

Cost/benefit analysis of constitutive laws and DEM approach for geotechnical simulations under various loading paths

Tarek Mohamed

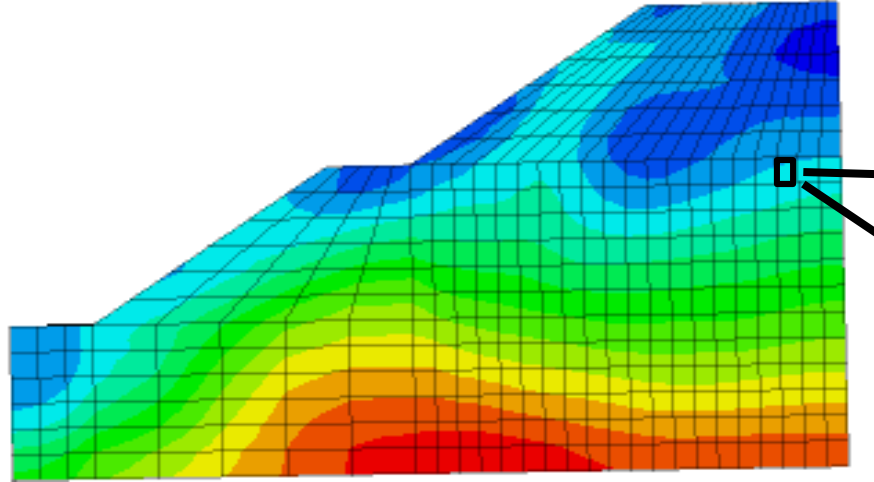
Jérôme Duriez, Laurent Peyras, Guillaume Veylon and Patrick Soulat
INRAE, Aix-en-Provence Unité RECOVER, France

20/02/2020

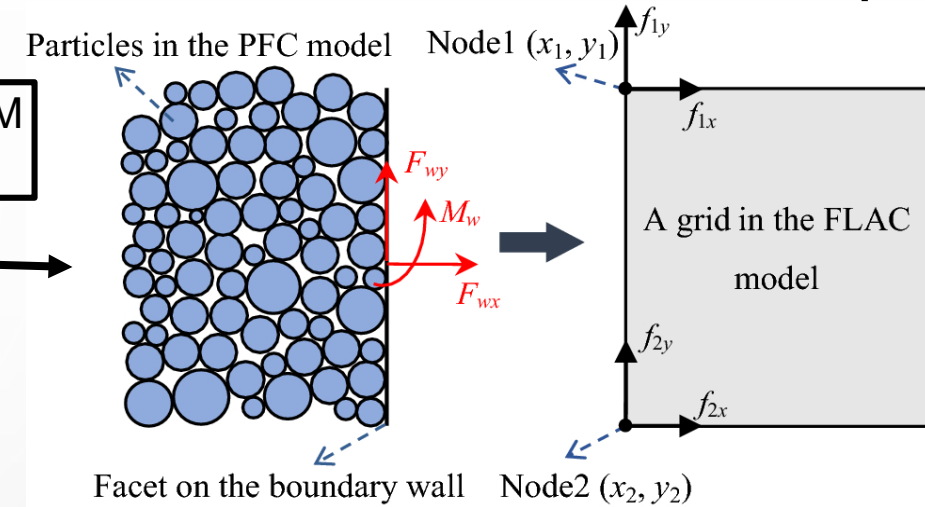


Introduction

1

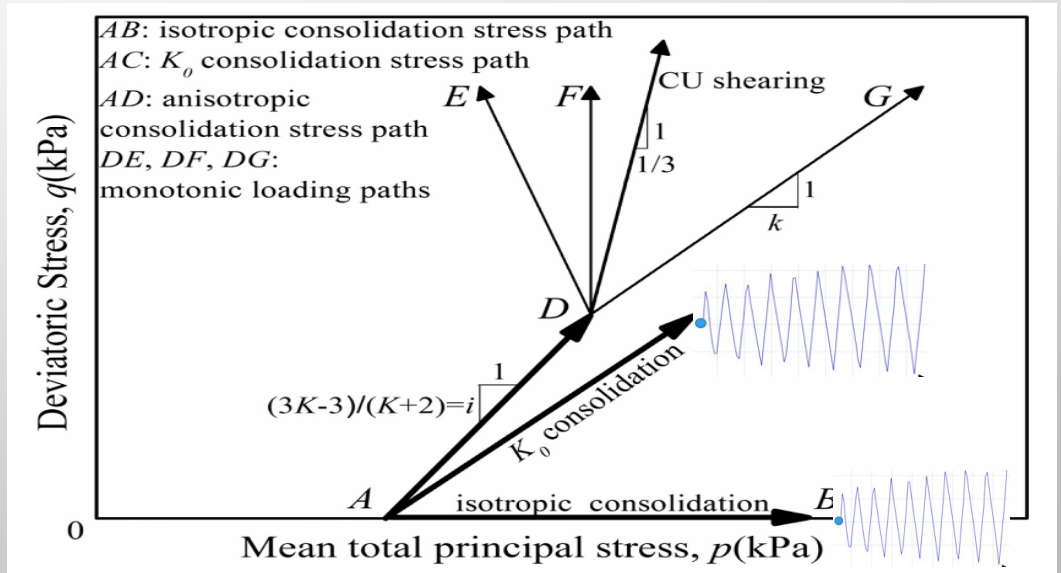


Representative volume of soil DEM REV



Mathematical formulation according to a theory of plasticity

- Soils are exposed to different stress paths during their life.
- The comprehensive predictions for these stress paths are not an easy issue and need e.g. a sophisticated soil model (with a lot of non physical parameters).
- DEM is a promising approach, since it deals with physics.



Yuanqiang et al 2018

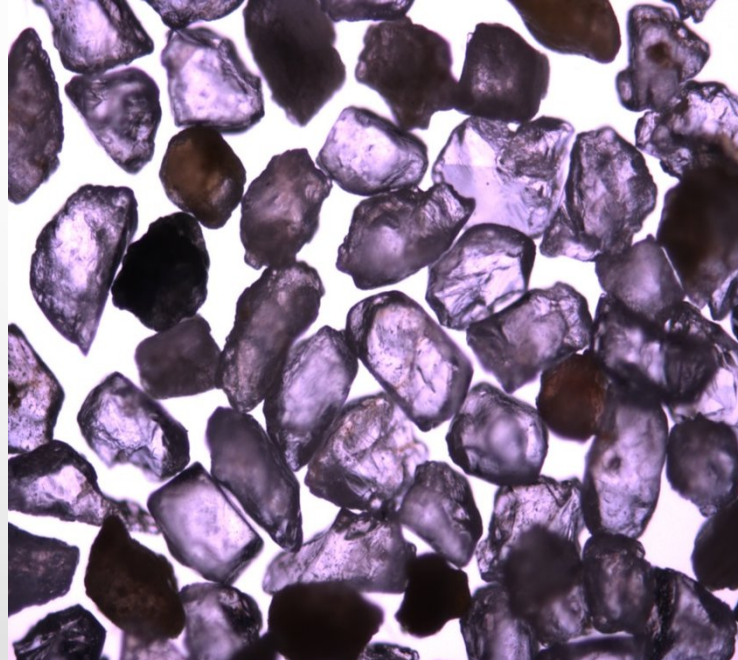
The Three Types of Soil Considered in This Study

Tropical Soil



Guadeloupe, France, SAFEGE

Toyoura Sand



(Bo Li , Xiangwu Zeng, 2011)

Christchurch Sand



Canterburymuseum.com

Tropical Soil

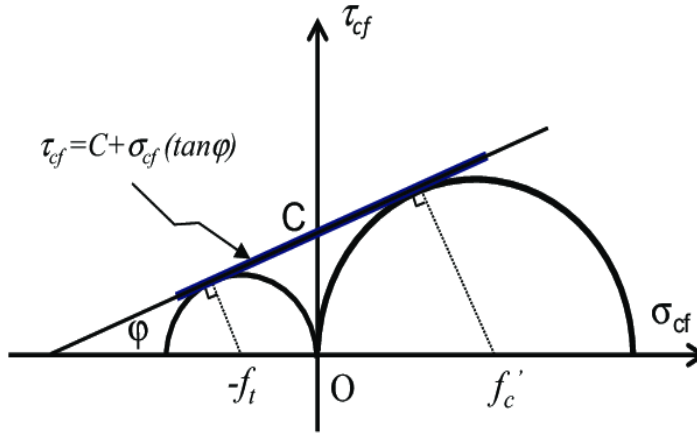


Guadeloupe, France, SAFEGE

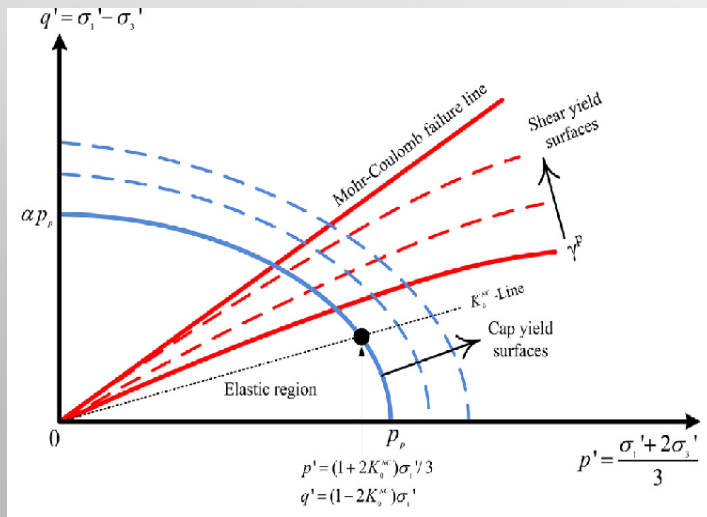
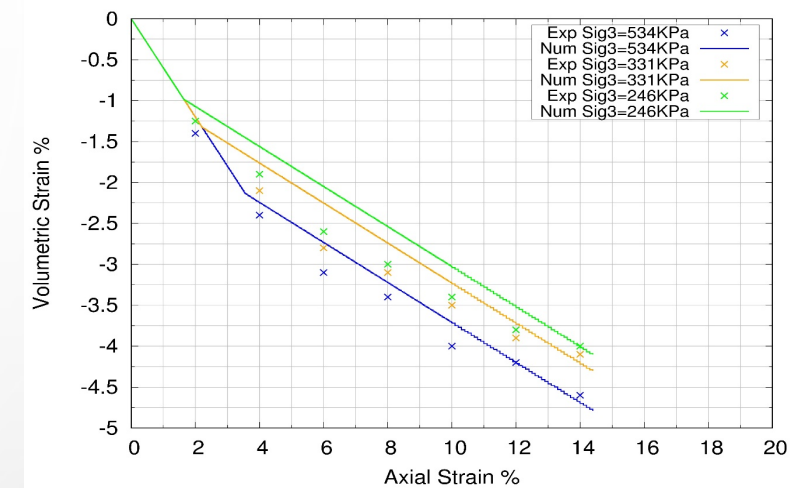
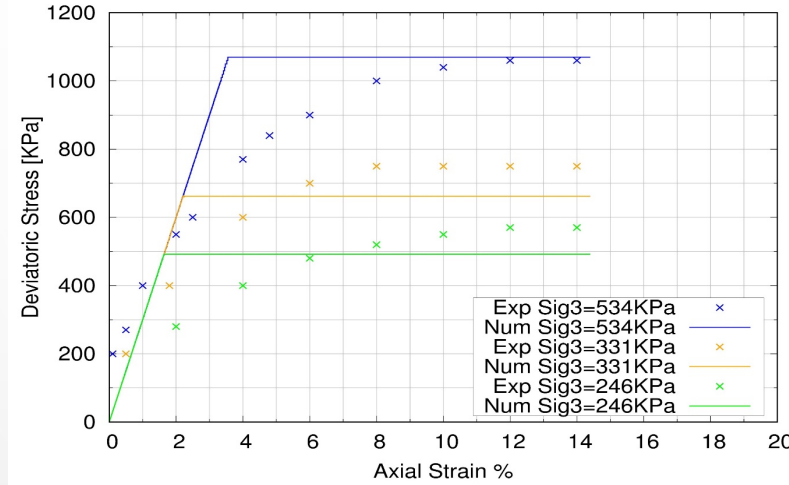
Calibration/Validation of Mohr-Coulomb and Cap-Yield Model Criteria on Tropical Soils

Drained triaxial Experimental data (Mouali et al 2018)

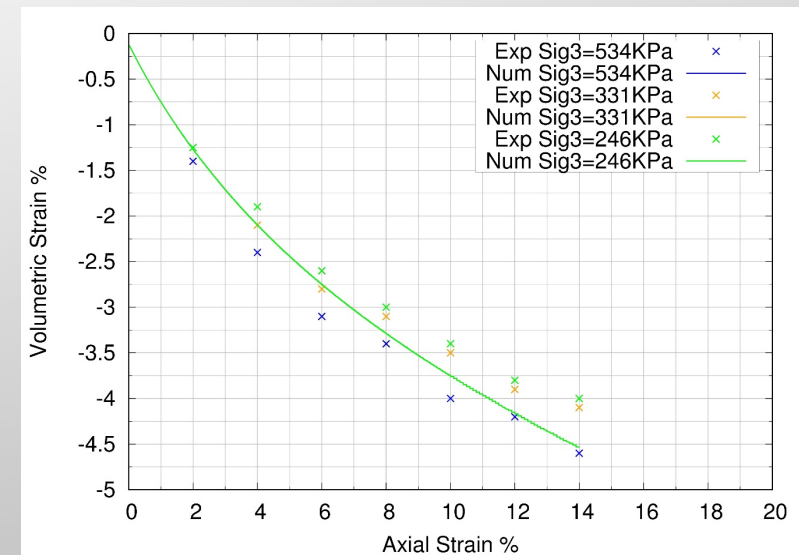
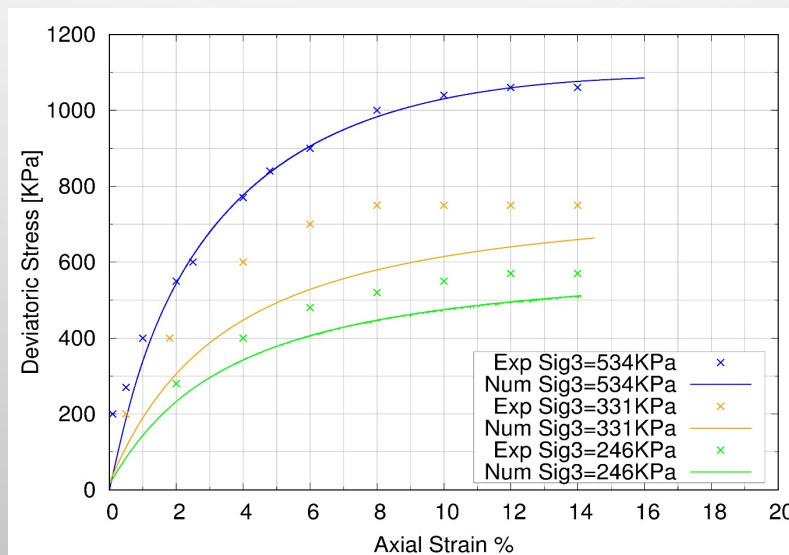
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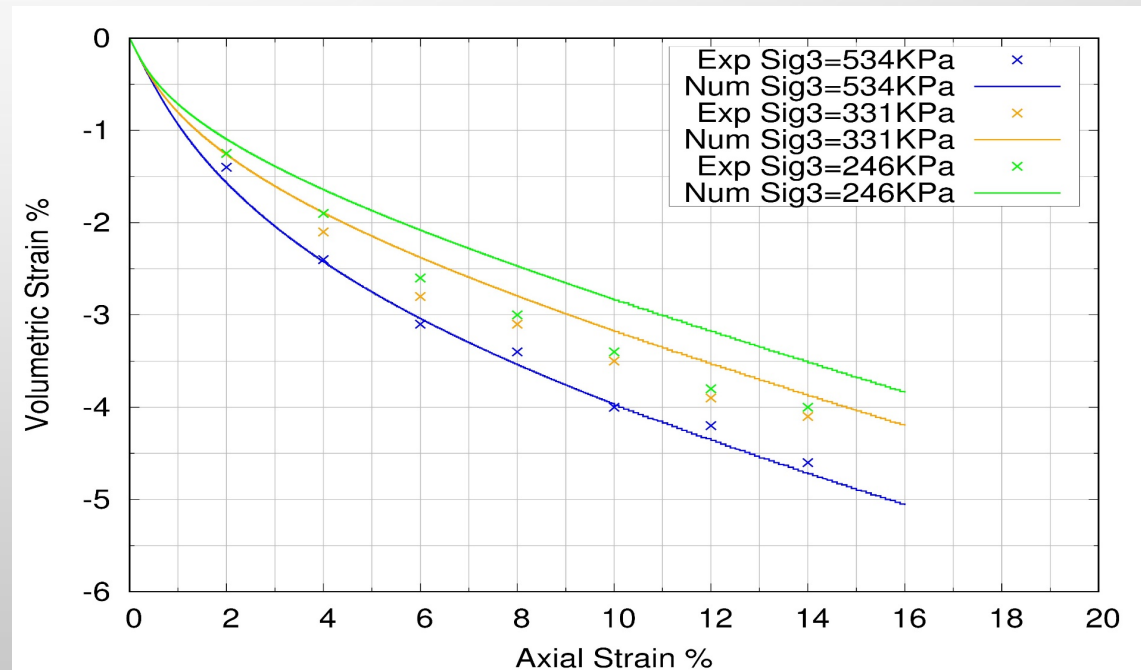
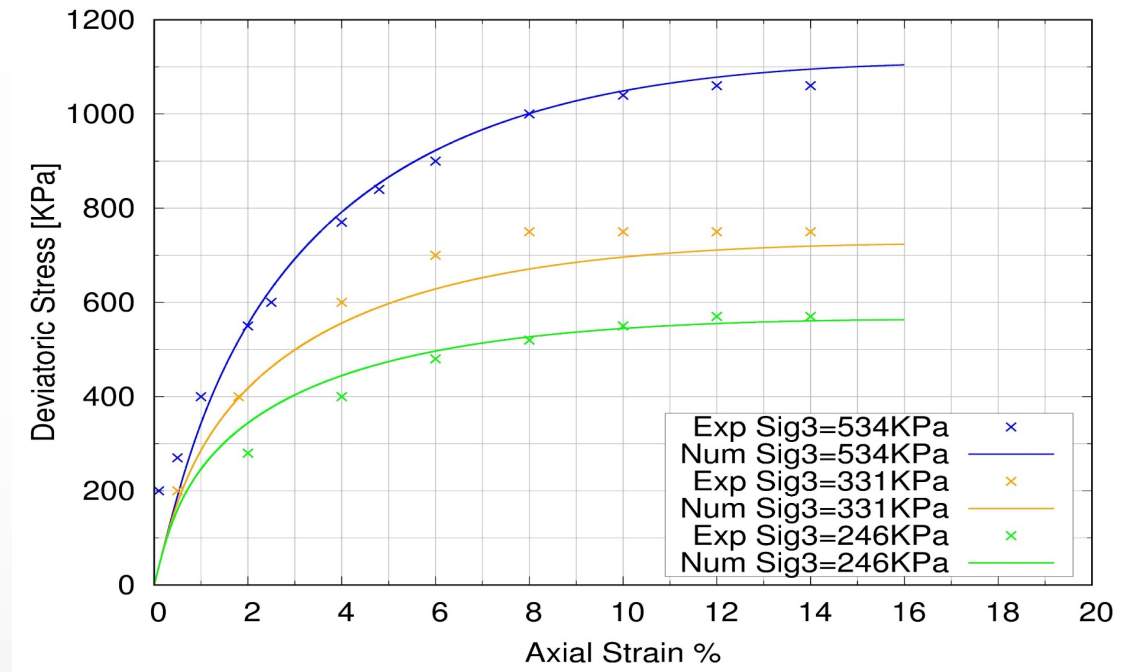
Mohr-Coulomb Model Parameters 5



Cap-Yield Model Parameters 14

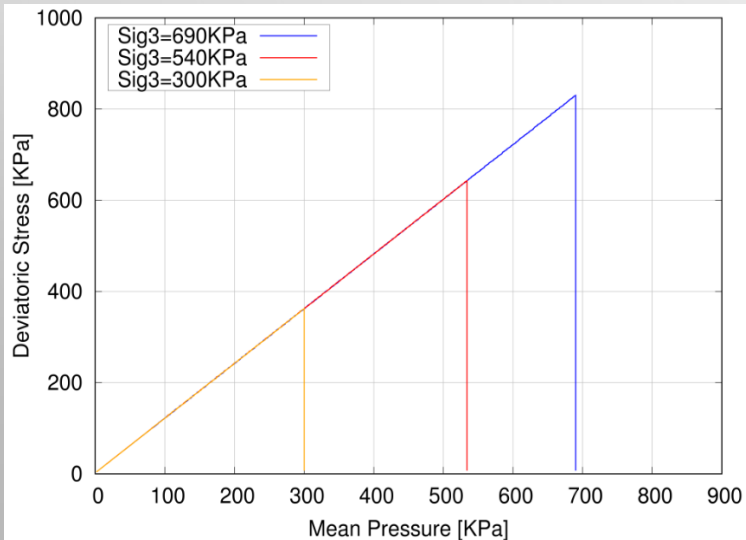
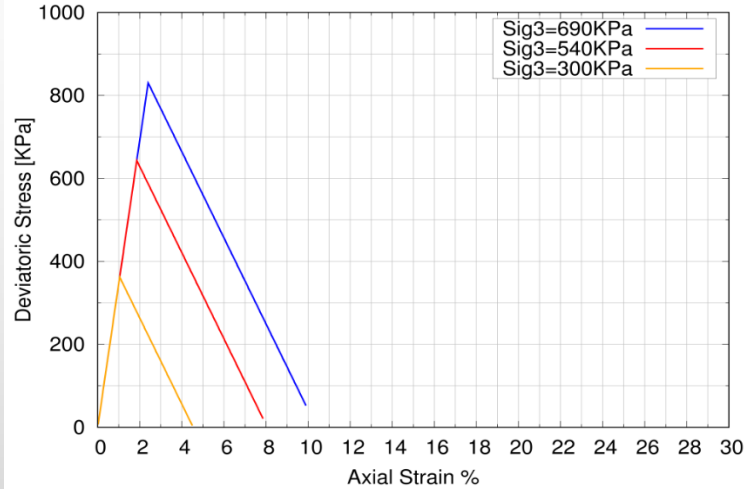


- By adding a limited elastic regime to the model, we can produce a behavior that depends on the confining pressure and therefore we have a better representation for the Tropical soil.

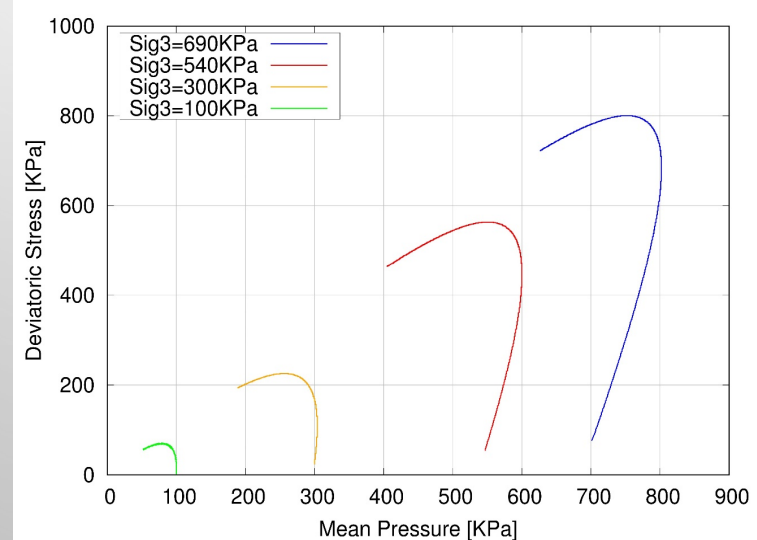
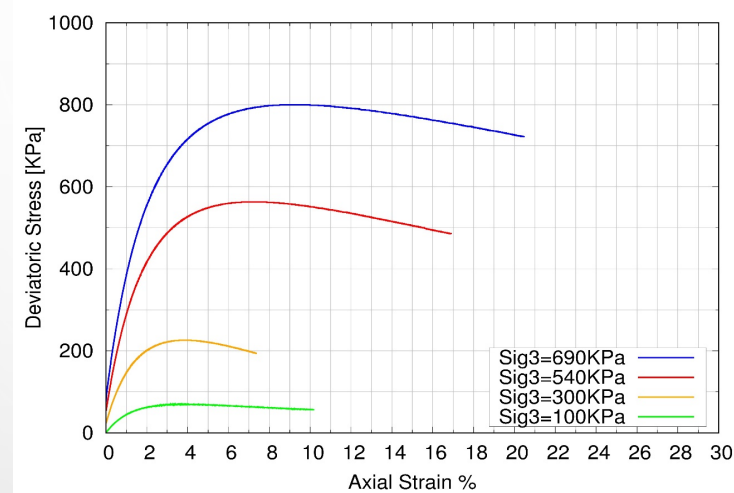


Validation of Mohr-Coulomb and Cap-Yield Model Criteria for Tropical Soil Undrained Triaxial Experimental Data (Futai et al 2004)

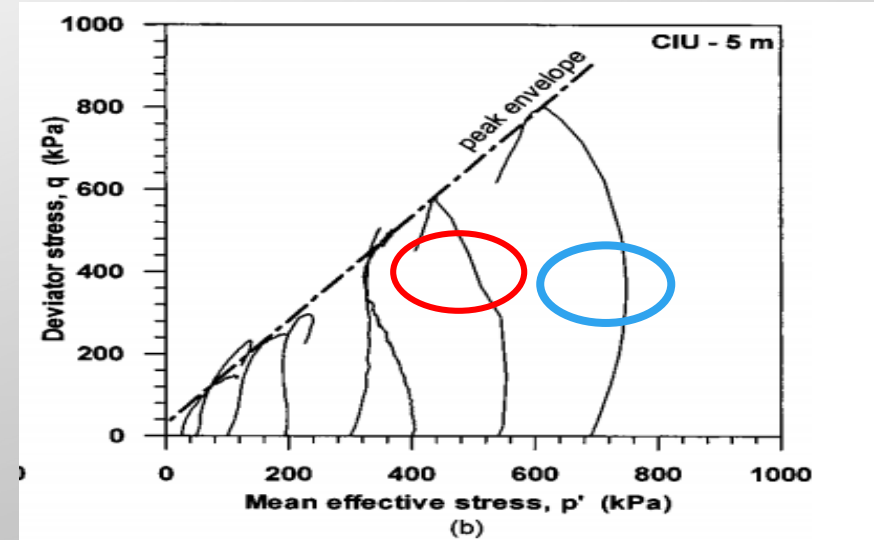
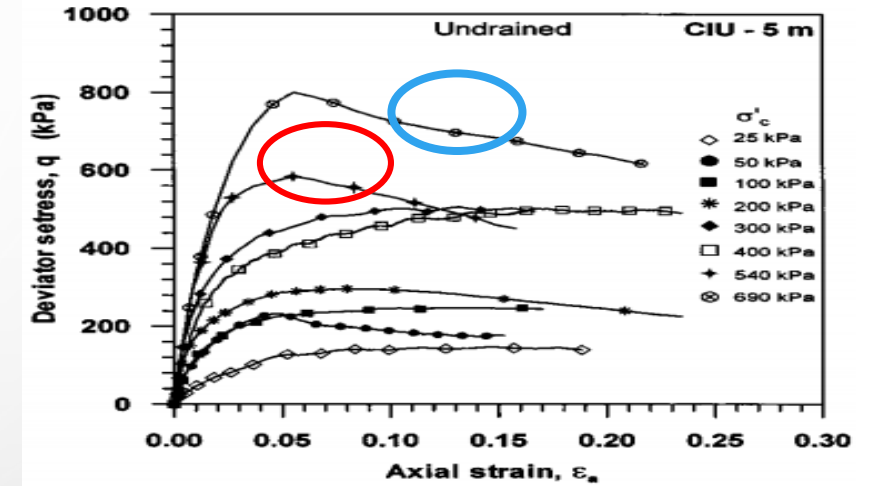
Mohr-Coulomb1



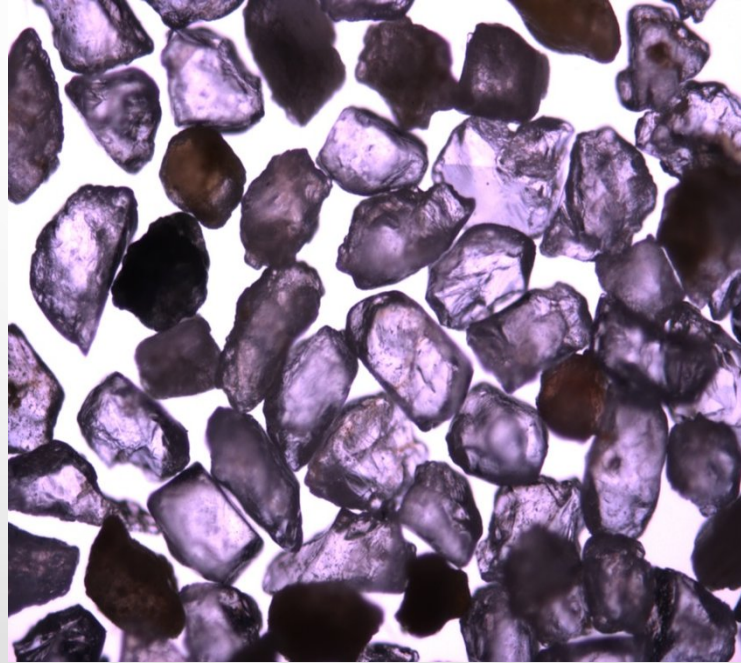
CY-Model



Experimental



Toyoura Sand



(Bo Li , Xiangwu Zeng, 2011)

P2PSand Model:

- Plastic Modulus

$$k_b = \frac{2}{3} Gh_0 D_r \frac{(\alpha^b_\theta - \alpha):n}{(\alpha - \alpha_{in}):n}$$

- Volumetric Plastic Strain

$$D = A_{d0} [(\alpha^d_\theta - \alpha):n]$$

DEM Model:

- 1000 Particles.
- 1 m3 REV.
- Same Cu Coefficient as Toyoura Sand.
- Quasi-static condition.

P2PSand

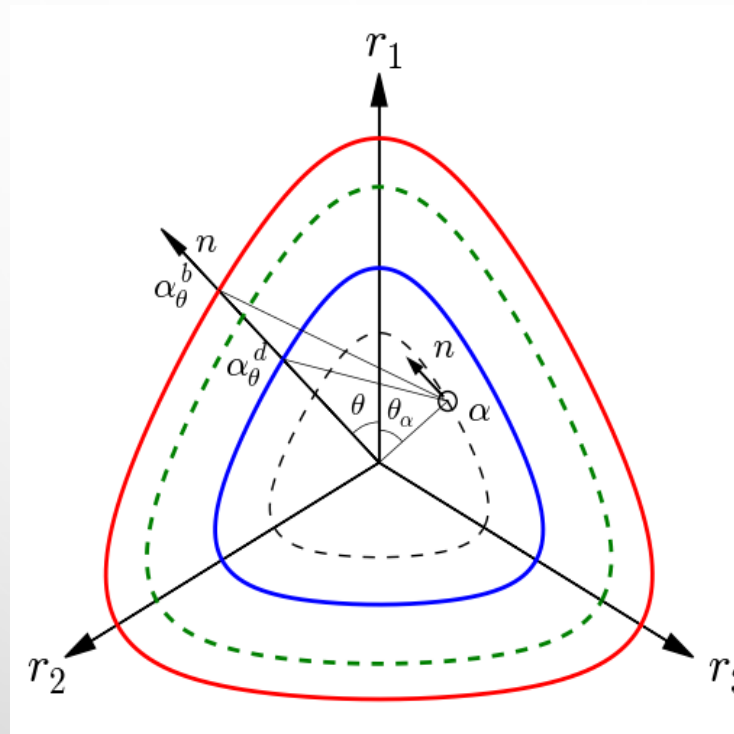
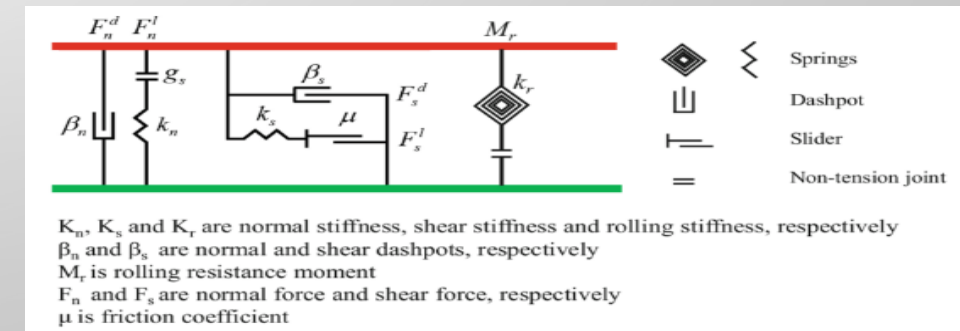
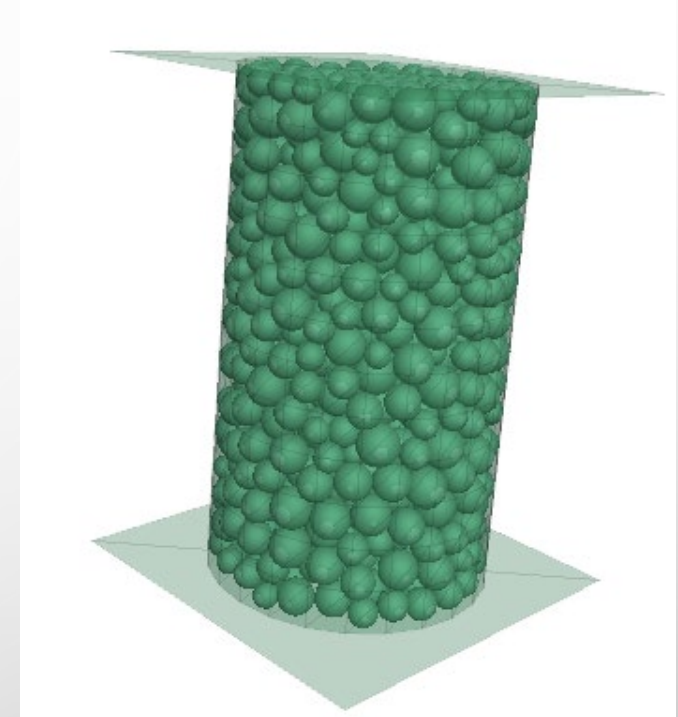


Figure 1: Schematic of surfaces in the π plane: bounding surface (red); dilatancy surface (blue); critical-state surface (green dash), maximum stress-ratio surface (black dash), and the yield surface (black circle).

FLAC Manual

Stiffness depends on the distance from the current stress state to the bounding surface.

DEM



P2PSand Model:

The Model consists of 17 parameters

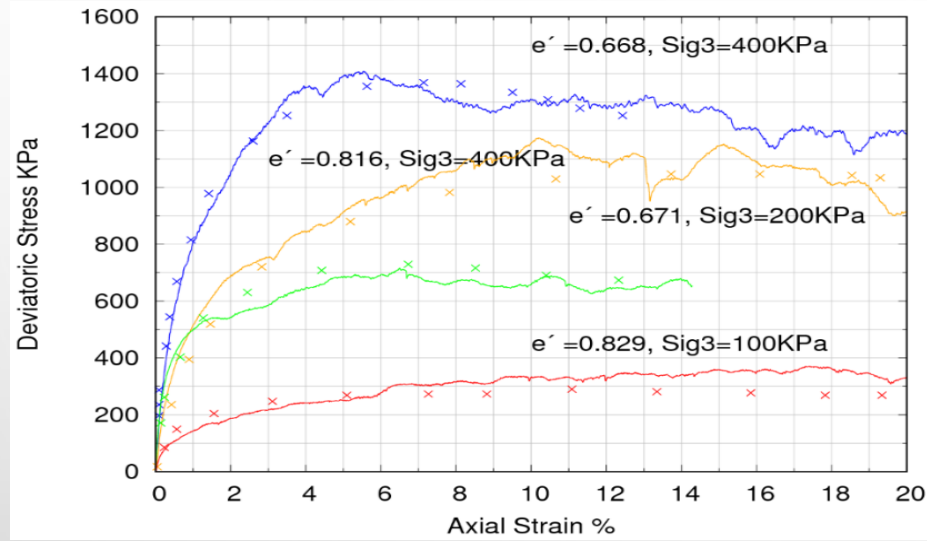
Criteria	Parameter Name in Flac	Parameter Symbole	Default
<i>Elastic moduli</i>	<i>Elasticity -1</i>	C_{DR}	0.01
	<i>Elasticity-2</i>	g_0	1.24e3
	<i>Poisson Coefficient</i>	ν	0.3
<i>Critical-state Surface</i>	<i>Ratio-strength</i>	C	—
	<i>Friction angle</i>	φ_{cs}	33°
<i>Critical-state Surface</i>	<i>Critical-state-1</i>	D_{rc0}	-
	<i>Critical-state-2</i>	λ_c	-
	<i>Critical-state-3</i>	ξ	0.7
<i>Bounding surface</i>	<i>Coefficient-bounding</i>	n^b	-
<i>dilatancy surface</i>	<i>Coefficient- dilatancy</i>	n^d	-
	<i>dilatancy-ratio-minimum</i>	K_{LB}^d	0.7
<i>Hardening Model</i>	<i>Rate-Plastic-Shear</i>	h_0	1.7
<i>Fabric Evolution</i>	<i>Rate-Fabric</i>	C_z	-
	<i>Rate-Plastic-Volumetric</i>	A_{d0}	-
	<i>Fabric-Maximum</i>	Z_{max}	-
<i>Cyclic Loading</i>	<i>Factor-Cyclic</i>	K_{Cyc}	-
<i>Loading/Unloading</i>	<i>Factor-Degradation</i>	K_d	-

Table. 1.P2PSand Model parameters

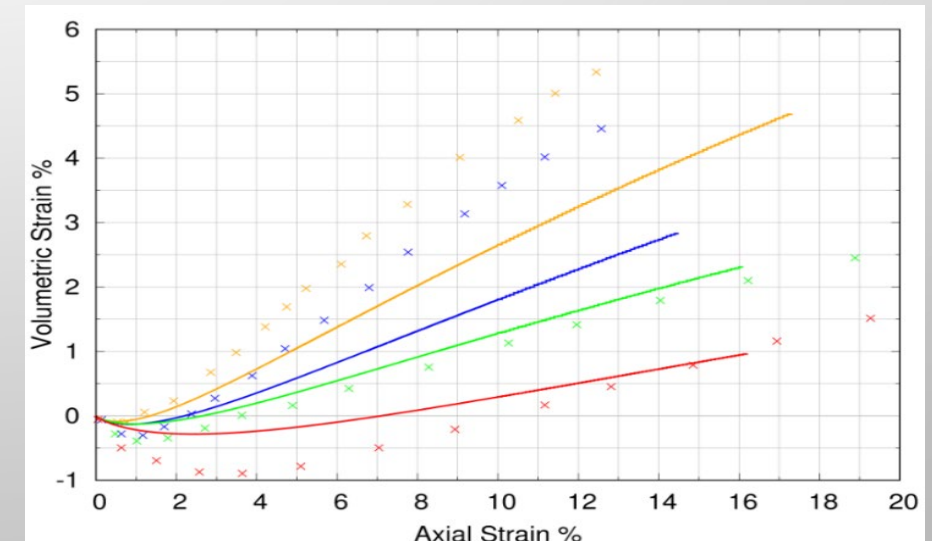
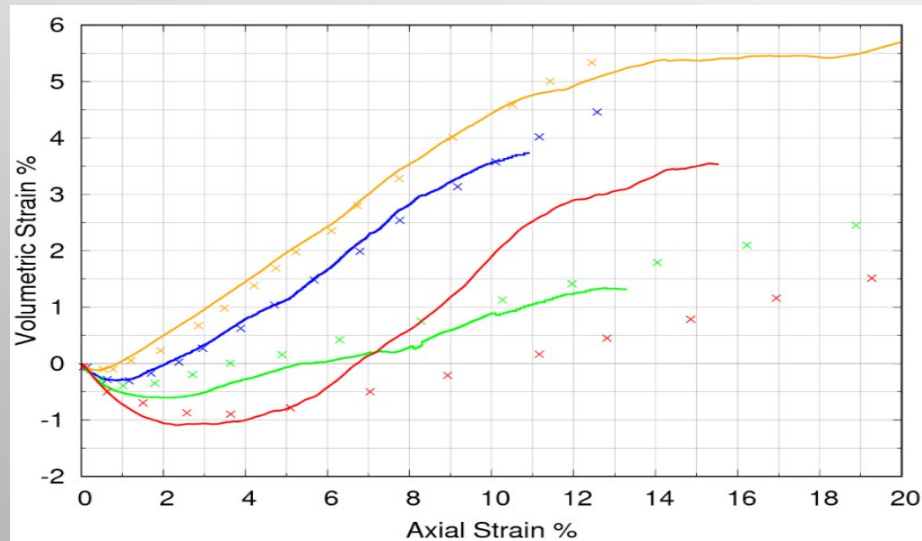
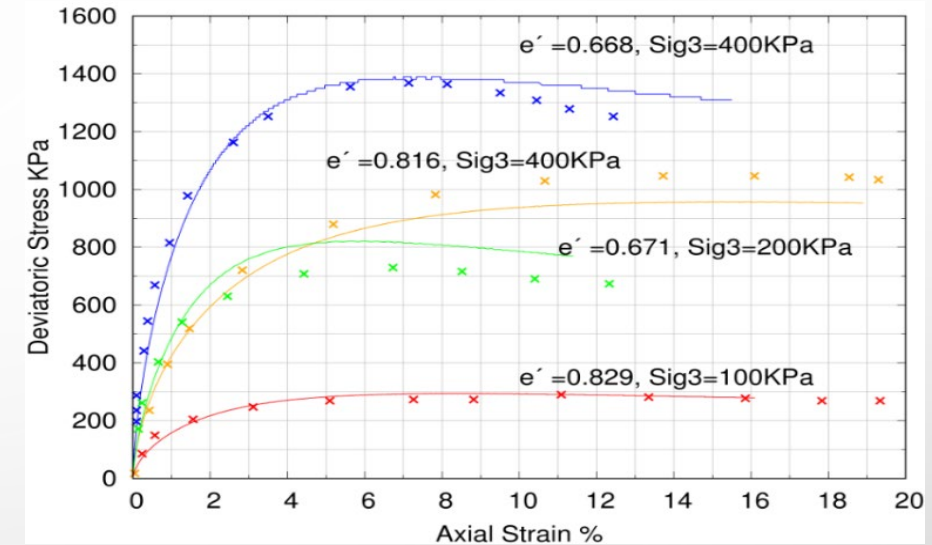
Calibration/Validation of P2PSand Model DEM Model Criteria for Toyoura Sand Experimental Data (Fukushima et al, 1984)

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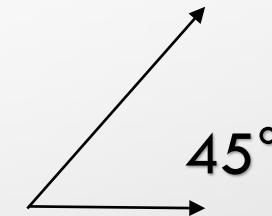
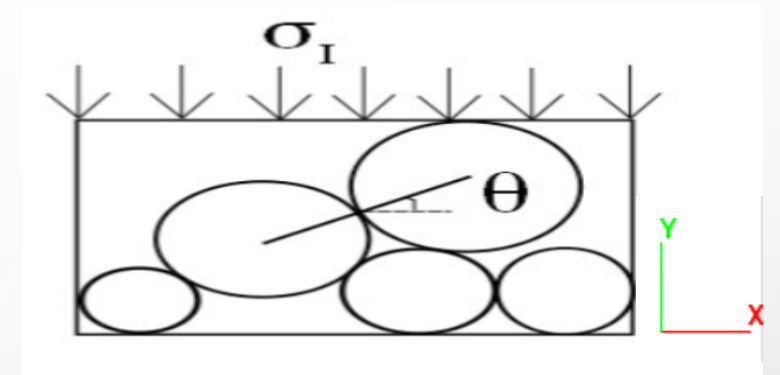
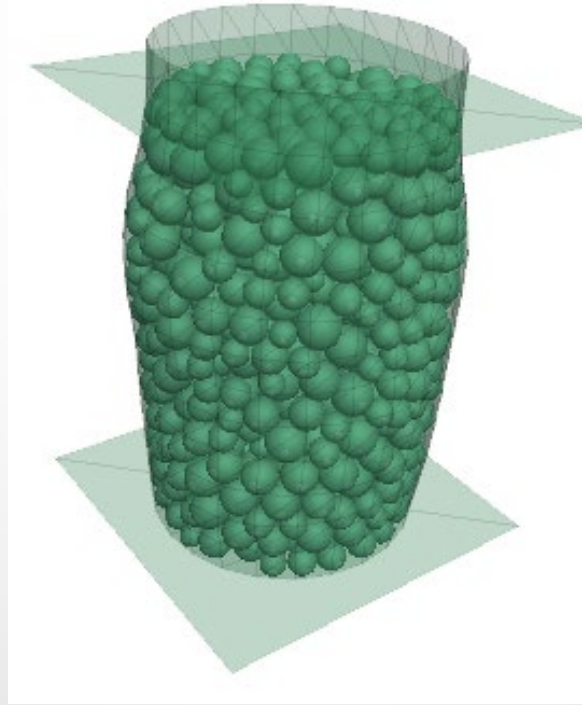
DEM



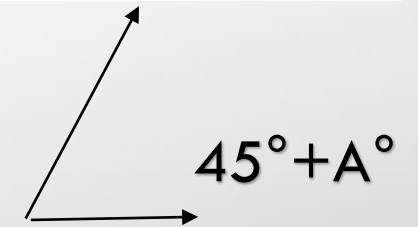
P2PSand



- The direction of the eigenvector of the fabric tensor will give the direction of the anisotropy.
- The behavior of the granular material is anisotropic behavior (and then requires different elastic moduli for different directions)



Isotropic Loading



Anisotropic Loading

From the previous example, at a vertical strain of 12% the average unit normal vector is = (0,52x, 0,52y, 0,67z)

$$\text{P2PSand Shear Modulus: } G = \underbrace{g_0(D_r + C_{Dr})p_{atm} \left(\frac{p}{p_{atm}} \right)^{0.5}}_{\text{Density \& mean pressure}} \underbrace{\left(1 - \left(K_d \ln \left(\frac{z_{cum}}{\max \|Z\|} \right) \right) \right)}_{\text{Fabric Evolution}} \text{ the anisotropy property is missing}$$

Christchurch Sand



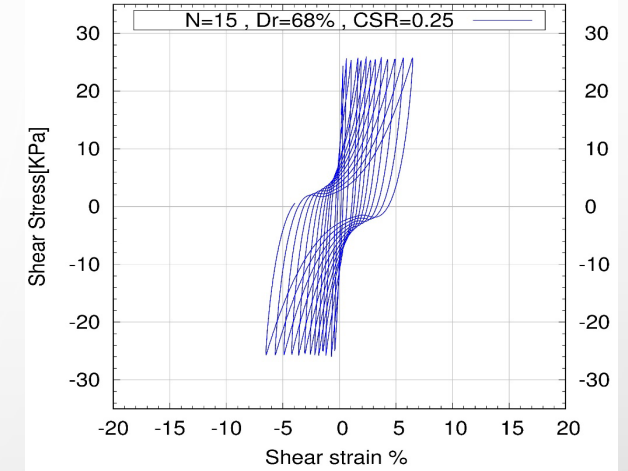
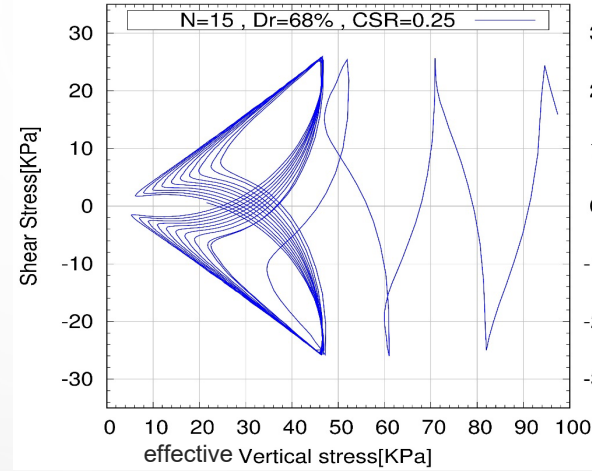
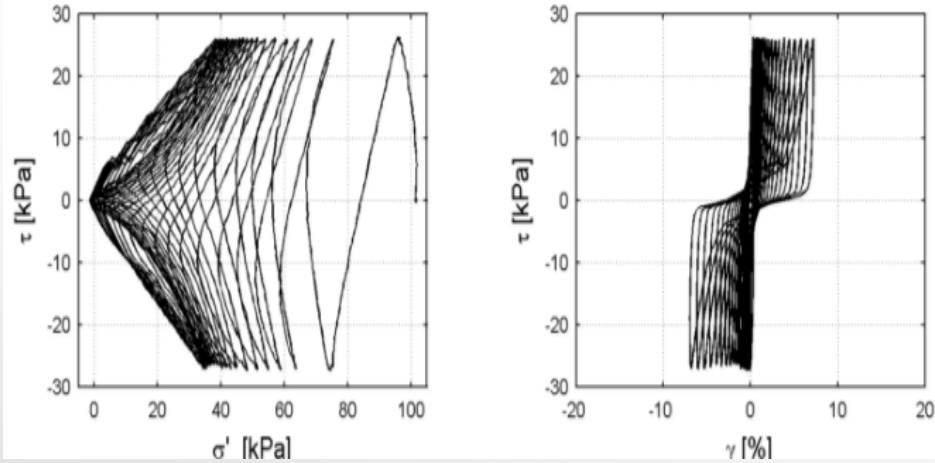
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P2PSand Model Prediction of Liquefaction Phenomena Christchurch Sand

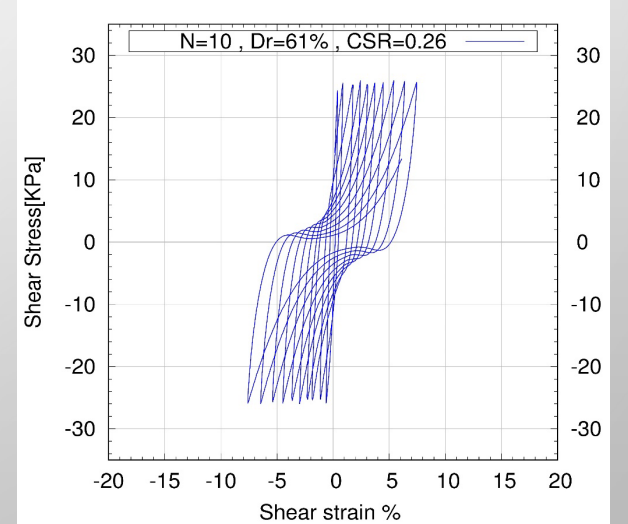
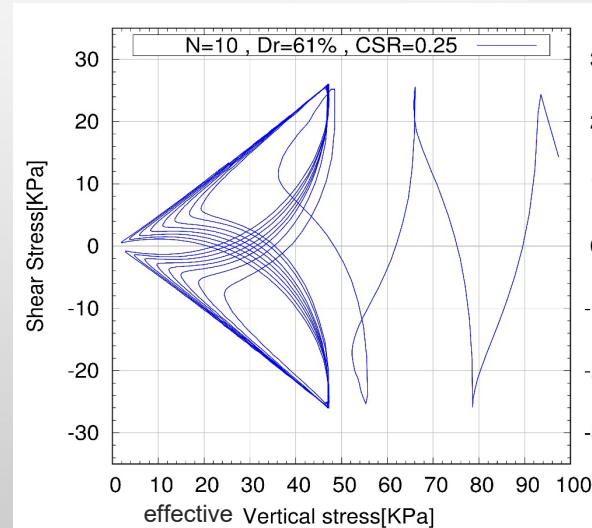
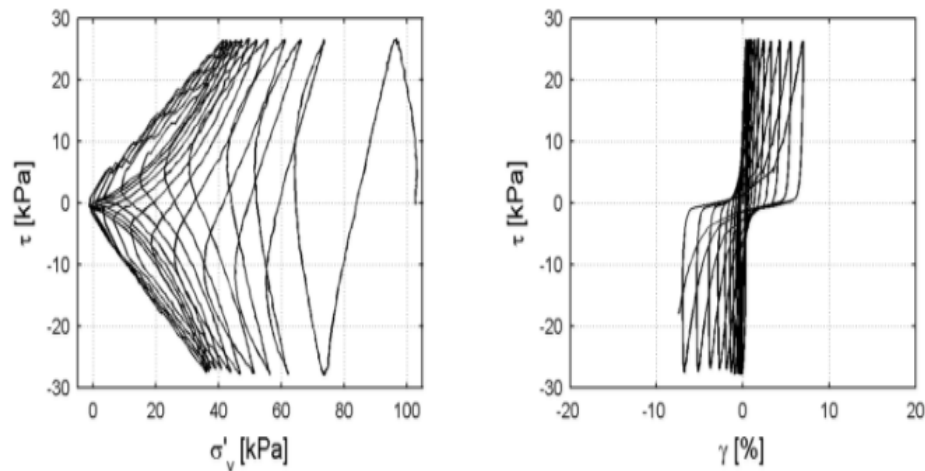
Undrained Cyclic Simple Shear Test

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$D_R = 68\%$, $CSR = 0.26$, $N_c = 17$



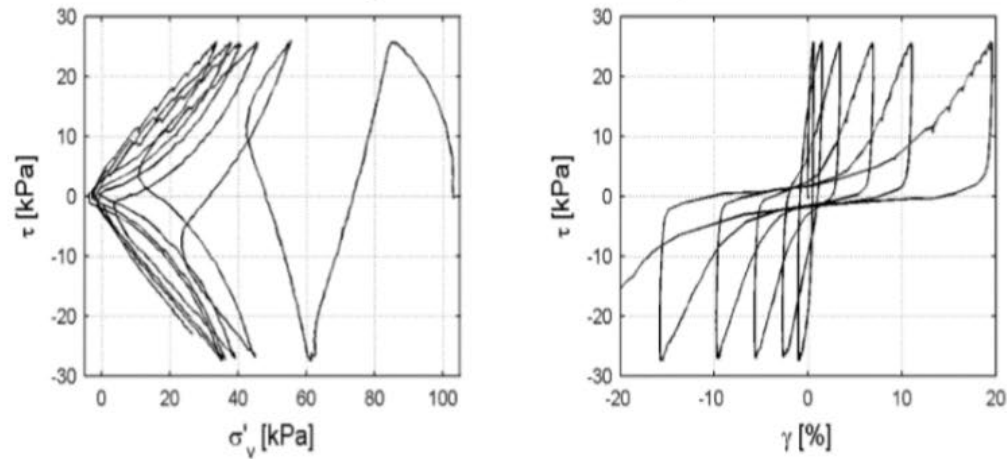
$D_R = 61\%$, $CSR = 0.26$, $N_c = 10$



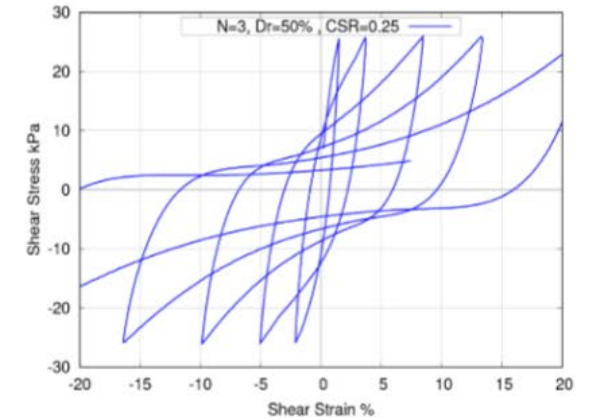
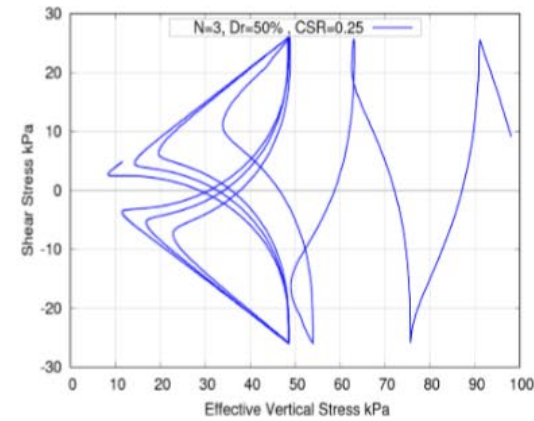
Experimental (Cappellaro et al, 2017)

Numerical

$D_R = 50\%$, $CSR = 0.25$, $N_c = 3$



Experimental

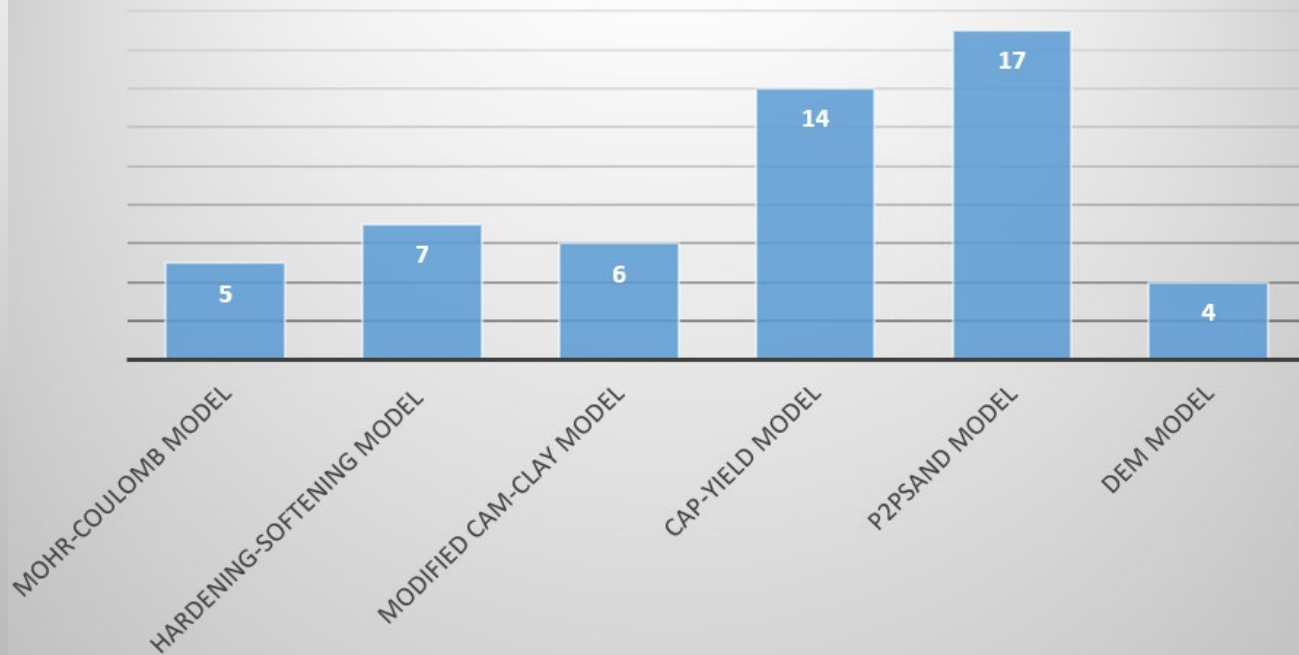


Numerical

- The simulation results show very good agreement with their corresponding experimental results, both qualitatively and quantitatively.

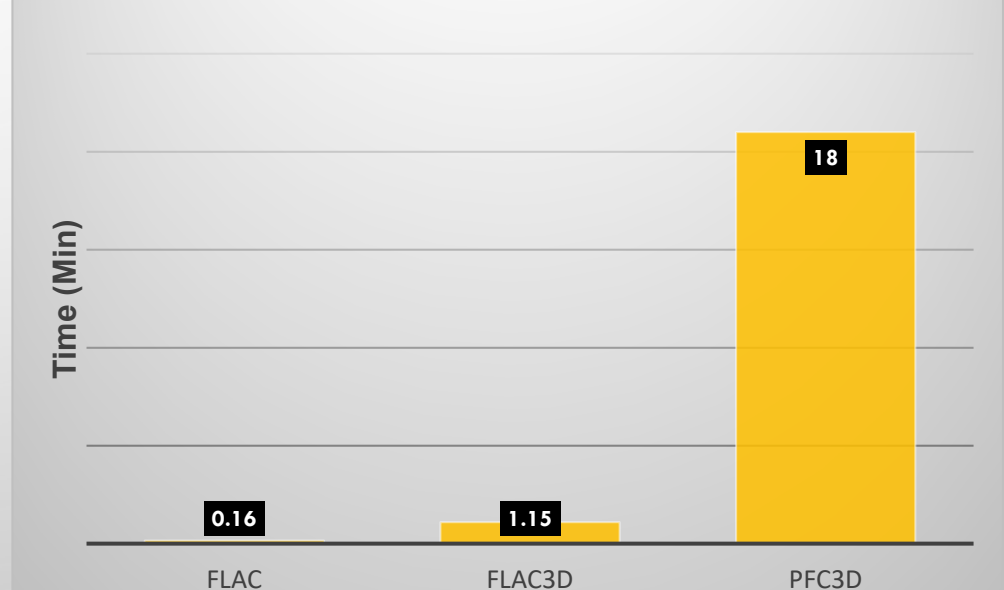
- Same Computer and same configurations unit, density, loading rate and size.
- There is no significant difference between the computational time of the different constitutive laws e.g. in Flac3D they vary from (1 to 1.33 min).

Number of Parameters / Model



Computational Time

One zone
Vertical Strain 14%

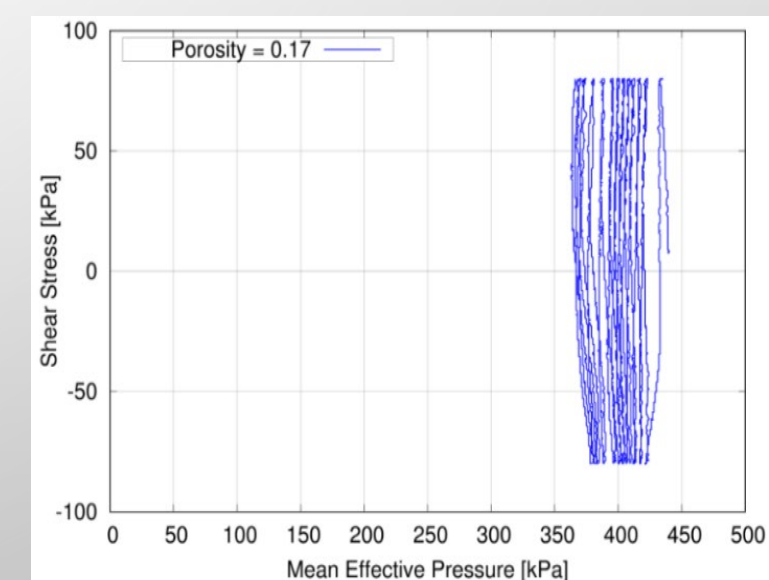
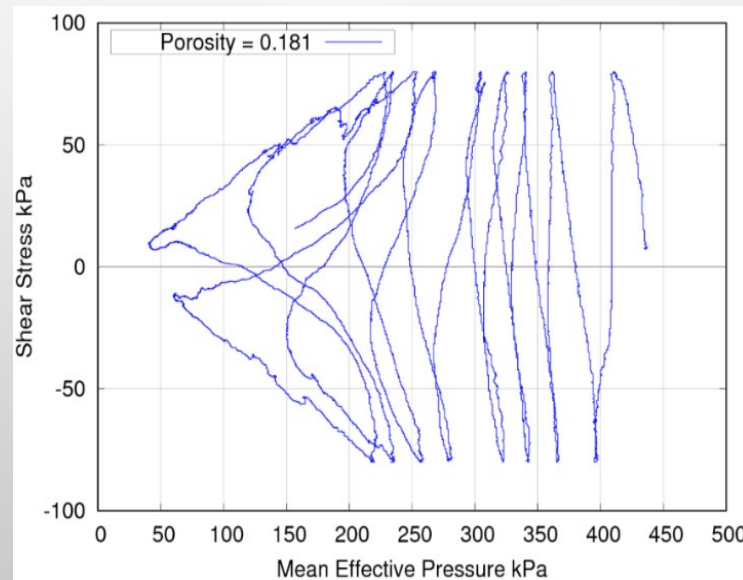
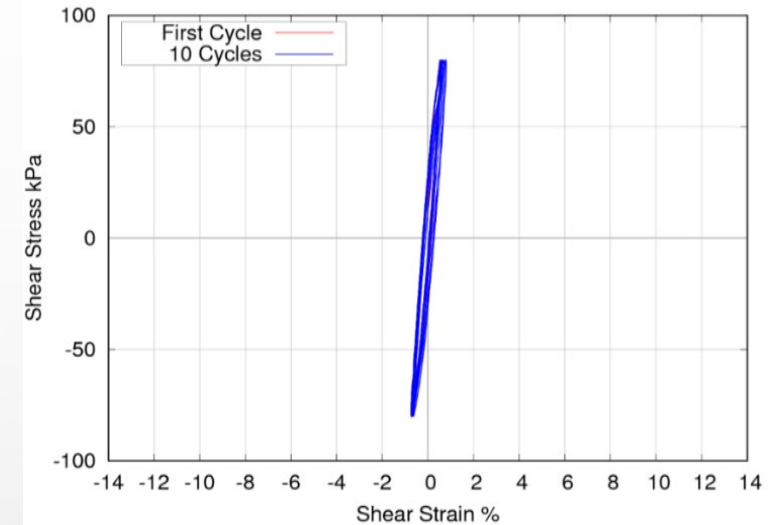
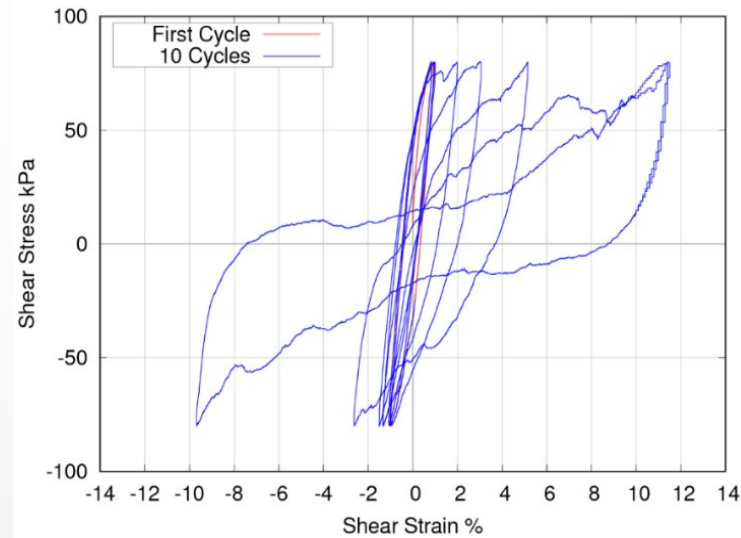
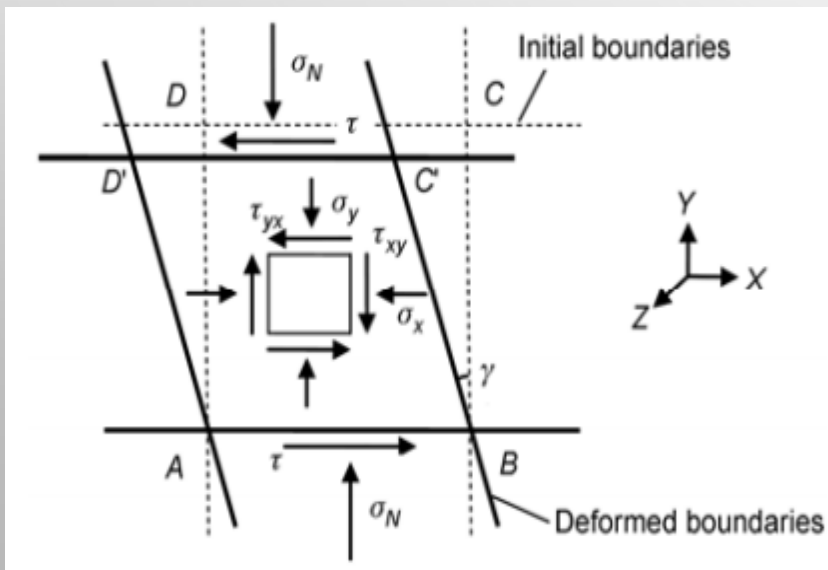


Perspective

Prediction of DEM for Undrained Cyclic Simple Shear Test

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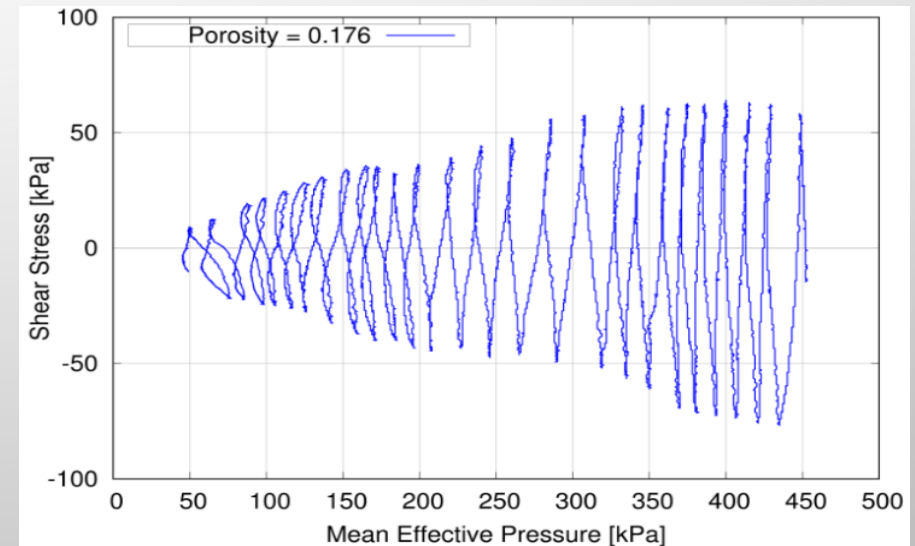
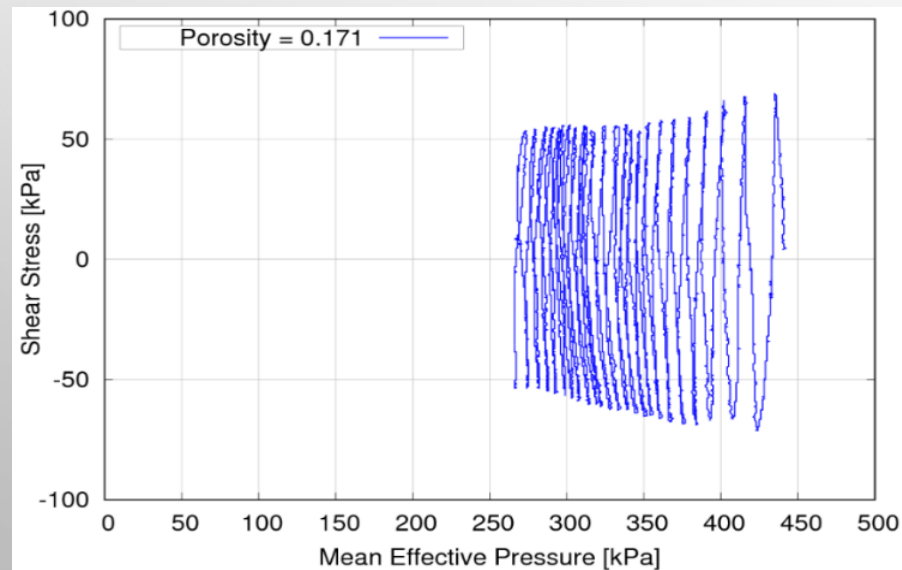
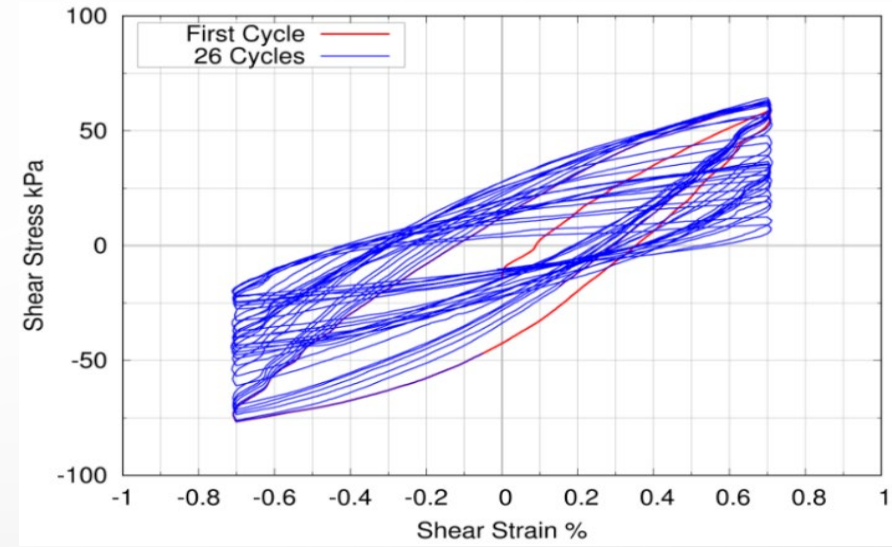
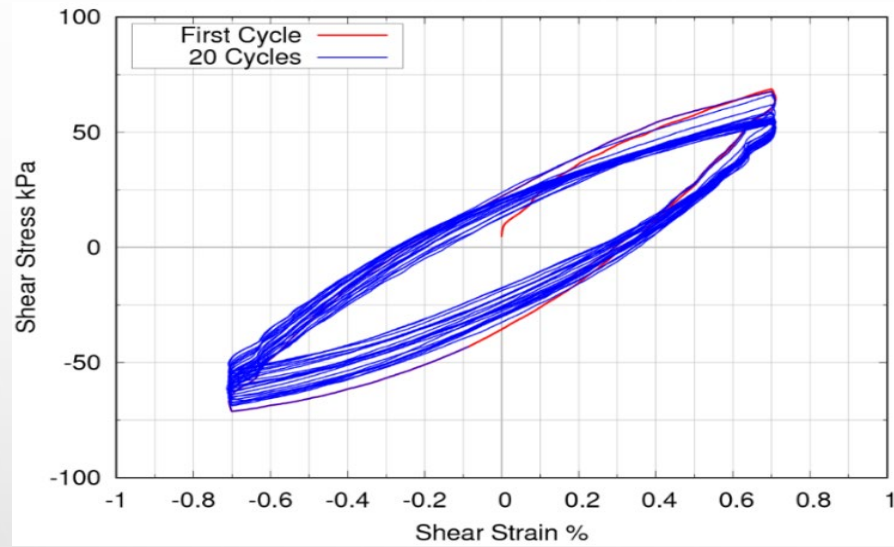
- The loading procedure includes two distinct stages, consolidation and shearing.
- The consolidation stage starts with an anisotropic pressure which is applied on the sample.
- During the shearing, cyclic horizontal displacement is applied along the top surface.



DEM2D UDSS Test Constant Shear Stress 80 kPa, friction coefficient 0.3 initial Porosity 0.17,0.18 Vertical Stress 500 kPa

Prediction of DEM for Undrained Cyclic Simple Shear Test

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DEM UDSS Test Strain Amplitude $\pm 0.7\%$, friction coefficient 0.3 initial Porosity 0.171, 0.176

Conclusions:

- The more the model is advanced/complex, the more the phenomena that could be described by the model.
- The more the model is complex, the more is the calibration effort (number of parameters).
- The most of the constitutive models are developed depending on ideal types of soil and on the classical stress paths.
- The discrete element method could be a good approach to simulate the behavior of the granular material.
- The computational time of the DEM is much higher (15 Times) than that of the soil models.

Thank You For Your Attention