
- It is possible to estimate a CSL for the samples.
- Slope seems to be controlled by the addition of cement
- Cemented and uncemented seem to join at a larger stresses.



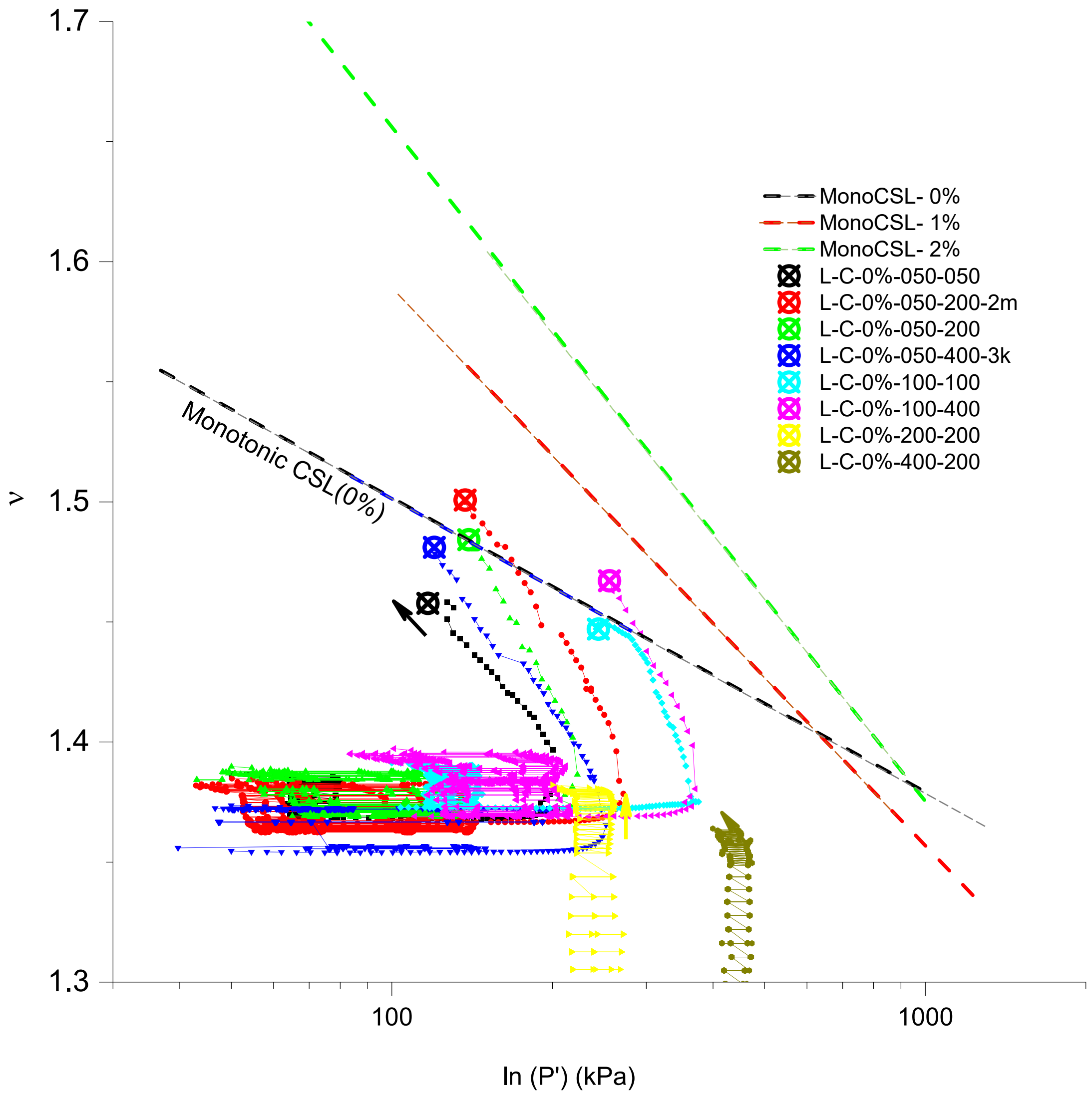
Cyclic and monotonic shearing comparison

- $\eta = \frac{q_{max}}{\sigma_3'}$
- Not all tests are shown here!
- Cemented samples are not affected by η=4
- η=8 affects samples with 1% cement.
- As the stress ratio increases the vertical strain increases
- Addition of cement reduce the effect of stress ratio



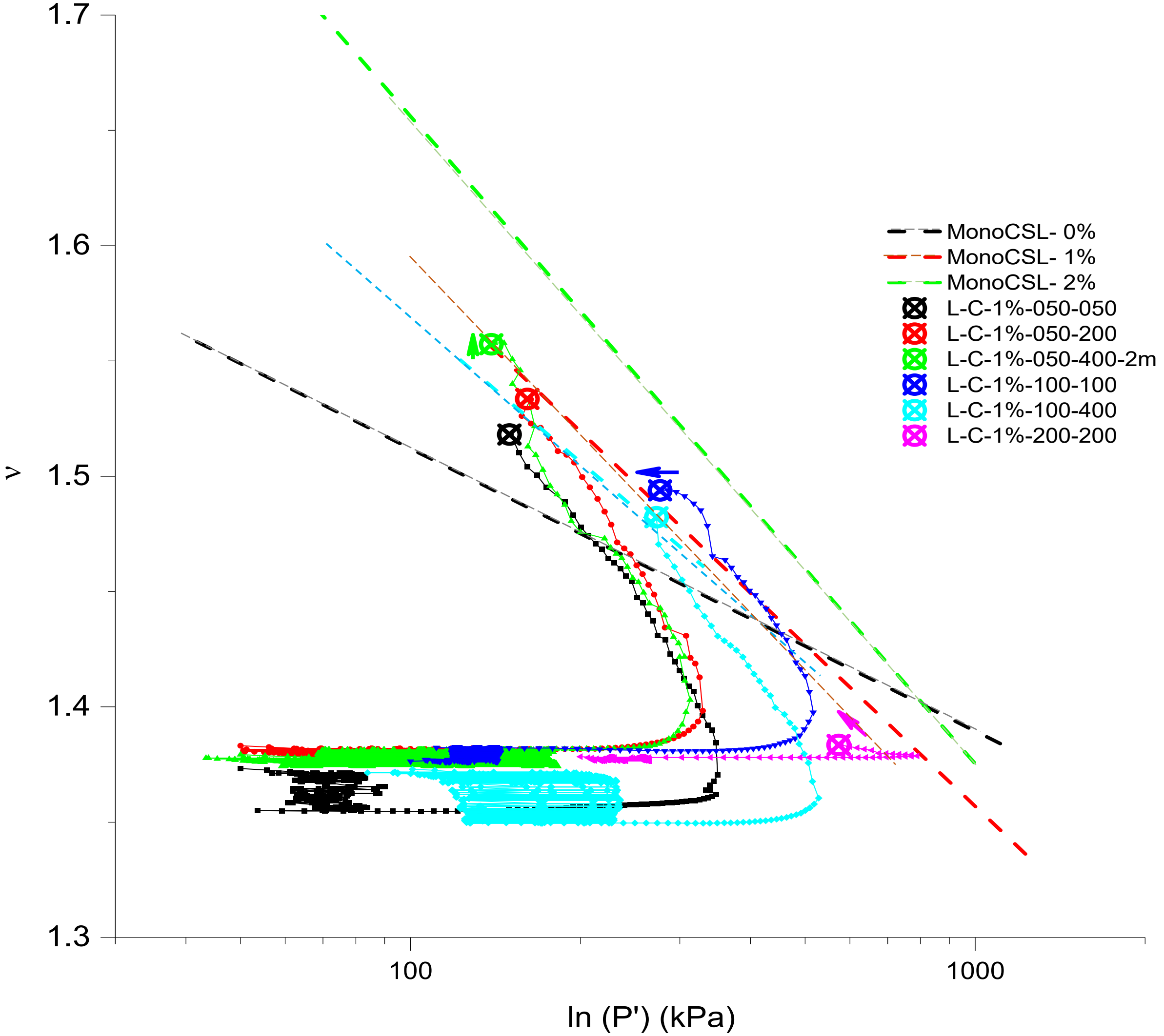
CSL - uncemented

- Tests 200-200 and 400-200 had punctures in the membrane and should be discarded
- Cyclic and monotonic uncemented seem to match the monotonic CSL with a wider scatter.
- No influence of stress ratio



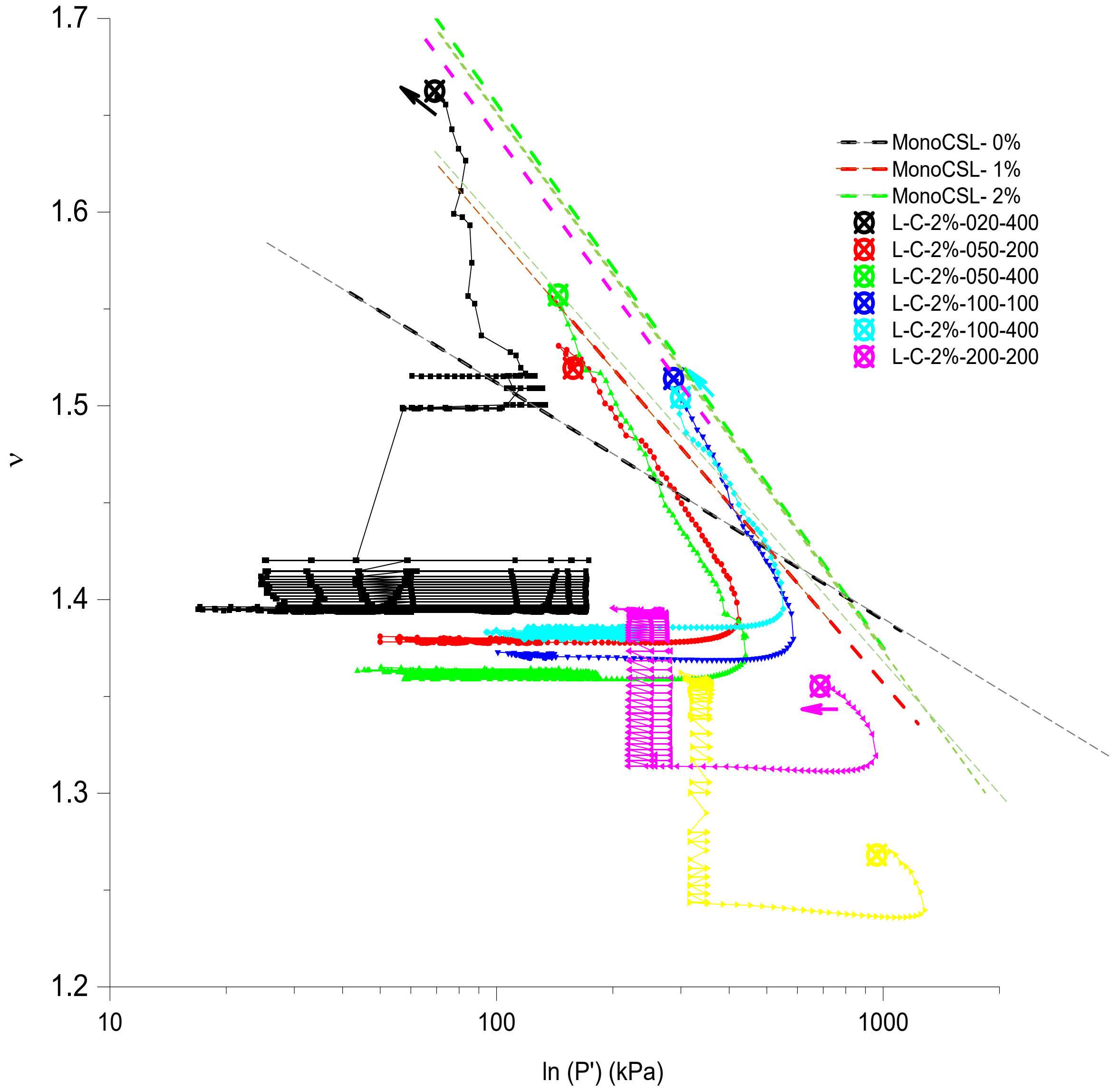
CSL – 1% cement

- Slightly below the CSL determined for the monotonic tests – influence of the number of cycles in the bonding.
- It appears that the stress ratio does not influence the location of the CSL



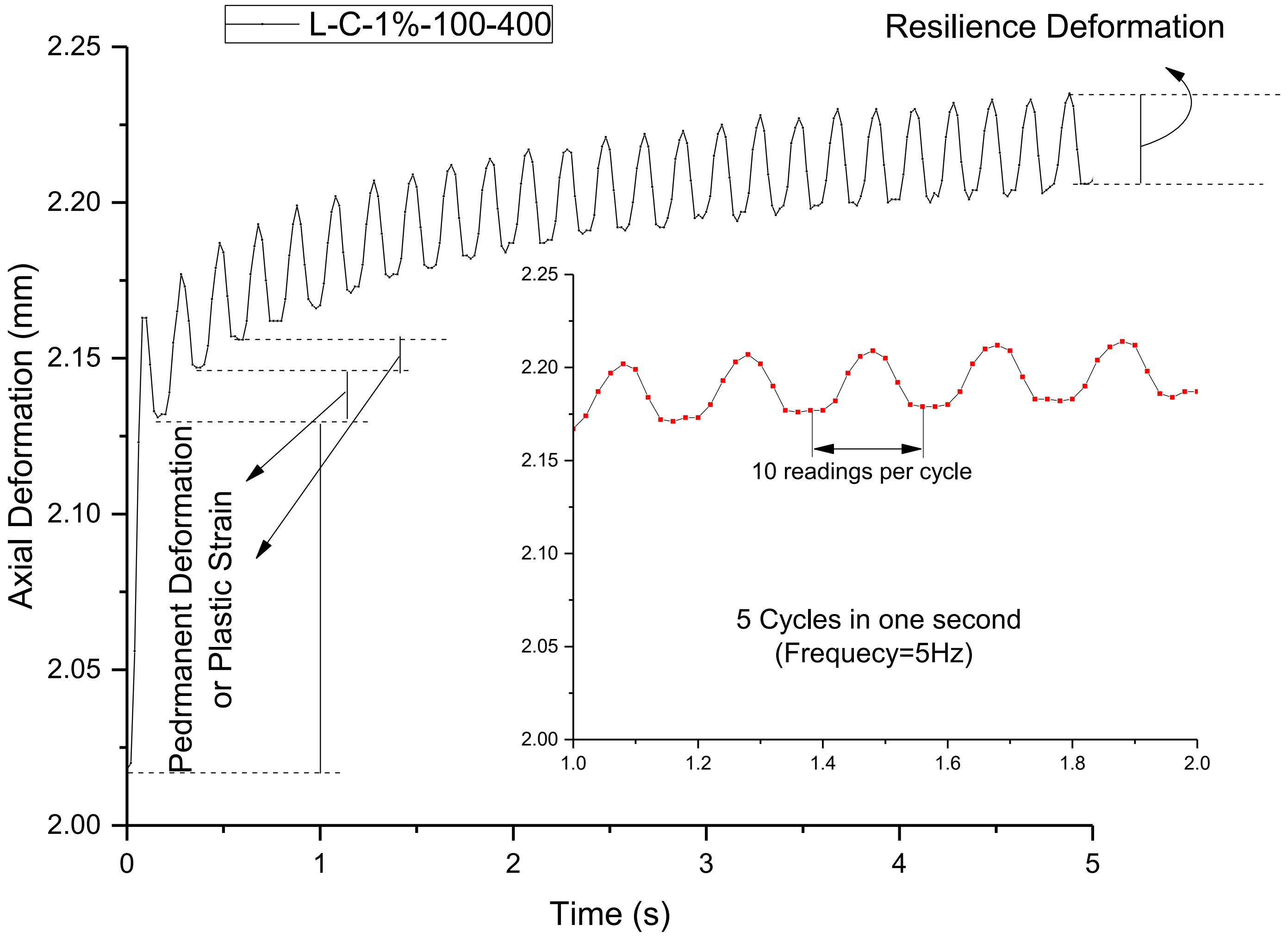
CSL – 2% cement

- Disregard yellow and magenta tests – membrane pucture.
- Clearly below the CSL defined for the monotonic tests.
- It is likely that the bonding is damaged by the cyclic loading.



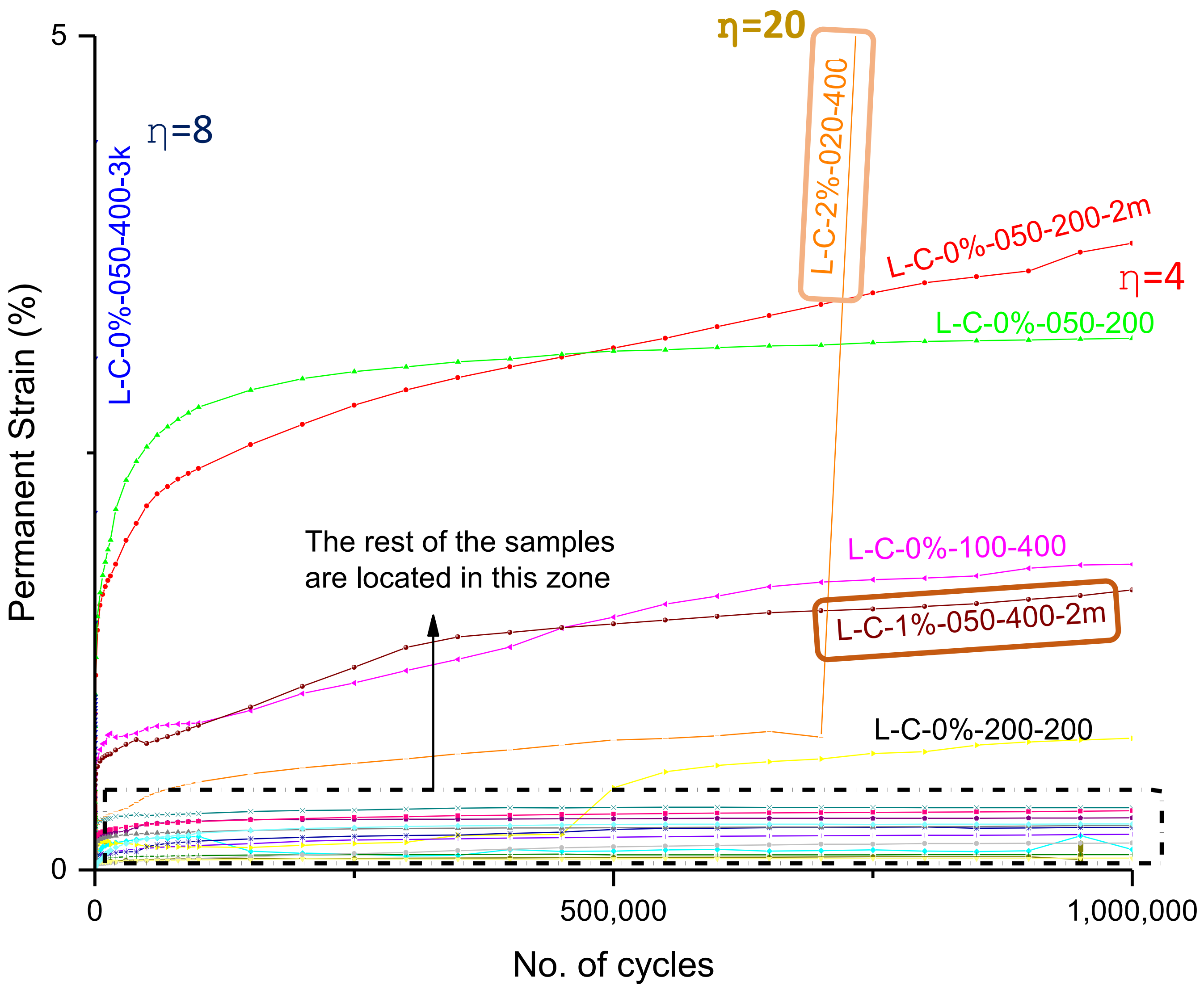
Cyclic loads

- To evaluate the evolution of irreversible deformations



Permanent strain

- All cemented samples have displayed permanent strains lower than 0.5%, with the exception of the ones tested at η=8 for 1% and η=20 for 2% cement.
- Uncemented samples show larger permanent strains apart for η=1



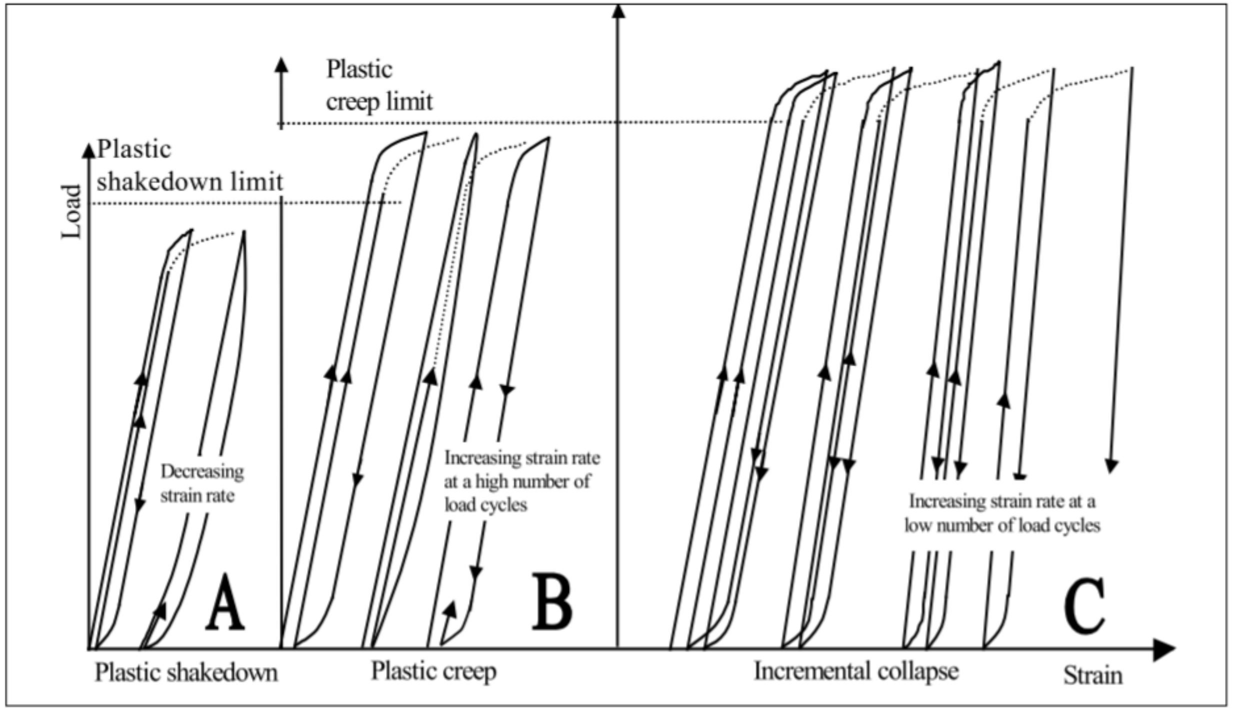
Shakedown

- Werkmeister et al. 2001 – Idealised behaviour of granular materials under repeated cyclic loads based on observation.
- Range A:
- Plastic Shake down: decreasing strain rate
- Range B:
- Plastic creep limit: increasing strain

rate at a higher number of cycles

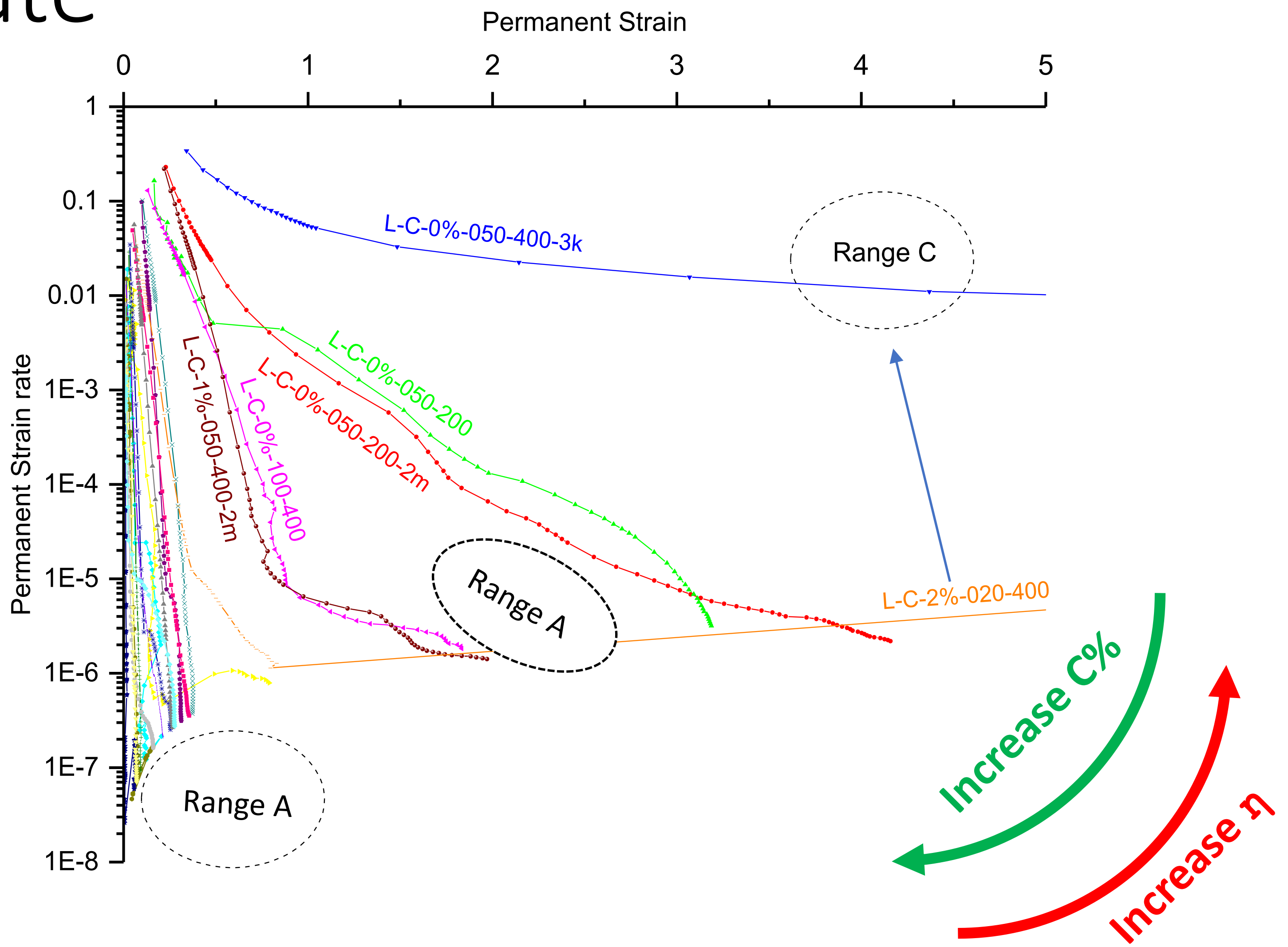
- Range C:
- Incremental Collapse, increasing strain

rate at a lower number of cycles



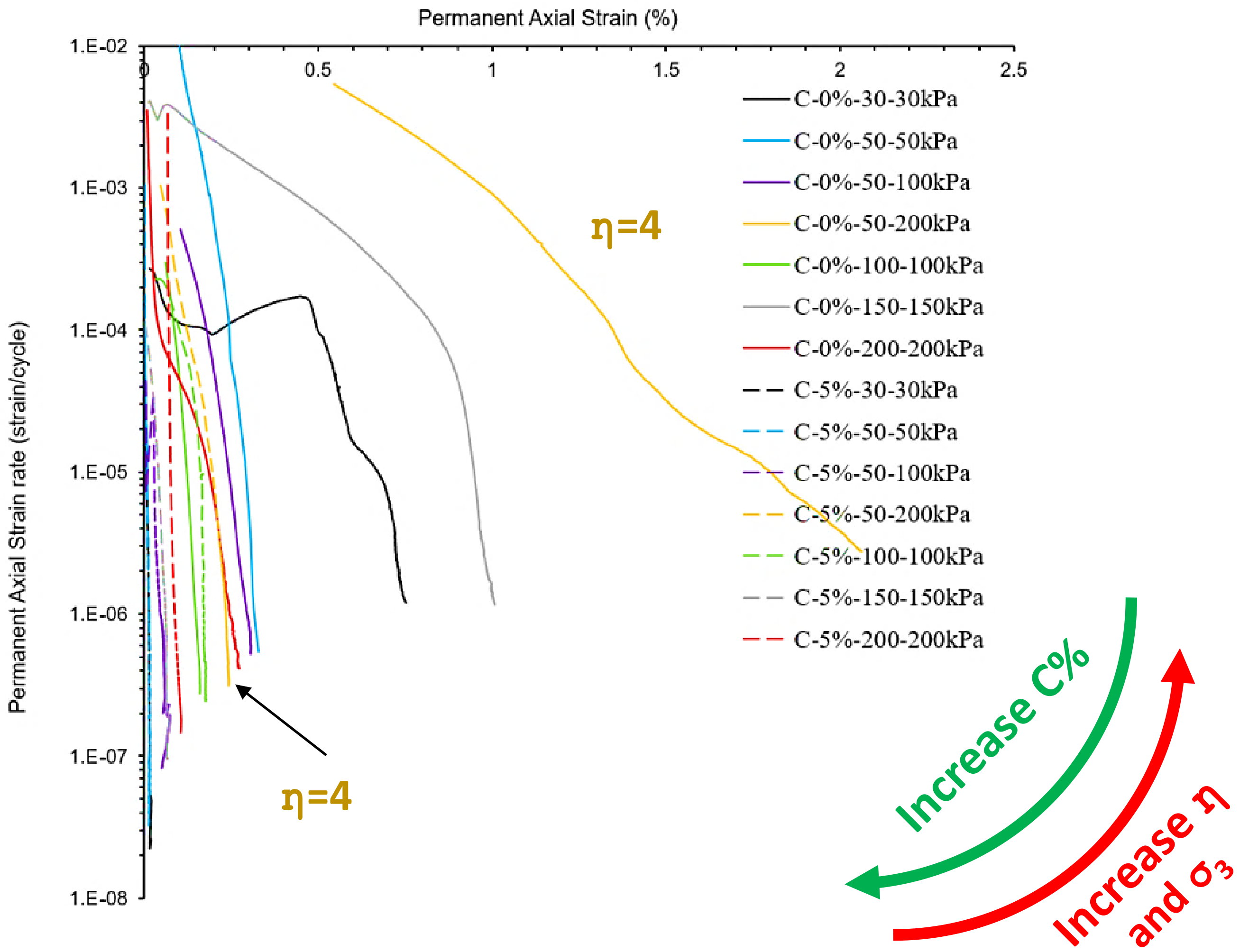
Permanent strain rate

- Increasing the stress ratio increase the permanent strain rate and the permanent strain. Moving the sample towards range C
- Increasing the cement ratio reduce permanent strain rates and consequently the permanent strain – Moving the behaviour towards range A



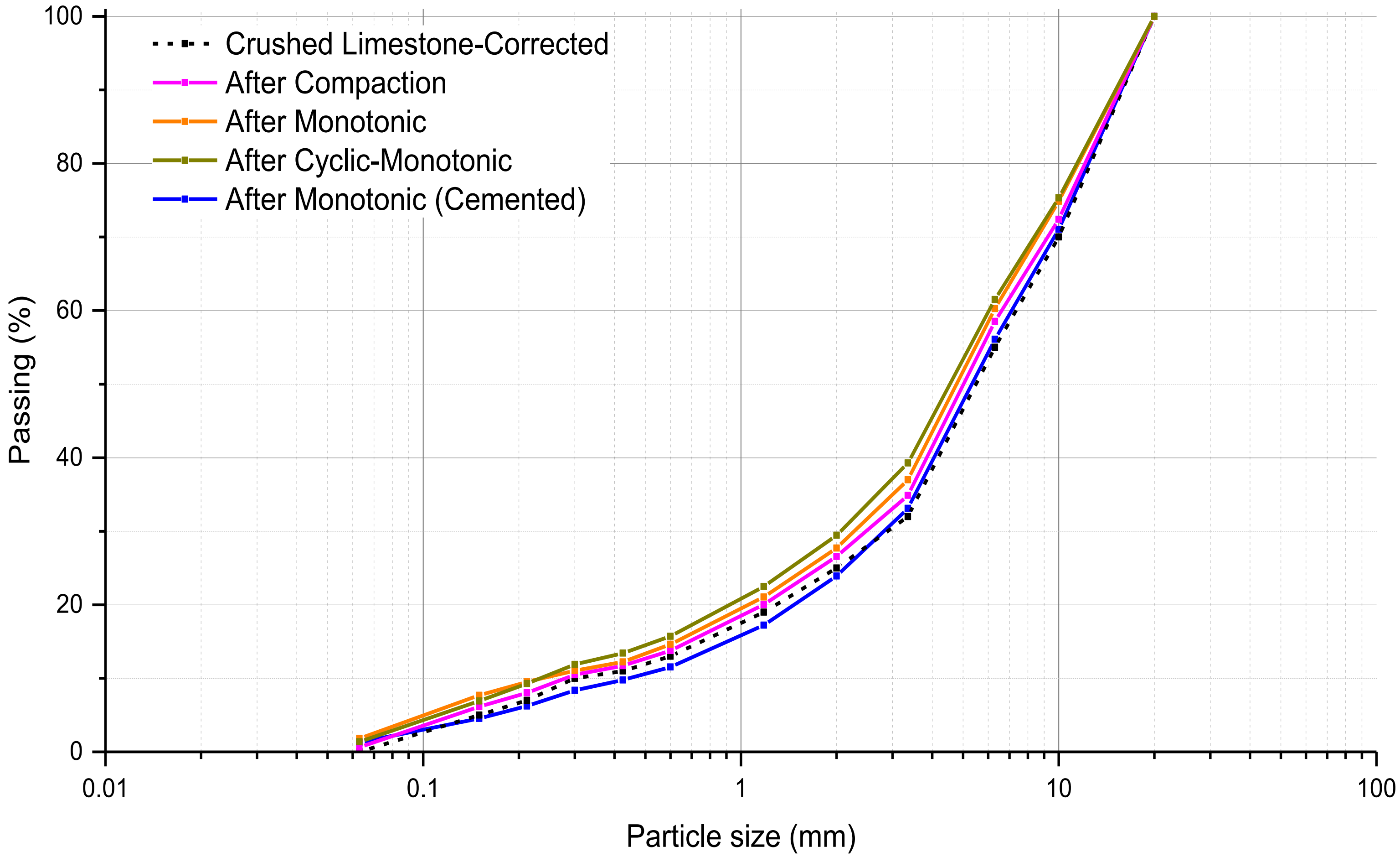
Permanent strain rate- Ballast

- Similar to the base results:
- Increase C% the curve moves towards Range A
- Increase η the curve moves towards Range C
- Increasing confining stresses increase the permanent strain rate



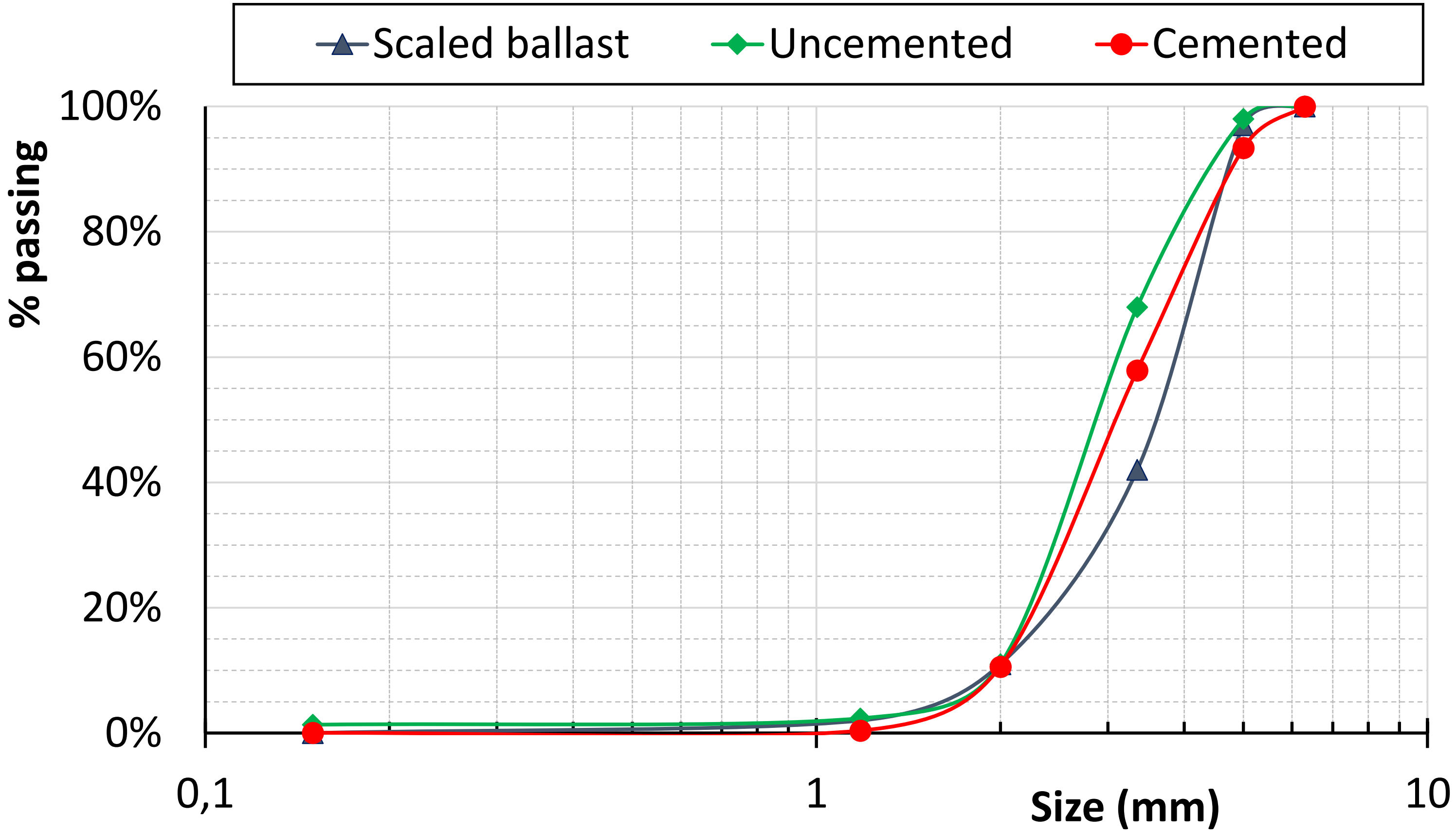
Breakage – base material

- Uncemented samples:
  - After compaction
  - After shearing
- Cemented samples
  - Show a coarser grain size distribution
  - Existence of clusters of bonded particles after shearing



Breakage - Ballast

- Ballast presented slightly more breakage than the base material
- Uncemented sample:
  - generated fines (1.3% passing 0.15)
- Cemented sample
  - Difficult to disaggregate
  - Finer particles still cemented to larger ones.
  - Generated a small amount of fines (0.03% passing 0.15)

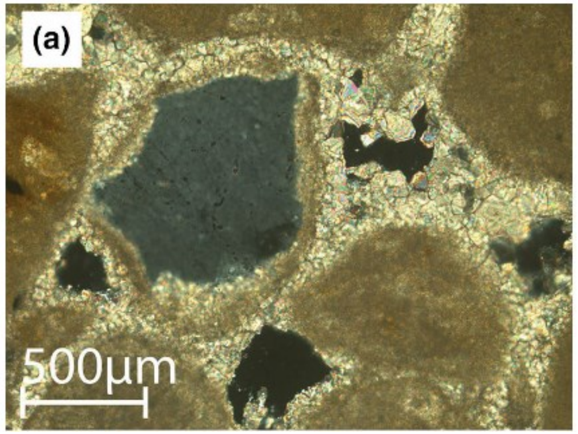


Conclusions

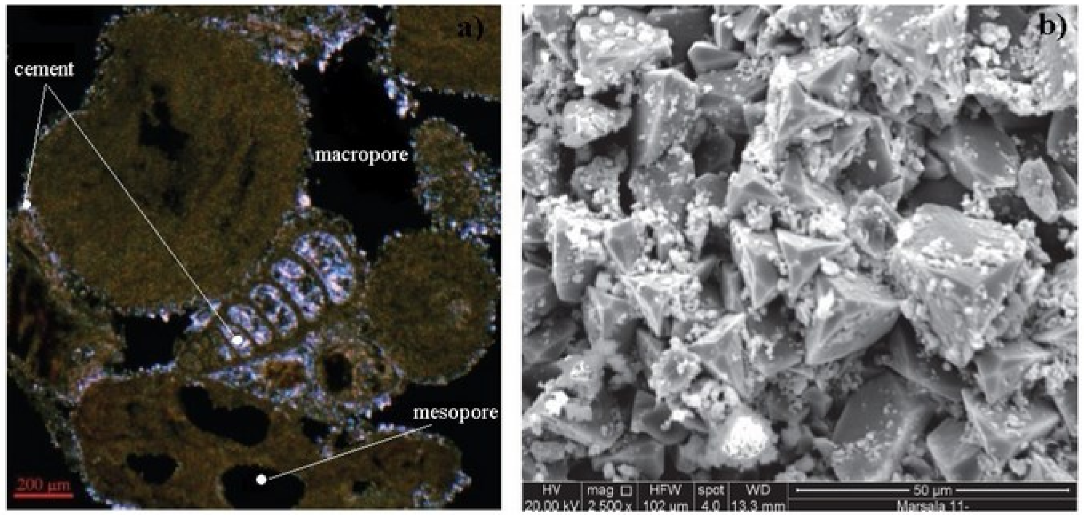
- The addition of small percentages of cement to well graded dense granular materials increase dramatically the strength and the stiffness, however it is a light bonding and slowly eroded by increasing confining stresses.
- CSL of the cemented samples is steeper than the uncemented
- CSL of the cemented samples converge towards the CSL of the uncemented samples.
- Nor the cyclic load or the stress ratio affect the location of the CSL for the uncemented soil.
- After cyclic loading, the cemented samples terminated below the CSL determined by the monotonic tests.
- It is clear that the use of small percentages of cement in base/subbase is beneficial to bring these materials to the safer Range A - decreasing strain rate.
- Breakage seems to show that the addition of cement produces less fines in both materials. Perhaps reducing fine production due to attrition in ballast?

Thank you to Mohamad Reza Rezaeian and Rozhin Soheili

Calcarenite from the catacombs of Kom-ash Suqqafa, Alexandria
Hemeda (2020)



Calcarenites deposits of the Kyrenia (Girne) Terrace
Palamakumbura et.al. (2016)



Marsala Calcarenites, Sicily
Zimbardo et al. (2022)

Thank you!

References

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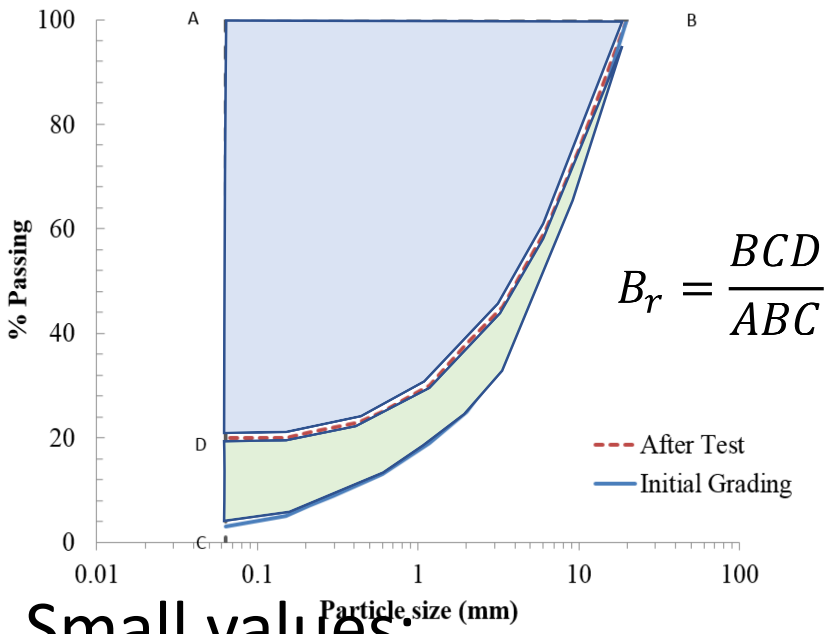
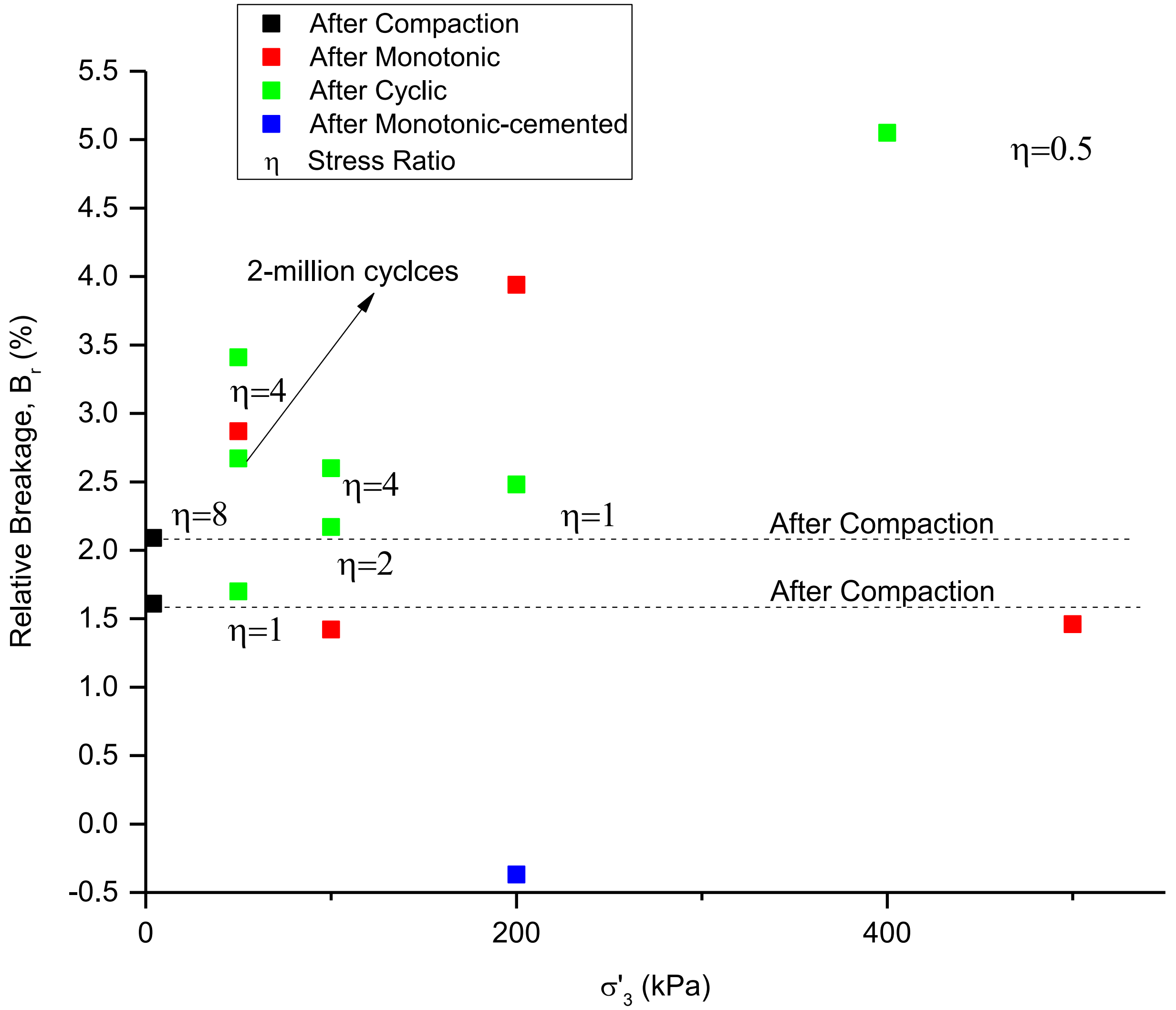
Breakage

- Quantified using Hardin (1985)



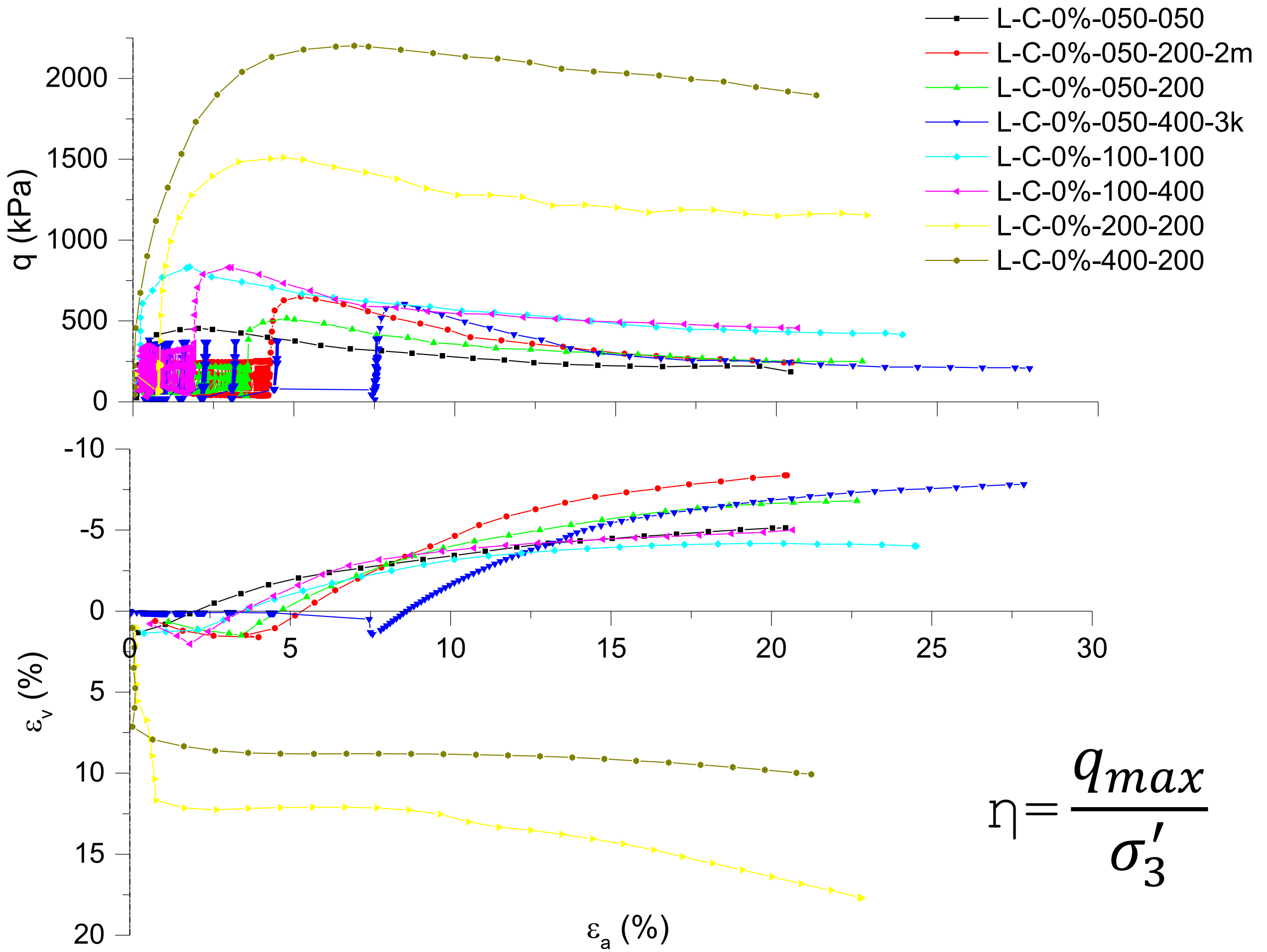
$$B_r = \frac{BCD}{ABC}$$

- Small values:
  - Dog's bay sand between 10 and 40%



Cyclic and monotonic shearing – 0% cement

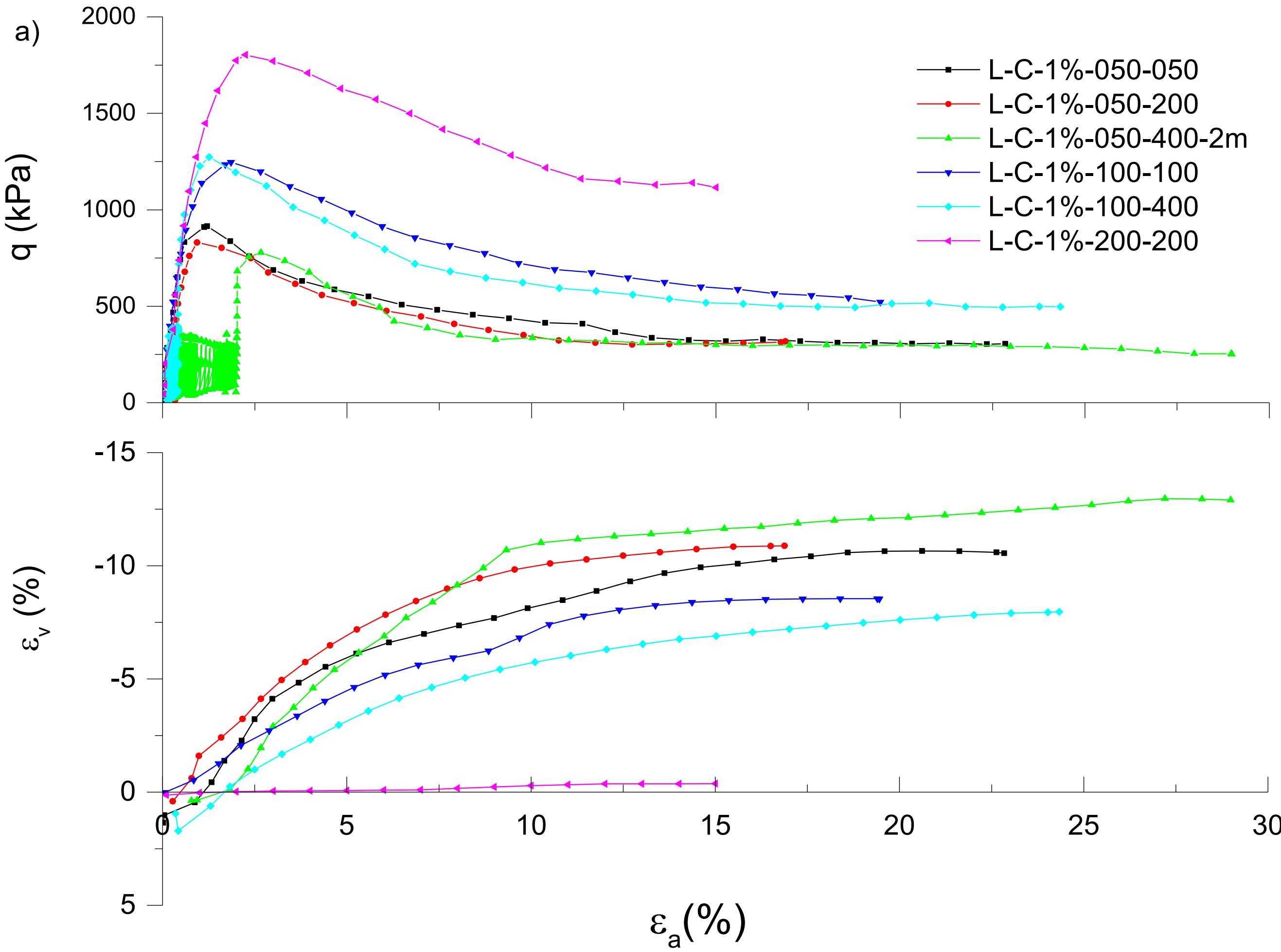
- The higher the stress ratio (η) the higher is the vertical strain
- Large vertical strains were measured for η=4, (3 tests magenta, red and green)
- Excessive strains found for η=8, 7.5% in 3k cycles (blue)
- In all tests, densification was measured during cyclic loading



$$\eta = \frac{q_{max}}{\sigma_3'}$$

Cyclic and monotonic shearing – 1% cement

- Much smaller axial strains than uncemented and very small influence of η<4
- Less than 2.5% vertical strains were measured for η=8 (7.5% in 3k cycles for 0%)
- Same confining stress and η=4, similar monotonic behaviour (negligible strains)
- η=8 lowest peak strength during monotonic loading for 50kPa tests.



Cyclic and monotonic shearing – 2% cement

- The lowest axial strains from all samples tested
- Much smaller axial strains than uncemented and very small influence of η<8
- Less than 1% vertical strain was measured for η=8 (2.5% for 1% cement and 7.5% in 3k cycles for 0%)
- Up to η=8, similar monotonic behaviour.
- η=20 at 20kPa excessive deformations during cyclic behaviour.