Soil microstructure and susceptibility to suffusion

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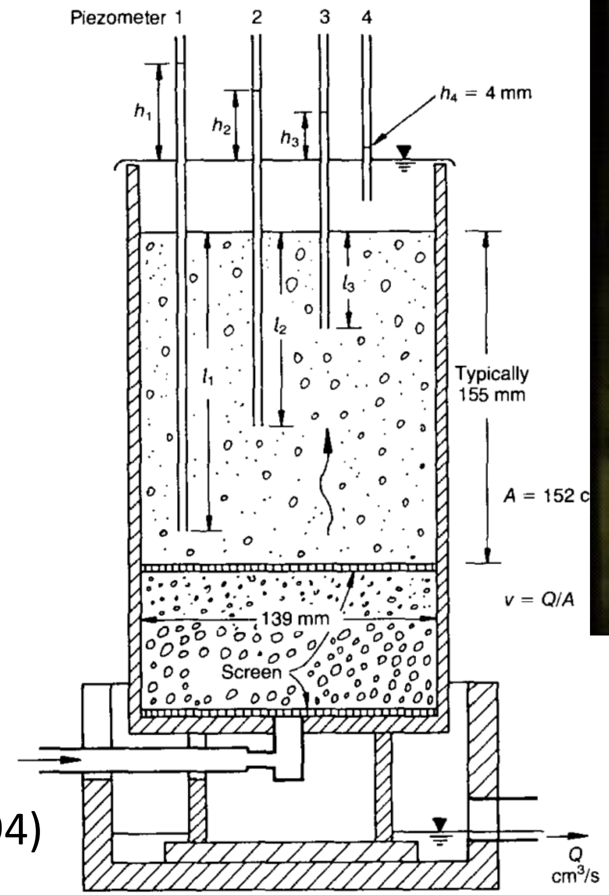
Outline

- Experimental evidence for effect of mechanical stress on suffusion
- DEM analysis: Effect of microstructure on fine particles under isotropic stress
- DEM analysis: Effect of microstructure on fine particles under shearing

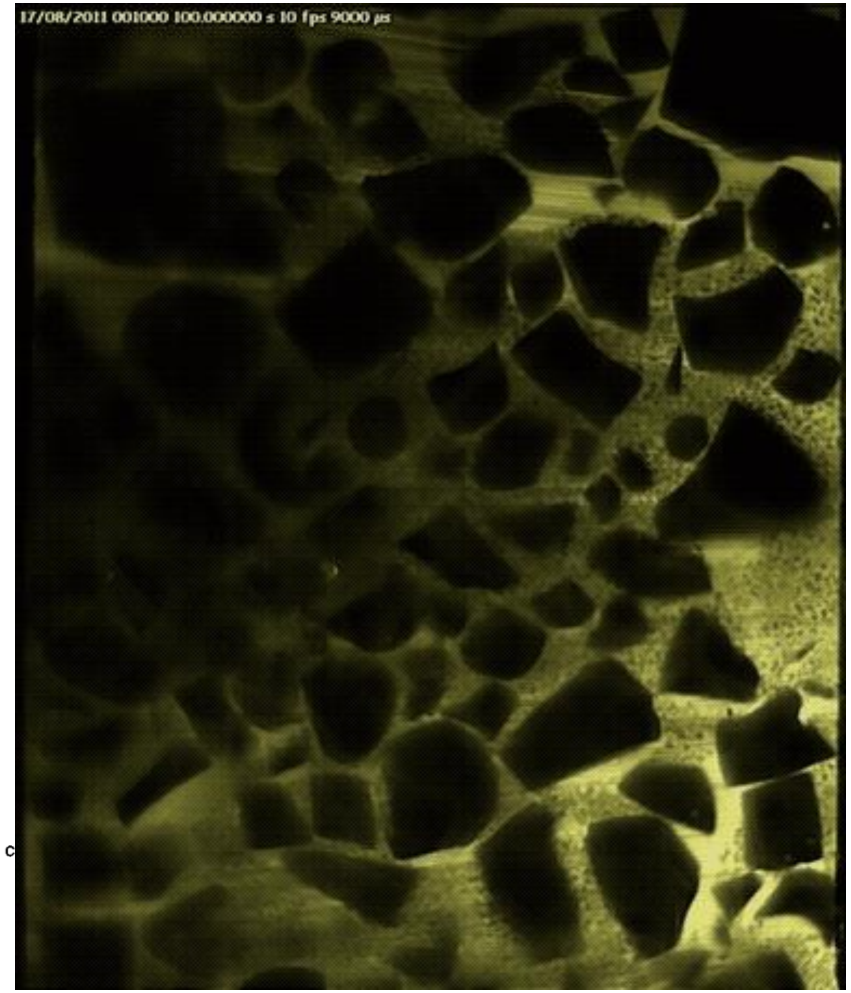
Effect of stress on the initiation of suffusion

Skempton and Brogan (1994):

- Experiments on ***unconfined*** gap and broadly-graded soils with upward flow
- "segregation piping" at low hydraulic gradients (icrit ≈ 0.2)



Skempton and Brogan (1994)

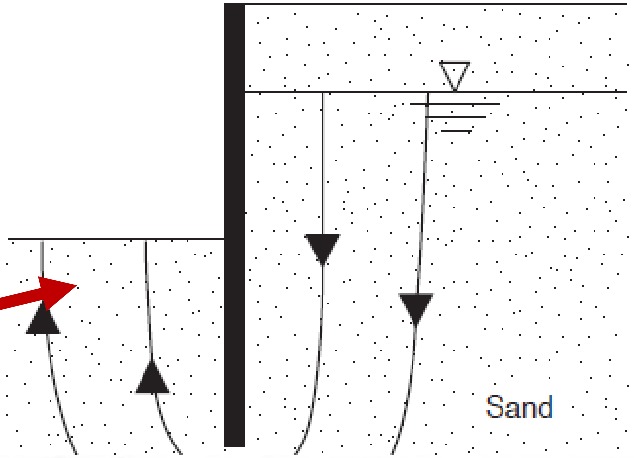


Hunter and Bowman (2018)
https://doi.org/10.1680/jgeot.17.P.161

Critical Hydraulic Gradient - i_{crit}

For internally <u>stable</u> soils:

$i_{crit(heave)}$: hydraulic gradient at which $\sigma_v' = 0$



$i_{crit(heave)} = \gamma'/\gamma_w \approx 1.0$ (Terzaghi, 1925)

For internally unstable soils:

$i_{crit(fine)} < 1$

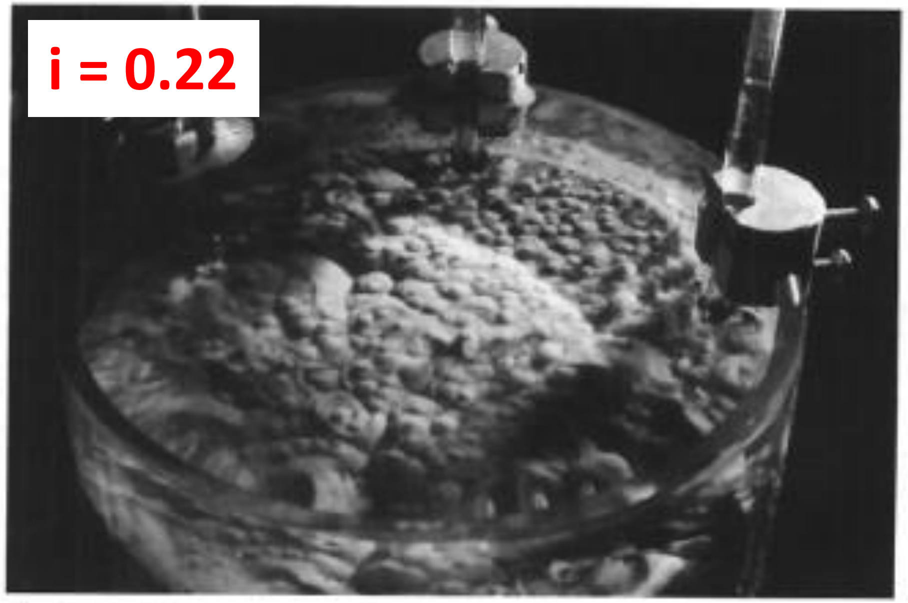


Fig. 9. Material A: strong general piping of fines ($i = 0{\cdot}22$, $v = 0{\cdot}27$ cm/s)

Skempton and Brogan (1994)

Hydromechanical criterion

Skempton and Brogan (1994):

Fines carry reduced effective stress:

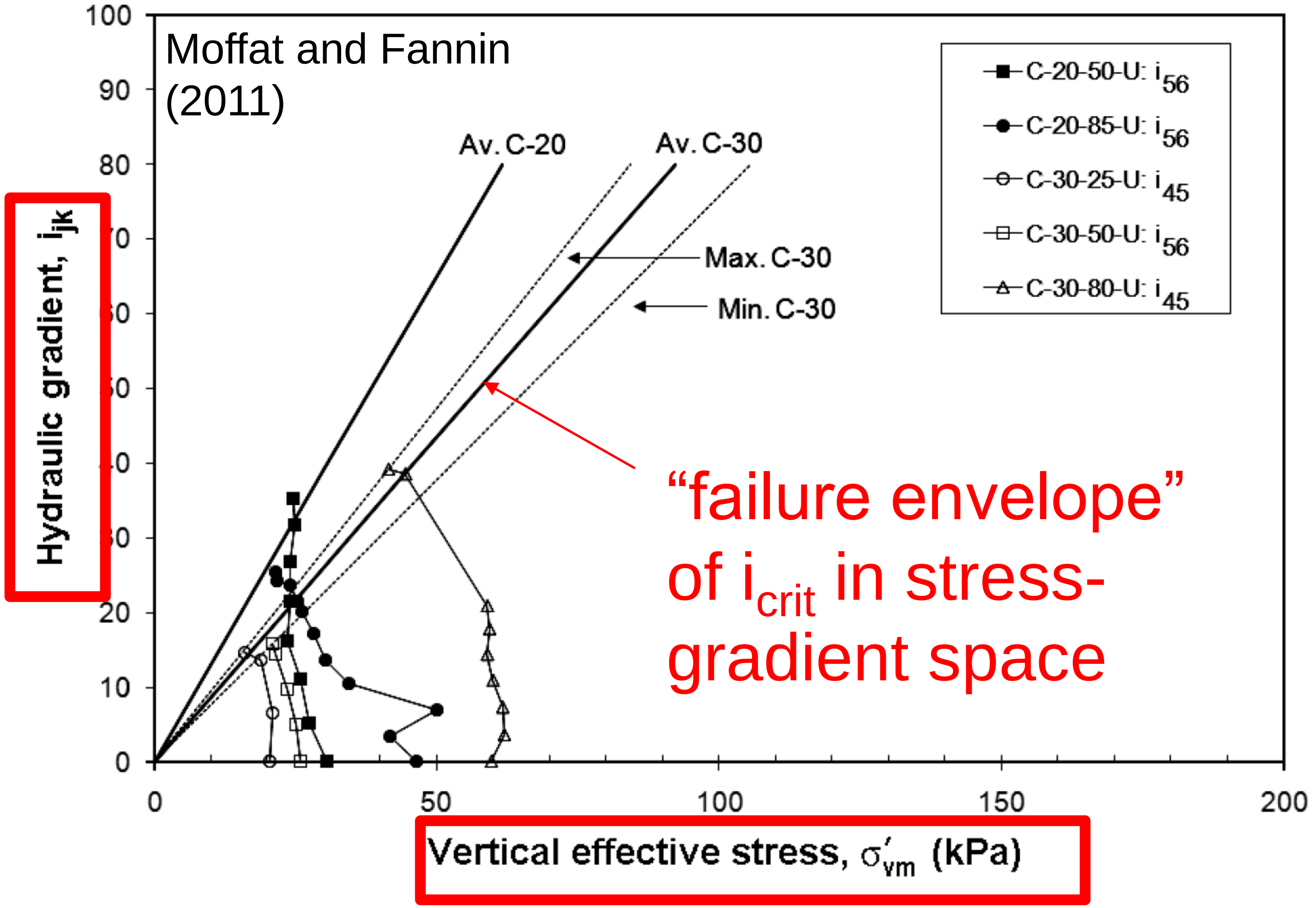
$$\sigma'_{fine} = \alpha \; \sigma'$$

↓ $\sigma'_{fine} = 0$

$$i_{crit(fine)} = \alpha \; i_{crit(heave)}$$

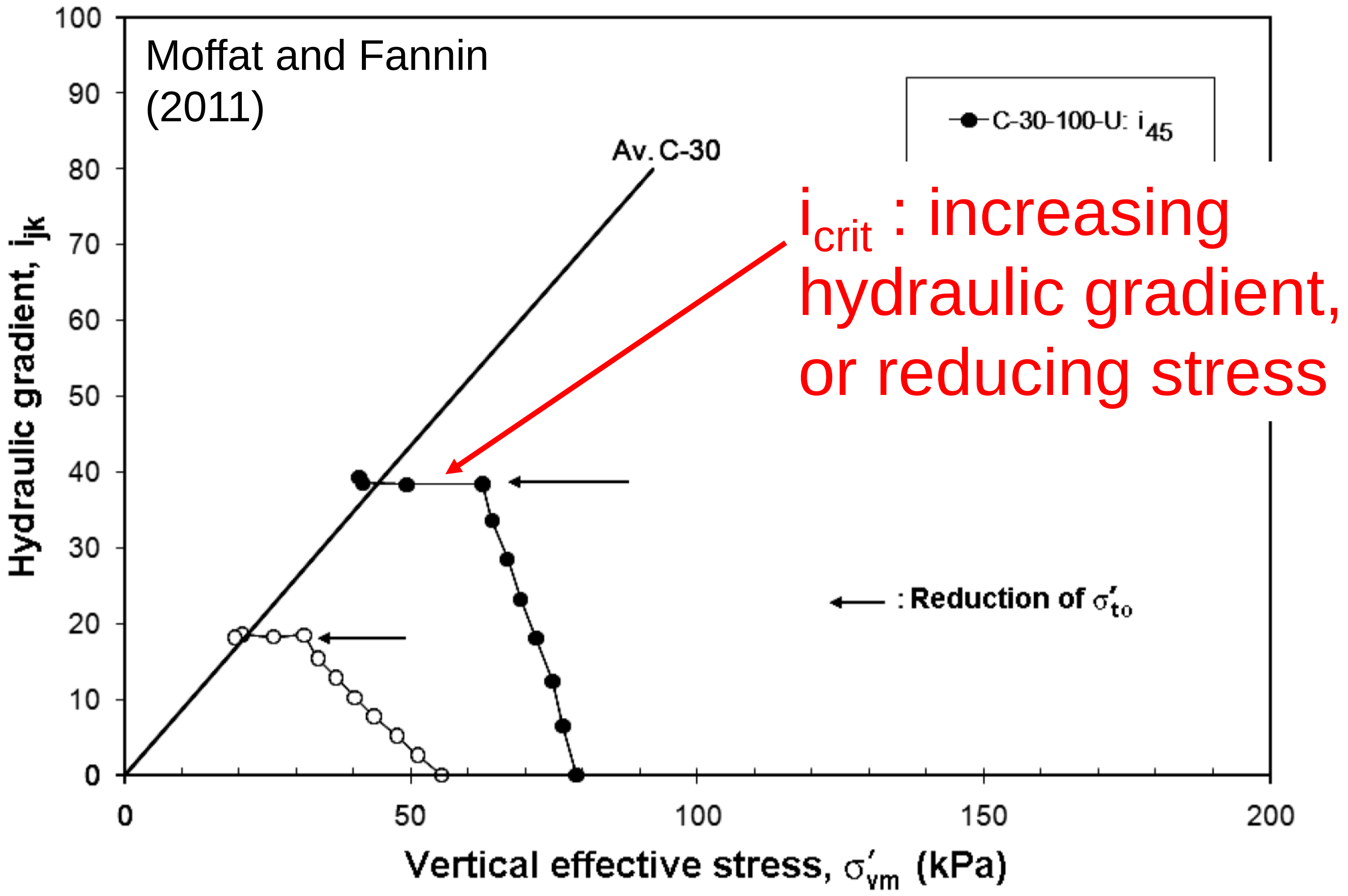
Suffusion in confined soils

Fannin and co-workers at UBC: permeameter with variable top-stress



UBC large permeameter

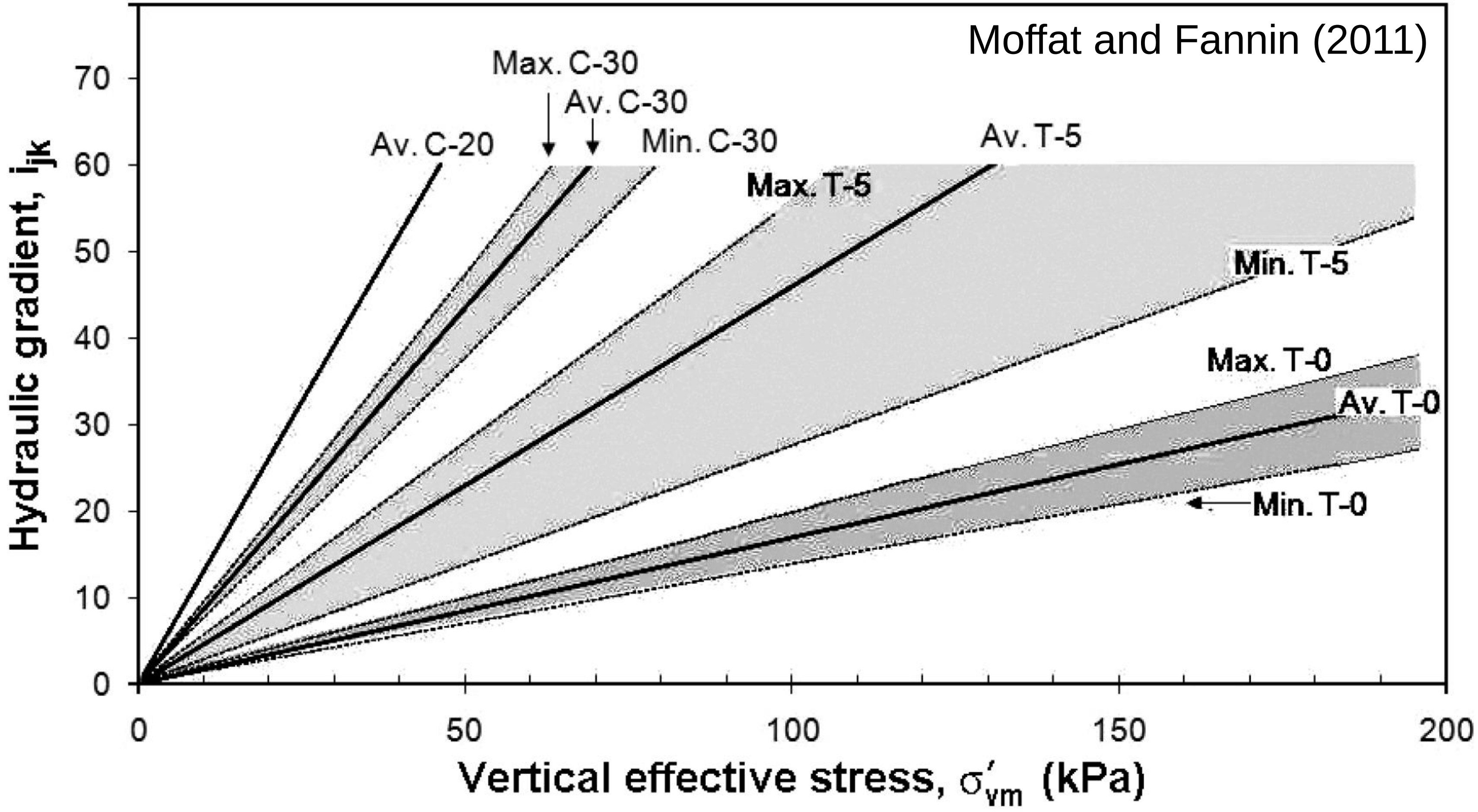
Suffusion in confined soils



UBC large permeameter

Suffusion in confined soils

Different soils produce failure envelopes with different gradients

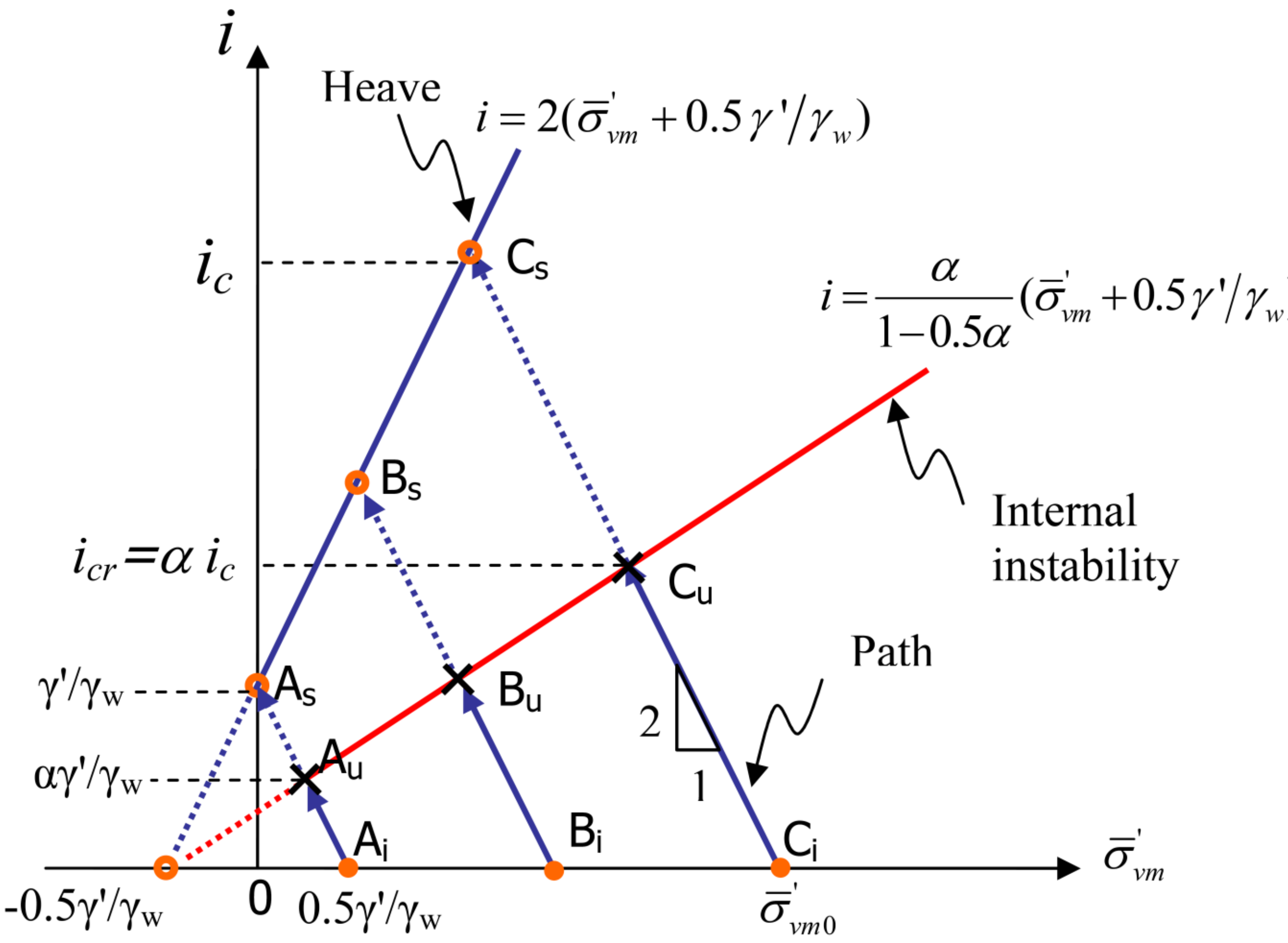


Suffusion in confined soils

Li and Fannin (2012) related slope of envelope to Skempton's α

Li (2008) related α to geometric criteria, e.g. $D_{15}^{coarse}/d_{85}^{fine}$ (Kezdi, 1979)

But effect of fines content and relative density not investigated (+ particle shape, stress state…)



Li and Fannin (2012)

DEM aims

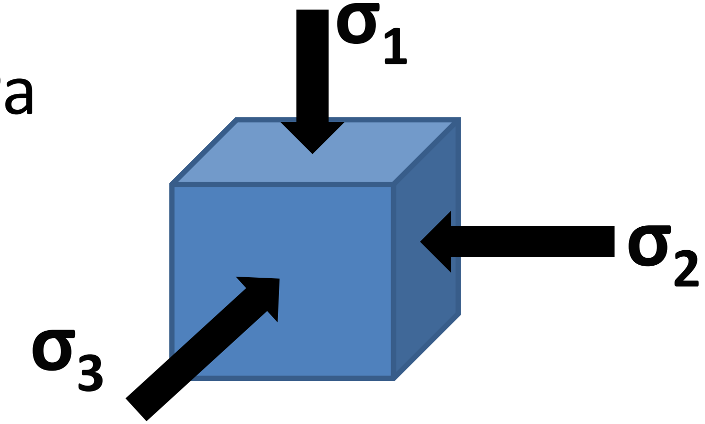
- Simulate gap-graded soils with DEM and measure stress in fines
- Could Skempton's hypothesis of reduced stress in fines be confirmed at microscale?
- Investigate link between α and:
  - Geometric criteria (i.e. PSD)
  - Relative density

DEM Simulations

Periodic cell containing gap-graded particles

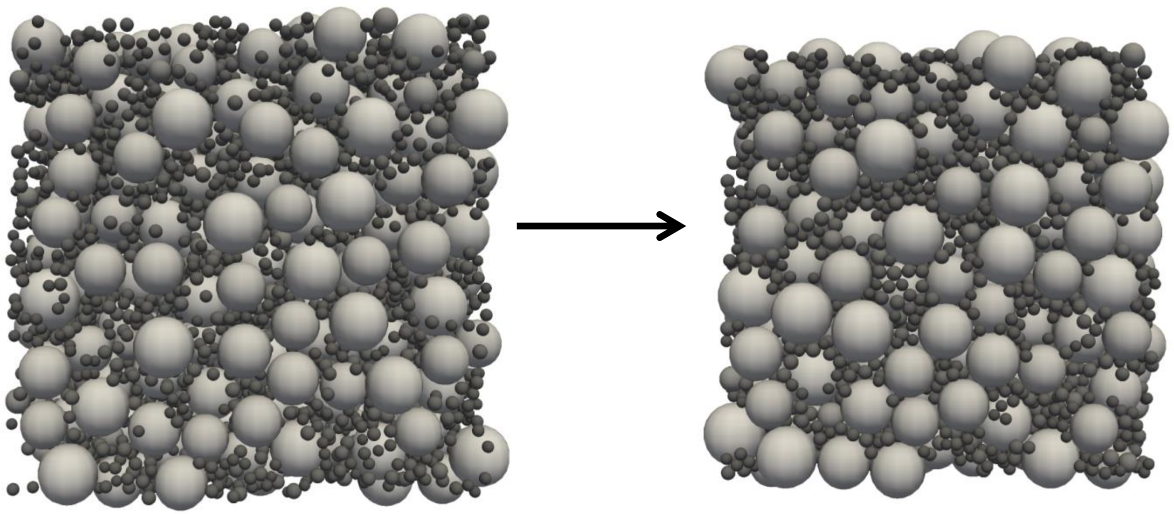
> 300,000 particles for large simulations

Servo-controlled compression to p' = 50 kPa to 200 kPa



Relative density controlled using interparticle friction:

$\mu = 0.0$ (Dense), $\mu = 0.1$ (Medium dense), $\mu = 0.3$ (Loose)



Following compression friction set to $\mu = 0.3$ for all samples

Samples tested

Gap-graded samples

Study effect of:

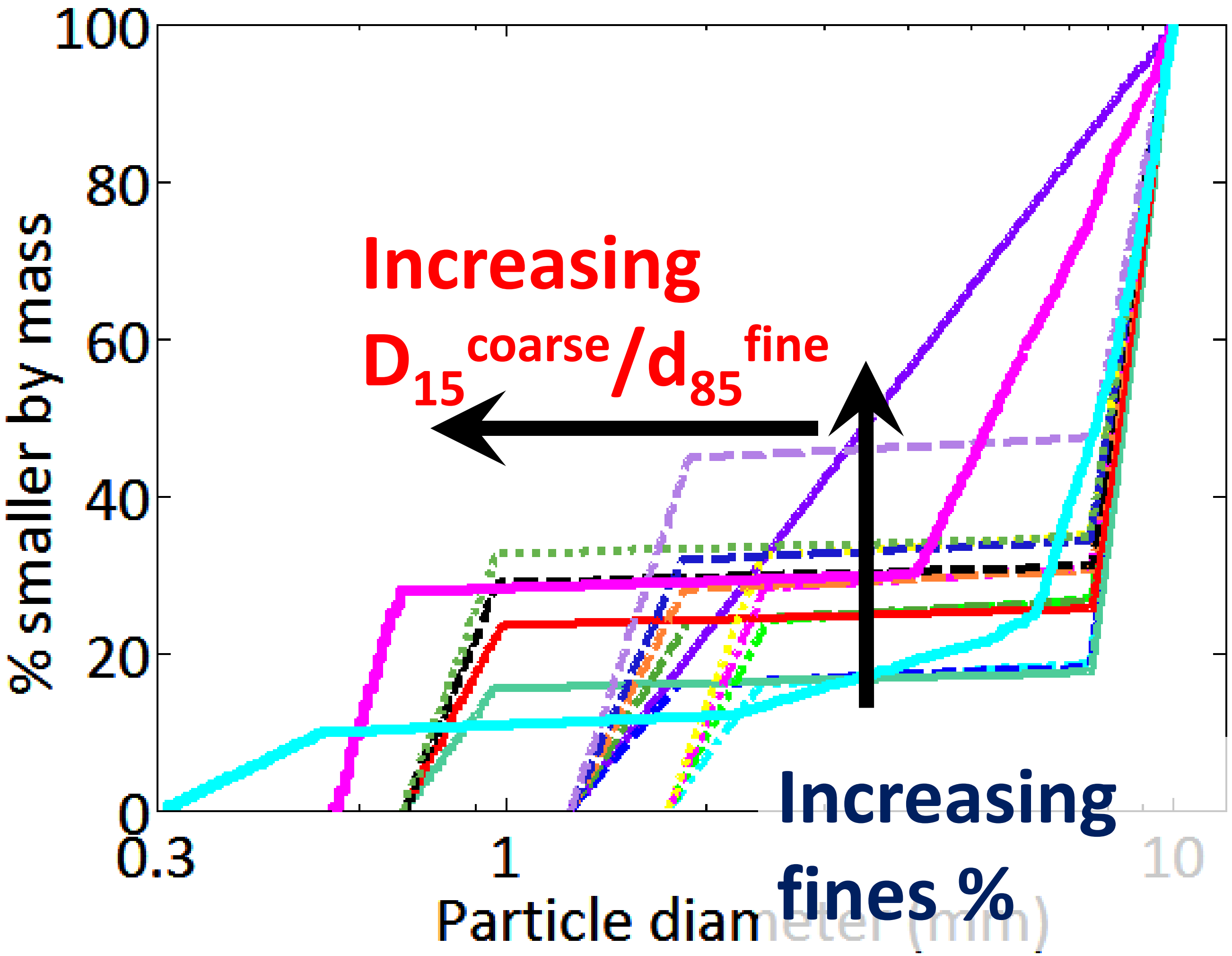
- **PSD (gap-ratio + fine-content)**
- **Relative density**

DEM Measurement of α-factor:

$$\alpha = \frac{p'_{fine}}{p'}$$

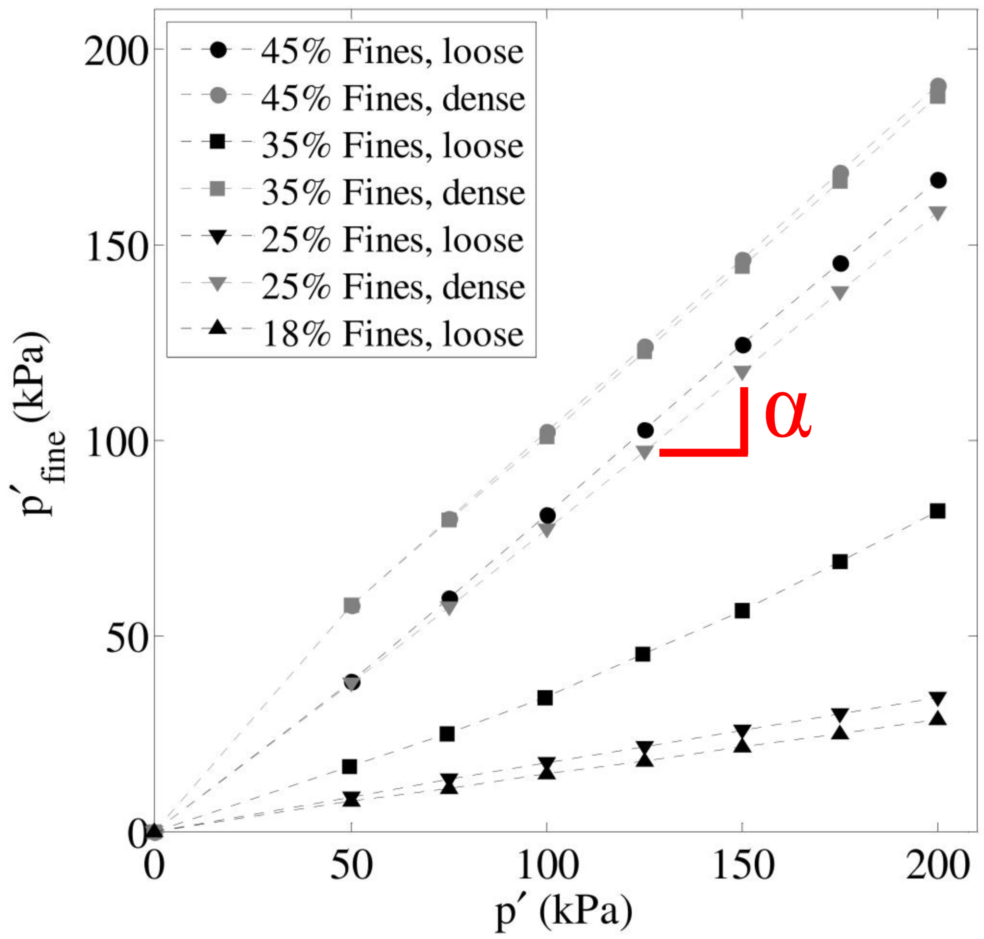
Mean stress in finer particles (p'_{fine})

Mean stress in all particles (p')

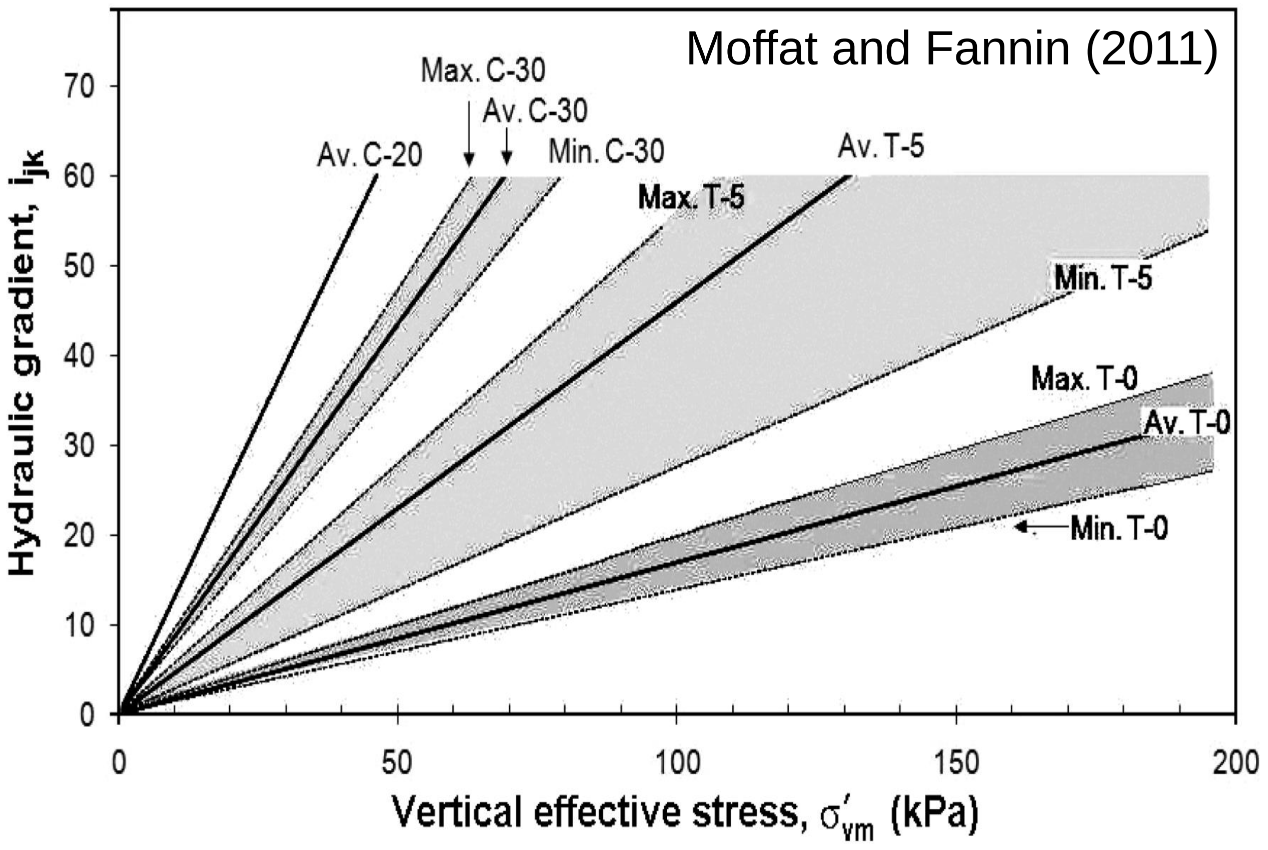


Results: Linearity of alpha

Fine stress ∝ overall mean stress

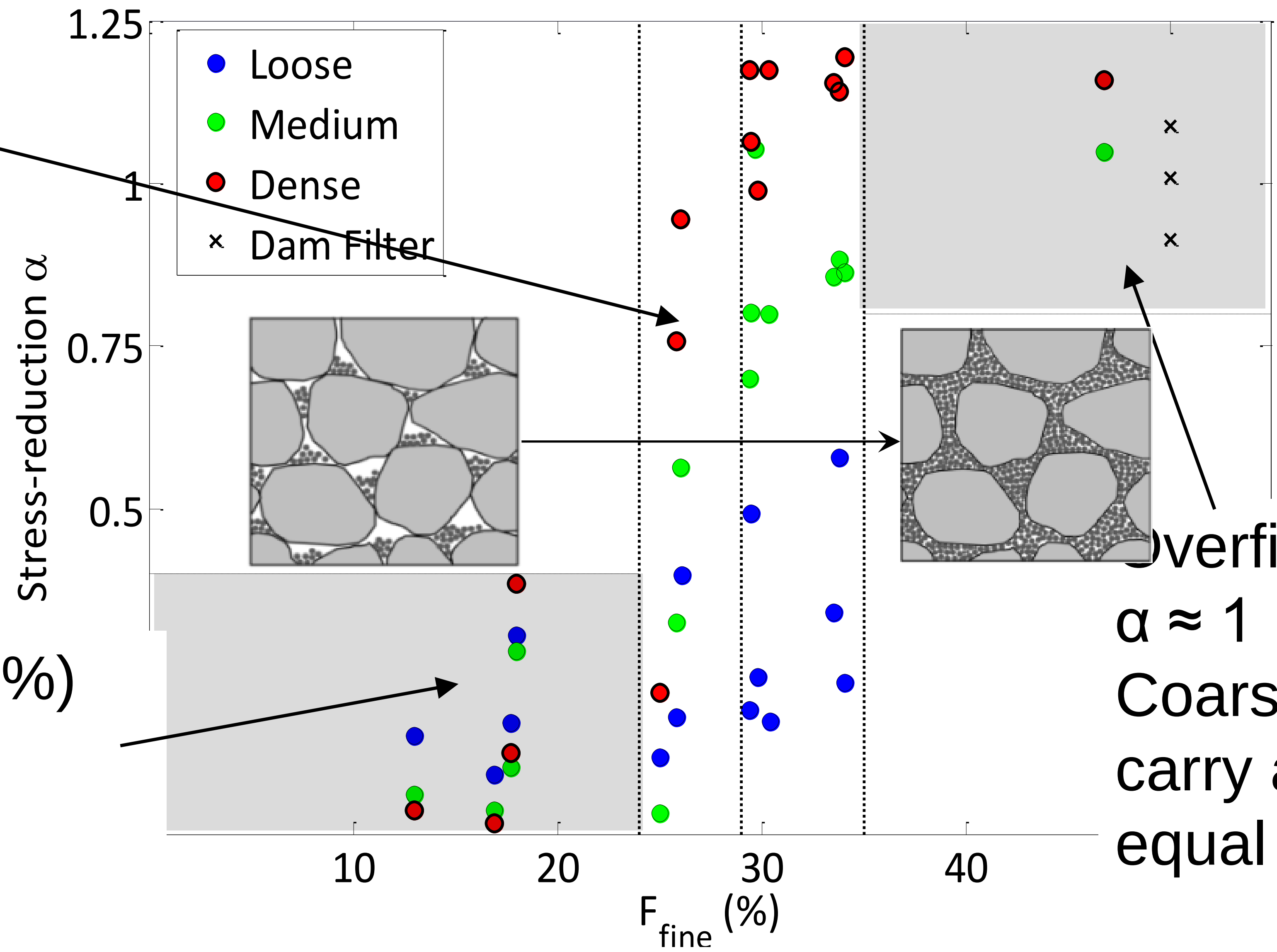


Similar to experimentally observed results for critical gradient



Results: Effect of % fines and relative density

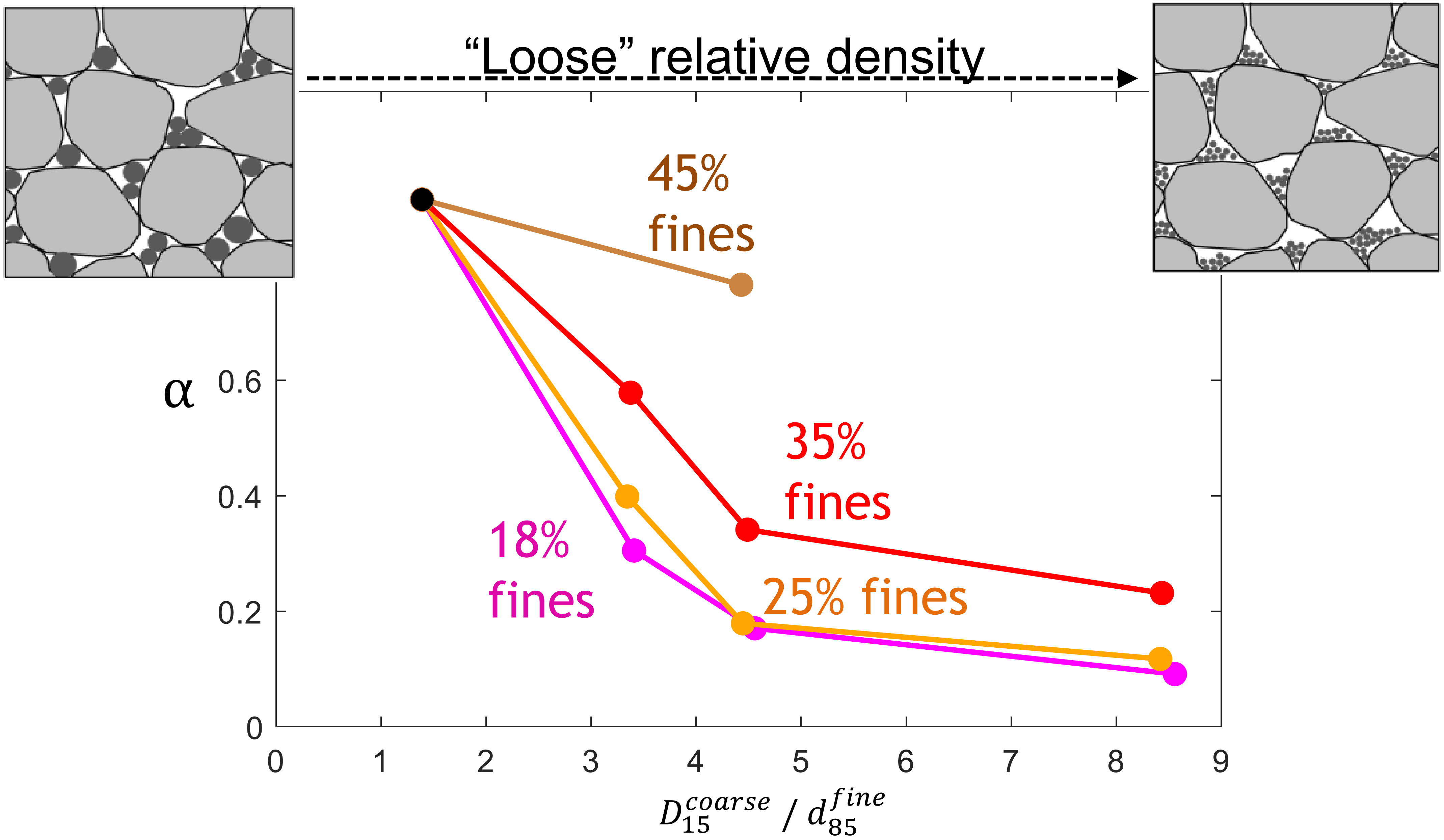
Intermediate:
Influence of
relative density



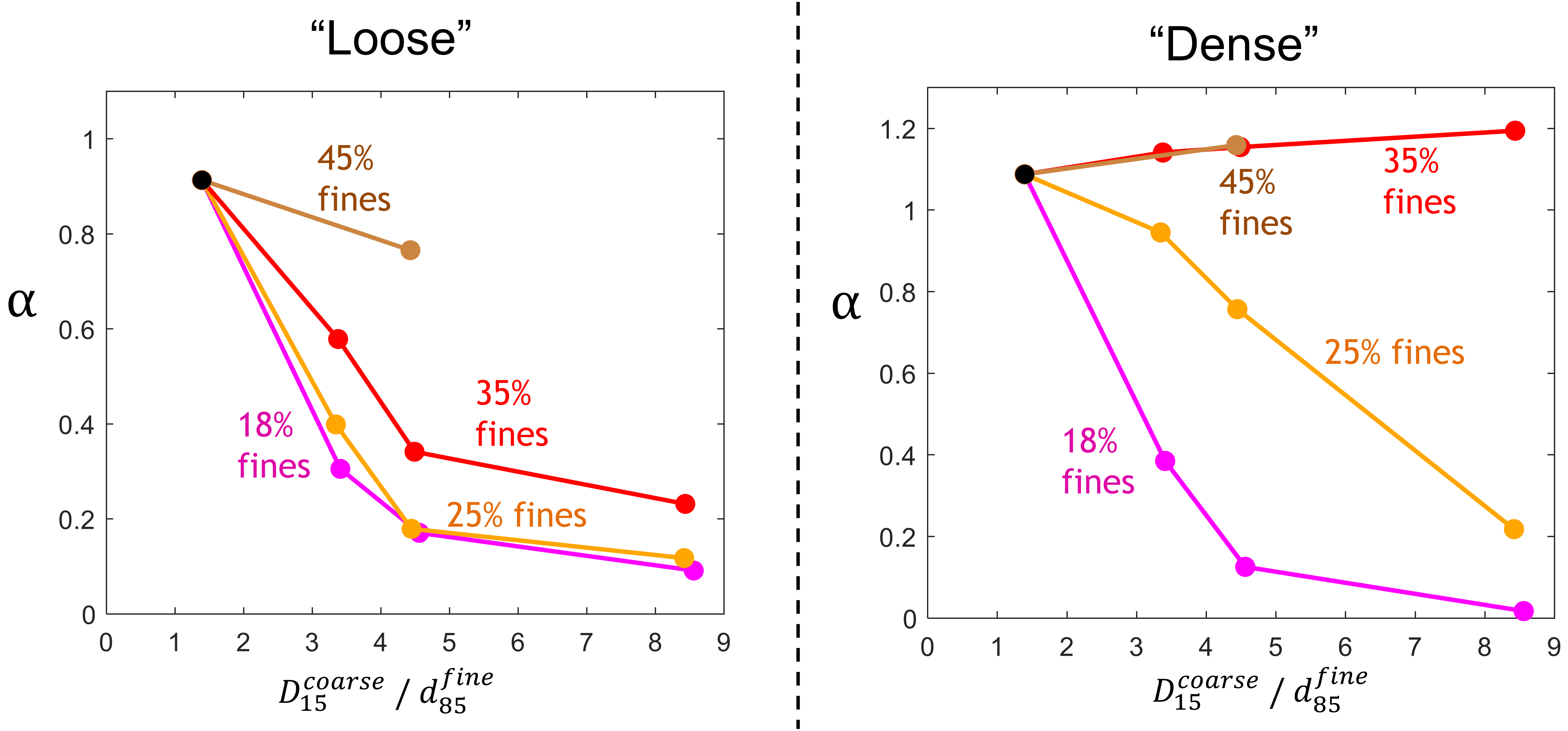
Underfilled (<25%)
α < 0.4
Fines carry low stress

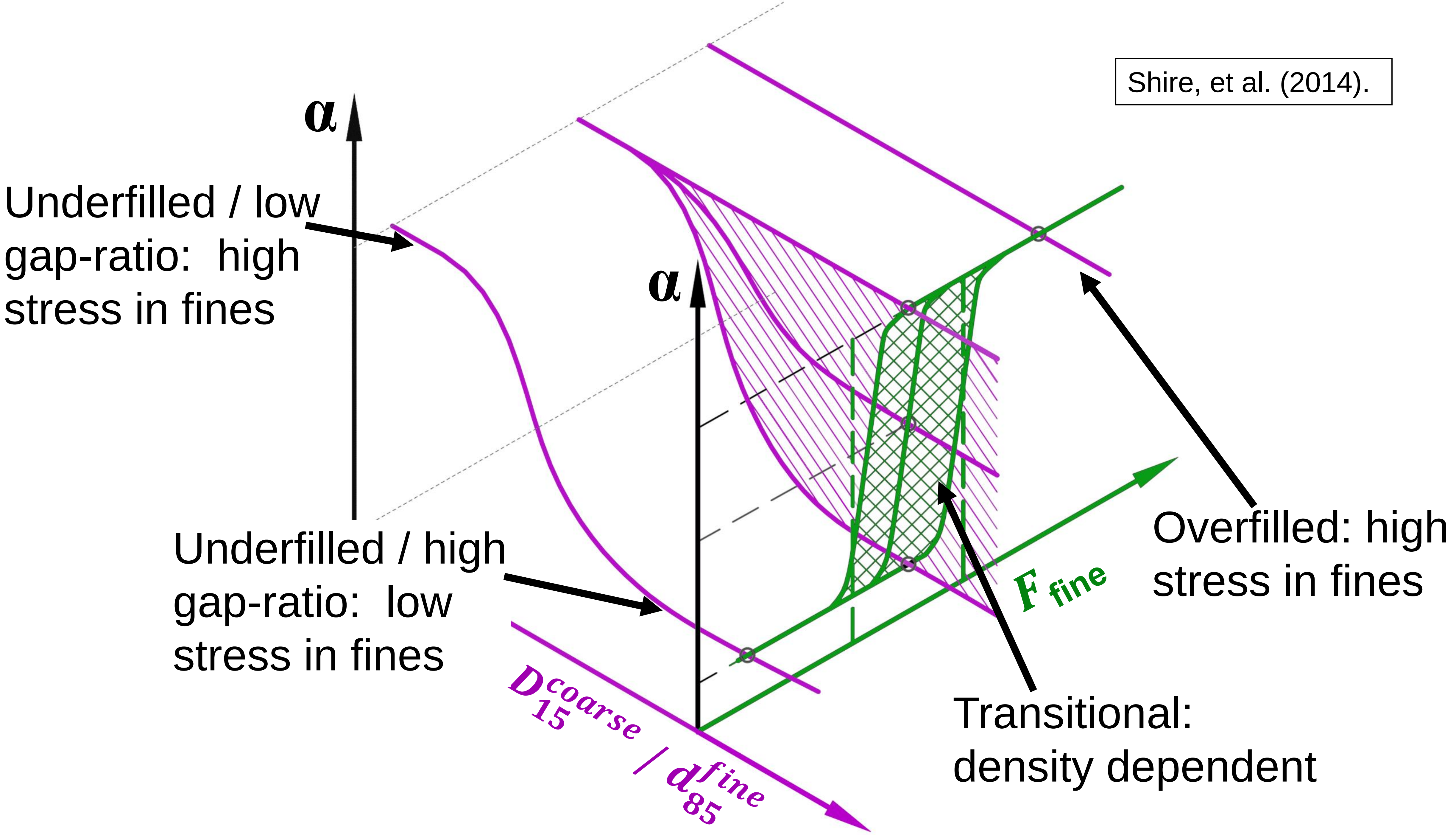
Overfilled (>35%)
α ≈ 1
Coarse and fine carry approx. equal stress

Results: Effect of gap-ratio



Results: Effect of gap-ratio




Shire, et al. (2014).
α
Underfilled / low gap-ratio: high stress in fines
α
Underfilled / high gap-ratio: low stress in fines
Overfilled: high stress in fines
F_{fine}
Transitional: density dependent
$D_{15}^{coarse} / d_{85}^{fine}$

Effect of shearing

- Results shown were for isotropic stress state (and experimental results K_0)
- No significant particle shearing
- Logical that α constant over a range of stresses?
- What happens if we shear?

Effect of shearing

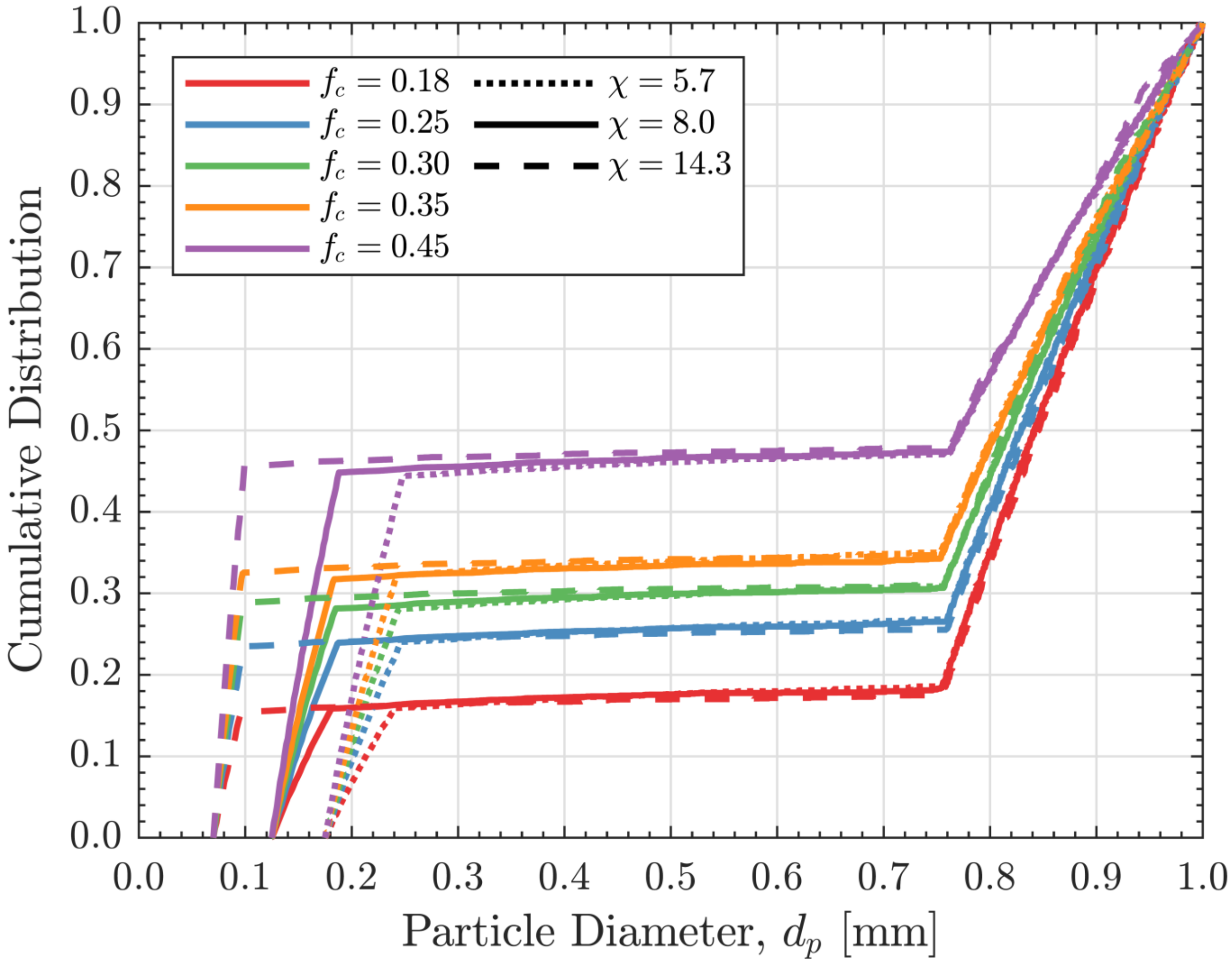
Sufian et al (2021):

Gap-ratios: 5.7; 8.0; 14.3

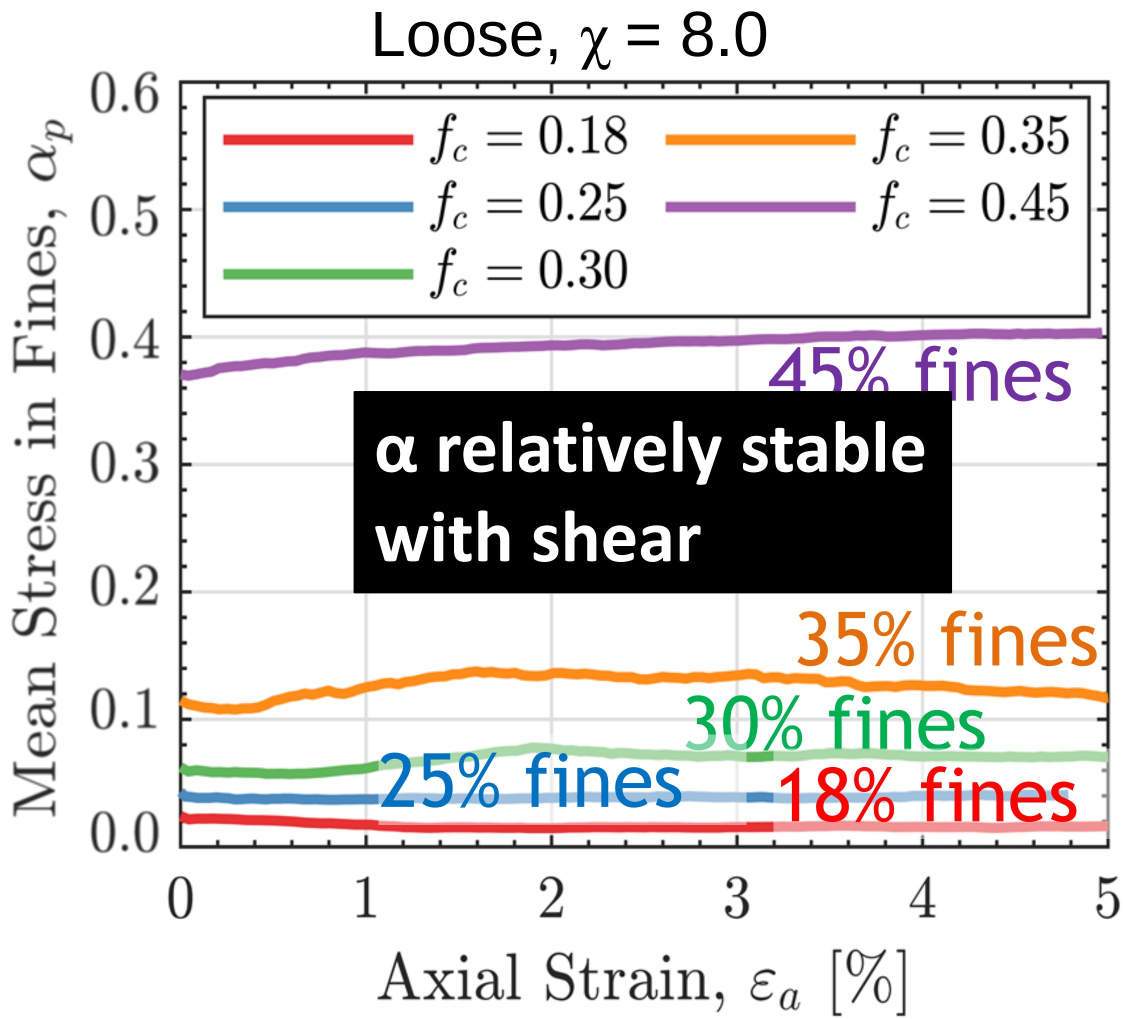
Fines content 18% to 45%

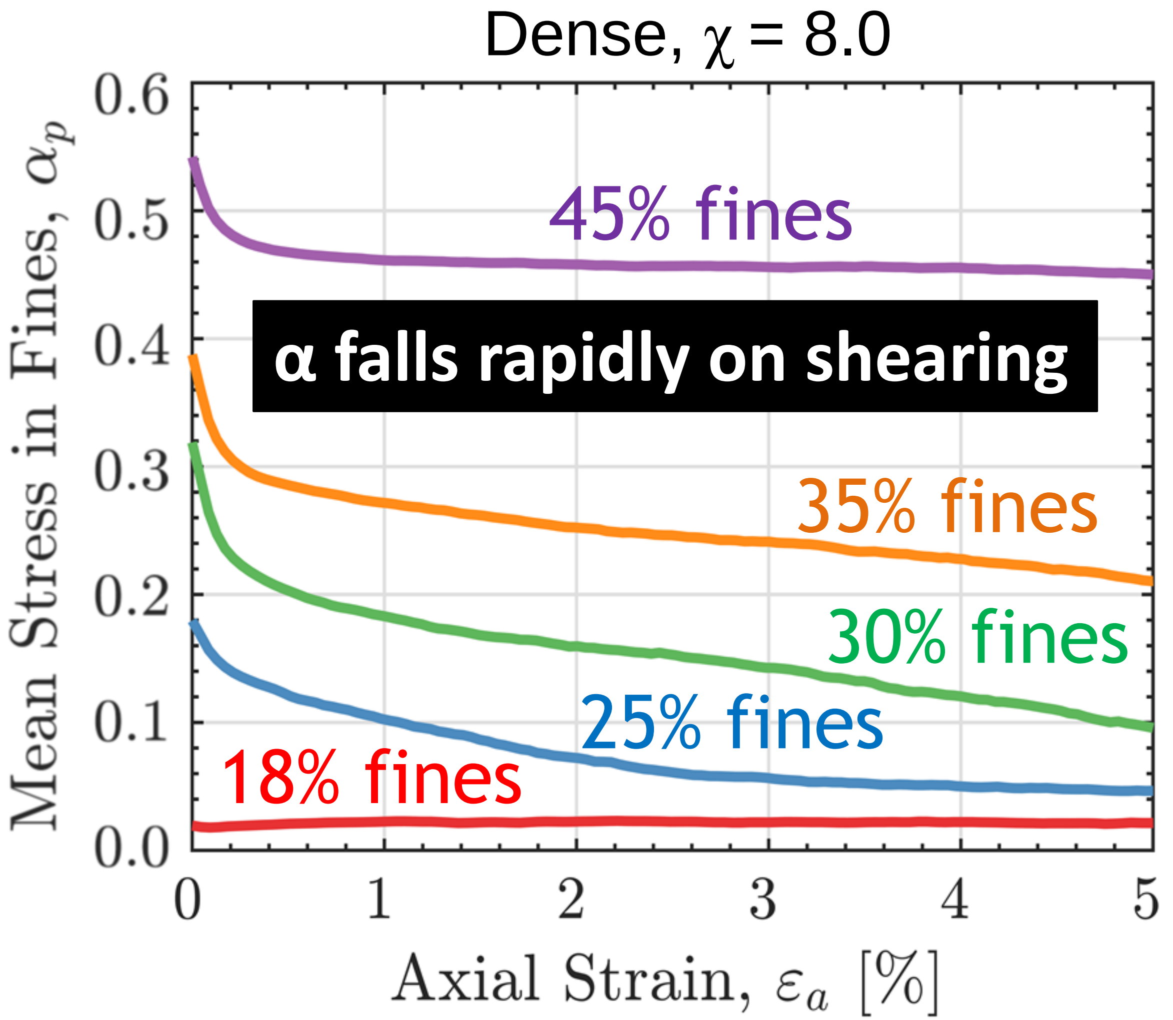
Up to 3.3 million particles

Constant p’ shearing



Effect of shearing





Converging on critical α at larger strains?

Summary

- For soils without significant rearrangement α is approximately constant over a range of stresses
- α is dependent on particle size distribution and relative density
- α changes rapidly when soils are sheared

Acknowledgements

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References

Sufian, A., Artigaut, M., Shire, T. and O'Sullivan, C. (2021) Influence of fabric on stress distribution in gap-graded soil. *Journal of Geotechnical and Geoenvironmental Engineering*, (Accepted for Publication)

Shire, T. , O'Sullivan, C., Hanley, K.J. and Fannin, R.J. (2014) Fabric and effective stress distribution in internally unstable soils. *Journal of Geotechnical and Geoenvironmental Engineering*