5th International Itasca Symposium

Paths of force chains

at the cyclic threshold shear strain in sand

Vedran Pavlić & Tomislav Ivšić

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  - System of grains and voids
  - Concept of the cyclic threshold shear strain
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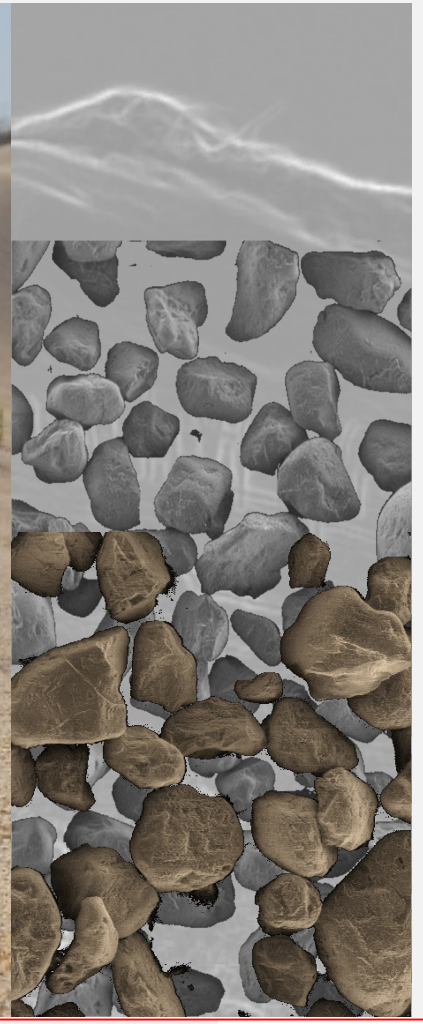
System of grains and voids

... there is presently no generally acknowledged theory of granular matter ... but only fragments of a theory, in contrast to solids, gases, and liquids where such theories exist.

Pöschel and Schwager, 2004.

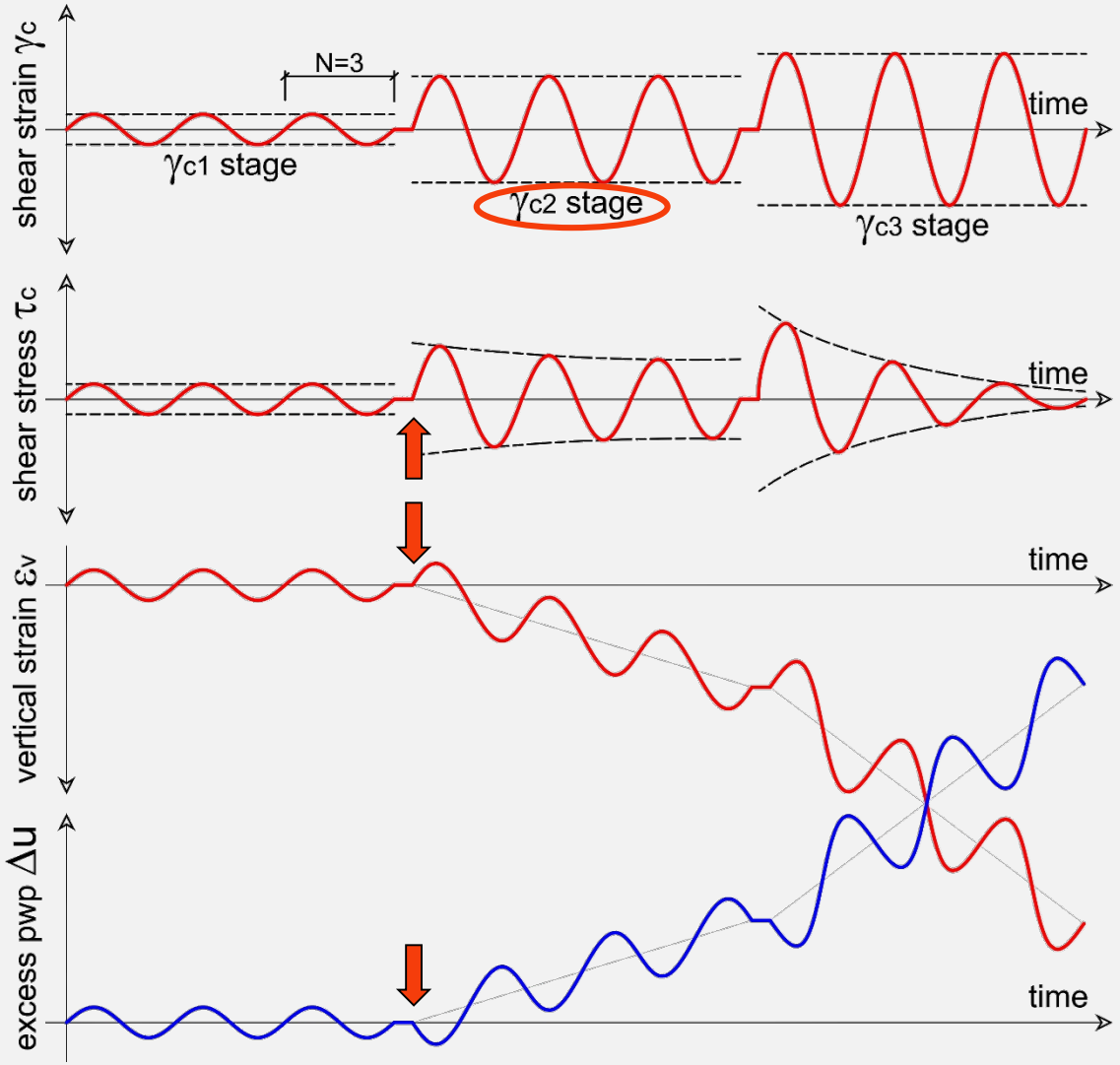
... recent developments in soil mechanics and physics suggest that a missing piece of the puzzle of constitutive theory for granular materials lies in the manner of force transmission and associated kinematics.

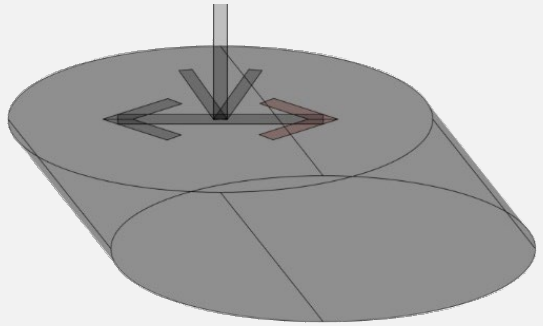
Tordesillas and Muthuswamy, 2009.

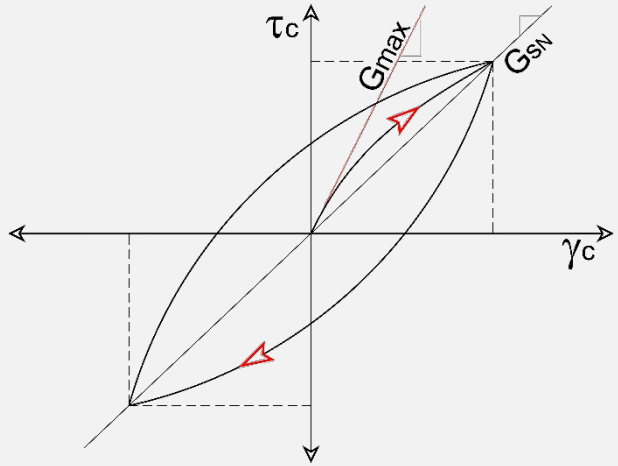


Concept of the cyclic threshold shear strain

- **Physical model – cyclic laboratory testing**

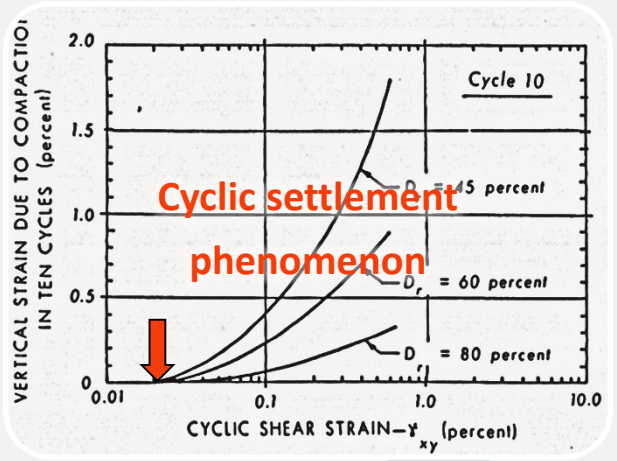


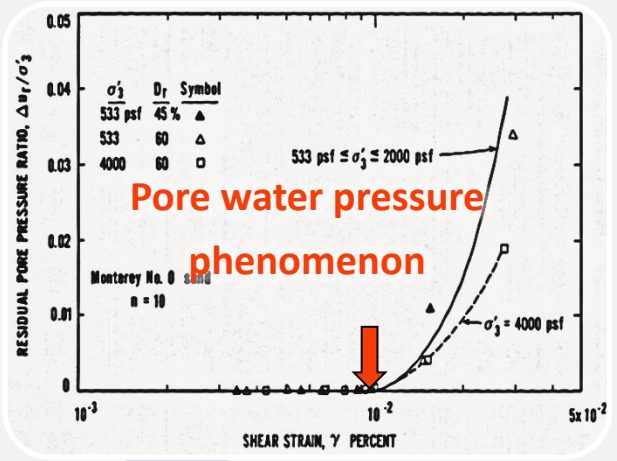




Concept of the cyclic threshold shear strain

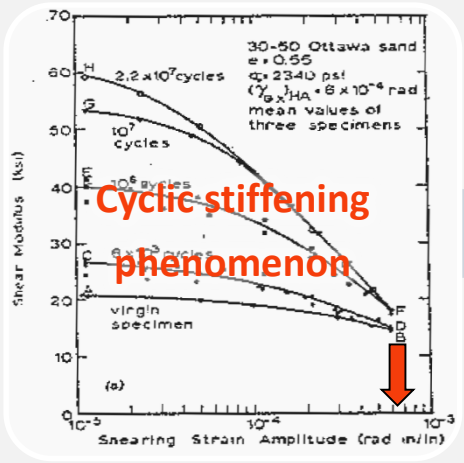
Silver and Seed, 1971.





Dobry et al., 1982.

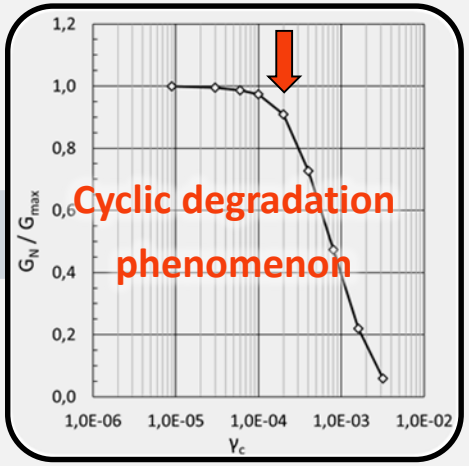
Drnevich and Richard, 1970.



Range of threshold magnitude:

0.007 – 0.03 %

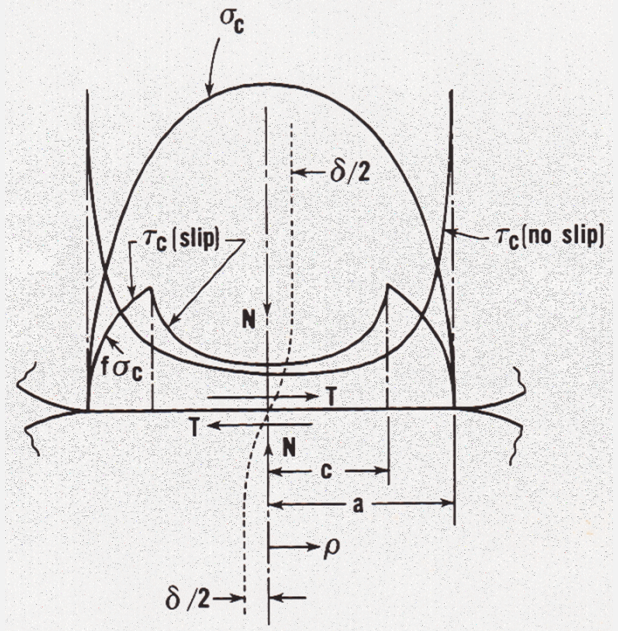
acc. Mortezaire, 2012.



- **The term "threshold of vibratory compaction" was introduced in 1948 by Barkan**

Concept of the cyclic threshold shear strain

- **Theoretical contact model**

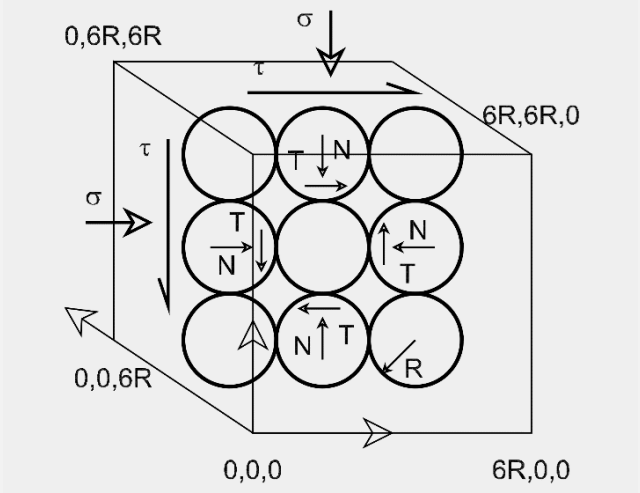


$$\delta = \frac{3fN}{8a}\left(\frac{2-v}{G}\right)\left(1-\frac{T}{fN}\right)^{2/3}$$

$$\delta_1 = \frac{3fN}{8a}\left(\frac{2-v}{G}\right)$$

Mindlin, 1954.

- **Theoretical model of nine spheres**



$$\gamma_t = 2.08\,\frac{(2-\nu)\,(1+\nu)f}{(1-\nu^2)^{1/2}\,(E)^{2/3}}\,(\sigma)^{2/3}$$

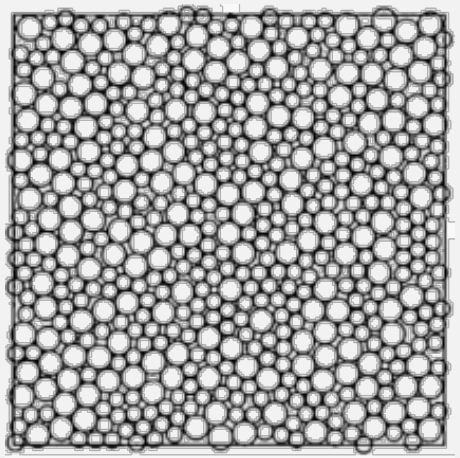
$$\frac{G}{G_{max}} = \frac{2}{3}\,\frac{1-(1-\frac{\gamma}{\gamma_t})^{3/2}}{\gamma/\gamma_t}$$

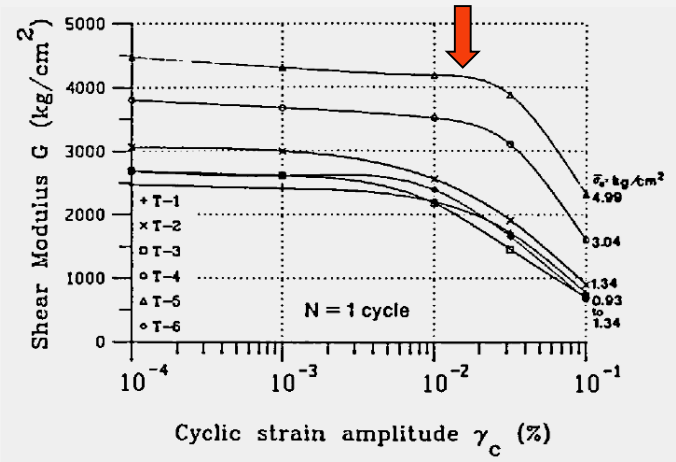
Dobry et al., 1982.

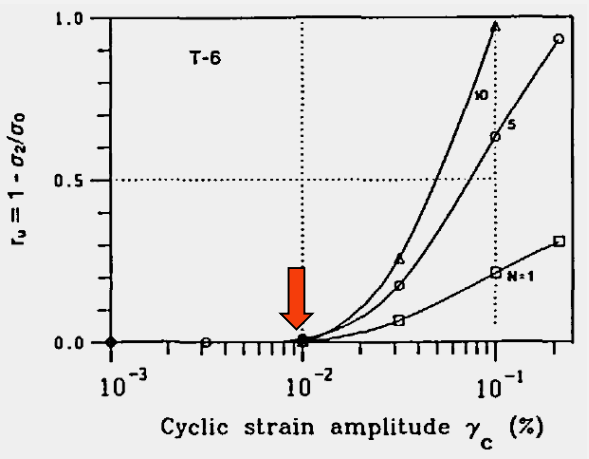
Concept of the cyclic threshold shear strain

- **Numerical model – discrete element method**

Test type	Program	Loading	Constant volume concept	Grain number	Grain shape	Size of grains	Contact model
DSS	CONBAL-2	Cyclic	Yes	531	Disc	Two fractions (radius ratio 1.5)	Modified Hertz model







Dobry and Ng, 1992.

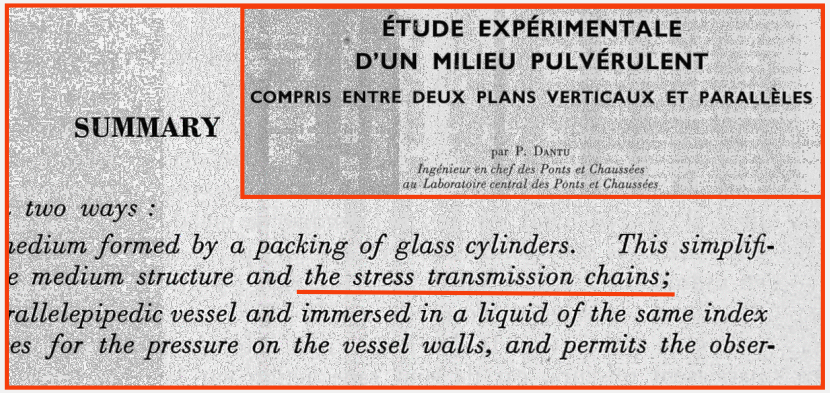
Concept of the cyclic threshold shear strain

- **Some unresolved questions from experiments and models**
  - **Which factors influence the threshold value?**
  - There appears to be a geometrical factor missing in the theory, which one?
  - Does the increase of vertical load causes increase of the threshold value?
  - What is the minimal number of grains in the sample that gives realistic results?
  - **When does degradation in sand start?**
  - Is there a common underpinning mechanism for all four phenomena?
  - **Are all of four thresholds similar?**

Force chains

- **Force transmission through granular material includes formation of force chains**
- **The force chain is an array of grains that carry large compressional loads**

Dantu, 1968.



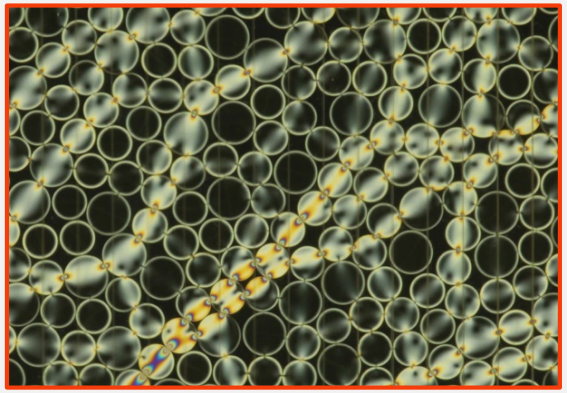
ÉTUDE EXPÉRIMENTALE
D'UN MILIEU PULVÉRULENT
COMPRIS ENTRE DEUX PLANS VERTICAUX ET PARALLÈLES

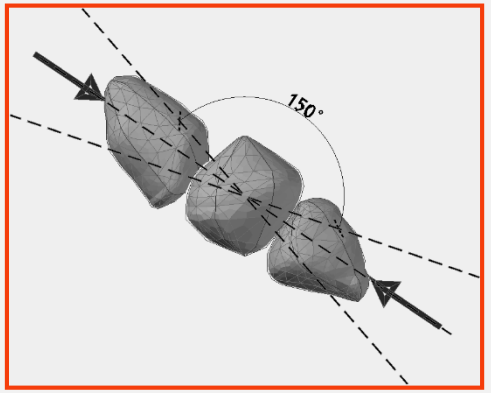
par P. DANTU
Ingénieur en chef des Ponts et Chaussées
au Laboratoire central des Ponts et Chaussées

SUMMARY

. two ways :
iedium formed by a packing of glass cylinders. This simplifi-
e medium structure and the stress transmission chains;
rallelepipedic vessel and immersed in a liquid of the same index
es for the pressure on the vessel walls, and permits the obser-

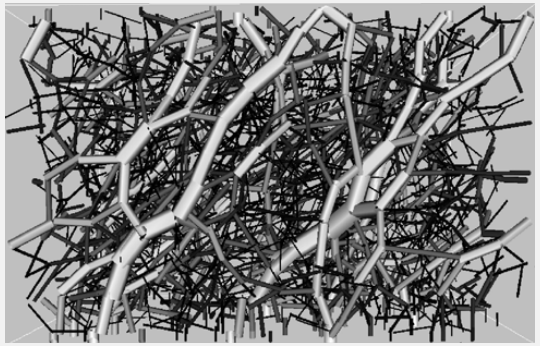
Ren et al., 2011.





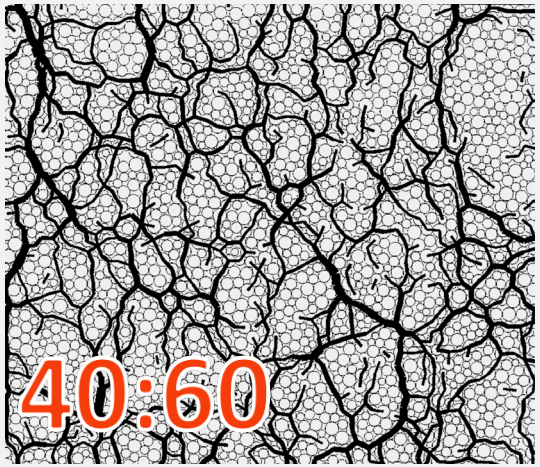
Force chains

Visualization of force chains



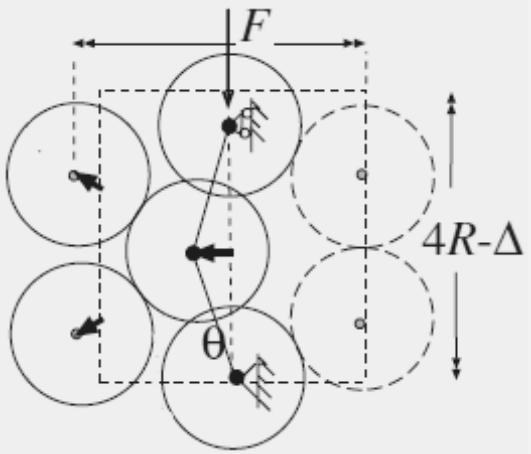
Mair and Hazzard, 2007.

Distribution of force chains



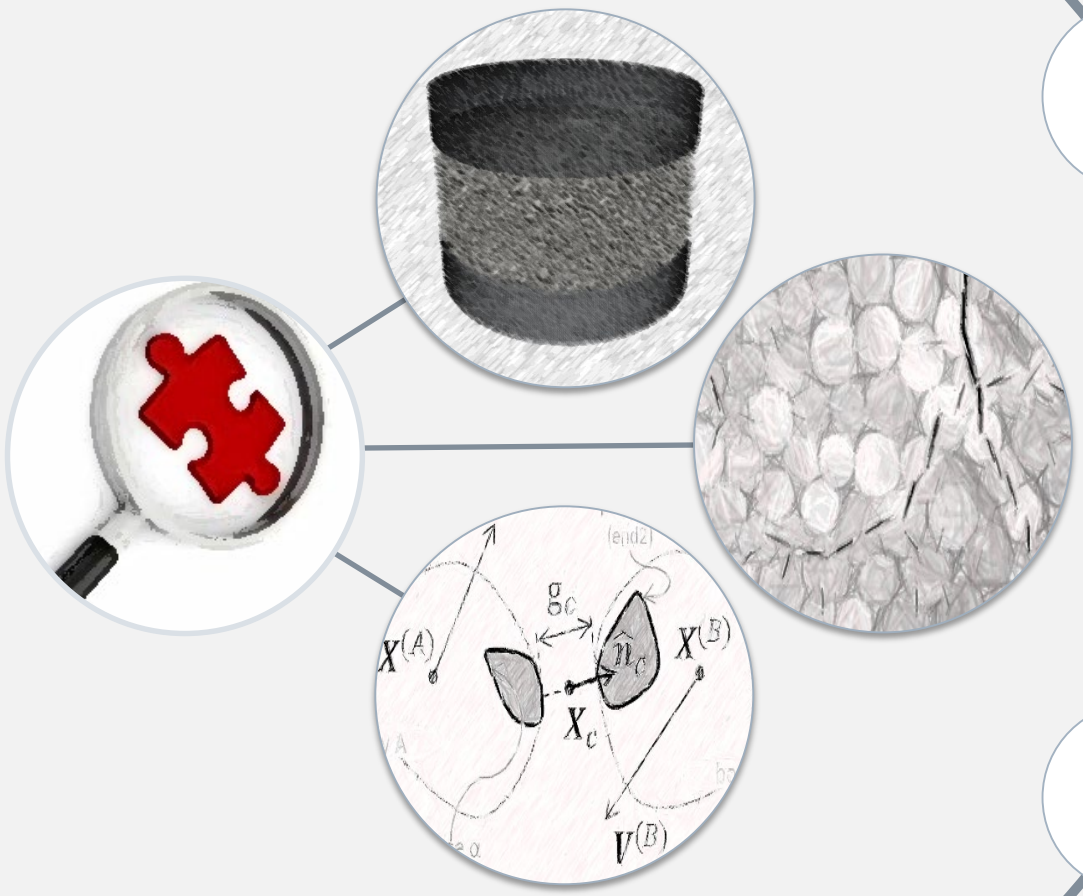
Radjai et al., 1998.

Stability of force chain



Tordesillas and Muthuswamy, 2009.

Research aims



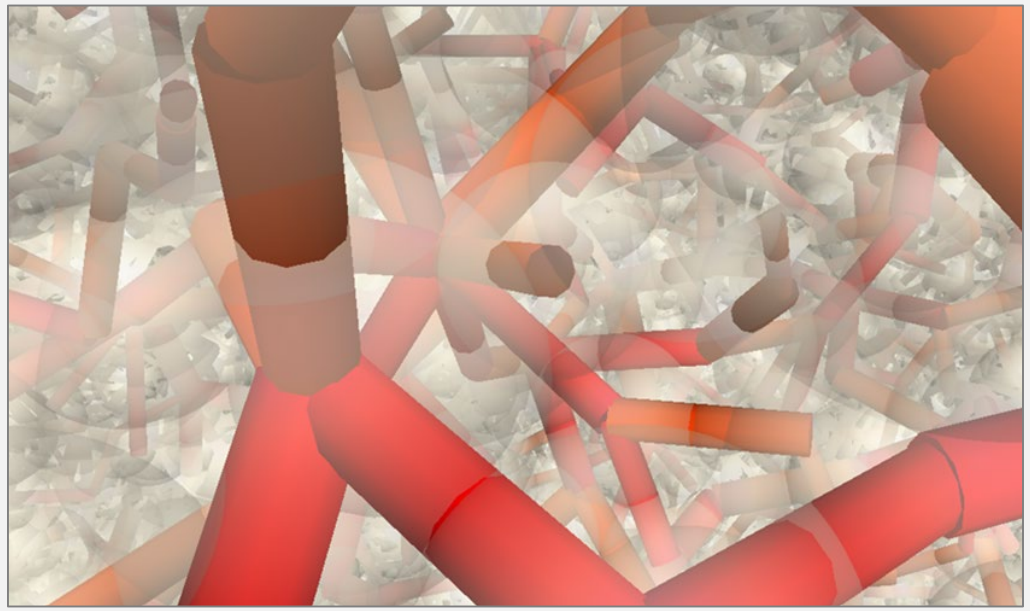
A Describe the mechanical behavior of granular material at multiple length scales

1a Laboratory sample

2a Group of grains

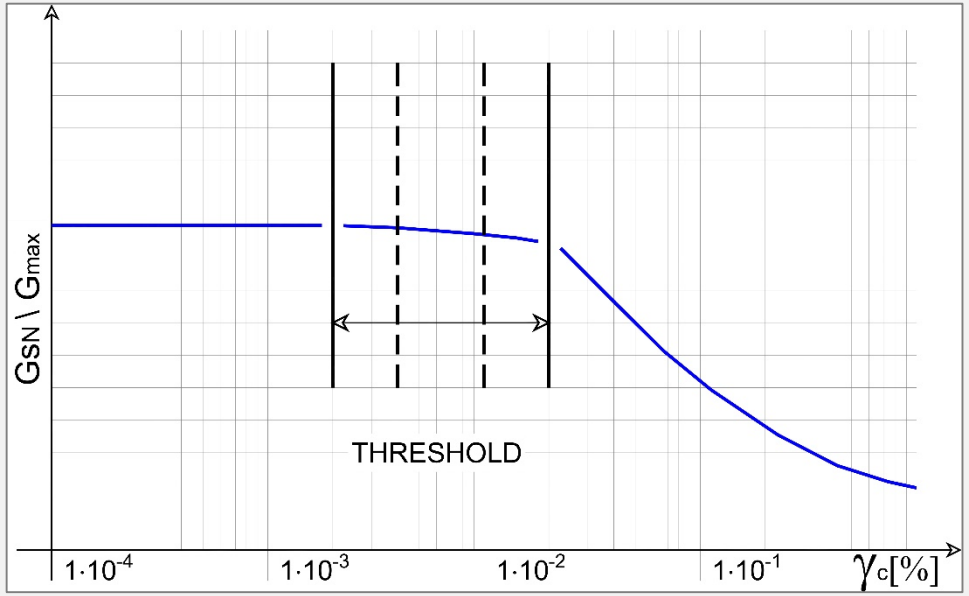
3a Two grains

Research aims



- **B** — Determine the way force is transmitted through granular material during shearing
- **1b** — Form of force distribution
- **2b** — Ratio of the strong and the weak force network
- **3b** — Bearing of force chain

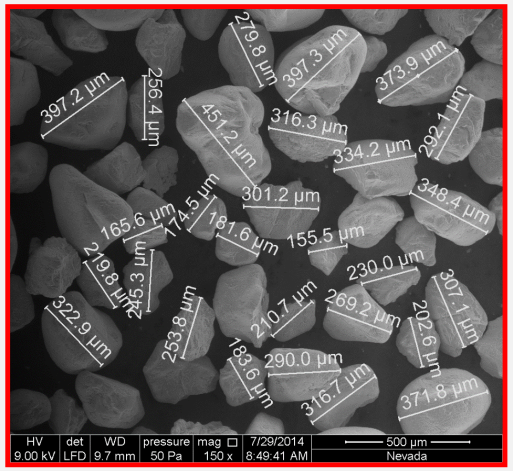
Research aims

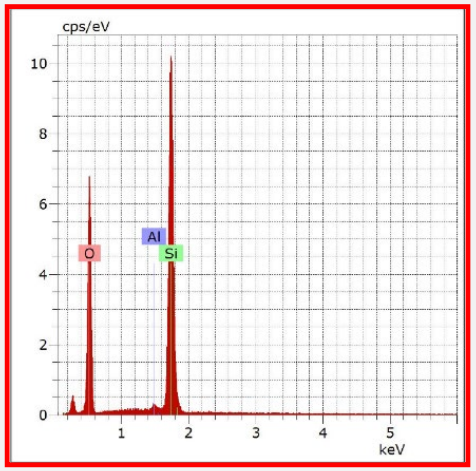


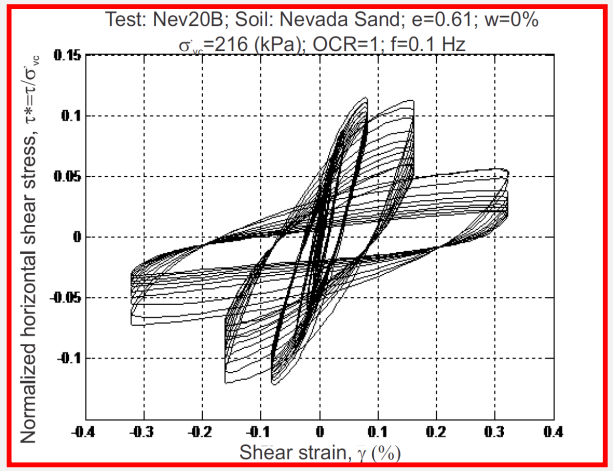
- **C** — Define the control mechanism of the mechanical sand behavior
- **1c** — Before the cyclic threshold strain
- **2c** — At the cyclic threshold strain
- **3c** — After the cyclic threshold strain

Research objectives

- **Testing of typical granular material (Nevada sand) in lab.**
  - **Standard laboratory tests**
  - **Imaging of grains (shape and size)**
  - **Microanalysis of chemical composition of grains**
  - **NGI-DSS tests (dynamic properties of the material)**



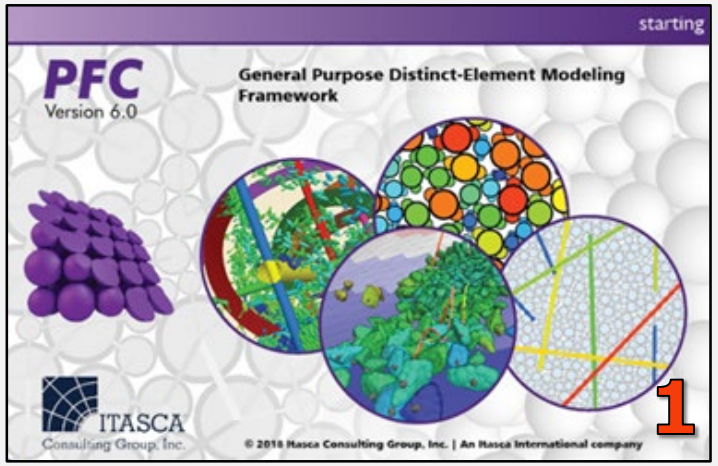


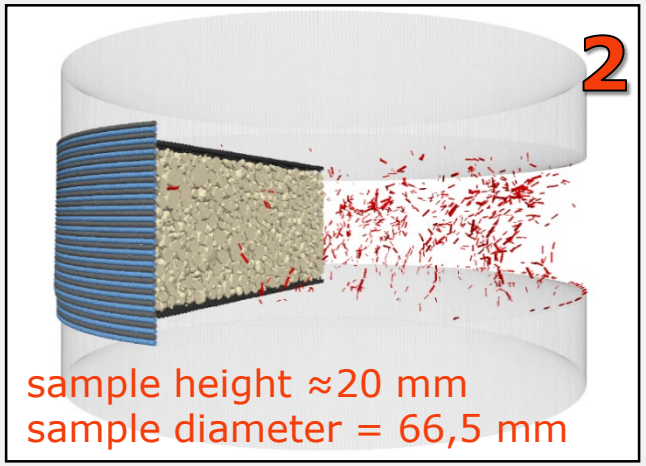


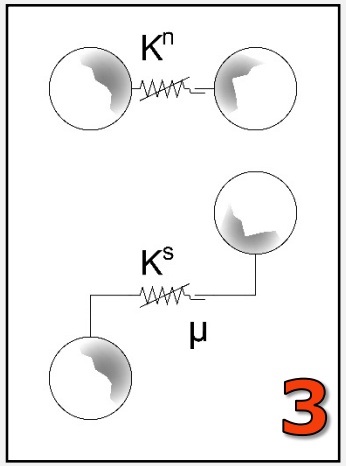
Research objectives

- **Numerical simulation of the NGI-DSS test using DEM**

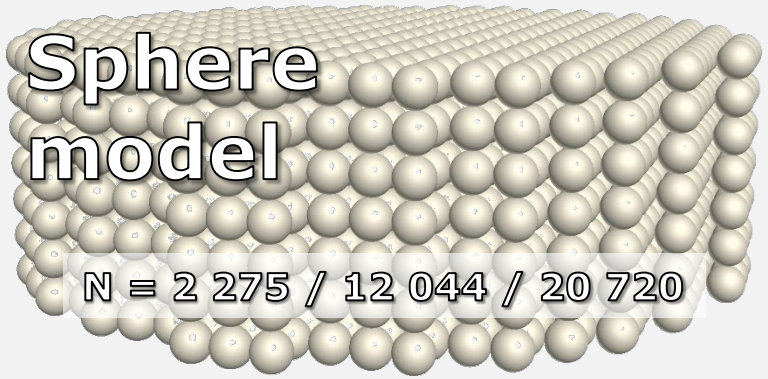
1 Selection of a basic numerical research tool
2 Modelling of NGI-DSS device
3 Selection of contact model
4 Material generation
5 Numerical test simulations
6 Data processing

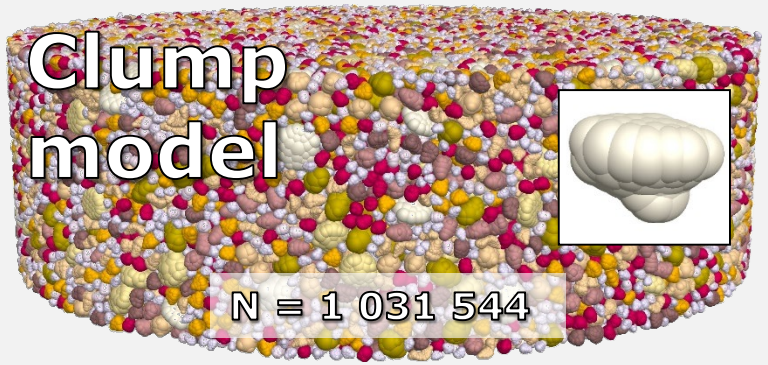


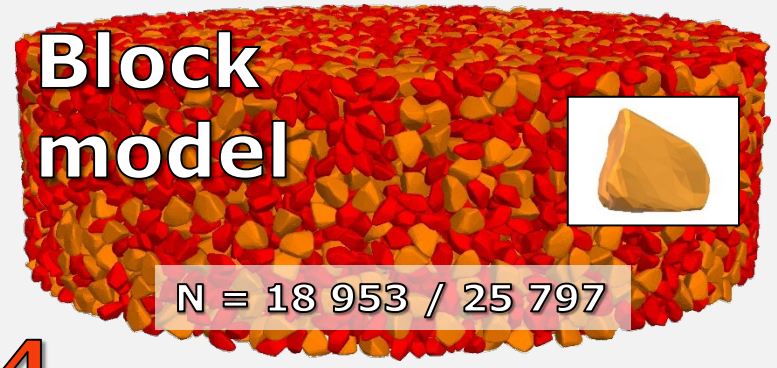




Research objectives



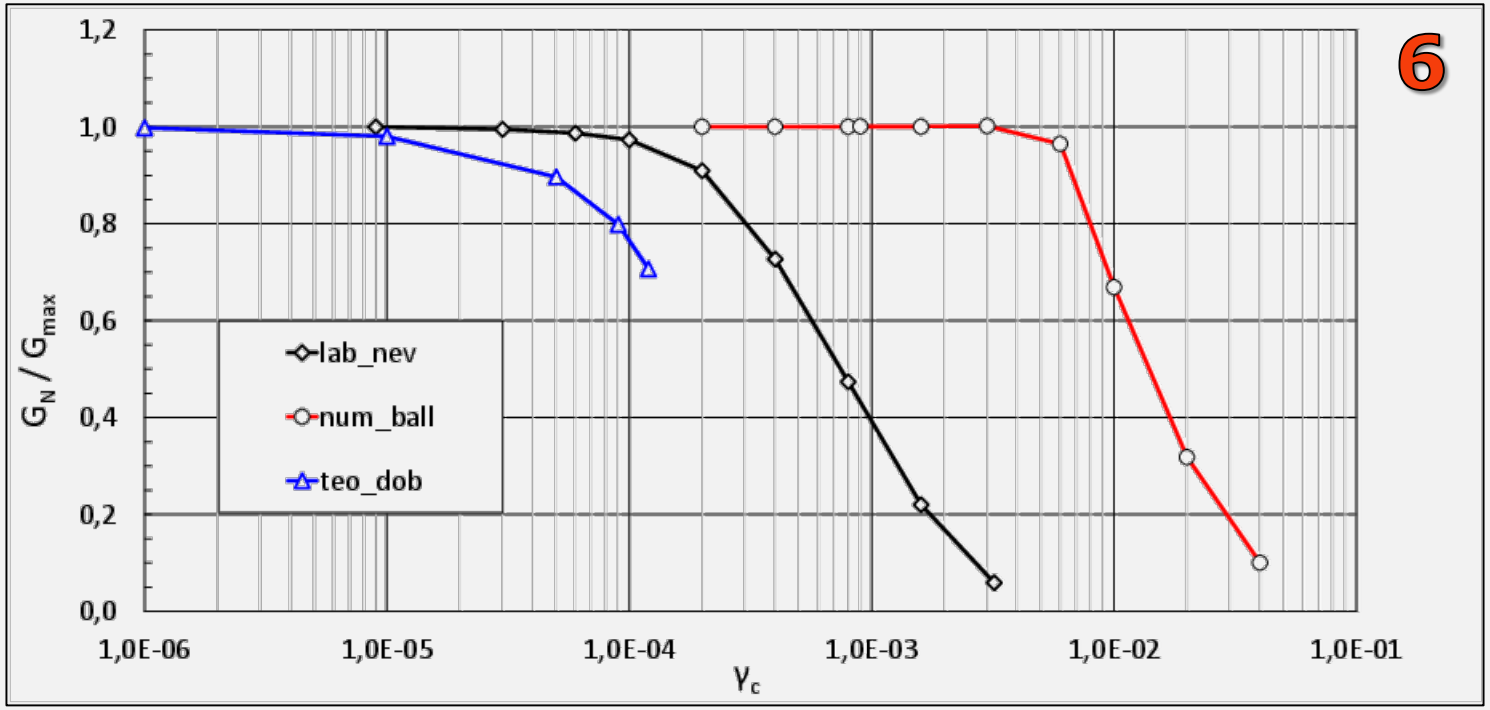




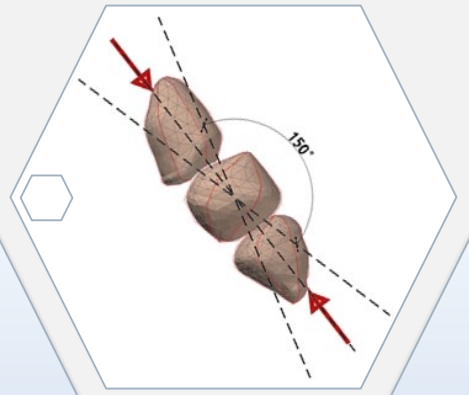
TEST	MODEL	GRAIN SHAPE	GRAD-ATION	GRAIN SIZE	PACKING
1	sphere	rounded	uniform	3.1 mm	regular
2			uniform	1.5 mm	random
3			gap graded	3.1 mm 1.5 mm	random
4	clump	sub-rounded	poorly graded	2.9 - 0.7 mm	random
5	block	angular	uniform	1.5 mm	random
6			gap graded	3.1 mm 1.5 mm	random

Research objectives

- grains individually (displacement, rotation, velocity)
- array of grains (direction, magnitude of contact forces, chain configuration)
- average values of stress and strain in a representative elementary volume

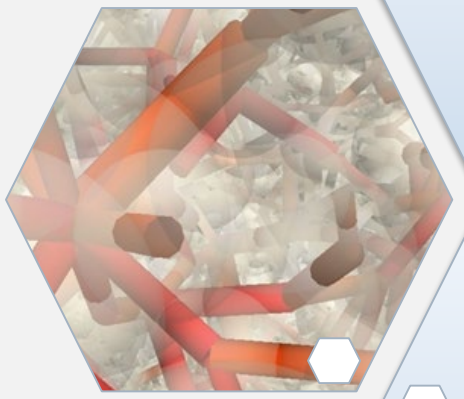


Expected research contribution

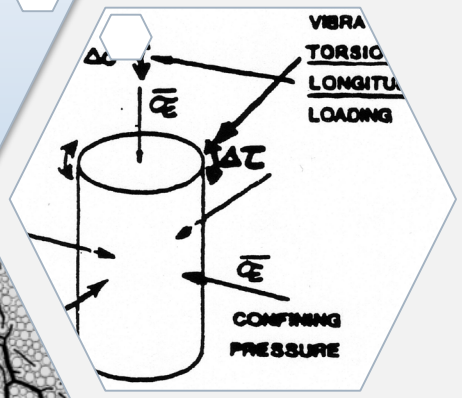


DEFINING ADDITIONAL CRITERIA FOR FORCE CHAINS

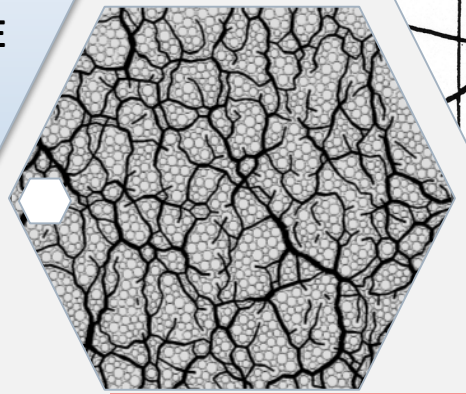
DEVELOPING A RESEARCH PROCEDURE FOR OTHER TESTS



EXPLANATION OF THE ROLE OF THE STRONG AND THE WEAK FORCE NETWORK



FORCE TRANSMISSION DESCRIPTION INSIDE GRANULAR MATERIAL



Research flowchart

Granular Matter (2017) 19:37
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CrossMark

ORIGINAL PAPER

Numerical modelling of the NGI-DSS test and cyclic threshold shear strain for degradation in sand

NGI-DSS, 2011

PFC3D, 2013

PhD, 2016

CC/Physical, 2017

Symposium, 2020

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