From plasticity to visco-plasticity

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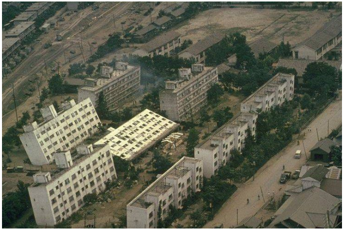
Introduction

Typical phenomena

- * Fluid or solid?
- * Immersed liquefaction (simulated 1/2)
- * Chichi earthquake (Japan)
- * Small scale demo
- * Lanslide (Philippines)
- * Debris flow



Introduction

Context Large movements of saturated geomaterials (e.g. debris flow) need advanced constitutive models, sometimes including a so-called solid-fluid transition (and a fluid-solid transition?)

Aim of this talk:

- microscopic origin of bulk viscosity in saturated materials
- question the concept of solid-fluid transition
- suggest an appropriate constitutive framework

Introduction

Solid-fluid transition

$$\text{solid+fluid} = \begin{cases} \text{solid (poro-elasto-plastic) material if } \mathcal{C} \\ \text{complex one-phase fluid otherwise (e.g. Bingham)} \end{cases}$$

Introduction

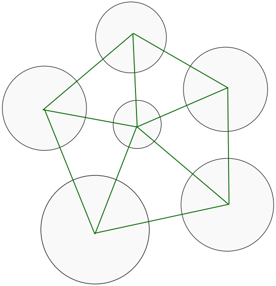
Solid-fluid non-transition

solid+fluid = solid+fluid

Outline

Plan

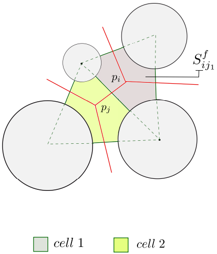
DEM-PFV scheme

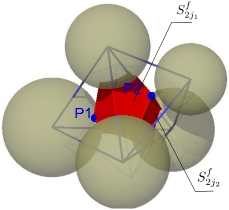


1 tetrahedron → 1 pore body
1 triangle → 1 pore throat
Implemented in http://yade-dem.org, and freely available.

Chareyre et al. Transp. Porous Med. (2012), Catalano et al., IJNAMG (2013)

Poromechanical coupling





1. Strictly incompressible viscous fluid in Stoke's regime viscosity = 1 parameter (implicit ALE scheme)
2. In this talk elastic-frictional contacts = 3 parameters (explicit DEM)

$$\dot{V} = \sum_{j=j_1}^{j=j_4} \int_{S^f_{ij}} (u^s - u^f) \, . \, n \, ds = \sum_{j=j_1}^{j=j_4} K_{ij} \, (p_i - p_j)$$

Poromechanical coupling

Consolidation problem:
Time evolution of a saturated medium under external load

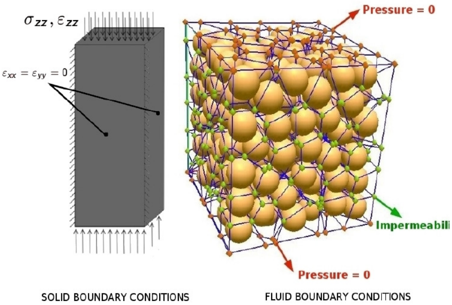
Terzaghi's theory of consolidation

Coefficient of consolidation:

$$C_v = \frac{kE_{oed}}{\gamma} \quad (1)$$

Consolidation time:

$$T_v = \frac{C_v t}{H^2} \quad (2)$$



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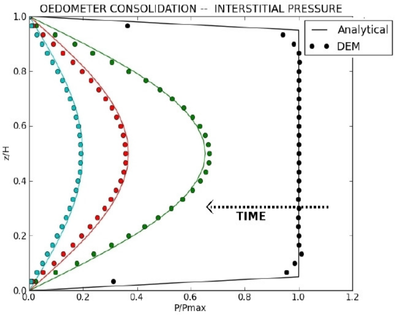
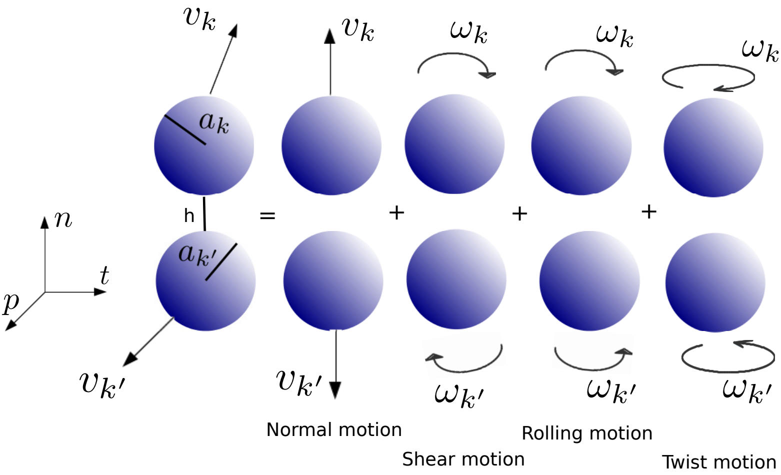


Poromechanical coupling

P1:

Poromechanical couplings (e.g. primary consolidation) cannot be reflected by single-phase rheology. Never.

Plan


v_k
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$\omega_{k'}$
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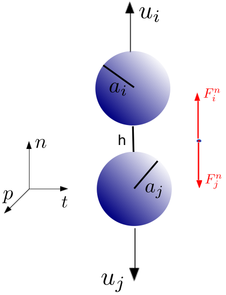
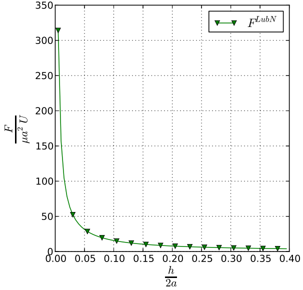
Normal motion
Shear motion
Rolling motion
Twist motion

Normal lubrication force (for instance)



$F_n^L = \frac{3}{2}\,\pi\,\mu\,\frac{r^2}{h}\,\dot{h}$
(*no additional parameter*)



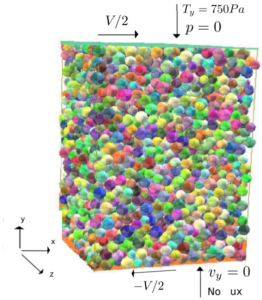
See Marzougui et al. *Granular Matter* (2015).
Note: don't replicate the conventional lubrication models from the literature, they are physically inconsistent in most cases.

Plan

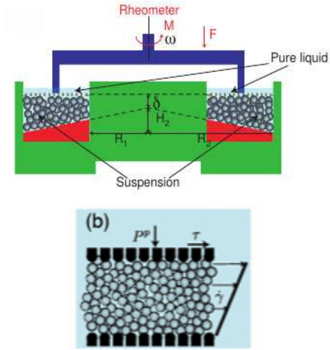
Configuration

Numerical configuration

shearFlow

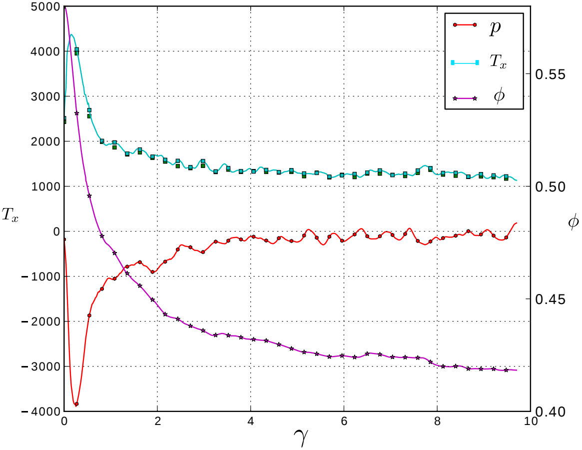


Experimental configuration of Boyer et al



Boyer et al, Physical Review Letters (2011)

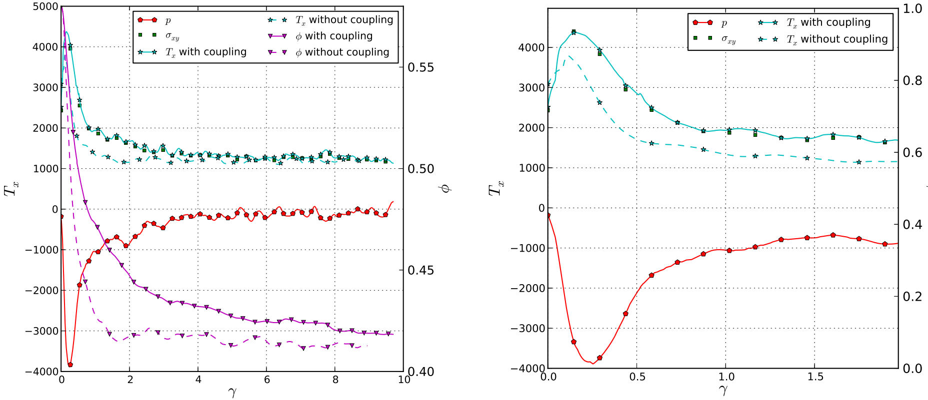
Imposed shear rate



$$I_v = 0.223$$

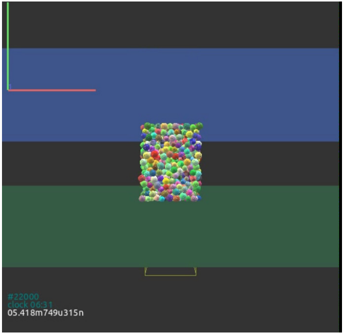
$$T_x = \frac{F_x}{S}$$

Shear stress

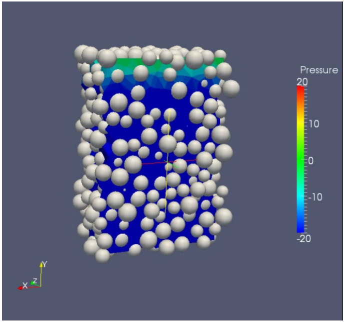


The poromechanical coupling has an effect in the transient regime, no significant effect at steady state.

shearFlow

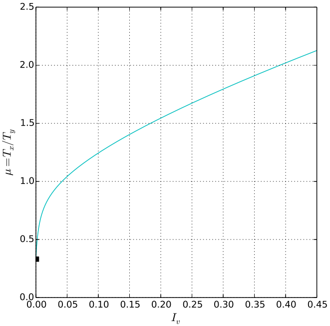


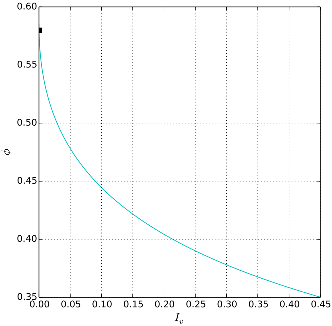
Pressure



Comparison with the rheometer measurements

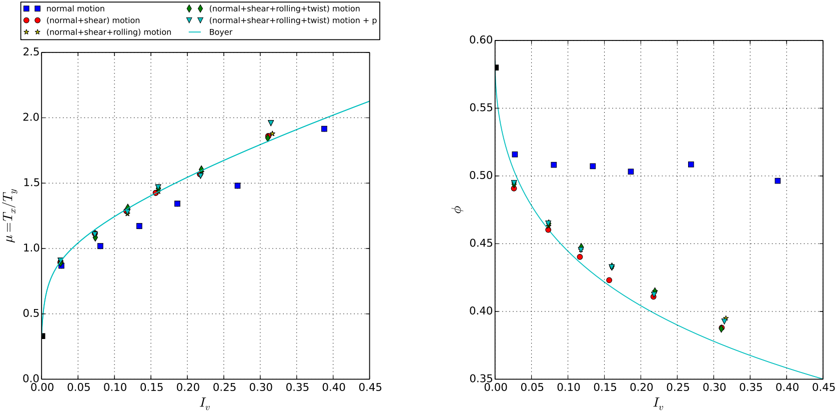
$I_v = \mu_w \dot{\gamma}/P$ dimensionless shear rate
(please forget "$\mu(I)$ rheology" for a moment)
$\mu = \tau/P$ apparent friction



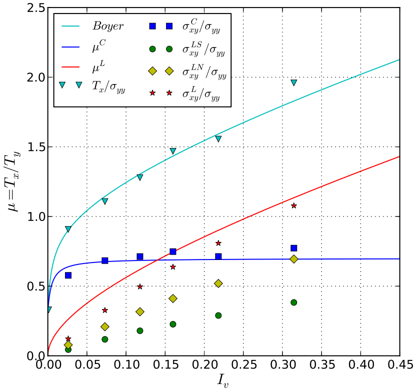


- * For $I_v = 0$, dry friction.
- * $\mu = 0.31$ and $\phi = 0.585$: the results match those measured

Comparison with the rheometer experiments



$$T_x = \sigma^C_{xy} + \sigma^{LN}_{xy} + \sigma^{LS}_{xy}$$



- The contribution of solid contacts to the bulk shear stress is significant even in more dilute systems.

See Marzougui et al., Granular Matter 2015.

Comparison with the rheometer experiments

P2:
Simple relationships at steady-state:

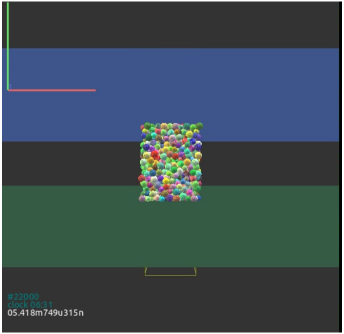
$$\mu = \mu(P, I_v) \text{ and}$$

$$\phi = \phi(P, I_v)$$

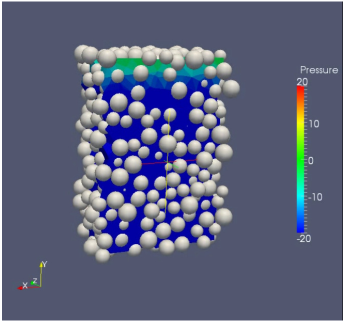
independently of particle size (particle shape anyone? ;)

Plan

shearFlow



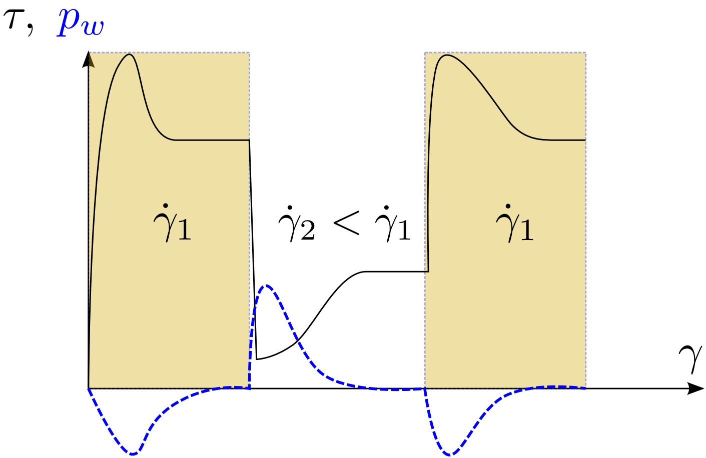
Pressure



Debris flow vs. single phase rheology

- P1. $\dot{\phi} \neq 0 \Rightarrow$ poromech. coupling $\Rightarrow$ not a single-phase rheology
- P2. at steady-state $\phi = \phi(I_v)$...
- P3. ... implying poromechanical coupling under changing conditions
- P4. GOTO P1

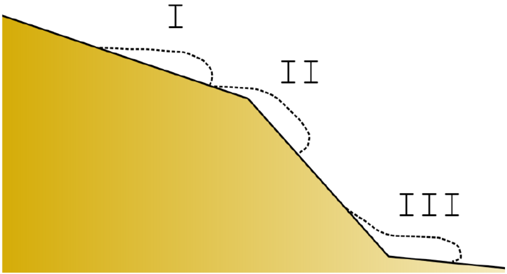
Transient effects vs. change of strain rate



Debris flow vs. single phase rheology

"Changing conditions"?

- From stable to (I) flowing...
- ... down a slope with ever changing slope angle (II)
- then stopped in a flat area (III) or after impacting a structure



Suggestion

- Add "visco-" in front of elasto-plasticity, don't trade elasto-plasticity for viscosity
- include $\dot{\gamma}$ in critical state soil mechanics based on $\mu(I_v)$, $\Phi(I_v)$, and effective stress
- find a good technique to solve coupled BVPs with such equations (~~DEM~~, FEMLIP, MPM, SPHxFEM, PFEM,...)

You are done. You can go from the "solid" state to the "fluid" state, then back to the "solid". In fact you are always in a solid+fluid state.

Further questions (possibly for DEM)

- Particle size distribution
- Non-newtonian pore fluid (clay suspension?)
- Segregation
- Micromechanics (fabric evolution and others)
- ...

Summary

- Robust and quantitative model for mixtures of spherical grains and newtonian fluids (yade-dem.org)
- Rate dependent critical state theory is sufficient
- Solid-fluid transition is not necessary
- Solving coupled problems cannot be avoided

THANK YOU FOR ATTENTION

References

Boyer, F., Guazzelli, ., & Pouliquen, O. (2011). Unifying suspension and granular rheology. *Physical Review Letters*, 107(18), 188301.
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