EWGIE online workshop on suffusion
Suffusion, what's up doc?

RECOVE, INRAE – Tuesday February 2nd 2021

The European Working Group on Internal Erosion of Dams, Dikes and Levees and their Foundations

Fine contribution to mechanical stability and constitutive modelling strategy

Antoine Wautier[1], Qirui Ma[3,1], Tao Wang[4,2], François Nicot[2]

[1]Aix Marseille University, INRAE, UR RECOVER, France

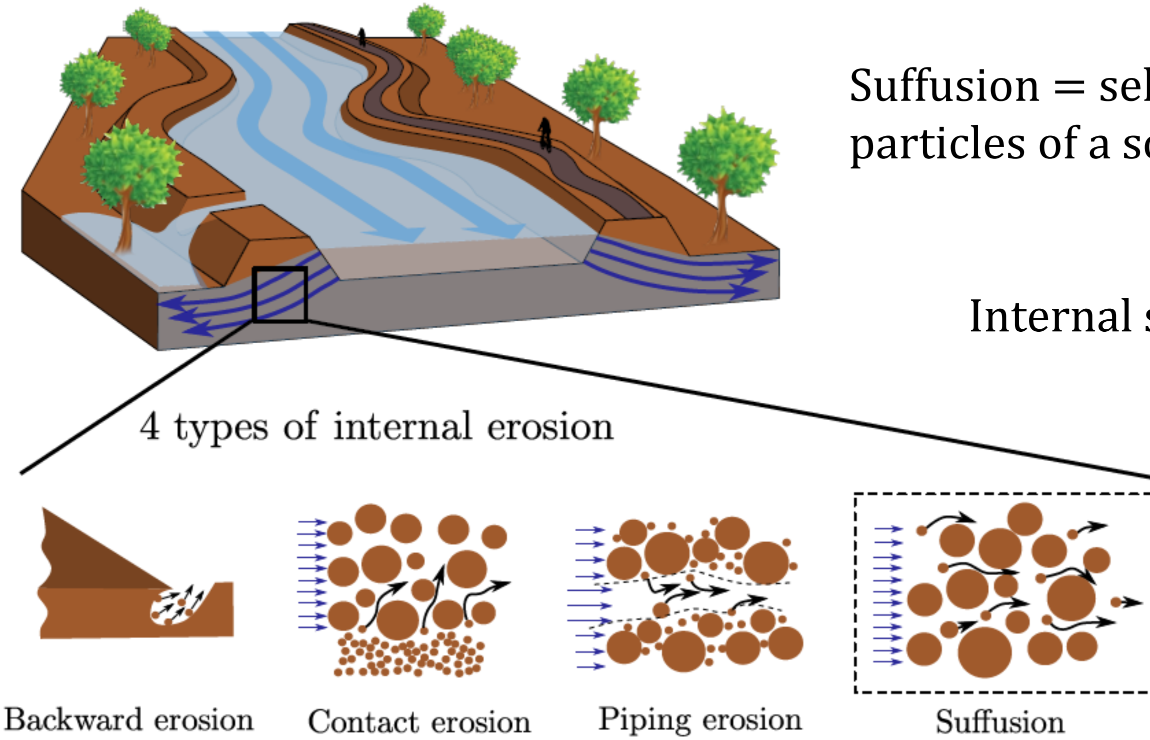
[2]University Grenoble Alpes, INRAE, UR ETNA, France

[3]Wuhan University, China

[4]Hohai University, China

e-mail : antoine.wautier@inrae.fr

Suffusion relationship with fine grains

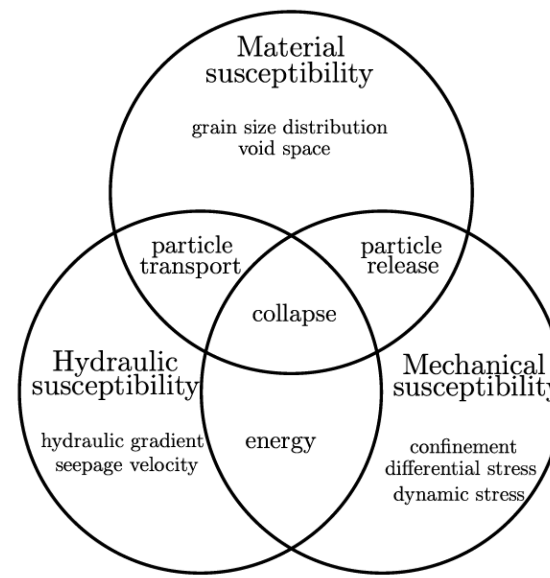


Suffusion = selective erosion of the finest particles of a soil

Internal stability ≠ mechanical stability

What are the consequences of **suffusion** in terms of **mechanical properties**?

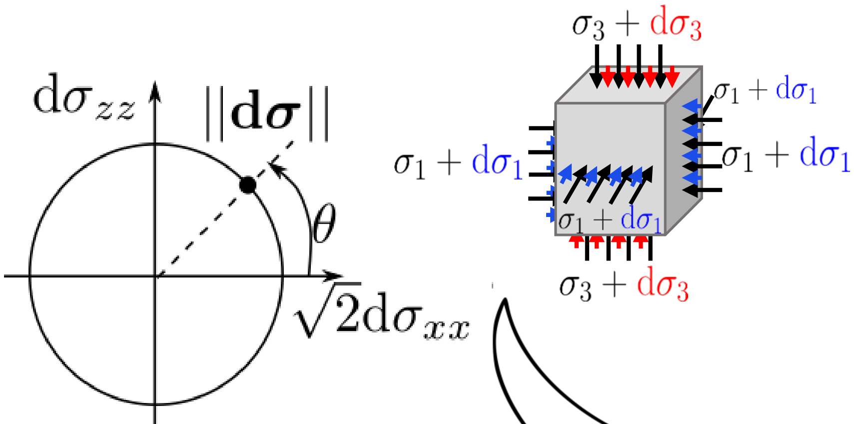
What are the consequences of **fine particles** in terms of **mechanical stability**?



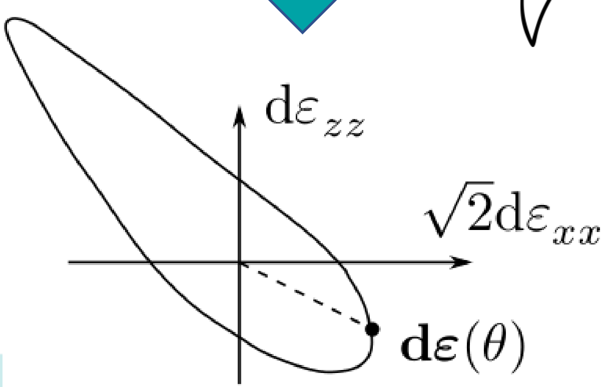
(Garner and Fannin 2010)

Mechanical stability: the second-order work criterion

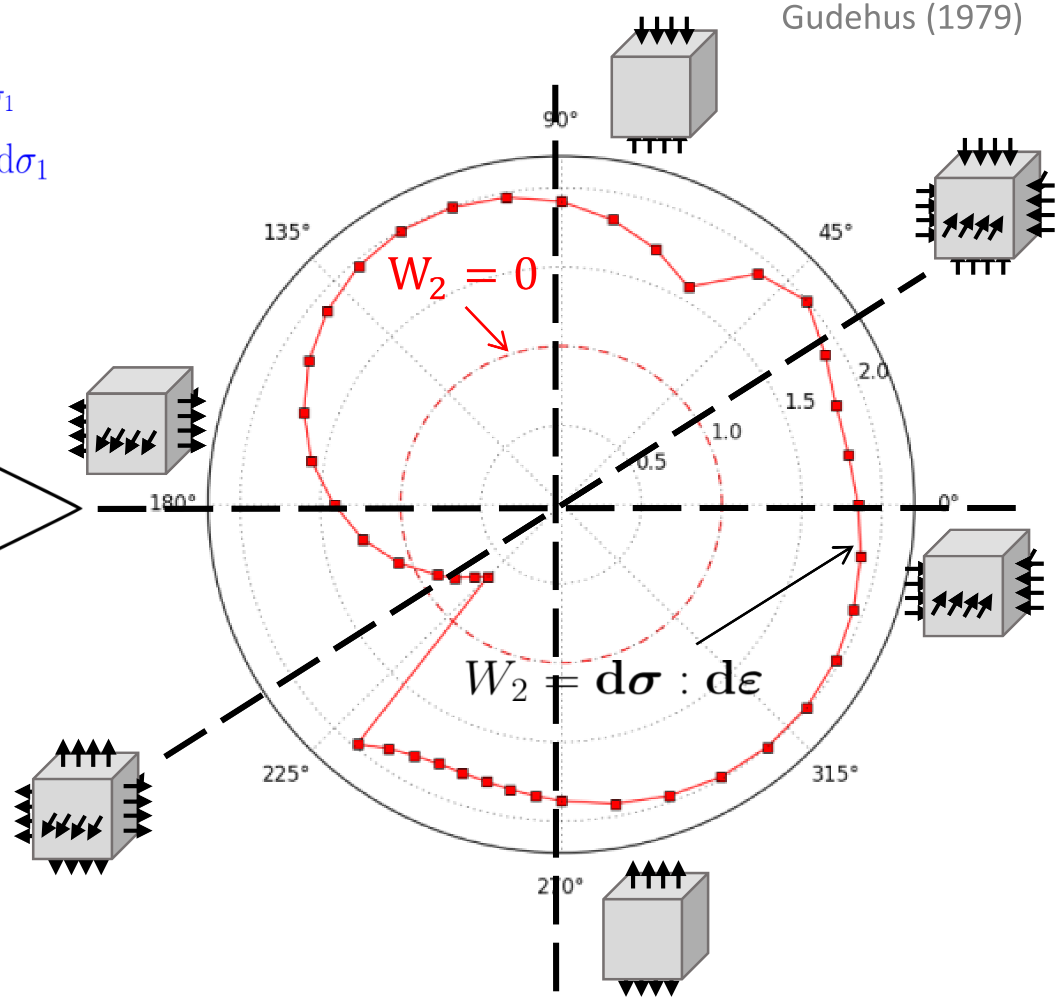
Gudehus (1979)



Incremental stress probes (axisymmetric plane)

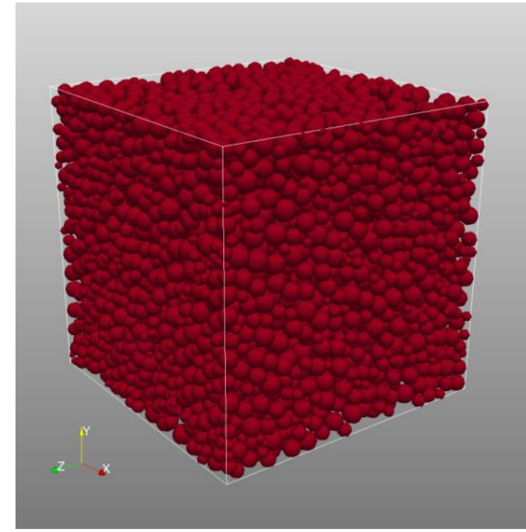


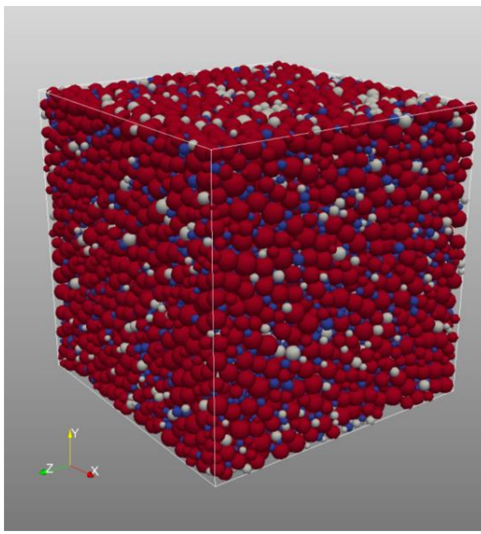
Incremental strain responses

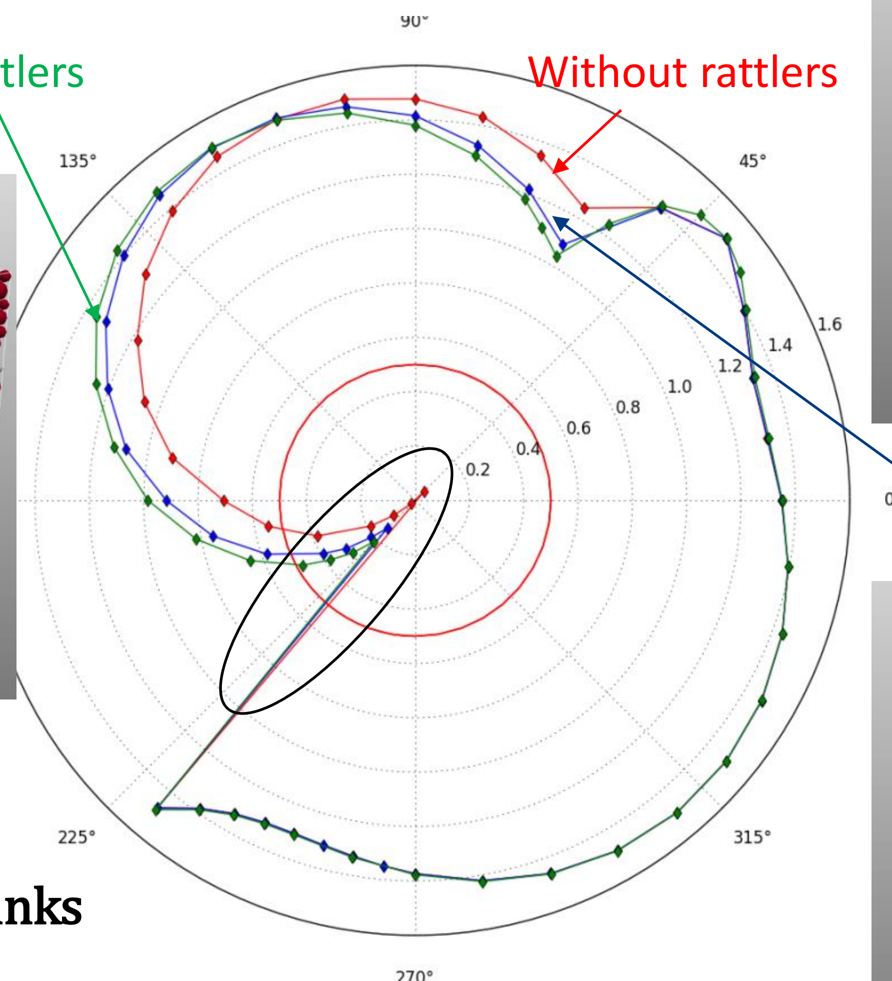


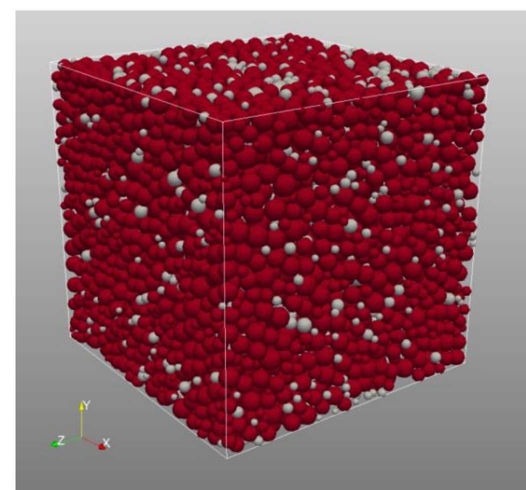
Second order work envelopes

Artificial microstructures and stability analysis







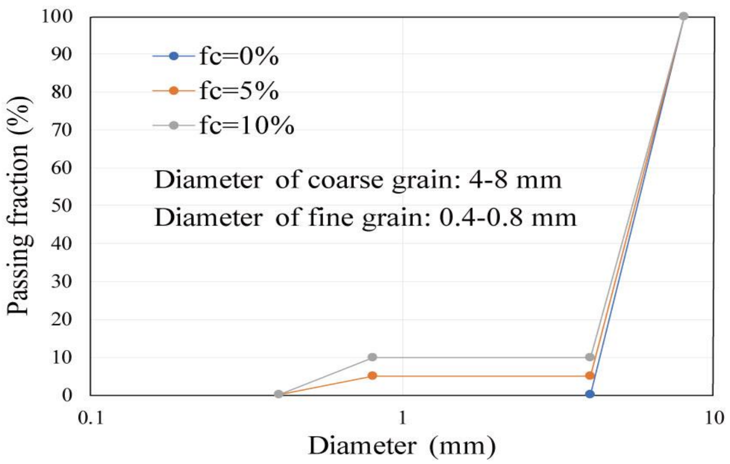


Instability cone shrinks with more rattlers

(Wautier et al. 2019)

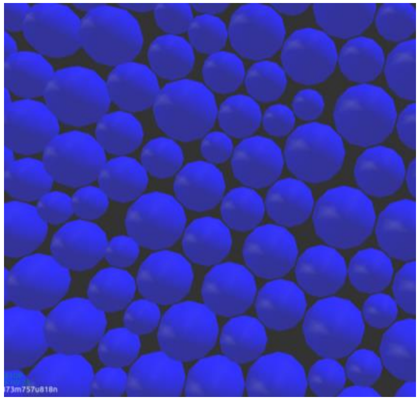
Fine content influence

Tao Wang PhD (2020)

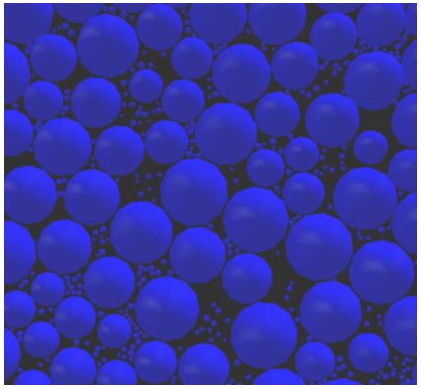


- Gap graded materials
  - $D_{coarse} = 10\, D_{fine}$
  - Uniform distribution of coarse and fine radii $\frac{D_{\max}}{D_{\min}} = 2$

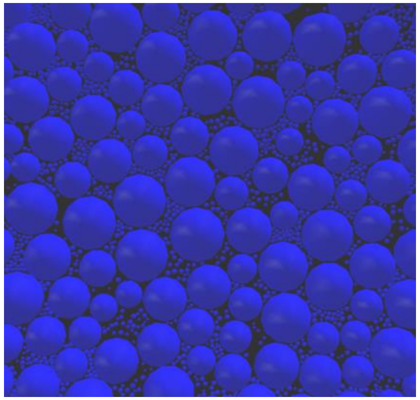
- Three fine contents :



Fine content = 0%



Fine content = 5%



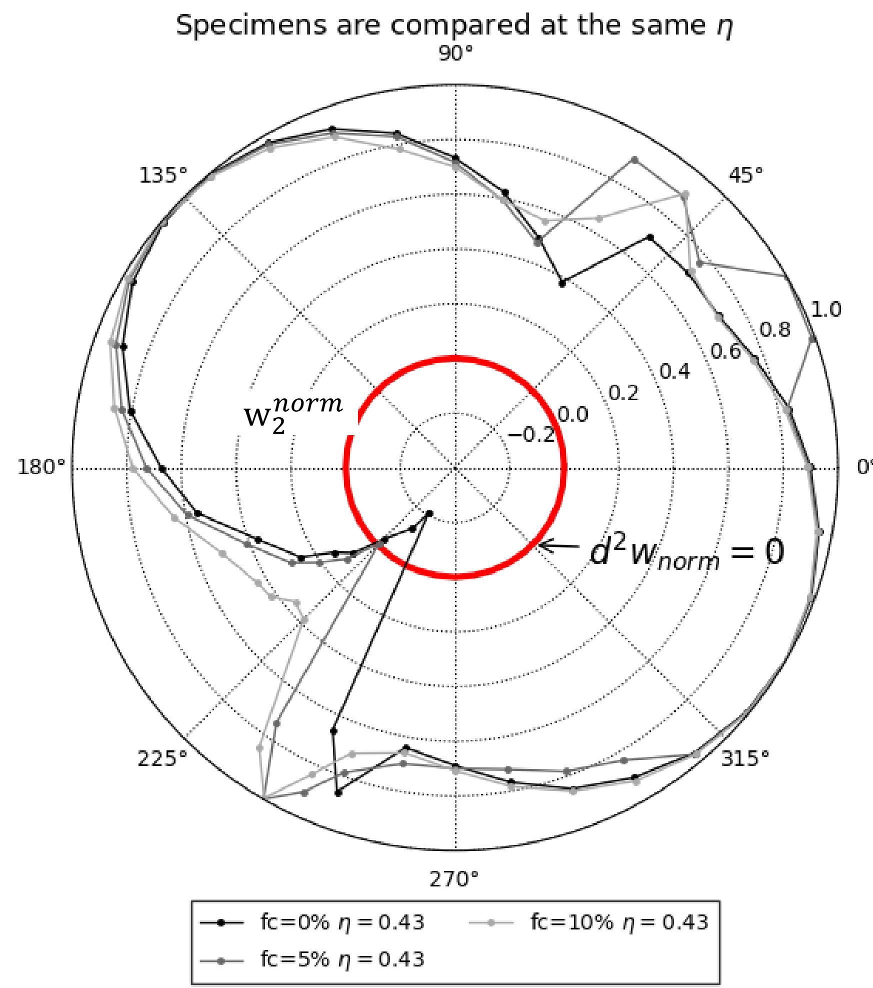
Fine content = 10%

- Same relative density (loose samples) : 10%

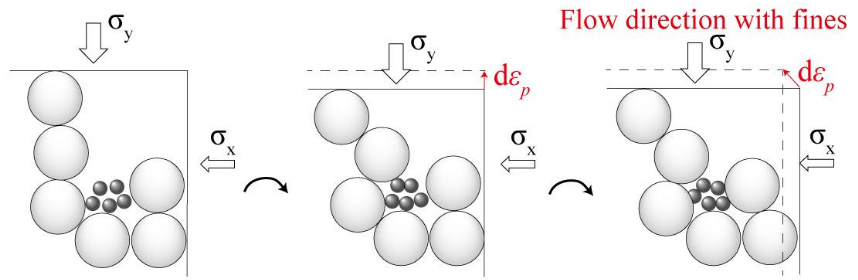
Fine stabilization effect

Tao Wang PhD (2020)

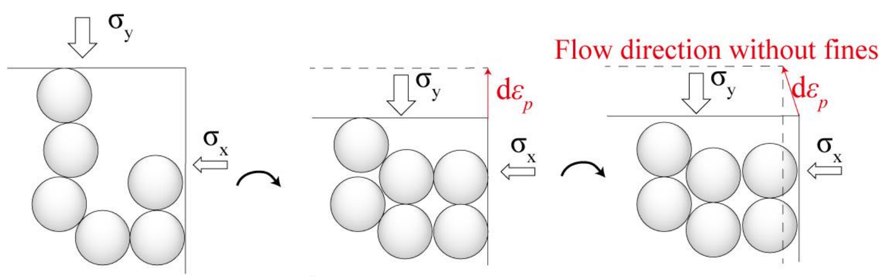
1. Cone of instability for FC = 0%
2. Cone shrinks for FC = 5 %
3. Cone vanishes for FC = 10 %



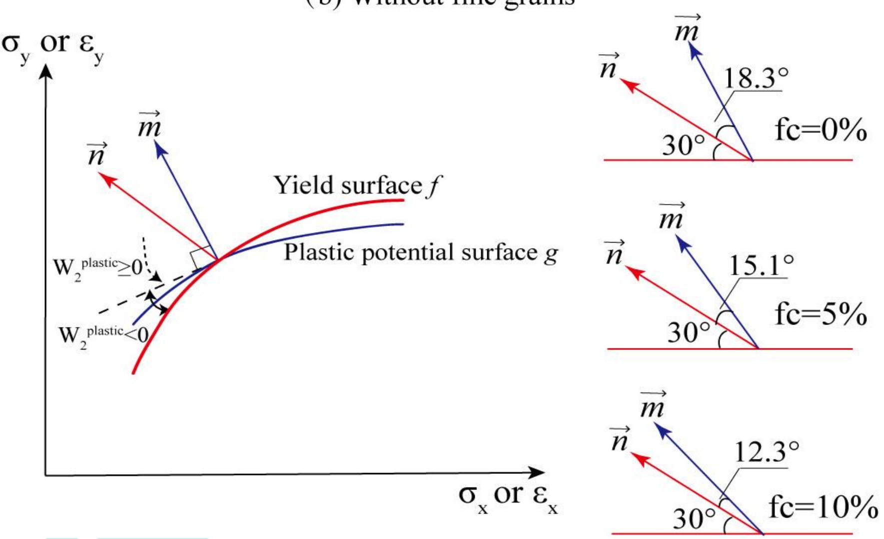
Fine effect on granular plasticity



(a) With fine grains



(b) Without fine grains



Fine particles have a stabilisation effect:

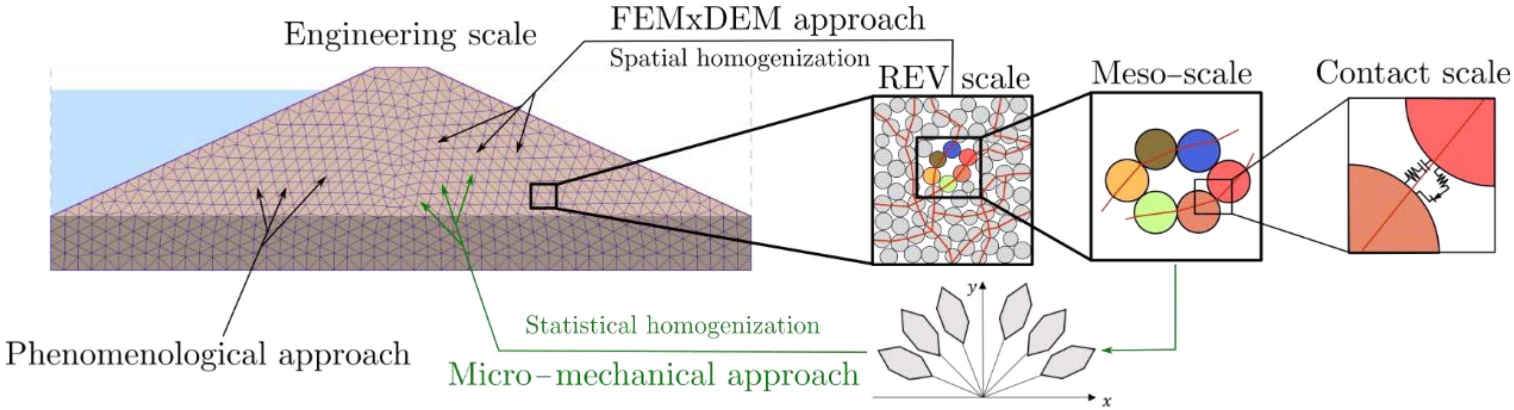
1. **Increase in dilatancy angle**
   Flow rule direction is modified

2. **Increase strain hardening**
   Plastic strain is reduced

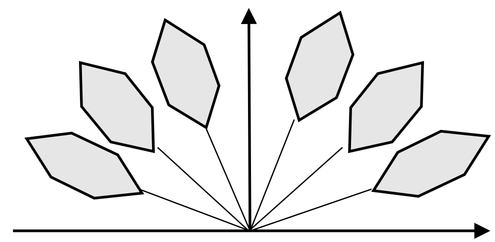
3. **No effect on the initial yield surface**
   Friction angle is not modified

NB : Valid for small fine contents (underfilled materials)

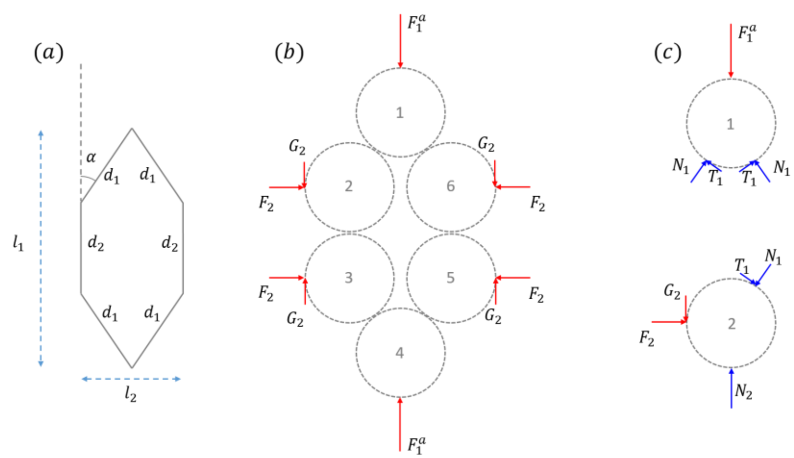
Multiscale constitutive behavior: the H-model

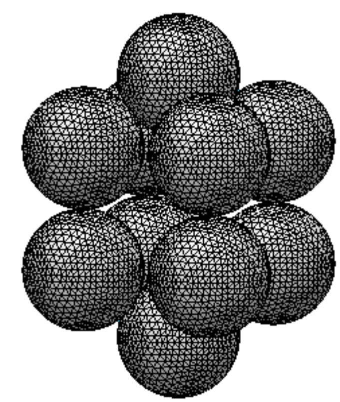


1. Collection of independent mesostructures oriented in different directions



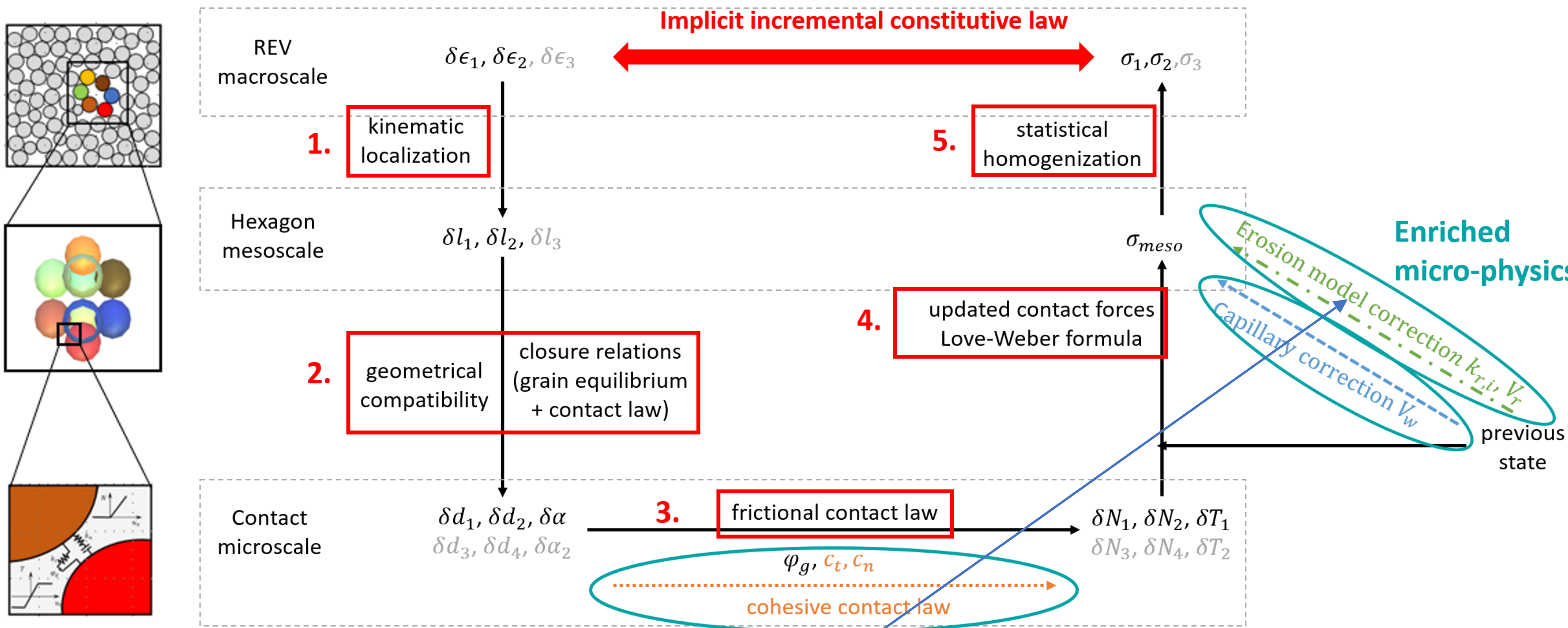
2. Analytical solution of the mechanical equilibrium of each cell





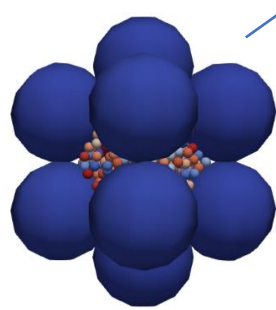
(Nicot and Darve 2011) (Xiong et al. 2017)

The standard H-model: homogenization scheme



Fine contribution to stress

Qirui Ma PhD, (2020)

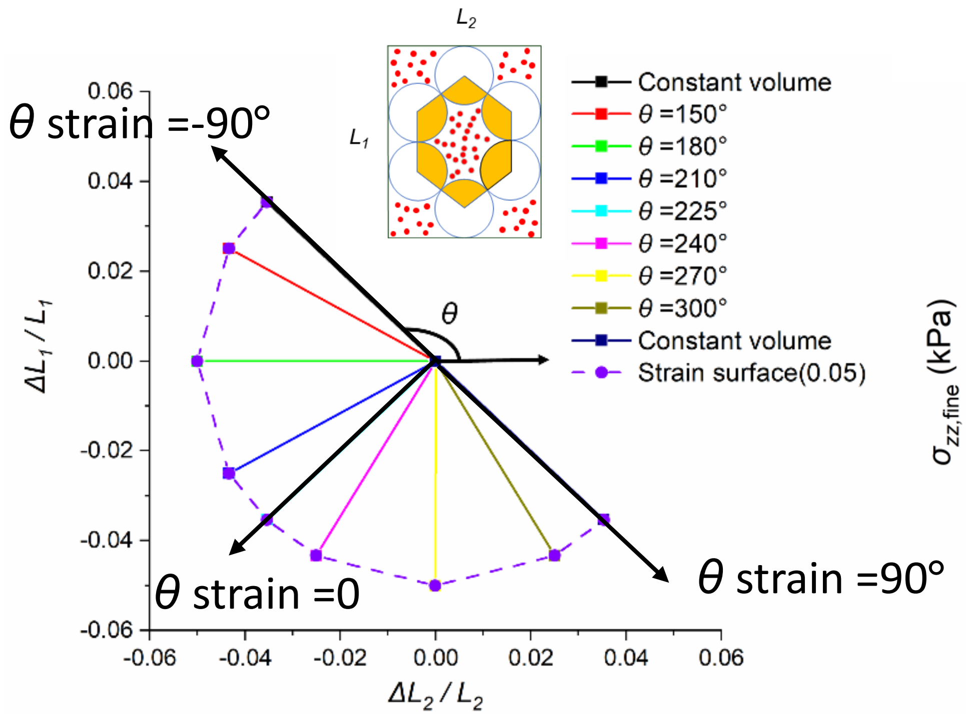


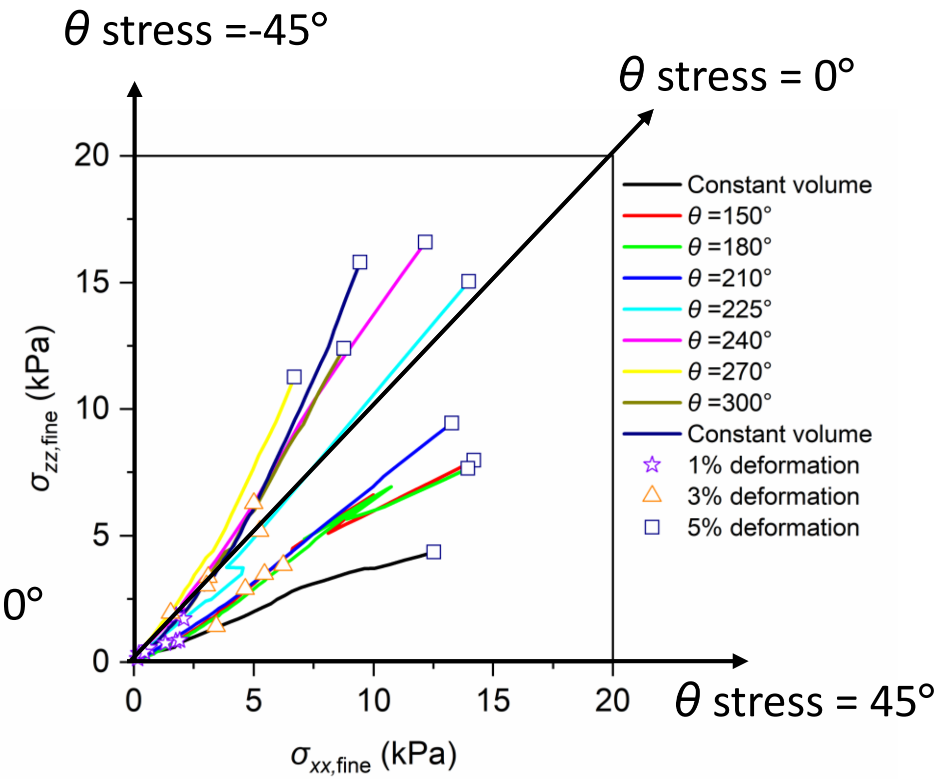
$$\sigma_{ij} = \frac{1}{V}\left(\sum_{c \in \text{c-c}} f_i^{\text{c-c}} d_j^{\text{c-c}} + \sum_{c \in \text{c-f}} f_i^{\text{c-f}} d_j^{\text{c-f}} + \sum_{c \in \text{f-f}} f_i^{\text{f-f}} d_j^{\text{f-f}} \right)$$

Standard H-model
(coarse-coarse contacts)

Fine contribution
(coarse-fine and fine-fine
contacts)

Systematic analysis for proportional strain paths



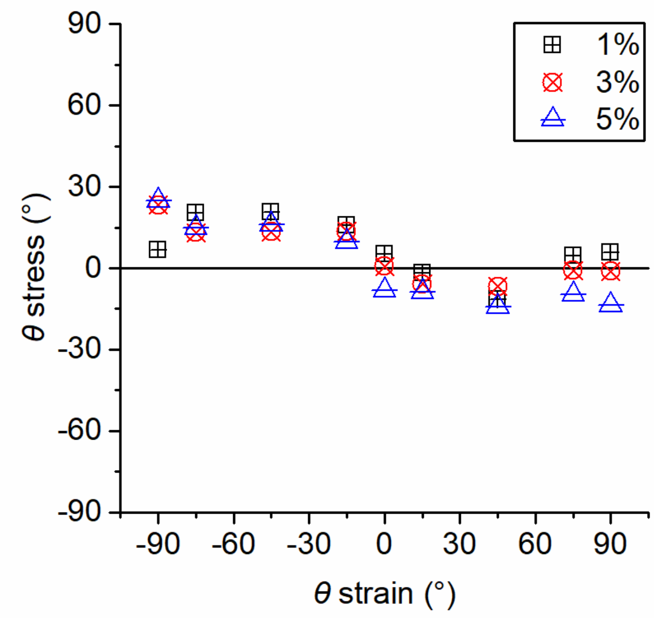


$$(\Delta L_1 / L_1)^2 + (\Delta L_2 / L_2)^2 = 0.05$$

The stress contribution of fine particles is

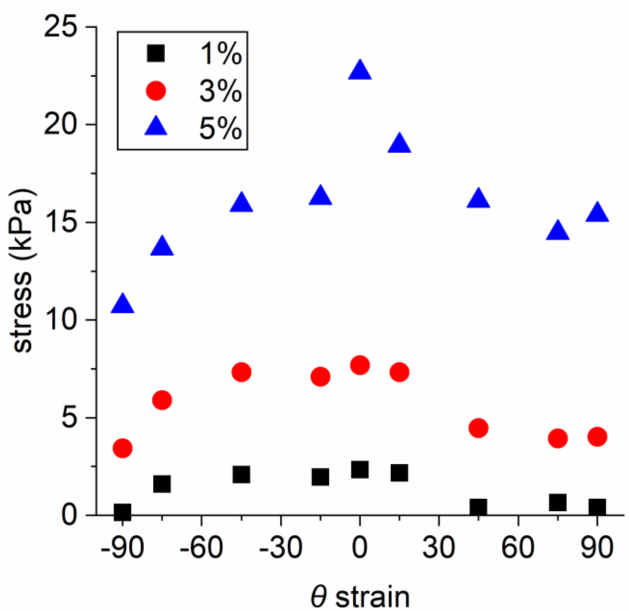
- quasi linear with strain intensity
- Slight anisotropy

Proposed model



Equivalent fine stress contribution

$$\sigma = \sqrt{(\sigma_{xx})^2 + (\sigma_{zz})^2}$$



$$d\sigma_f = \left\|d\sigma_f\right\| \begin{pmatrix} \cos(\frac{\pi}{4} - \theta_{stress}) & 0 \\ 0 & \cos(\frac{\pi}{4} + \theta_{stress}) \end{pmatrix}$$

$$\left\|d\sigma_f\right\| = \left\|d\varepsilon\right\| \cos(\omega \theta_{strain})$$

$$\theta_{stress} = \theta_0 \arctan(\beta \theta_{strain})$$

Model parameters depending on fine content and size ratio

Conclusion and outlook

Done

- DEM simulations showed that fine particles have a stabilisation effect:
    1. **Increase in dilatancy angle**
    2. **Increase strain hardening**
    3. **No effect on the initial yield surface**
- An analytical relationship for the stress contribution has been derived from DEM simulations at mesoscale

Remains to be done

- Relate the model parameters to fine content and particle size ratio
- Implement the enriched version of the H-model
- Assess the effect of fluid on fine content (REV and structure scale)
- Assess the impact of suffusion on mechanical stability (material and structure scales)

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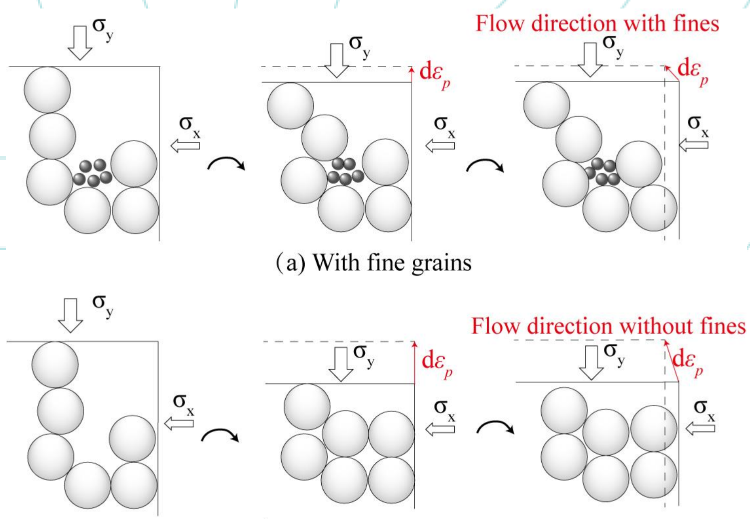
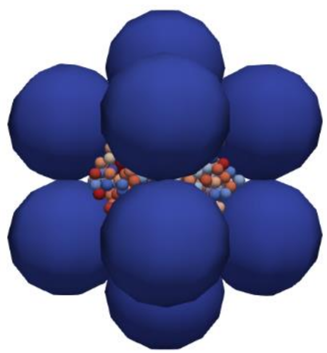


(a) With fine grains
(b) Without fine grains



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