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What can Particle size distribution tell us about soil fabric?

James Leak, Daniel Barreto & Vasiliki Dimitriadi

18th UK Travelling Workshop – Geo-Mechanics: from Micro to Macro

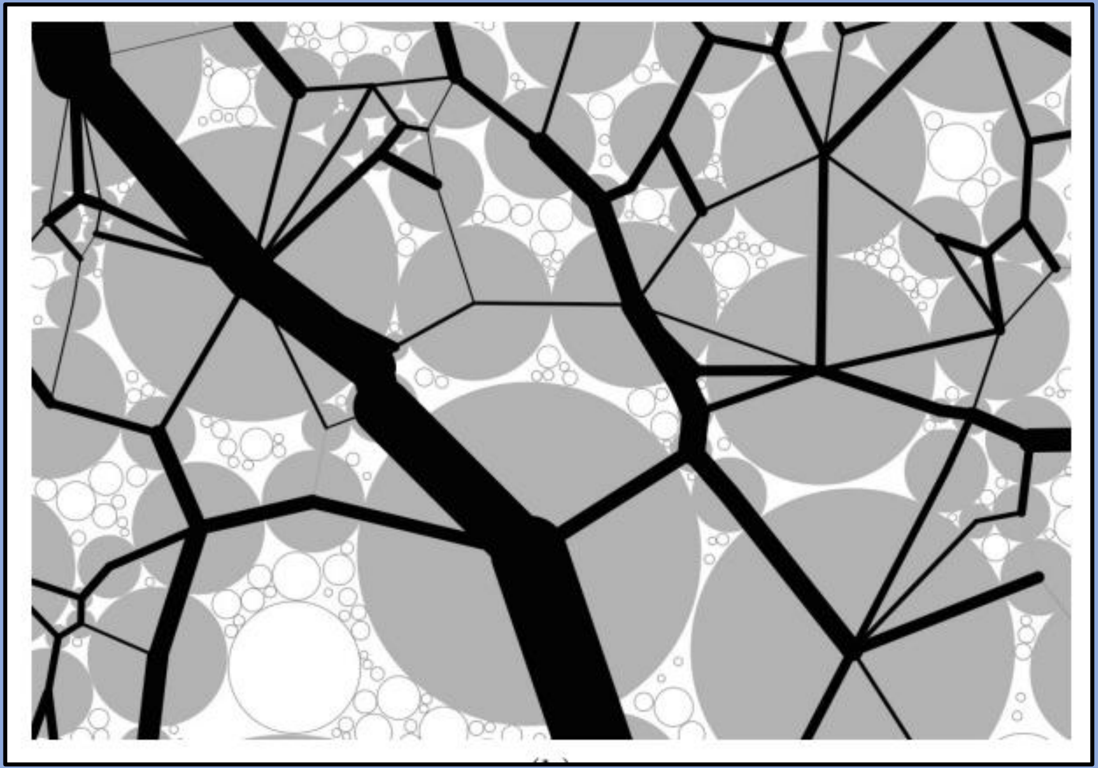
PSD & Fabric

Radjai et al. (1998) observed that forces are (generally) transmitted via fabric in two ways:

- **Strong** (vertically orientated) force chains
- **Weak** (orthogonally supporting) force chains

Voivret et al. (2009) found that:

- **Larger** grains transmit strong force chains
- **Smaller** grains transmit weak(er) supporting force chains

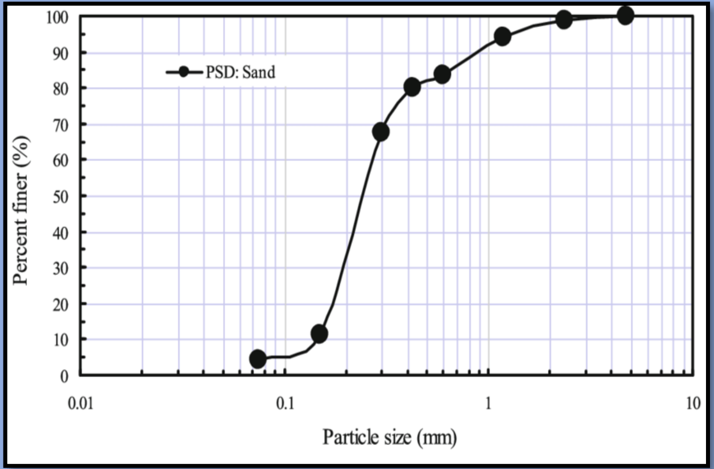


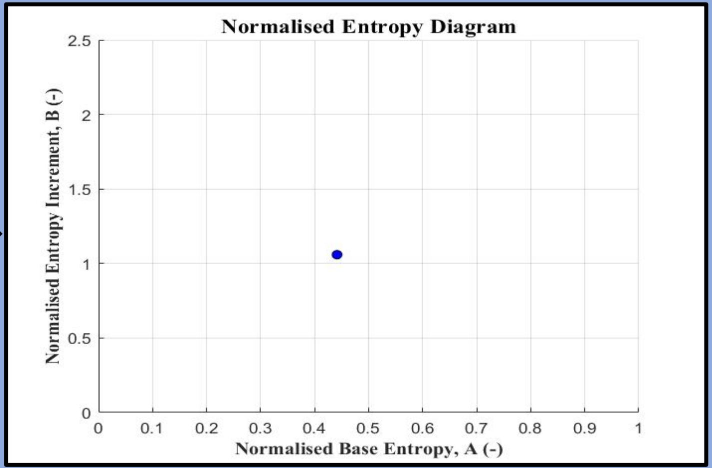
A polydisperse PSD. Larger grains transmit vertically aligned (strong) force chains, & smaller grains facilitate orthogonally aligned (weak) force chains. From Voivret et al. (2009)

Grading Entropy

Proposed by Lőrincz (1986),

- Grading curve is ‘condensed’ to a single point via the sum of the grading entropy of each sieve fraction
- **Normalised base entropy** $'A'$ describes the mean particle diameter (skewness/symmetry)
- **Normalised entropy increment ‘B**’ is a measure of fraction variety in a PSD (kurtosis)





$$S = \Delta S + S_0$$

Total grading curve Entropy

Entropy Increment (y-axis)

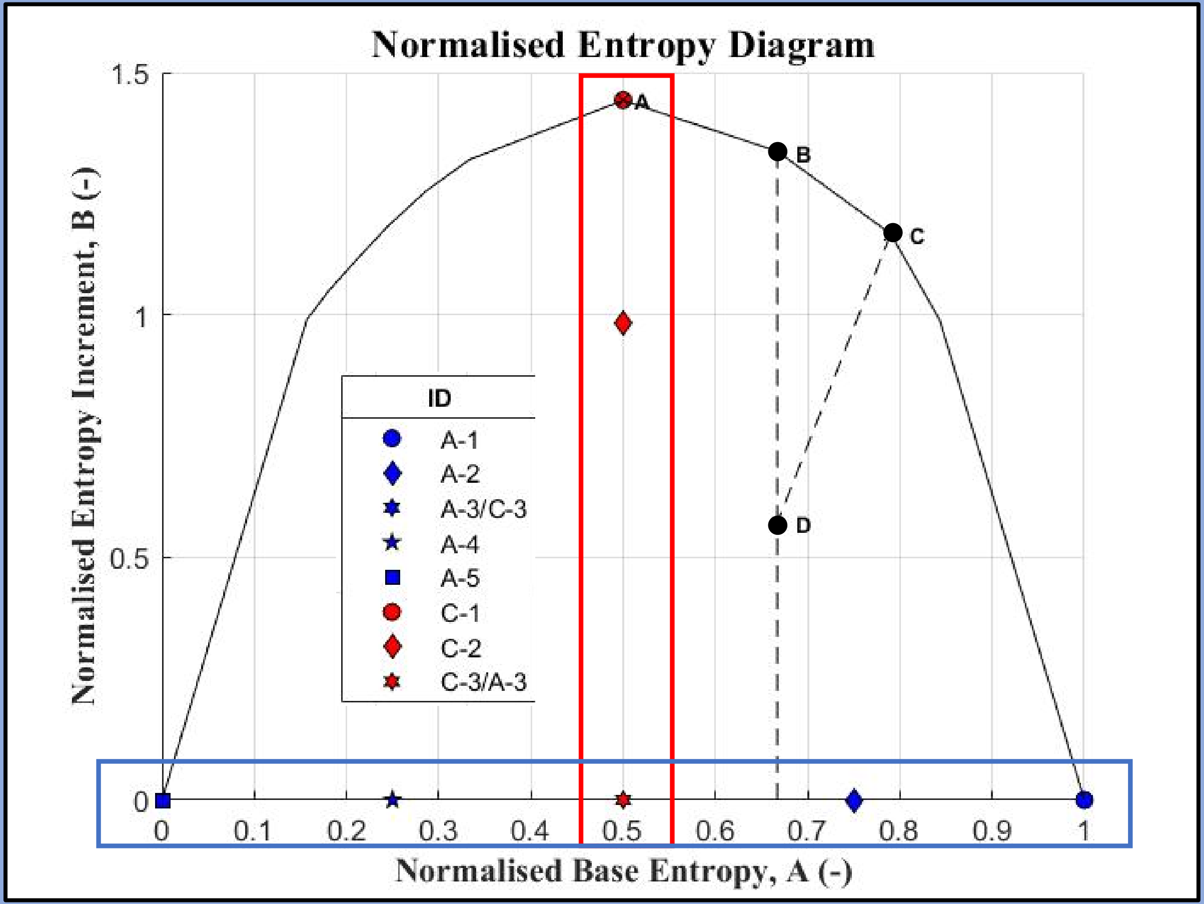
Base Entropy (x-axis)

$$A = \frac{S_0 - S_{0min}}{S_{0max} - S_{0min}}$$

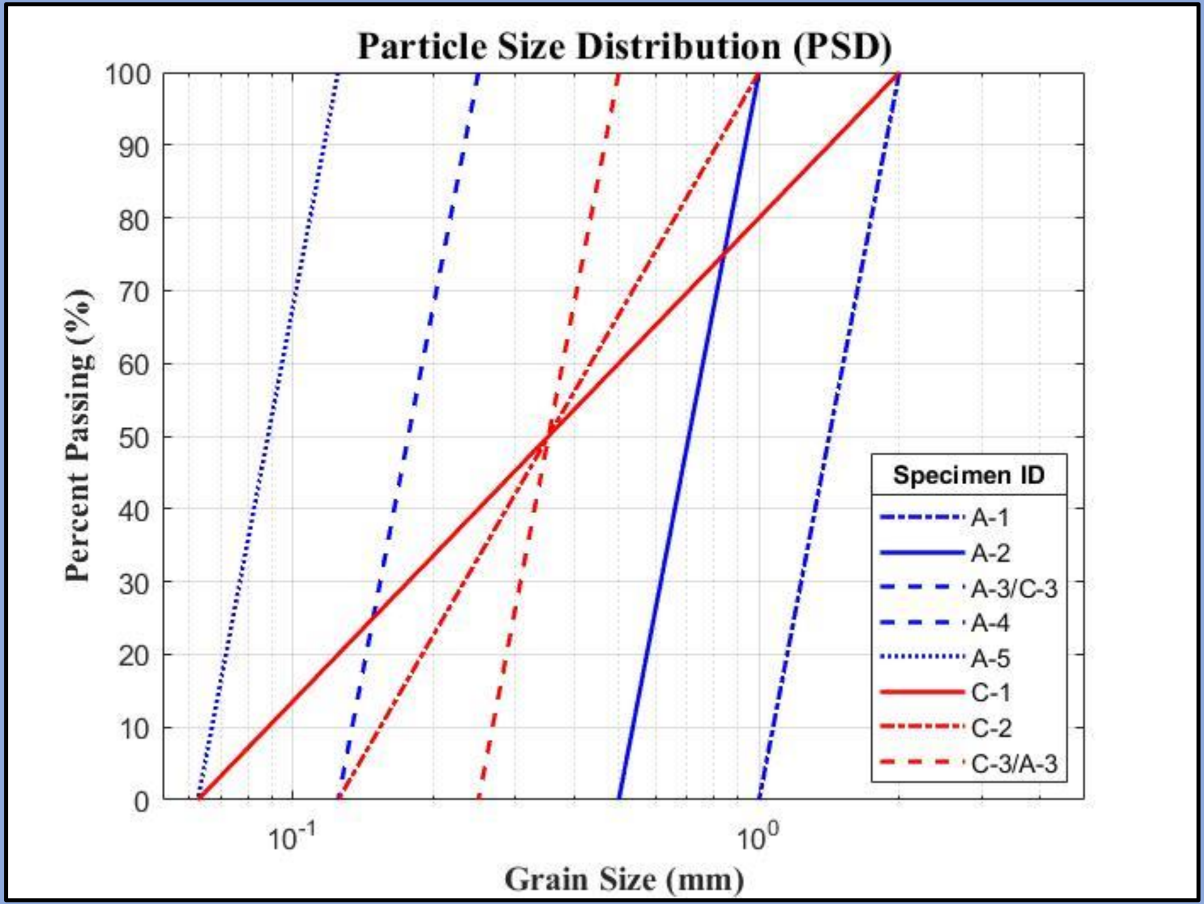
$$B = \frac{\Delta S}{ln(N)}$$

Number of fractions

PSDs & Normalised Entropy Diagram



a)



b)

a) PSDs from groups A & C on a normalised entropy diagram **b)** Grain size distributions for groups A and C

Simulation Overview

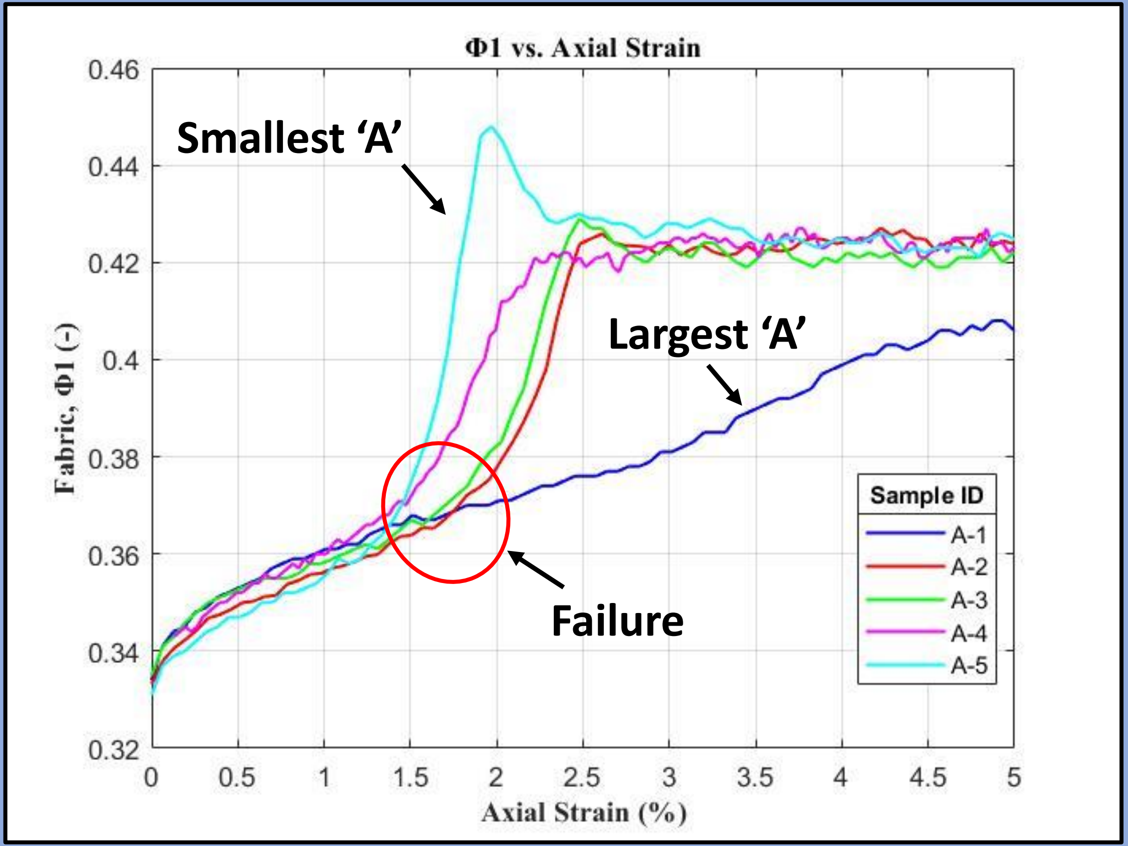
- YADE
- 10 000 spherical particles (randomly generated)
- Isotropically compressed
- Undrained (constant volume)
- Loose specimens (to initiate liquefaction)
- Φ_1 , major principal fabric (**strong force chains**)
- Φ_3 , minor principal fabric (**weak force chains**)

Confining Stress	200 kPa
Poisson's ratio (*v*)	0.22
Particle density (*ρ*)	2650 kg/m^3
Angle of inter-particle friction (*μ*)	26.6
Young's Modulus	70 GPa
Unbalanced force ratio criterion	0.0001

$$\boldsymbol{\Phi_d = \Phi_1 - \Phi_3}$$

$$\Phi_{ij} = \frac{1}{N_c}\sum_{k=1}^{N_c} n_i^k n_j^k$$

Fabric analysis, group A (changing A-coordinate, constant B-coordinate, B=0)



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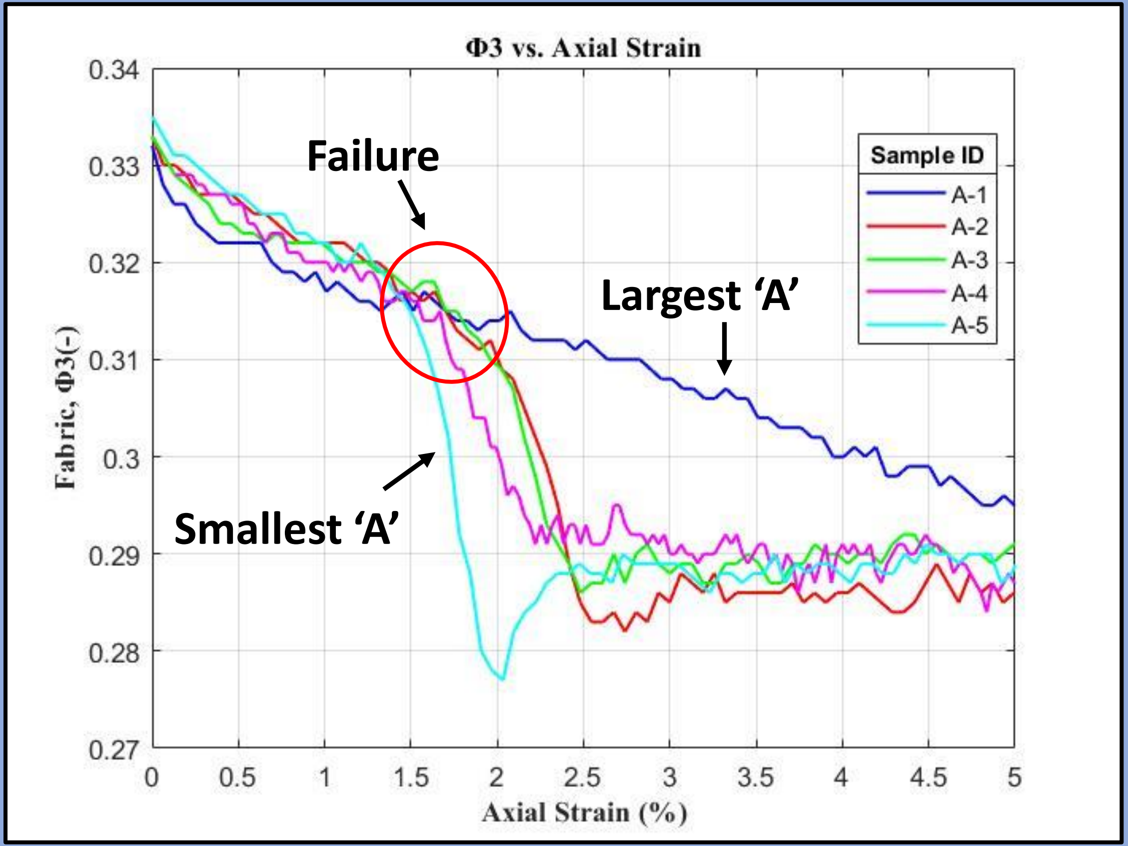
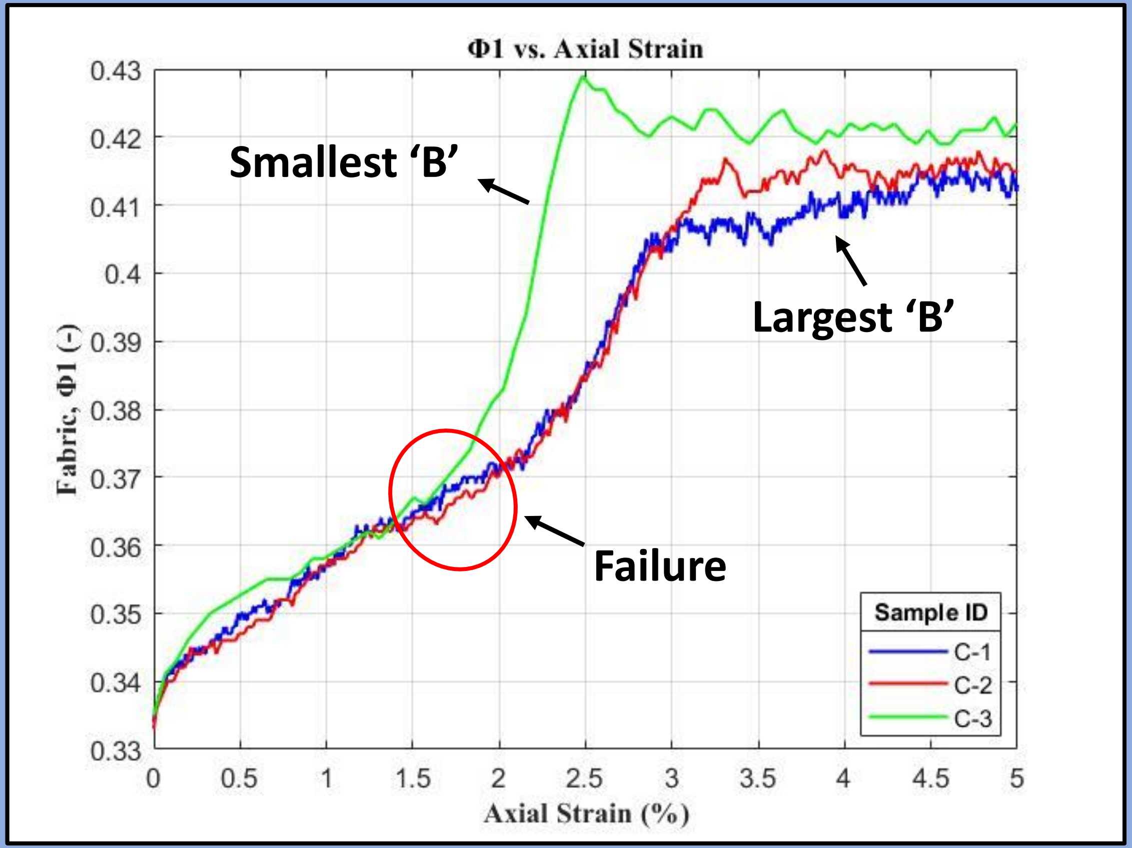


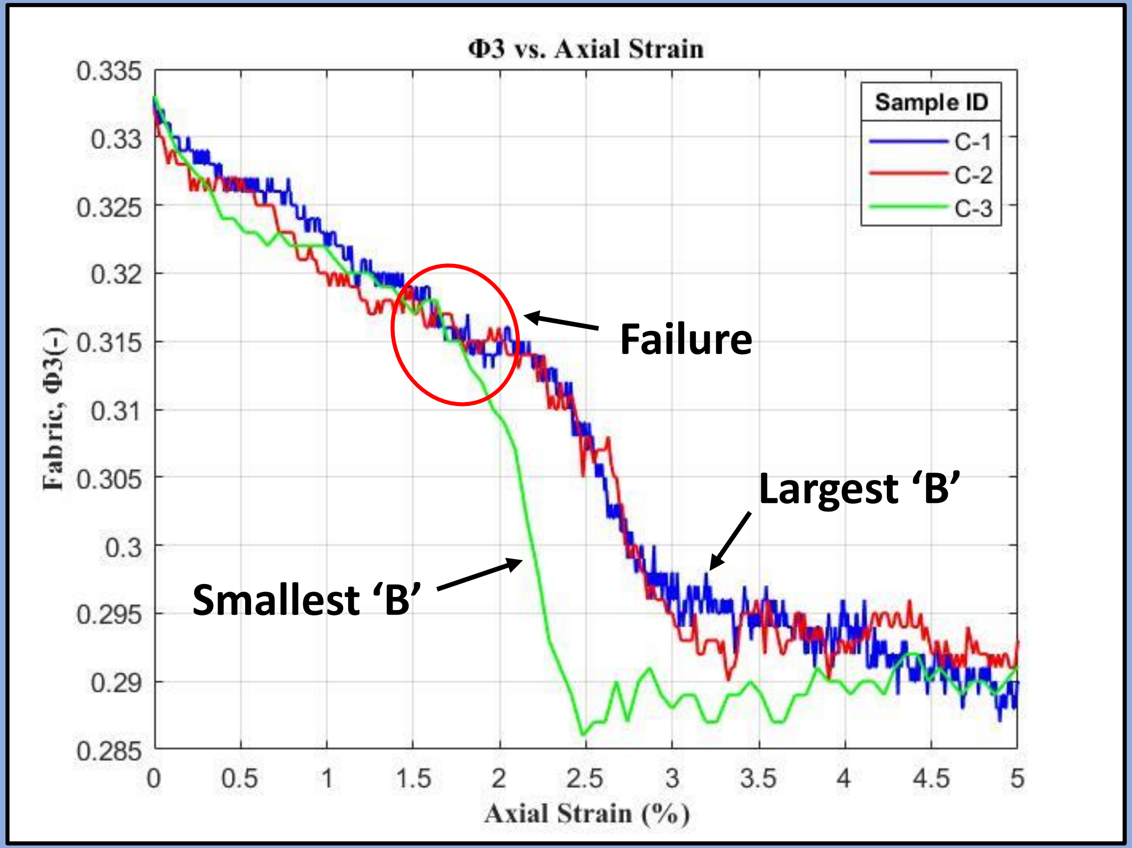
b)

a) Value of the major principal fabric (Φ_1) for Group A **b)** value of the minor principal fabric (Φ_3) for Group A

Fabric analysis, group C (changing B-coordinate, constant A-coordinate, A=0.5)



a)

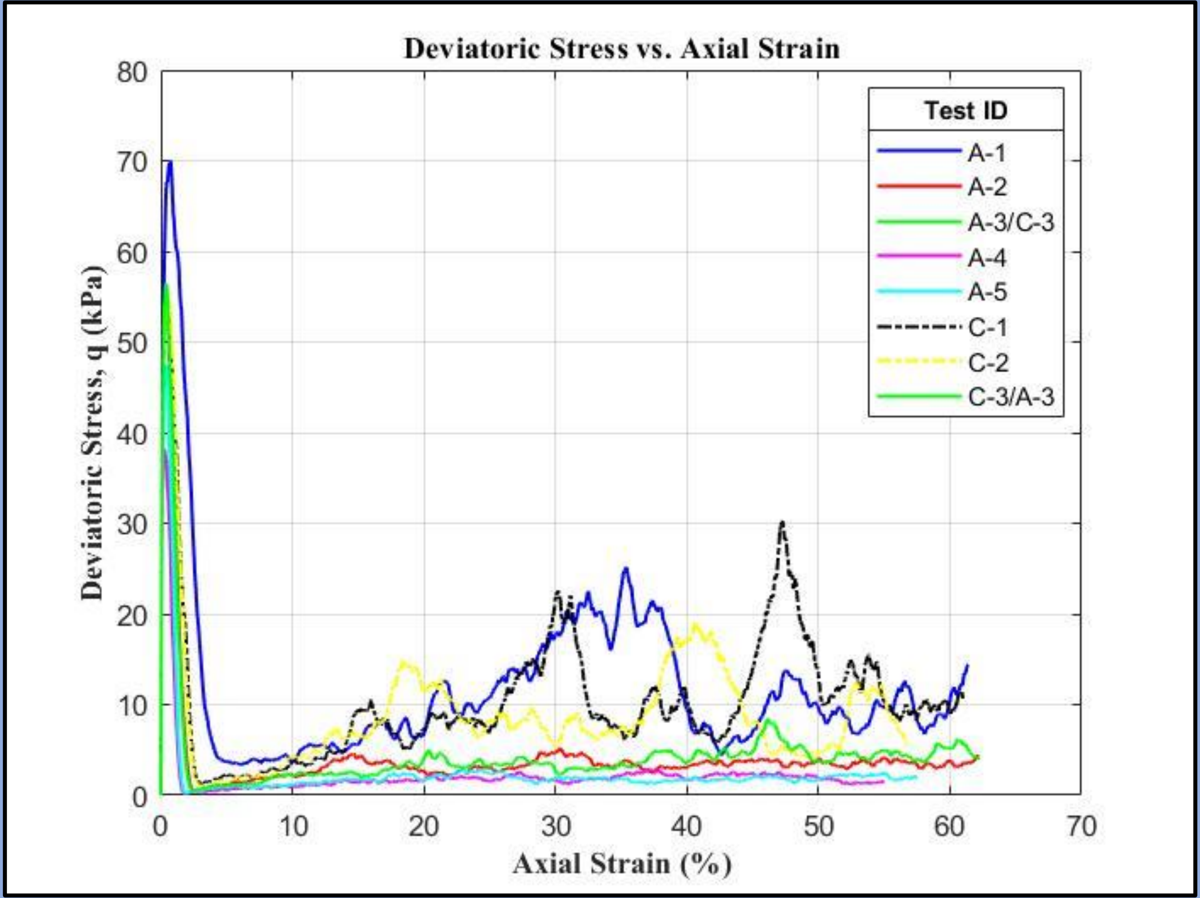


b)

a) Value of the major principal fabric (Φ_1) for Group C **b)** value of the minor principal fabric (Φ_3) for Group C

Conclusions

- Larger A-coordinates facilitated more **strong force chains** prior to failure (i.e. greater Φ_1). Subsequently, a greater proportion of the stress distribution was then taken by orthogonally orientated weak force chains.
- B-coordinate was associated with increasing contact variety and the formation of **weak force chains** (i.e. greater Φ_3). Contributing to the stability of the strong force chains.
- Specimens with greater proportions of A and B exhibited more stable tendencies post failure.



Deviatoric stress plotted with axial (shear) strain up to termination. Greater stability is associated with greater values of A and B.

Contributing Researchers

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Thank you

If you have any questions, I am happy to answer them

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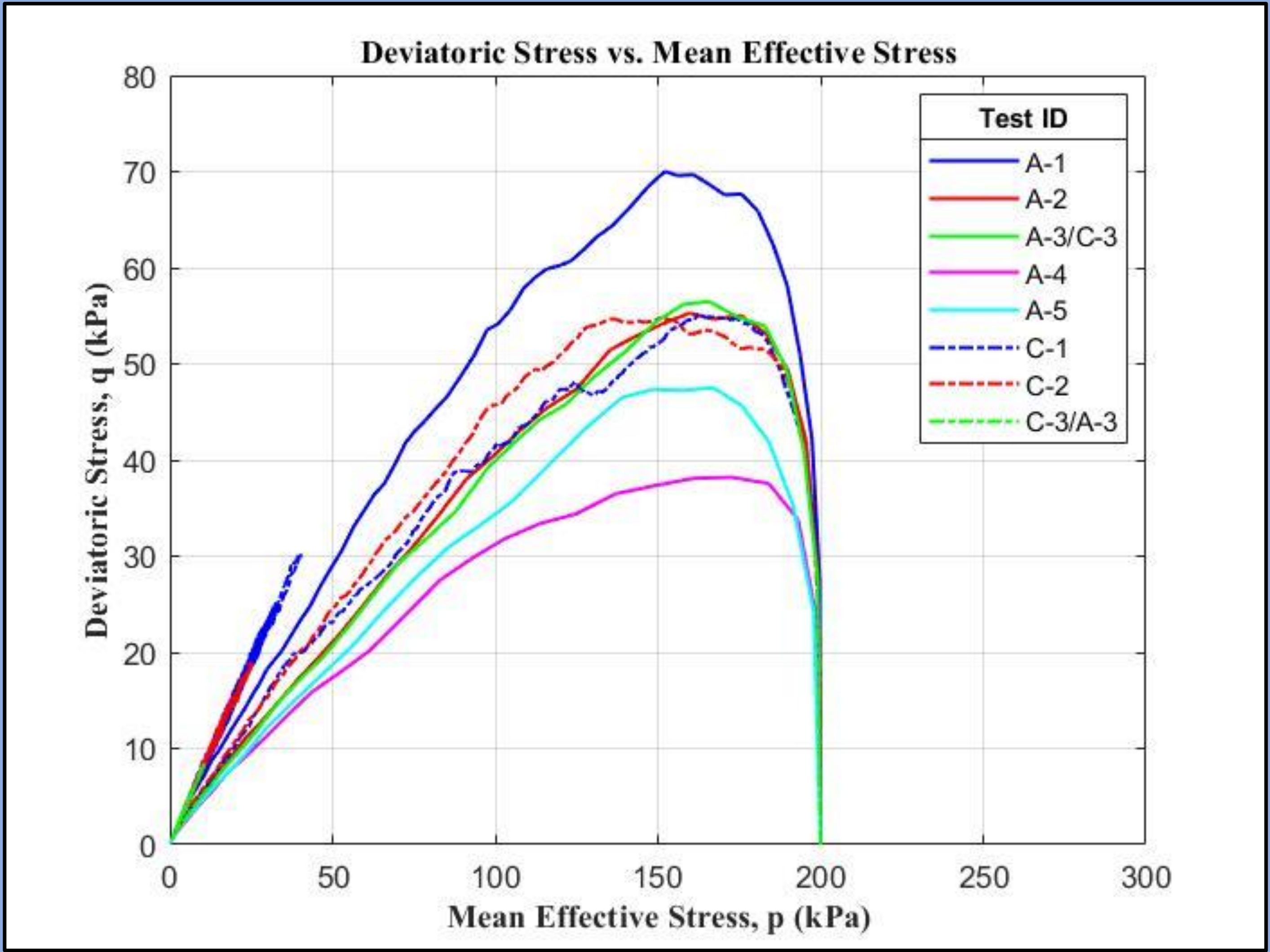
PSD ranges

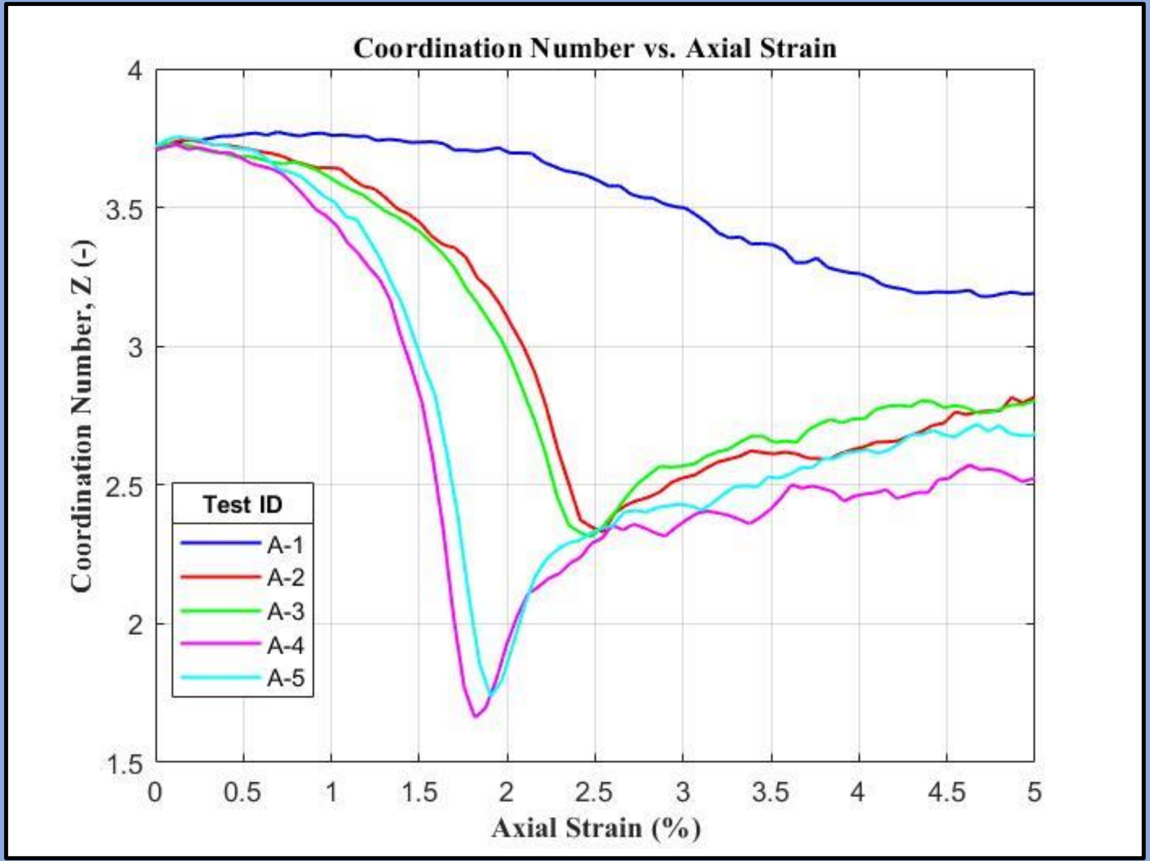
ID	PSD range (mm)	A (-)	B (-)
A-1	1-2	1	0
A-2	0.5-1	0.75	0
A-3	0.25-0.5	0.5	0
A-4	0.125-0.25	0.25	0
A-5	0.0625-0.125	0	0

ID	PSD range (mm)	A (-)	B (-)
C-1	0.0625-2	0.5	1.442
C-2	0.125-1	0.5	0.984
C-3	0.25-0.5	0.5	0

Macroscale response, q-p’



Coordination numbers, Group A



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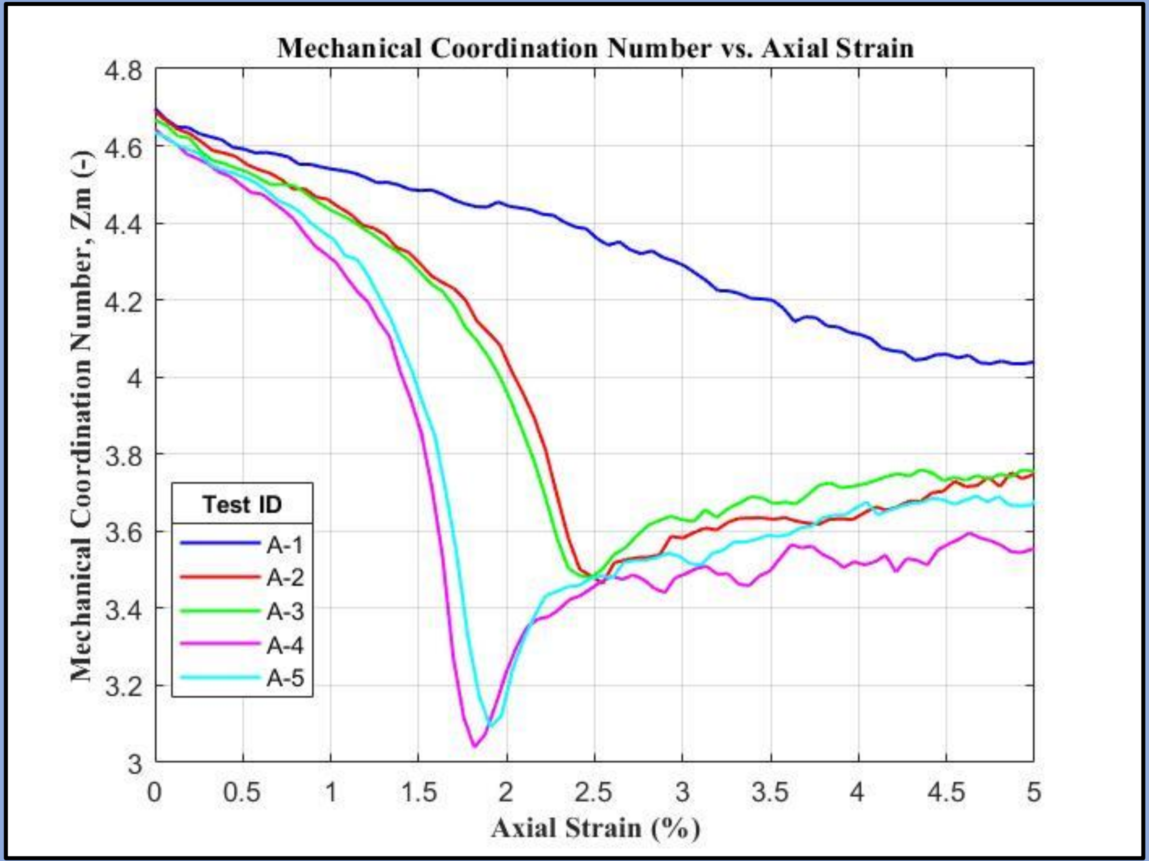
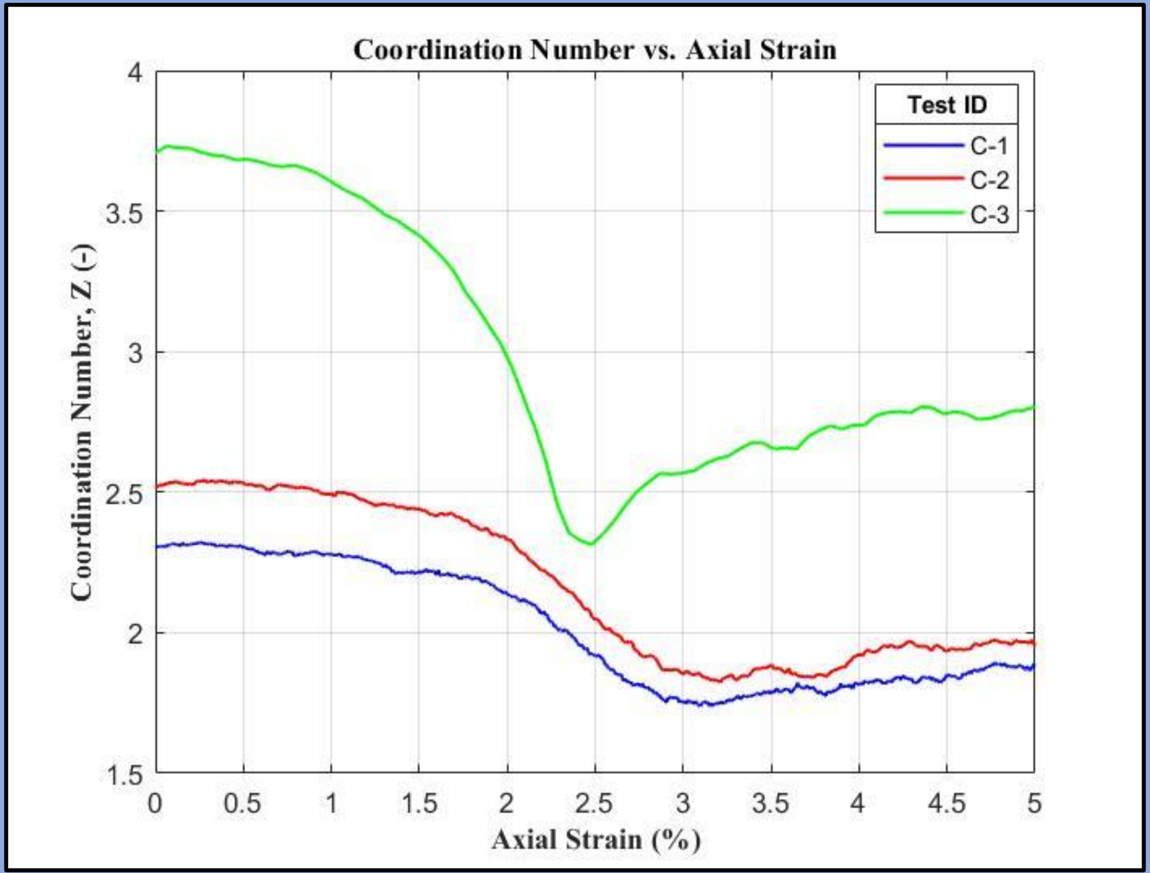


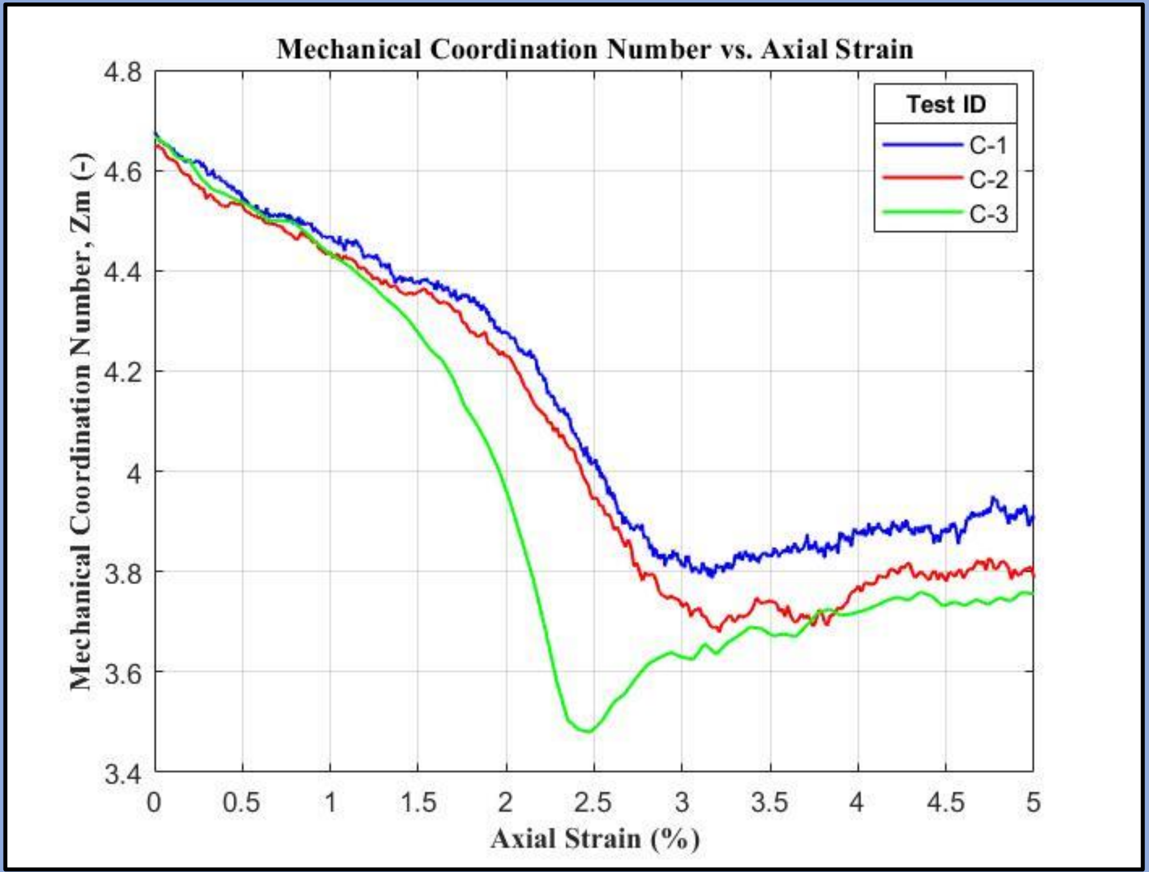
b)

a) Average coordination number (Z) for group A **b)** Mechanical coordination number (Zm) for group A

Coordination numbers, Group C



a)



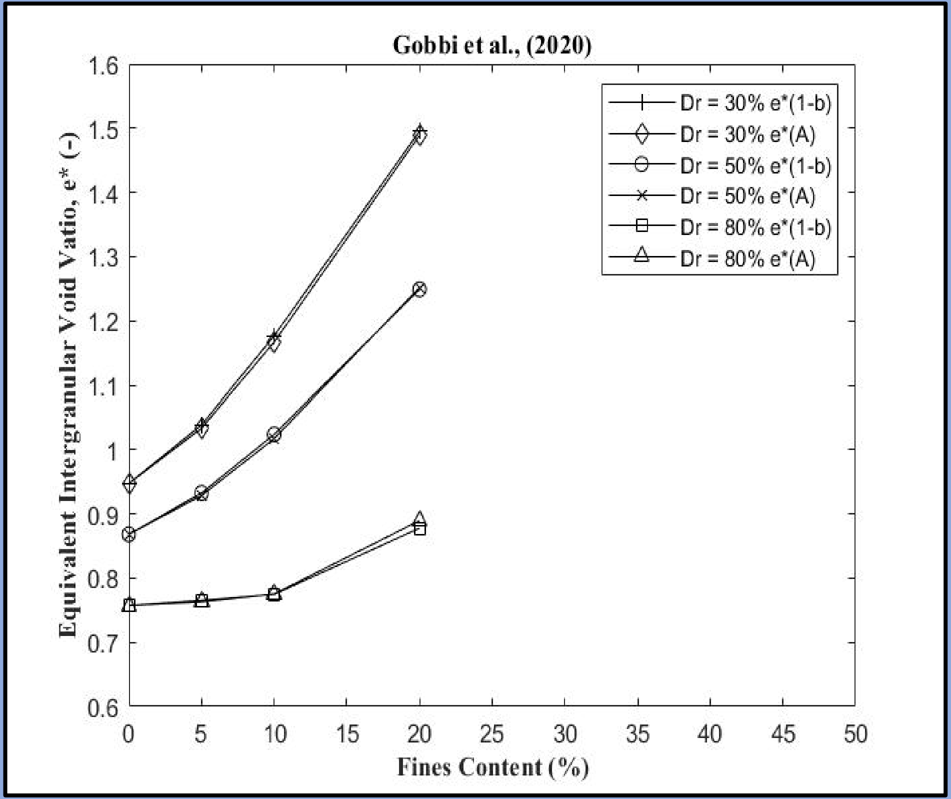
b)

a) Average coordination number (Z) for group C **b)** Mechanical coordination number (Zm) for group C

Fabric & ‘A’

Previous work has demonstrated…

- Links between ‘A’ and coarse grain fabric
- Preliminary DEM simulations have shown Z & Zm increase with ‘A’
- ‘A’ been used to determine the equivalent intergranular void ratio (e*)

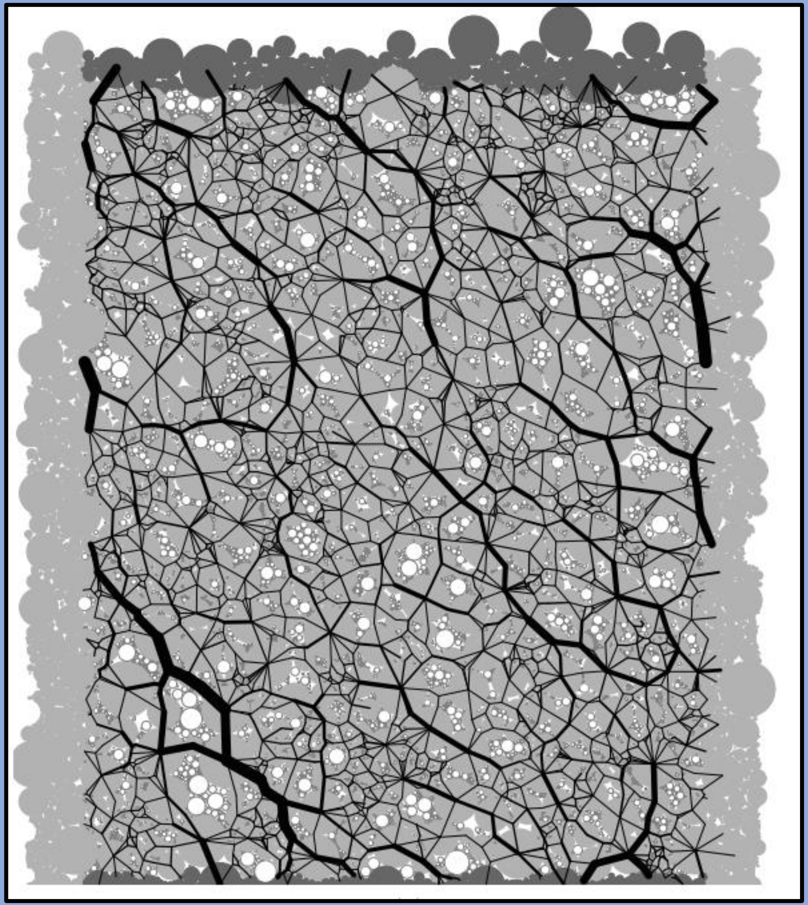


$$e^* = \frac{e + (1-b)Fc}{1-(1-b)Fc} \rightarrow e^* = \frac{e + (A)Fc}{1-(A)Fc}$$

PSD & Soil Fabric

- Whilst other definitions of force chains exist (e.g. Tordesillas and Muthuswamy, 2008; Kruyt, 2016)…
- It is agreed that a bimodal distribution exists between contact orientations

i.e. primary force network is supported structurally by neighbouring particles.

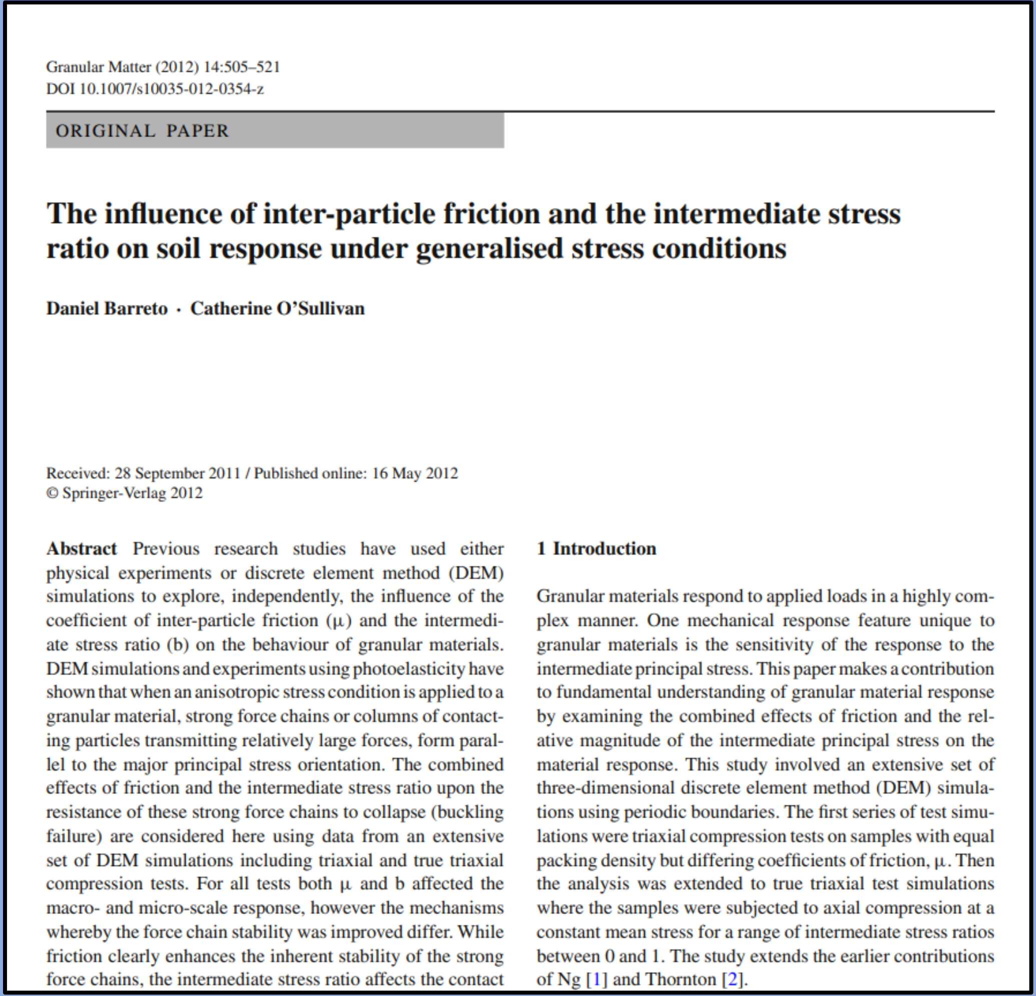


A polydisperse PSD, larger grains transmit vertically aligned (strong) force chains, & smaller grains facilitate laterally aligned (weak) force chains. From Voivret et al. (2009)

A final note…

- Whilst it is established that larger fabric anisotropy relates to larger strength and stiffness, these results may appear to contradict these findings.

- However, it must be noted that the results here differ as changes in anisotropy are the result of PSD, not loading direction or stress path as in previous studies (e.g. Barreto and O'Sullivan 2012).



Granular Matter (2012) 14:505–521
DOI 10.1007/s10035-012-0354-z

ORIGINAL PAPER

The influence of inter-particle friction and the intermediate stress ratio on soil response under generalised stress conditions

Daniel Barreto · Catherine O'Sullivan

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Abstract Previous research studies have used either physical experiments or discrete element method (DEM) simulations to explore, independently, the influence of the coefficient of inter-particle friction (μ) and the intermediate stress ratio (b) on the behaviour of granular materials. DEM simulations and experiments using photoelasticity have shown that when an anisotropic stress condition is applied to a granular material, strong force chains or columns of contacting particles transmitting relatively large forces, form parallel to the major principal stress orientation. The combined effects of friction and the intermediate stress ratio upon the resistance of these strong force chains to collapse (buckling failure) are considered here using data from an extensive set of DEM simulations including triaxial and true triaxial compression tests. For all tests both μ and b affected the macro- and micro-scale response, however the mechanisms whereby the force chain stability was improved differ. While friction clearly enhances the inherent stability of the strong force chains, the intermediate stress ratio affects the contact

1 Introduction

Granular materials respond to applied loads in a highly complex manner. One mechanical response feature unique to granular materials is the sensitivity of the response to the intermediate principal stress. This paper makes a contribution to fundamental understanding of granular material response by examining the combined effects of friction and the relative magnitude of the intermediate principal stress on the material response. This study involved an extensive set of three-dimensional discrete element method (DEM) simulations using periodic boundaries. The first series of test simulations were triaxial compression tests on samples with equal packing density but differing coefficients of friction, μ. Then the analysis was extended to true triaxial test simulations where the samples were subjected to axial compression at a constant mean stress for a range of intermediate stress ratios between 0 and 1. The study extends the earlier contributions of Ng [1] and Thornton [2].