Soil Mechanics: Limitations and Future Directions

Amy Rechenmacher

Dept. Civil and Environmental Engineering
University of Southern California

Example of disconnect between granular physics and geomechanics

Excerpt from an email from a colleague (Applied Mathematician) regarding a joint paper on dense granular flows:

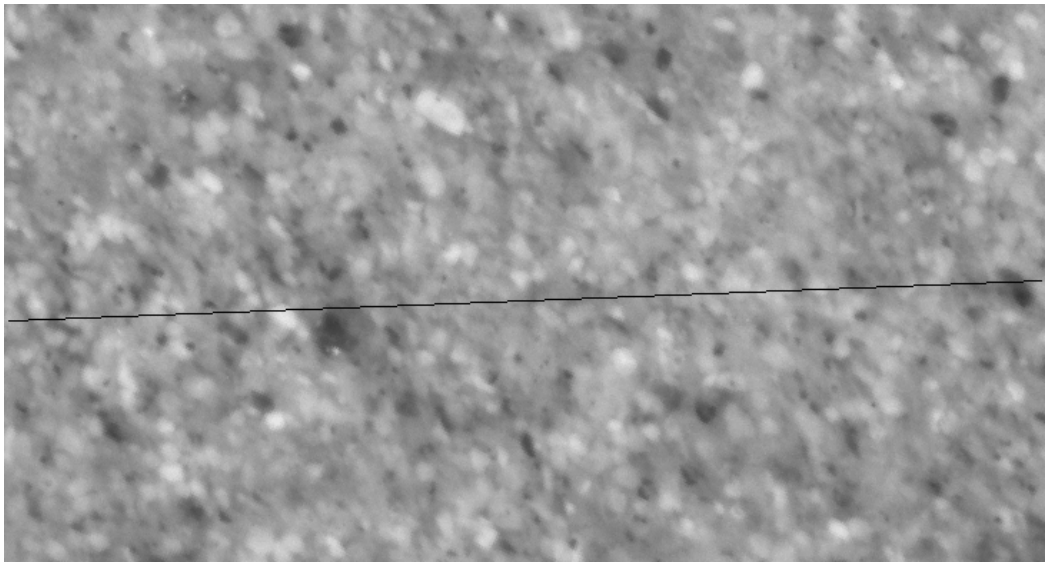
> "The reason for going for a high visibility physics journal is to ensure the physicists see your work. Some in that community have a terrible habit of ignoring papers in geomechanics…"

Outline

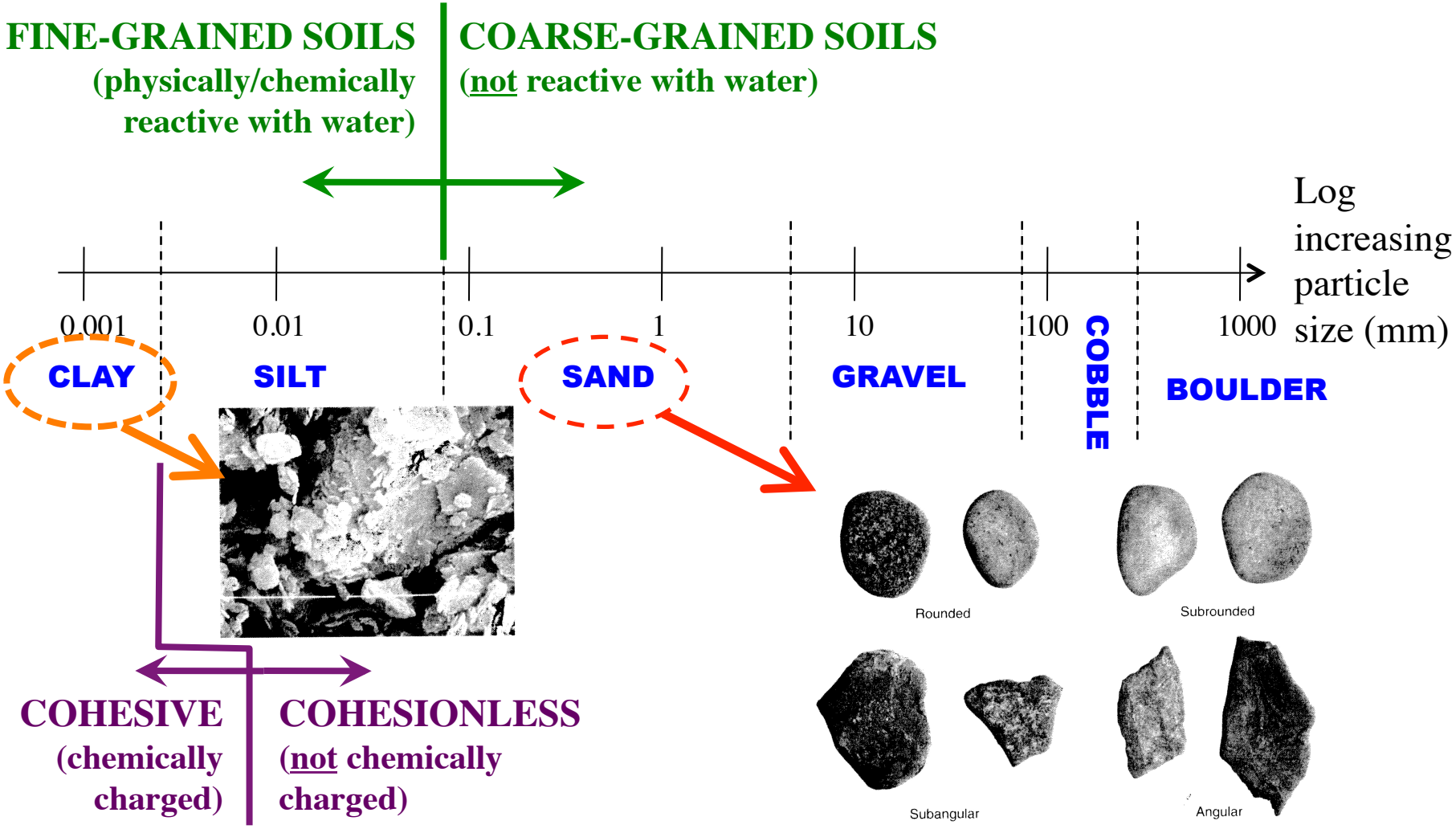
- Definitions and characterizations
- Soil strength, components of friction
- Effect of “state”: critical state
- Current limitations in Soil Mechanics
- Future Directions

Background: About me…

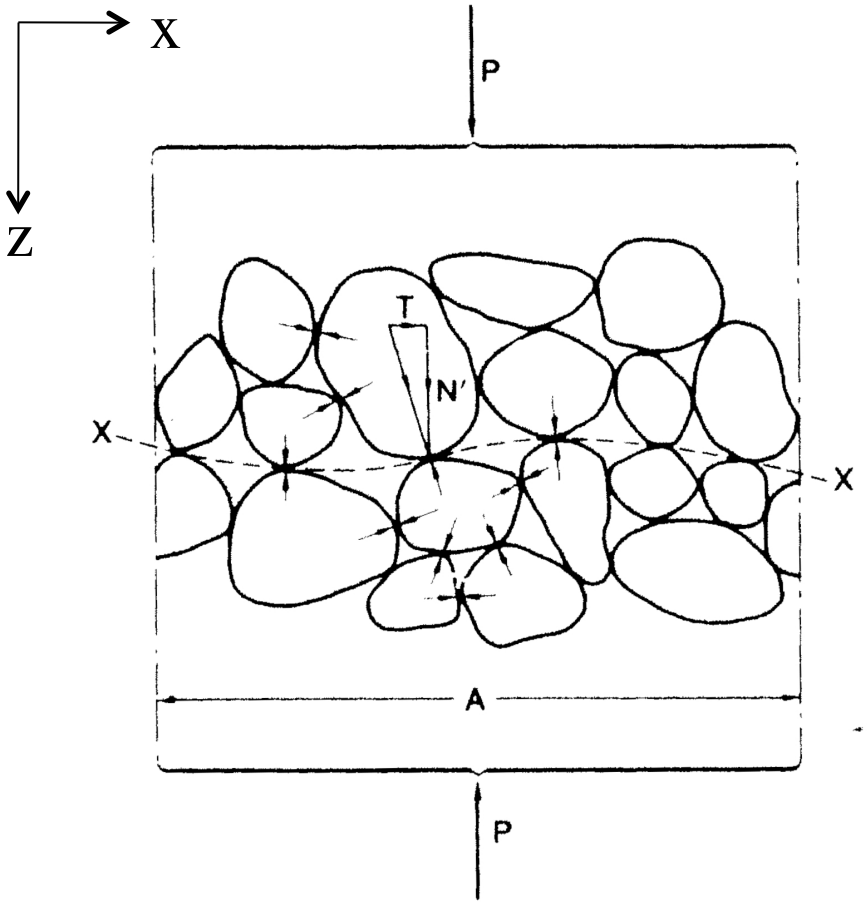
- BS, MS, PhD in Civil Engineering
- Worked in geotechnical practice 3 yrs b/w MS and PhD
- PhD research: experimental study of strain localization and critical state soil mechanics
- Current research:
  - Experimental imaging methods
  - Granular mechanics/ granular physics
  - Non-affine deformation in dense granular flows (force chains and vortices)
  - Geophysics: fault gouge



Soils: Classification by Grain Size



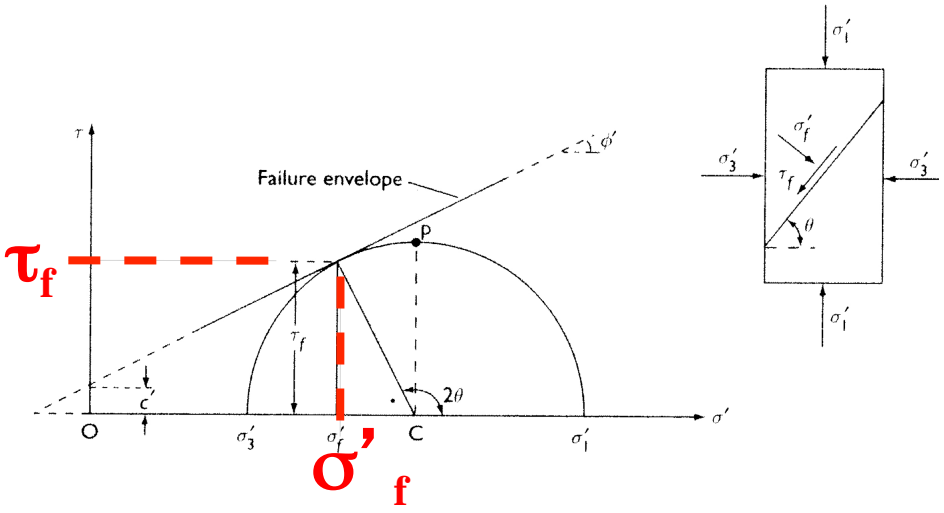
Effective Stress Concept



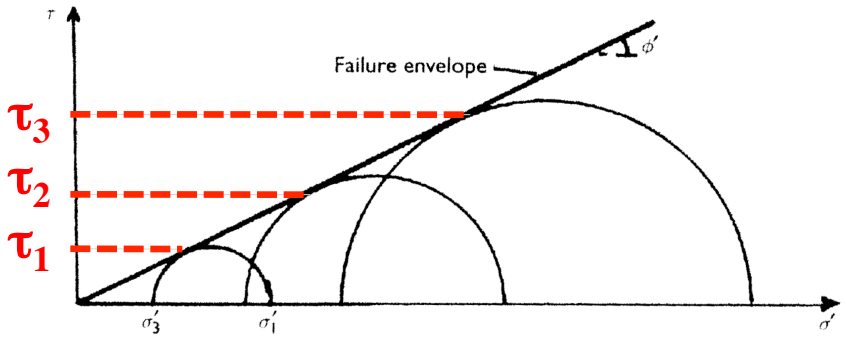
$$\sigma_z' = \frac{\Sigma N'}{A}$$

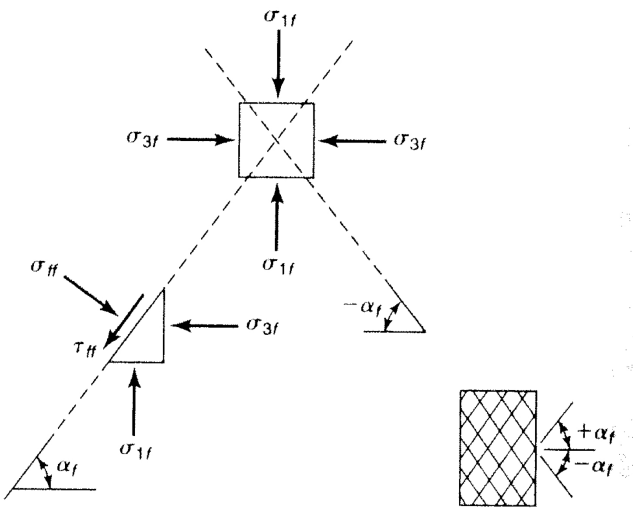
$$\sigma_z' = \sigma_z - u$$

Soil Strength:
Mohr-Coulomb Strength Criterion



σ'f

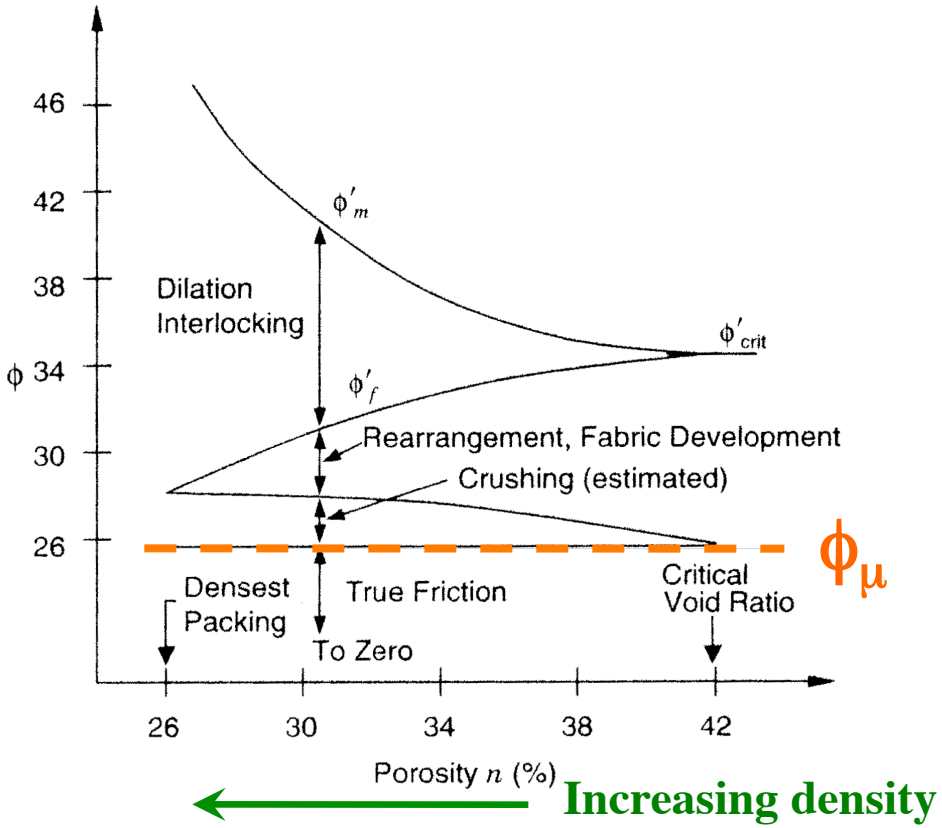




$\tau = \sigma' \tan\phi' + c' =$ shear *strength*

ϕ', c' = shear strength *parameters*

Components of Friction, ϕ'



(After Rowe, 1962)

4 components of ϕ':

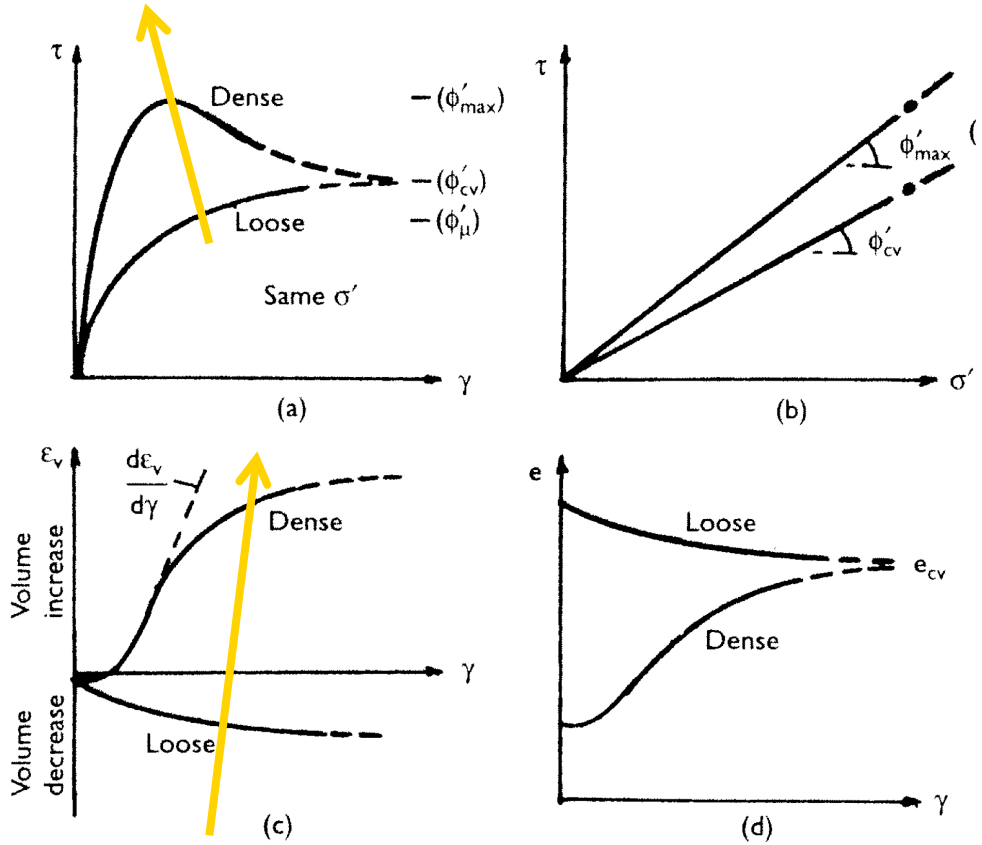
- Grain-grain friction, ϕ_μ
- Particle rearrangement
- Dilation
- Particle crushing

Factors affecting ϕ' in sands

- Grain size distribution
  - Well-graded (poorly sorted) sands “stronger”
- Grain shape
  - Angular grains more interlocking
- Grain Minearology
- Soil “state”
  - State = density *and* confining pressure

Effect of state: effect of density ($e = V_v/V_s$)

Increasing density/ decreasing e

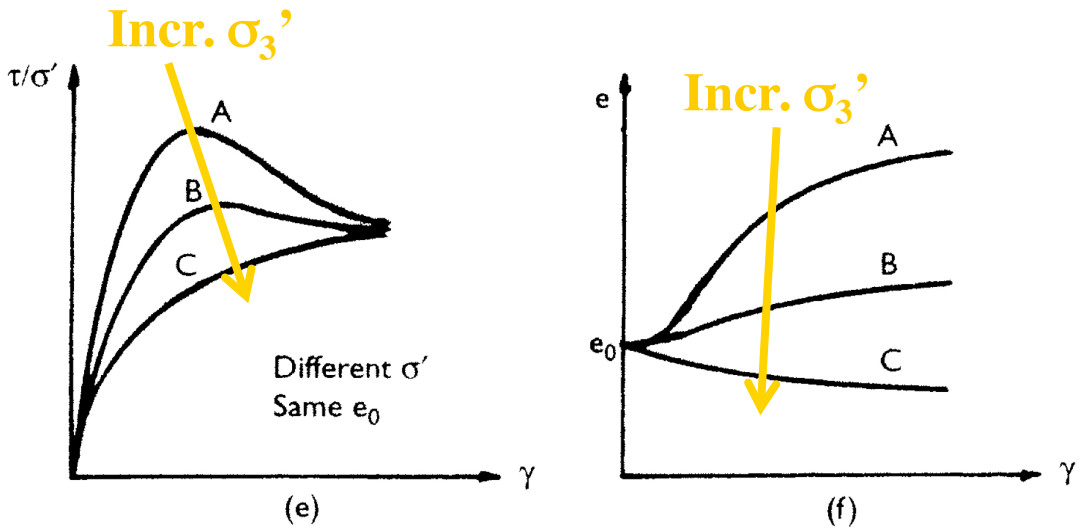


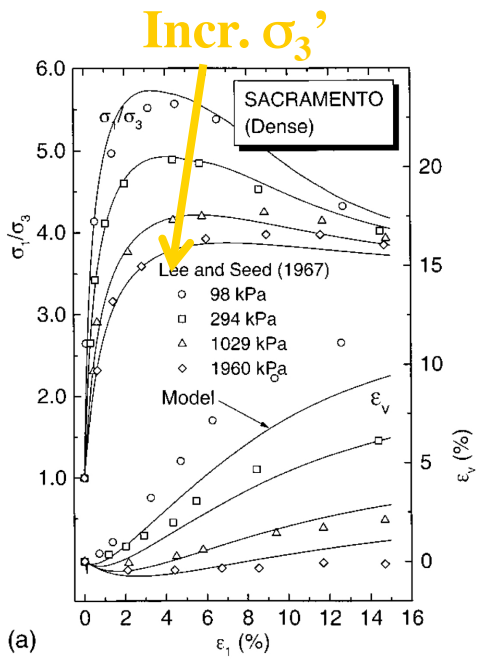
Increasing density / decreasing e

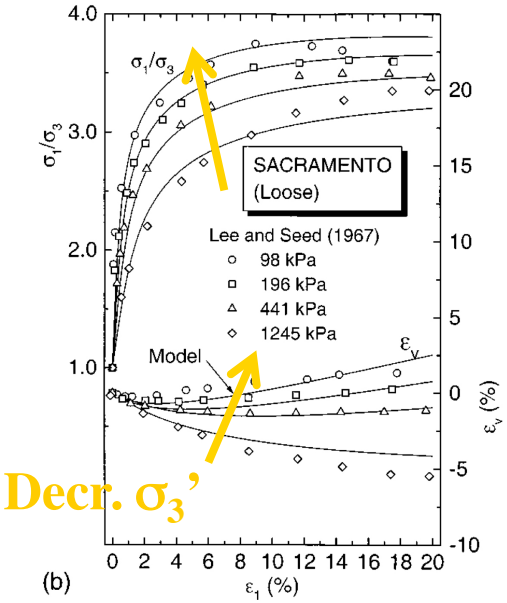
Observations:

- Dense sands (low e) "stronger": more energy required to dilate
- Dense sands soften
- All specimens approach a **"Critical State" (CS)** = *state of shearing at constant stress and volume*
- Both sands approach SAME e at CS

Effect of state: effect of confining pressure

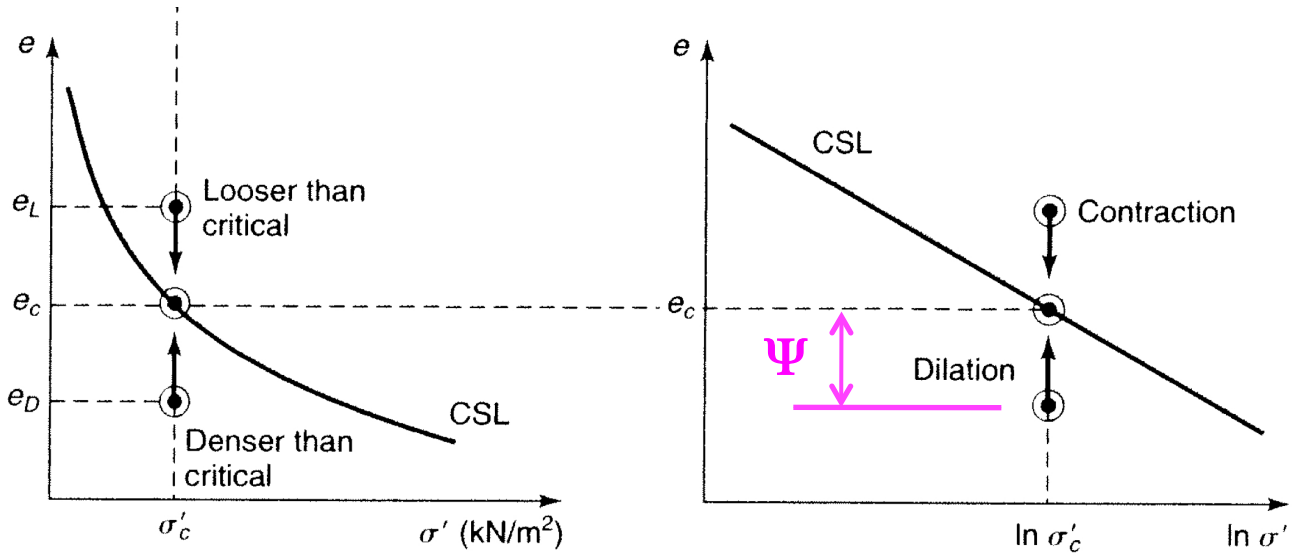






- High σ_3' supresses dilatancy:
  - at v. high σ_3', a “dense” sand will contract
  - at v. low σ_3', a “loose” sand will dilate

Effects of State: State Diagram



- CSL = critical state line:
  - Locus of final states of shearing at constant stress and volume to which all states approach during shear
  - Locus of initial states for which $\varepsilon_{vol} = 0$ during shear

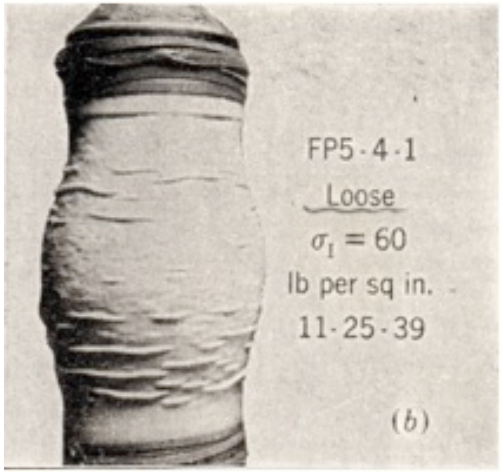
Critical State Concept

- Used as a framework for prediction
- CSL position unique for a given sand
- CSL position depends on:
  - Particle shape
  - Grain size and grain size distribution
  - *Mode of shearing*
- In practice, determination of CSL position very difficult (mainly due to strain localization)

Current limitations in Soil Mechanics

- Conventional test methods
- Geotechnical community's preference toward empirical methods
- Progressive failure
- Strain localization
- Soil behavior prediction is a multiscale problem

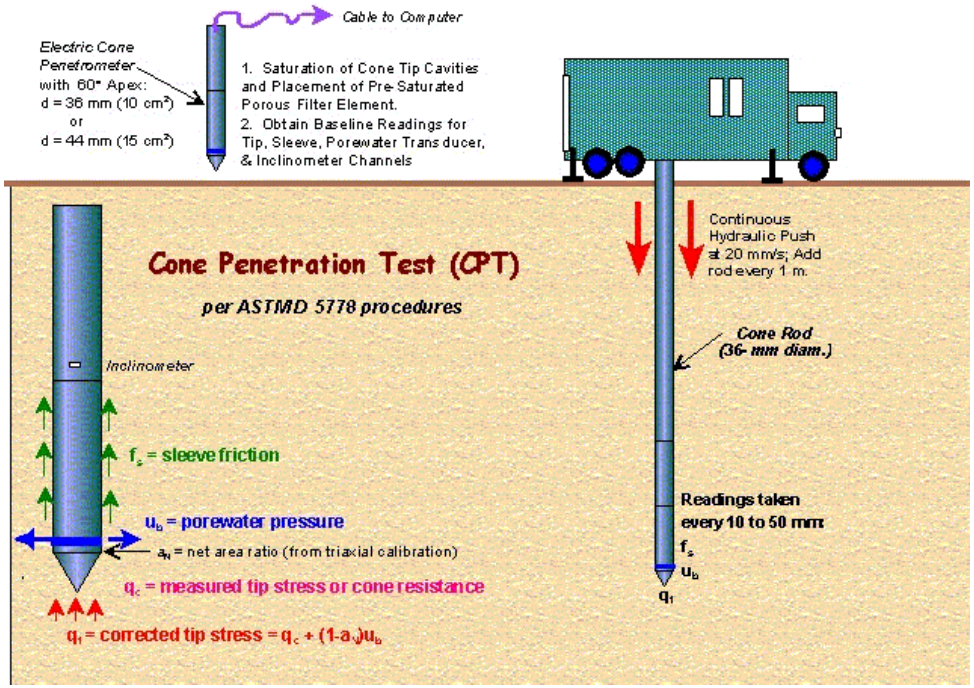
Limitation 1: traditional soil testing

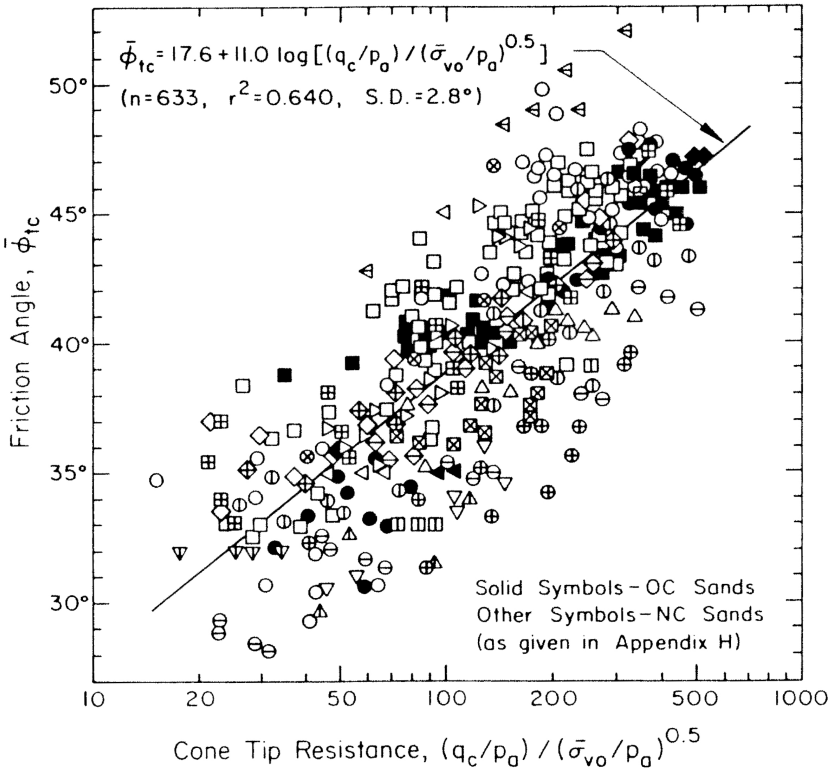


- Axisymmetric most popular
  - Not a realistic failure mode
  - Strength, critical state dependent on mode of shearing
- Boundary effects/interference
  - Soil/platen friction: non-uniform soil response
  - Membrane effects
  - Difficulty mimicking field boundary condition
- Behavior quantified from boundary measurements (only adequate for diffuse deformation)

Limitation 2: Empirical methods

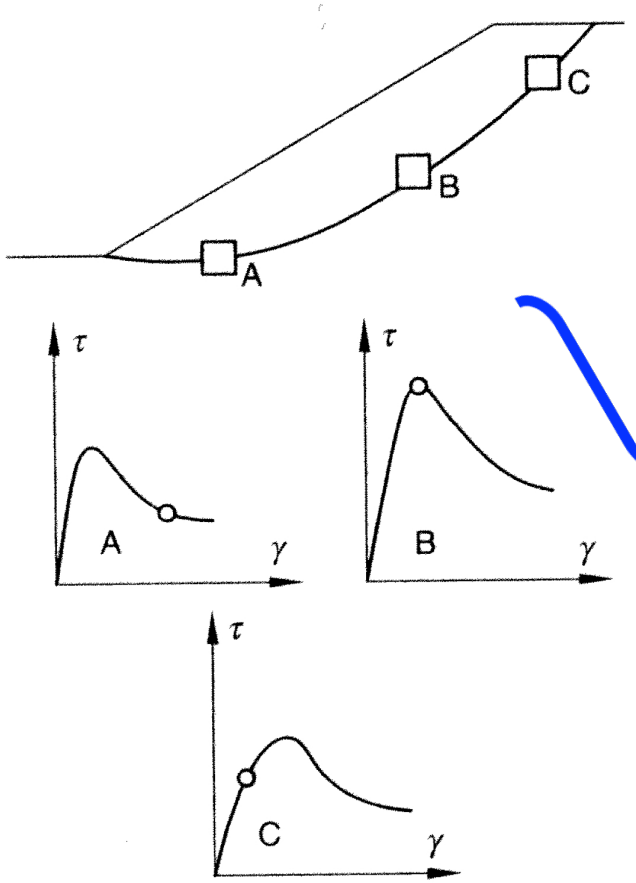
(motivated largely by sample disturbance)





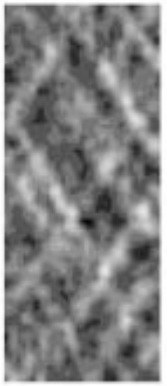
EPRI (1990)
"Manual on Estimating Soil Properties for Foundation Design"

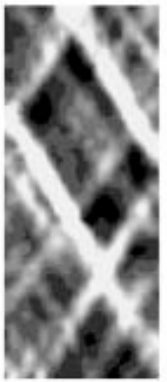
Limitation 3: Progressive failure (soil heterogeneity)



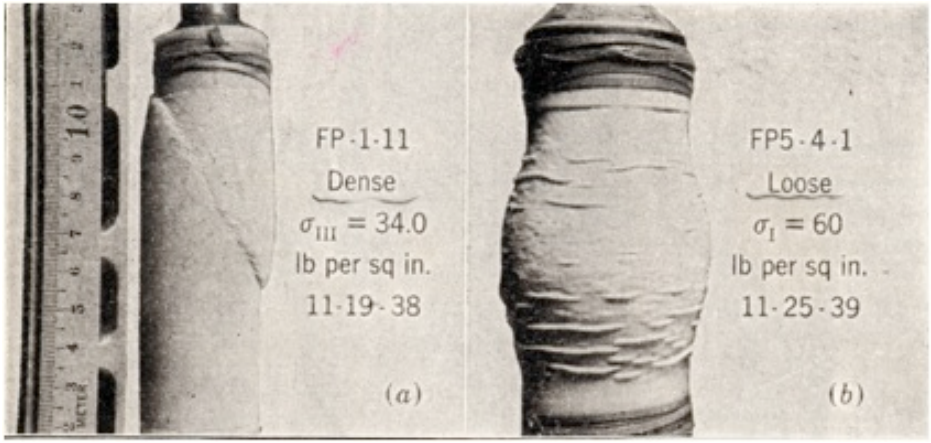
Needed: better understanding of progression of post-peak response!

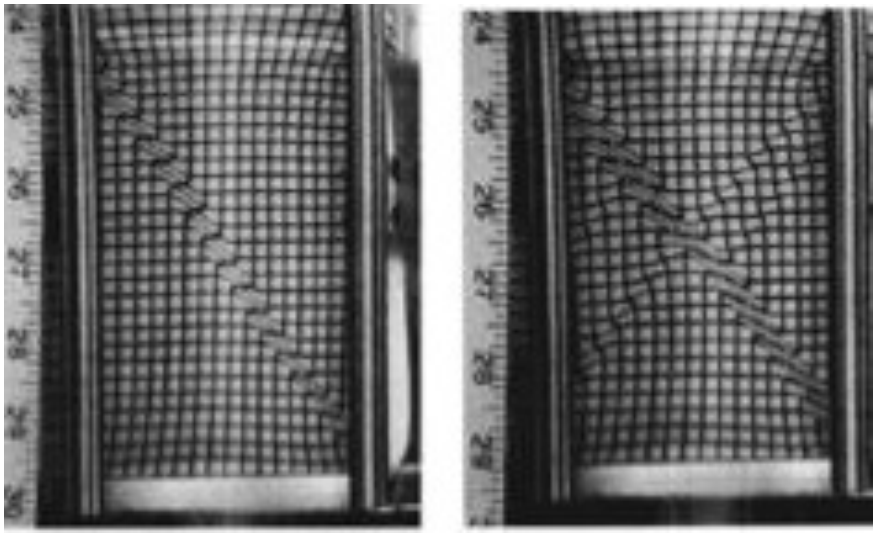
Gudehus and Nubel (2004)





Limitation 4: Strain Localization

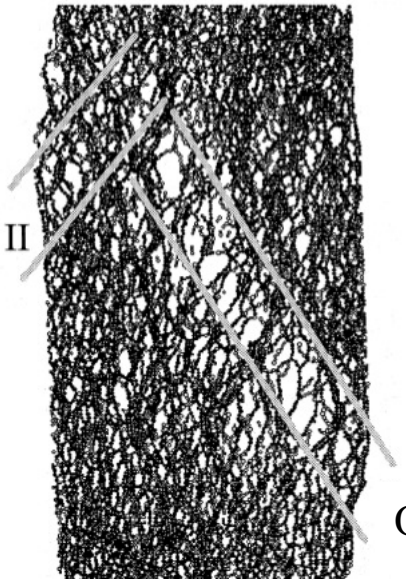




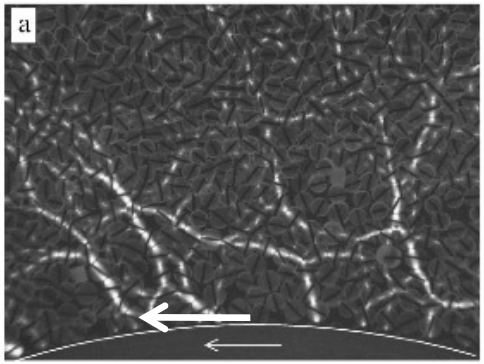
X-Ray Computed Tomography (CT)

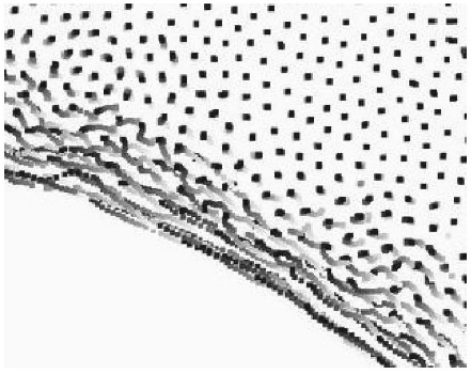
- Shear bands form in most cases
- Can't assess evolution to critical state using conventional tests when shear band present
- Scale v. small relative to specimen size: hard to characterize behavior inside

Limitation 5: Multi-scale behavior



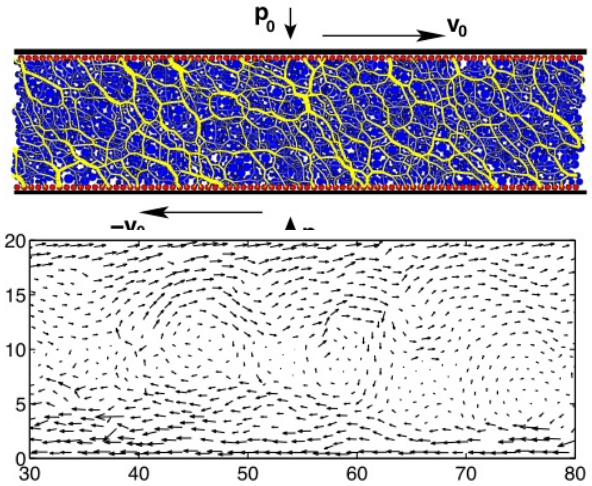
Oda and Iwashita (2000)



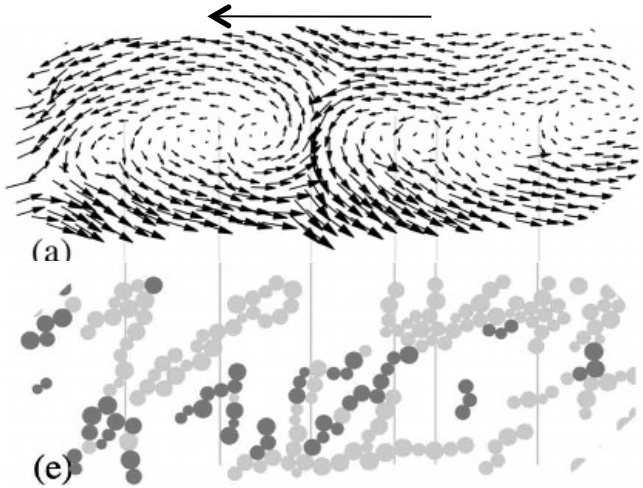


Utter and Behringer (2004)

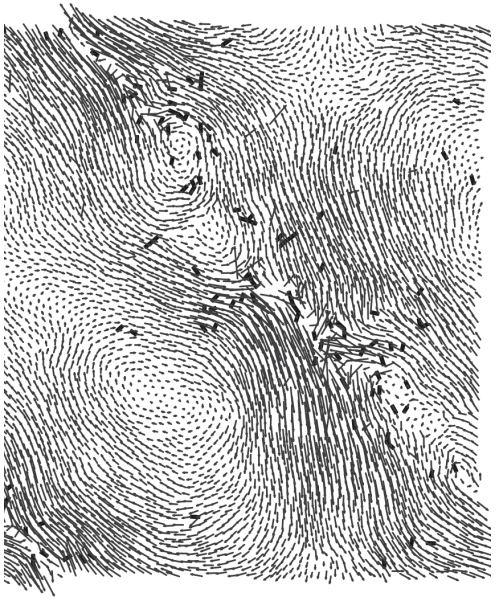
Note: grain vs. structural scales very different



Alonso-Marroquin et al. (2004)



Tordesillas et al. (2008)

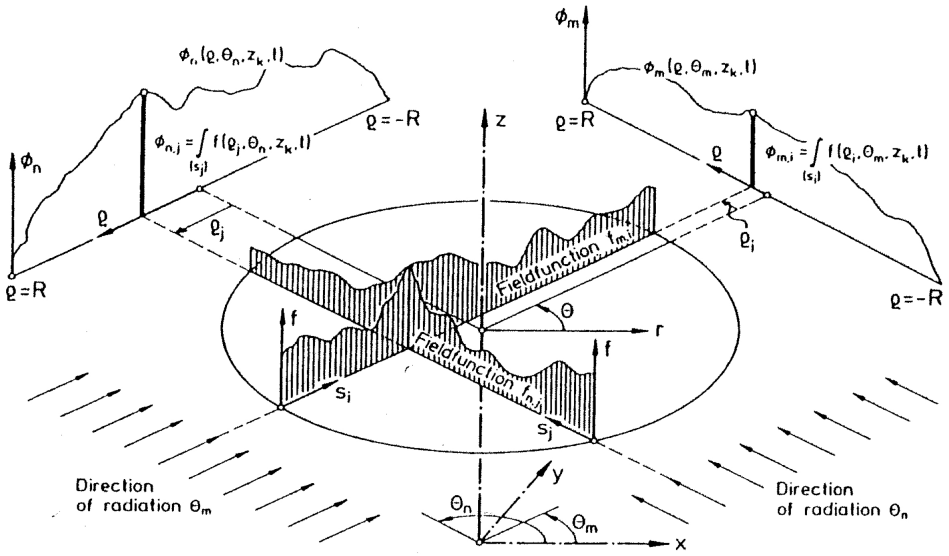


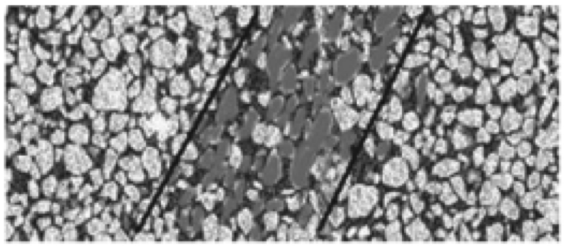
Thornton and Zhang (2006)

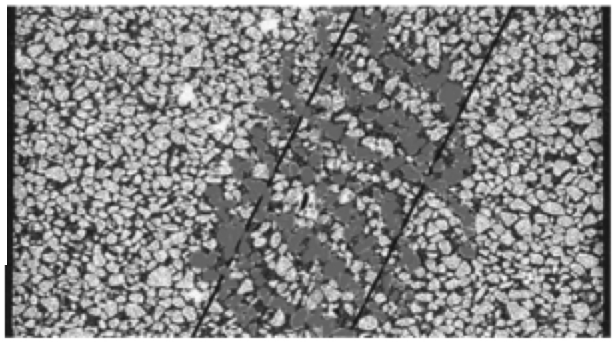
Future Work: Better physics-based understanding

- Multi-scale models: link micro-, meso-, and macro-scale responses
- Statistical Thermodynamics/Conservation of Energy
- Advanced testing to characterize micro- and meso-scale behavior

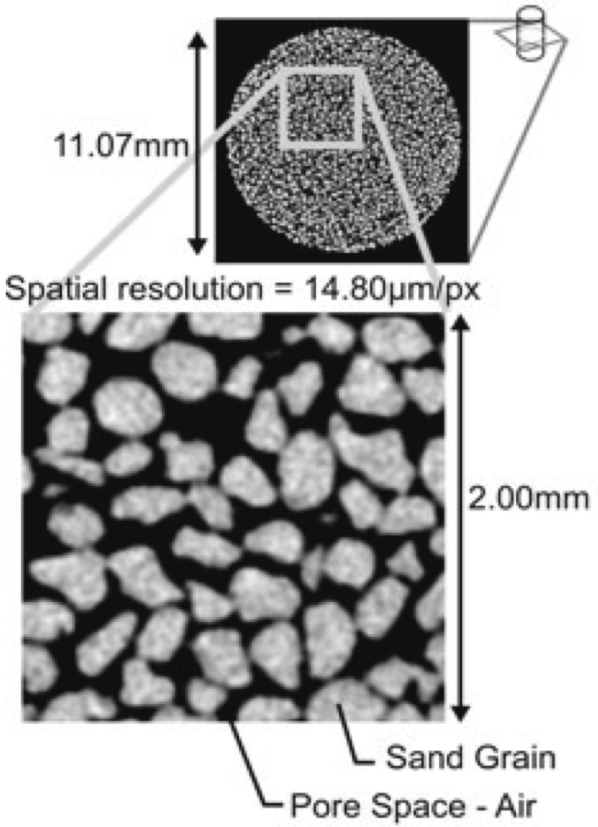
Future Work: Advanced experimental methods: μCT







Hasan and Alshibli (2010)



Tagliaferri et al. (2011)

Future Work: Advanced experimental methods: **DIC**