PARTICLES 2017
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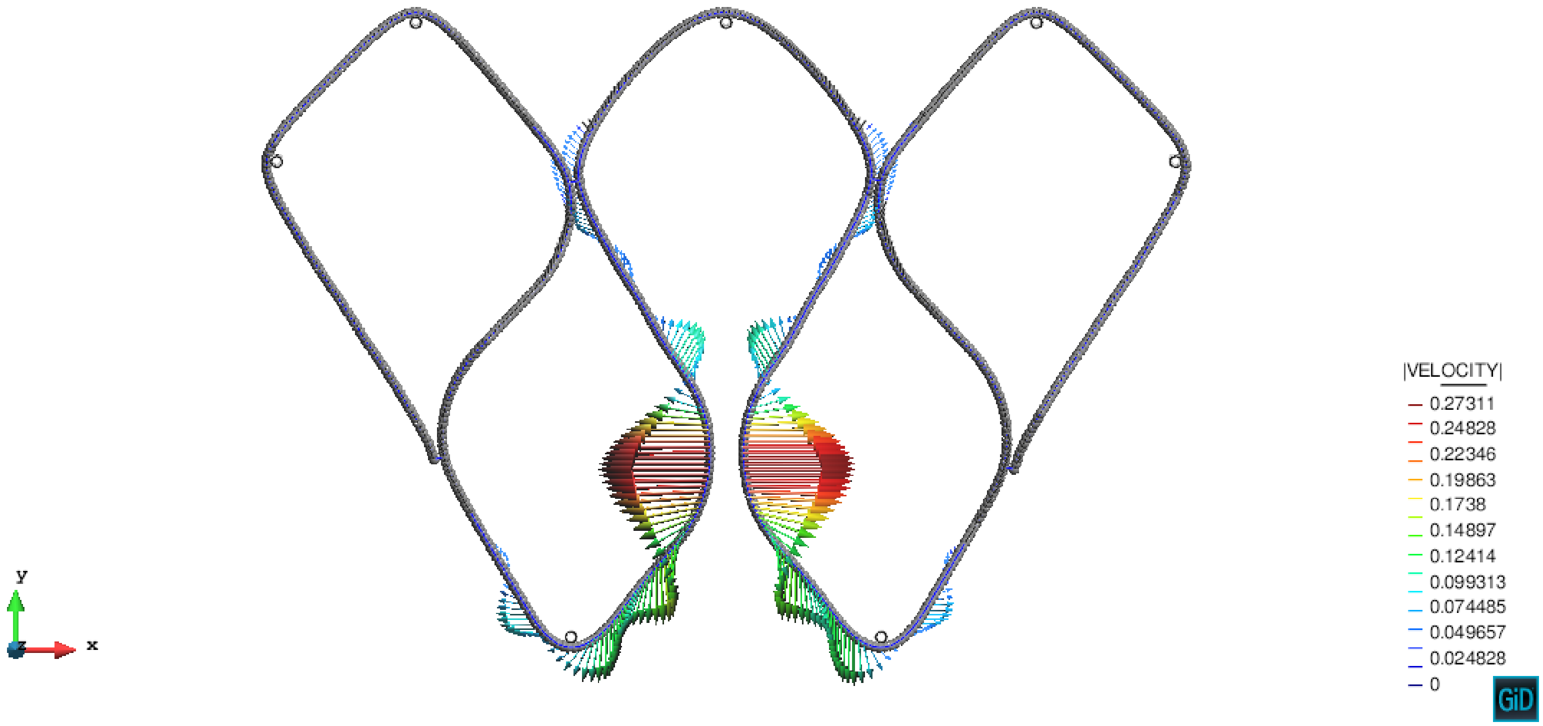
V International Conference on Particle-Based Methods

Numerical modelling with discrete elements of rockfall protection systems

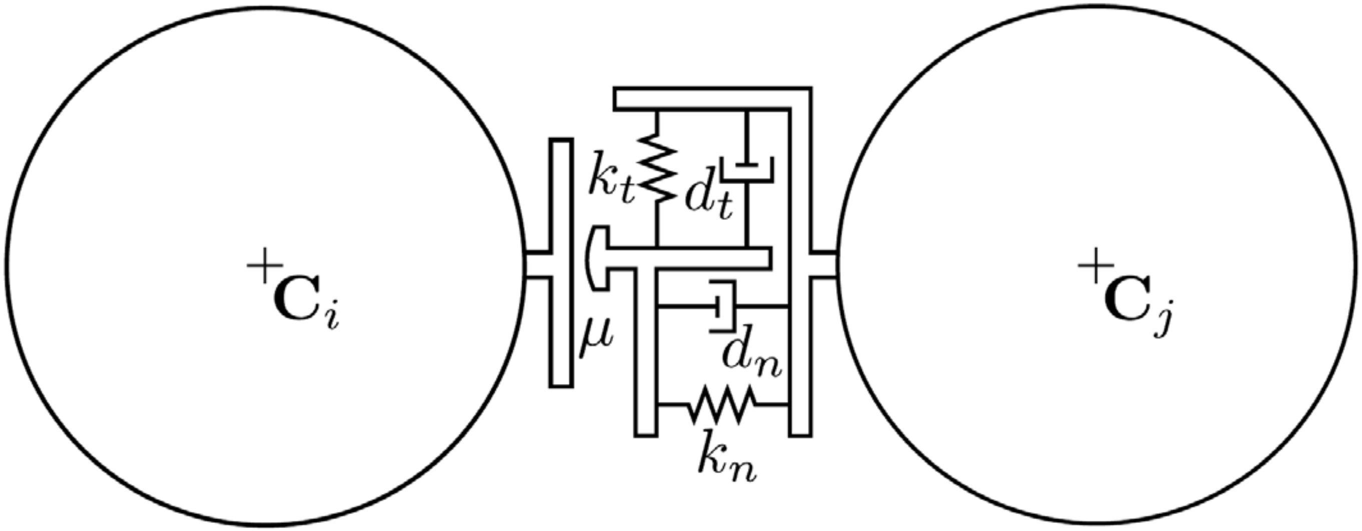


Authors: Joaquín Irazábal, Salvador Latorre, Fernando Salazar, Miguel Ángel Celigueta and Eugenio Oñate

Outline

1. Discrete Element Method (DEM)
2. Loose materials
3. Cohesive materials
4. Membranes and cables
5. Validation
6. Current work
7. Conclusions

Discrete Element Method (DEM)



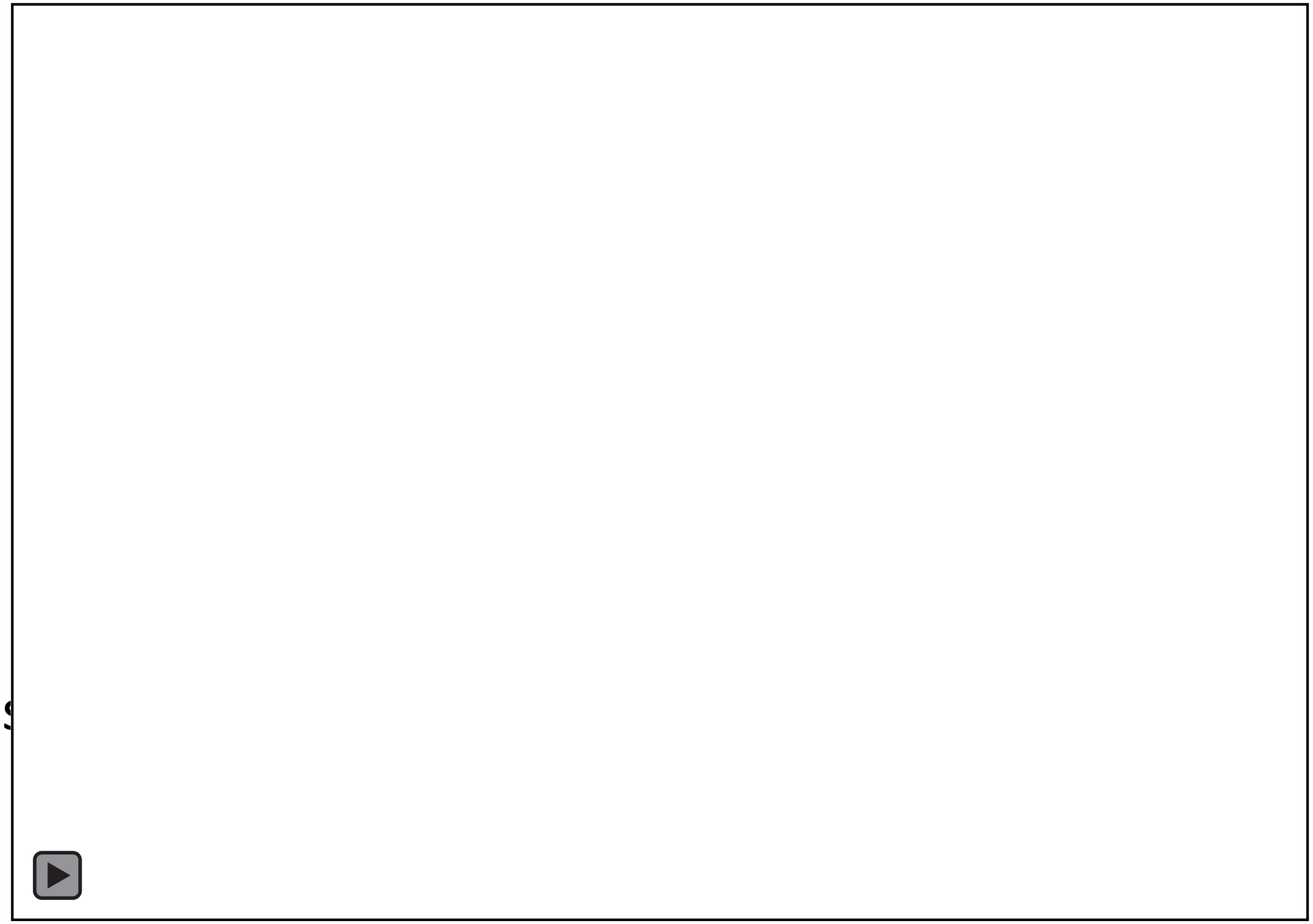
Force balance

$$m_i \ddot{\mathbf{u}}_i = \mathbf{F}_i^{ext} + \sum_{j=1}^{n_i^c} \mathbf{F}^{ij}$$

Torque balance

$$\mathbf{I}_i \dot{\boldsymbol{\omega}}_i = \mathbf{T}_i^{ext} + \sum_{j=1}^{n_i^c} \mathbf{r}_c^{ij} \times \mathbf{F}^{ij}$$

Loose materials

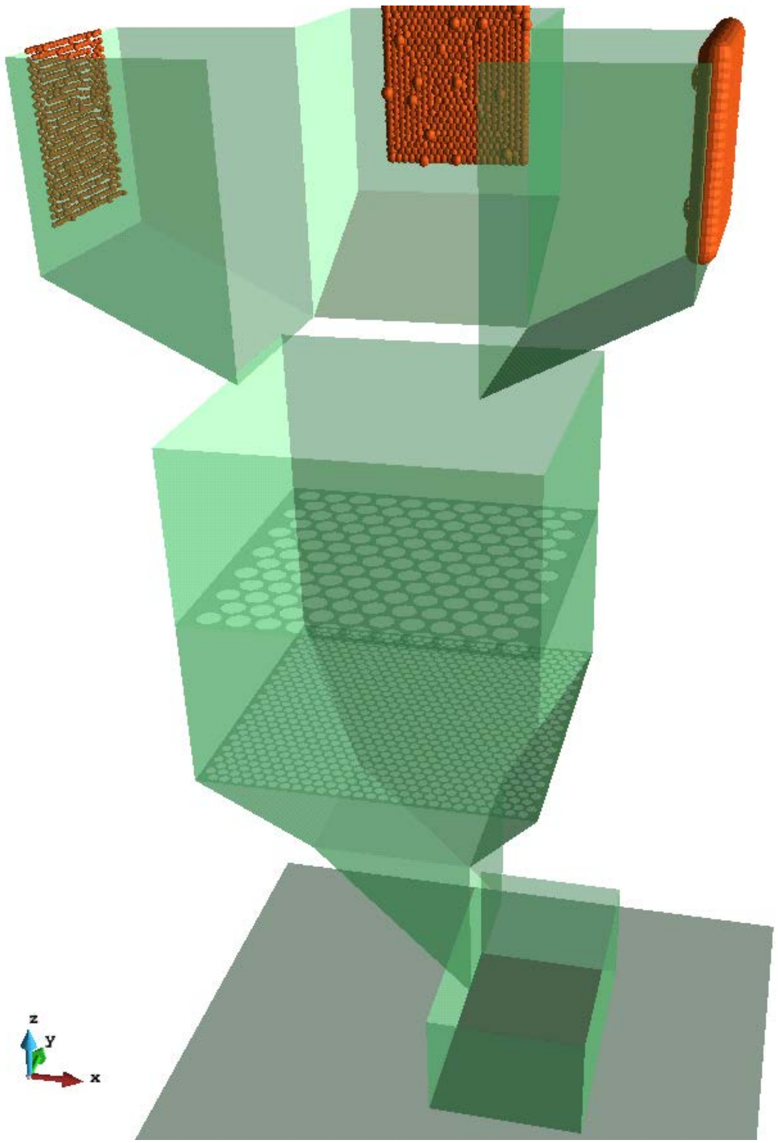


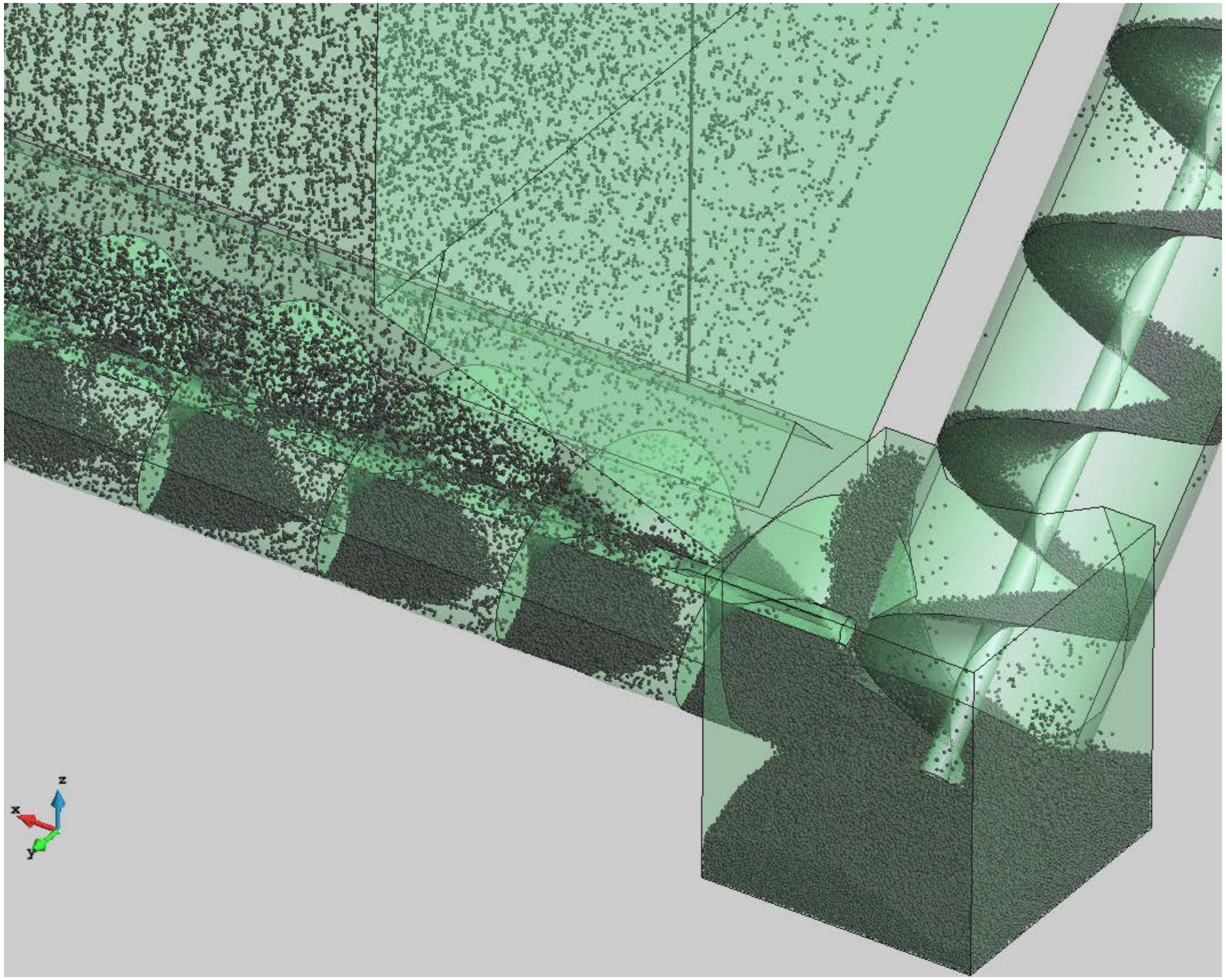
Evaluate:

- Performance
- Power needed
- Wear
- Stresses

Help to design tools

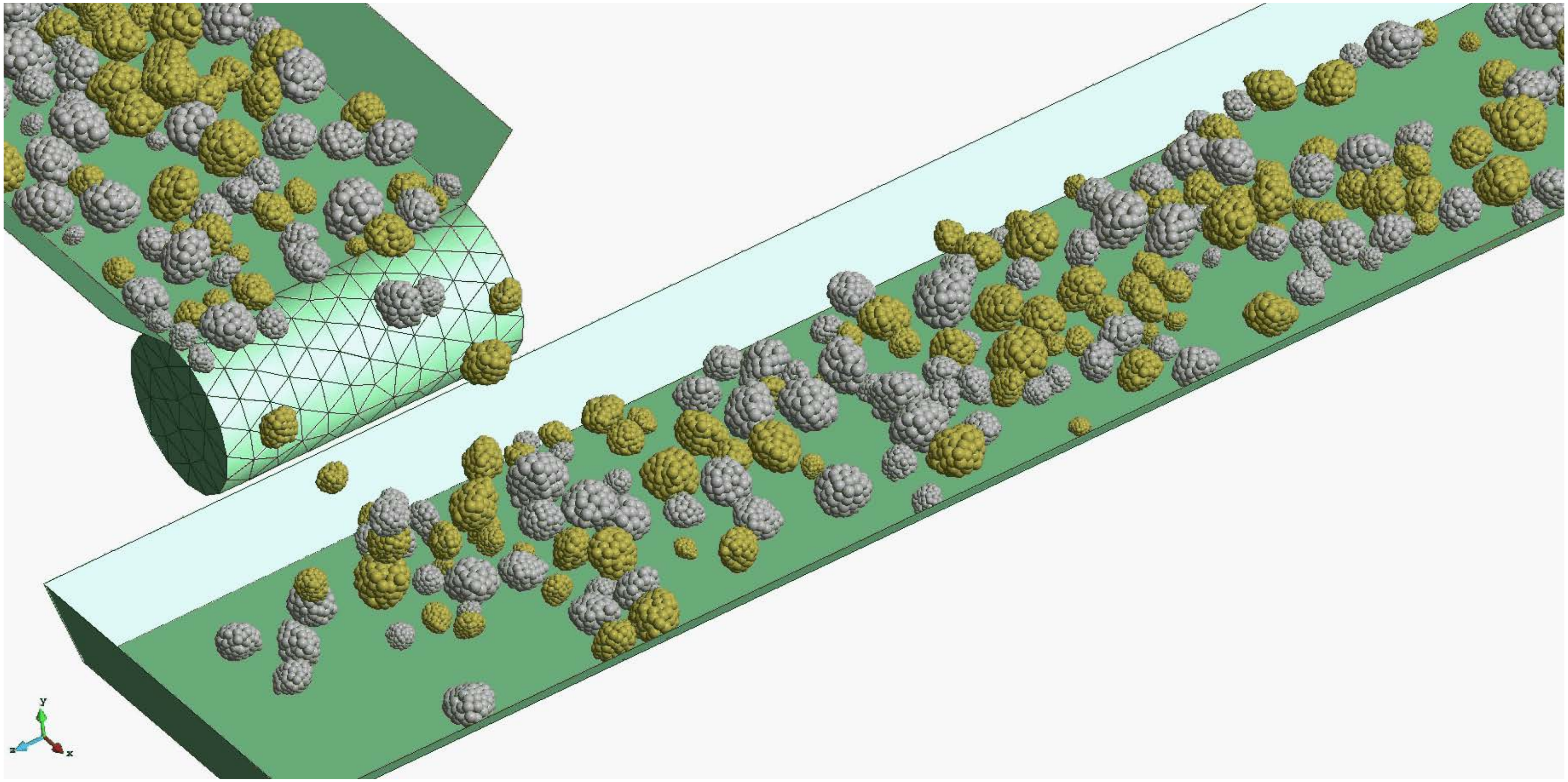
Sieve: 3 diferent sizes





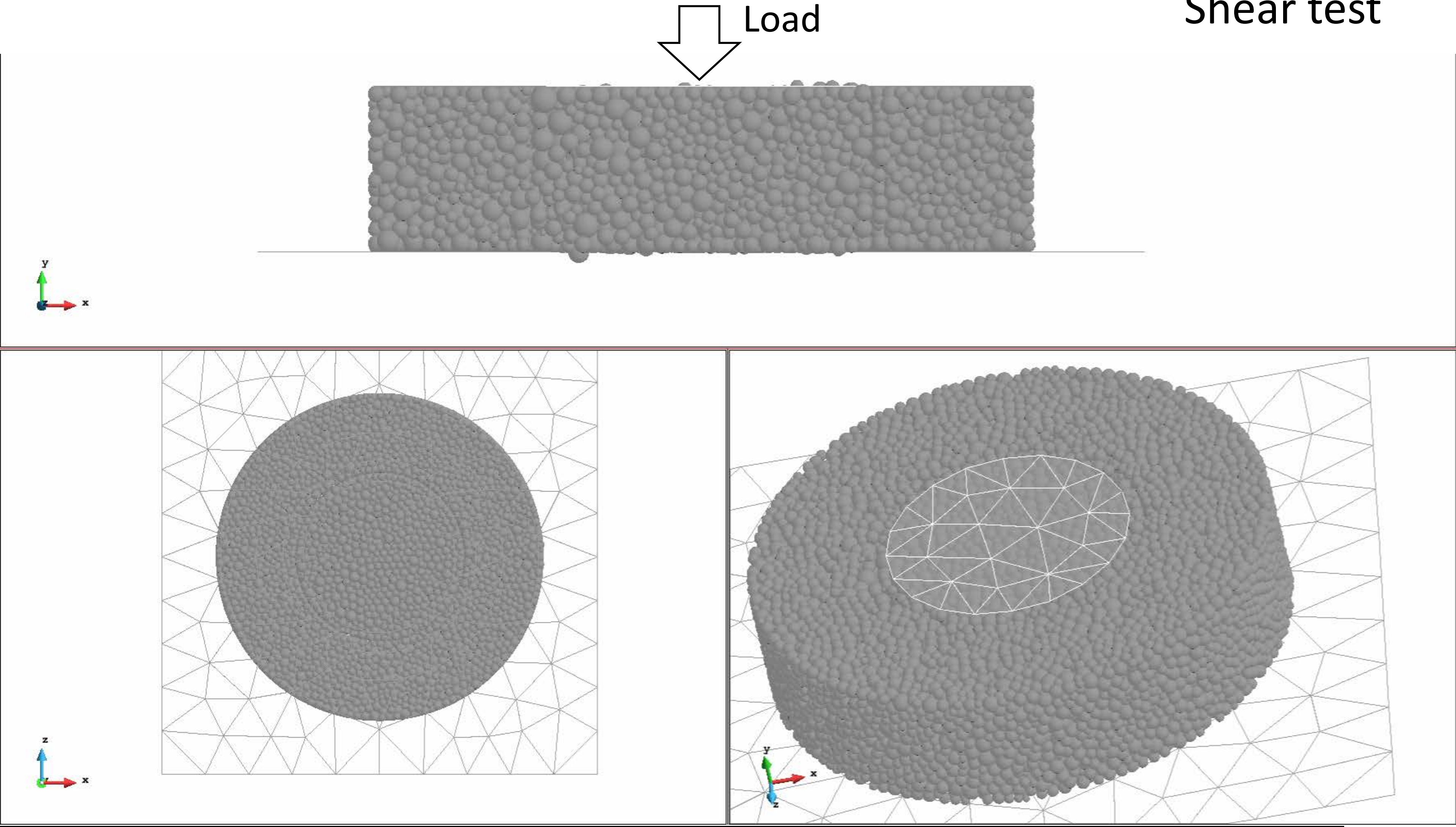
Feeding and conveying

Non spherical particles: Conveyor belt with rocks of different sizes

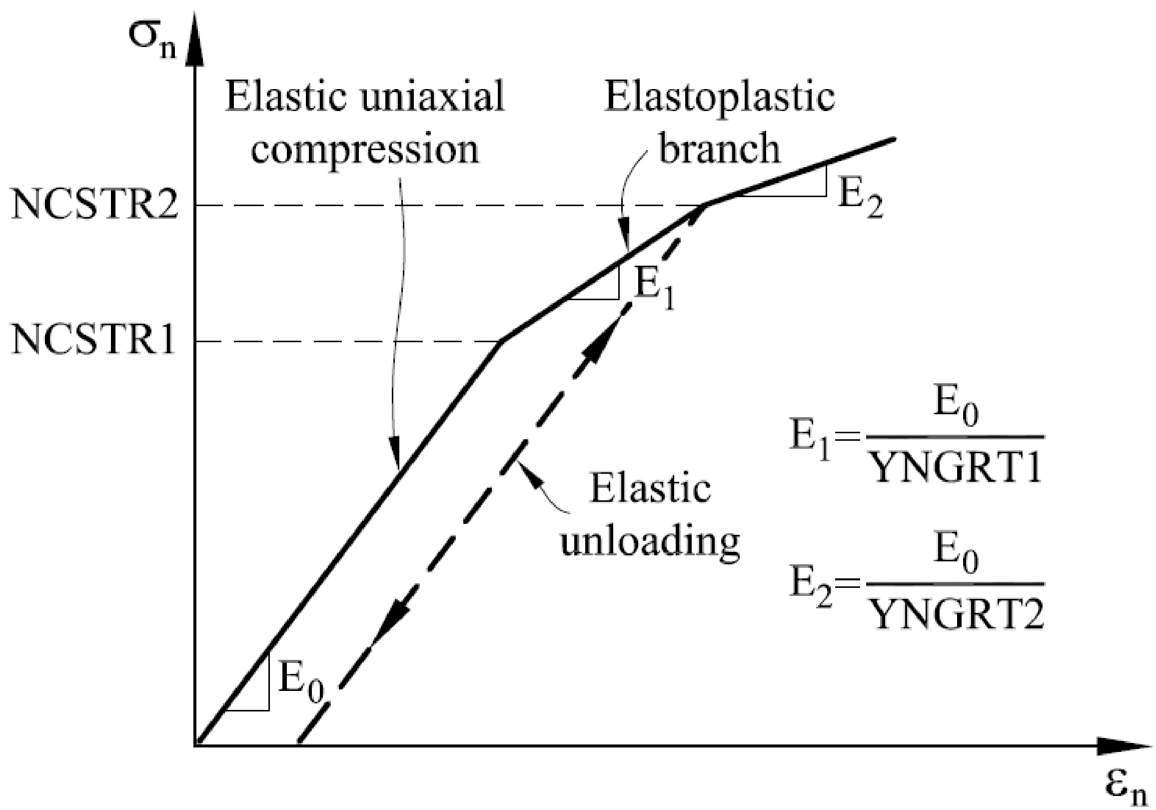


Cohesive materials

Shear test

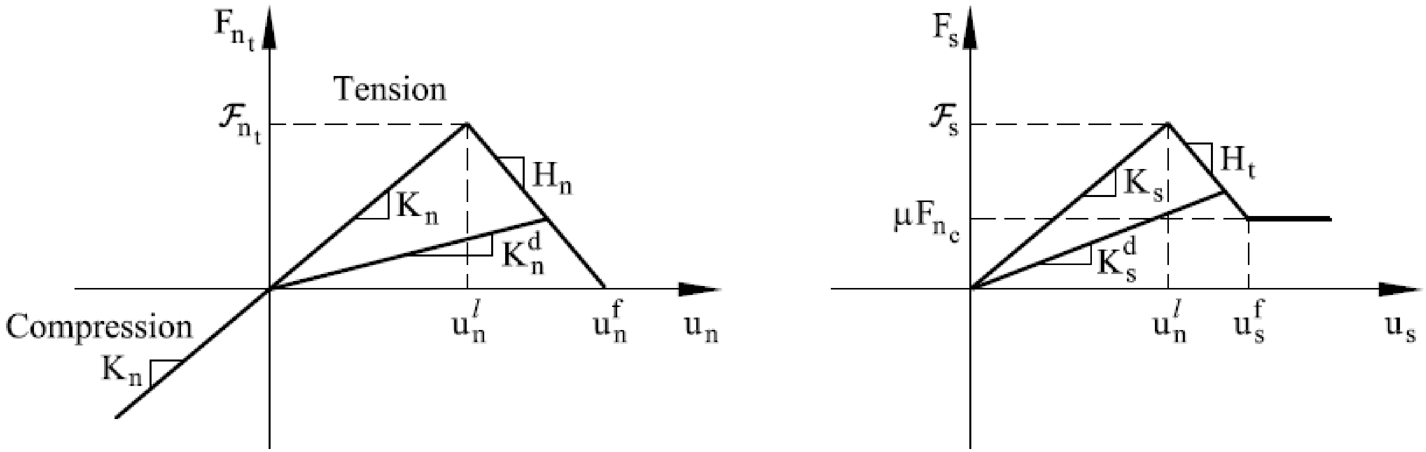


Elasto-Plastic Model in compression



Oñate, E., Zárate, F., Miquel, J., Santasusana, M., Celigueta, M.A., Arrufat, F., Gandikota, R., Valiullin, K., & Ring, L. (2015) A local constitutive model for the discrete element method. Application to geomaterials and concrete. *Comput Part Mech,* 2(2) 139–160.

Damage model in tension



Normal (tensile) direction

For $0 < d_s \leq 1: \; F_{n_t} = (1-d_n)K_n u_n = K_n^d u_n$ with $K_n^d = (1-d_n)K$

For $d_n \geq 1: \; F_{n_t} = 0$

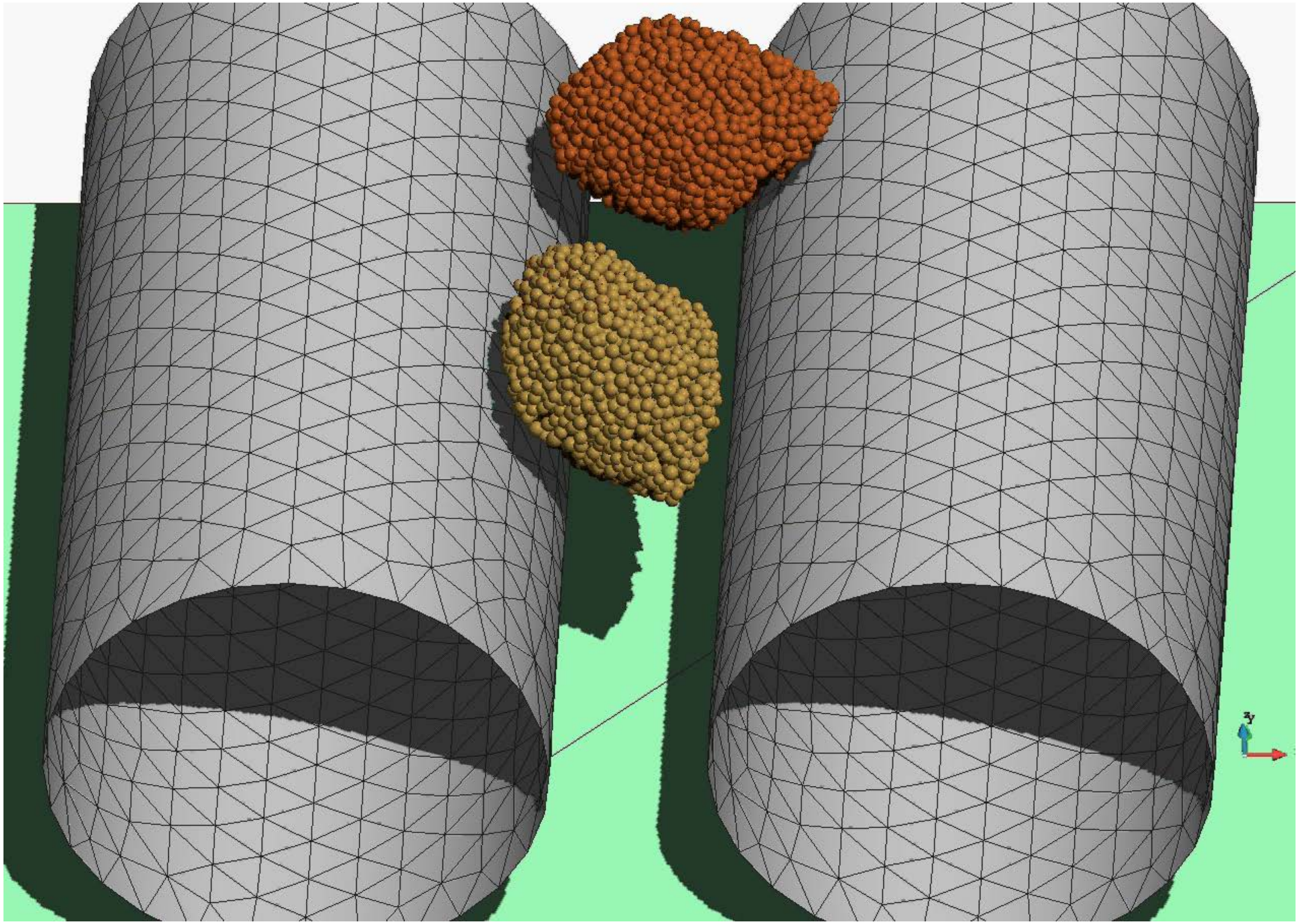
Tangential direction

For $0 < d_s \leq 1: \; F_s = (1-d_s)K_s u_s = K_s^d u_s$ with $K_s^d = (1-d_s)K_s$

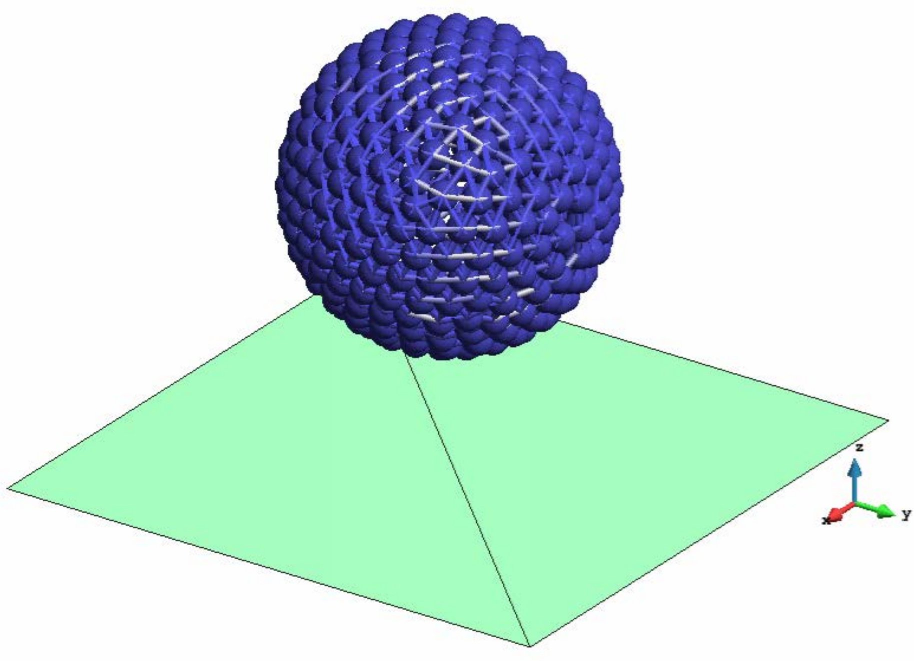
For $d_s > 1: \; F_s = \mu F_{n_c}$

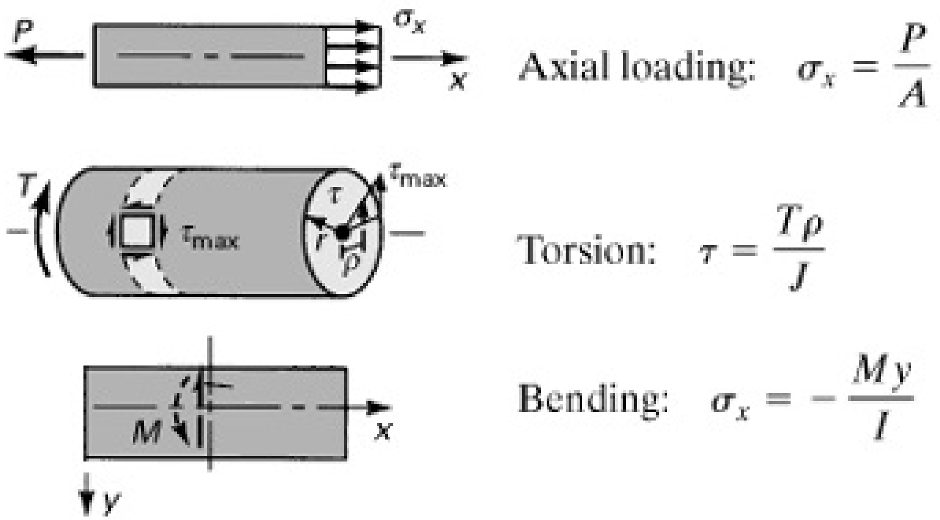
Oñate, E., Zárate, F., Miquel, J., Santasusana, M., Celigueta, M.A., Arrufat, F., Gandikota, R., Valiullin, K., & Ring, L. (2015) A local constitutive model for the discrete element method. Application to geomaterials and concrete. *Comput Part Mech,* 2(2) 139–160.

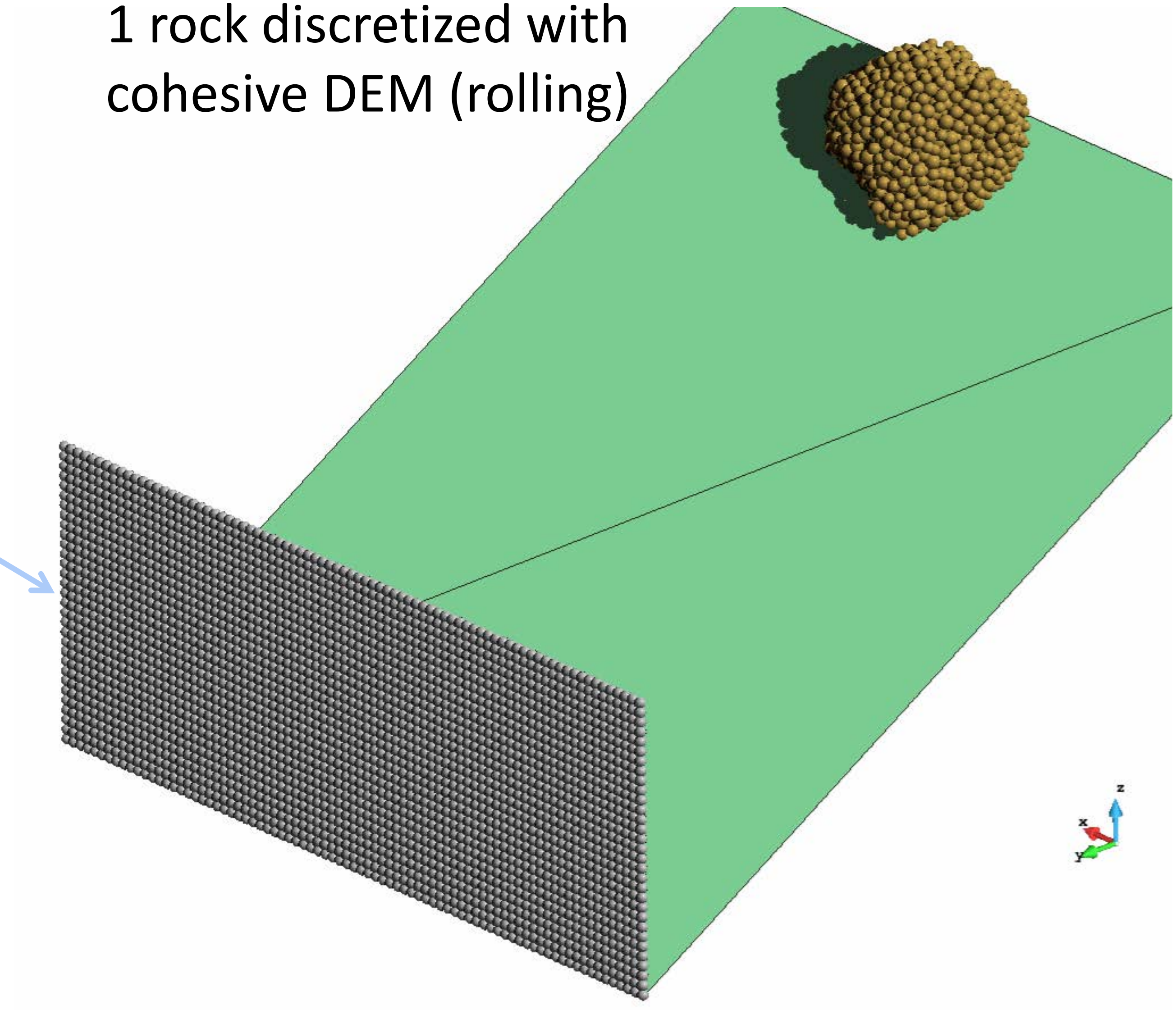
Crushing



Membranes and cables

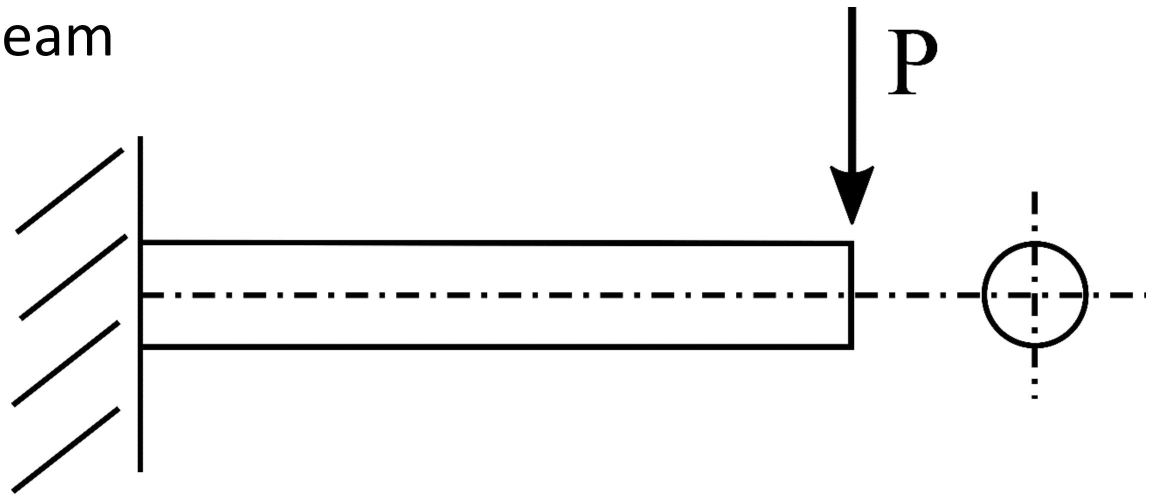




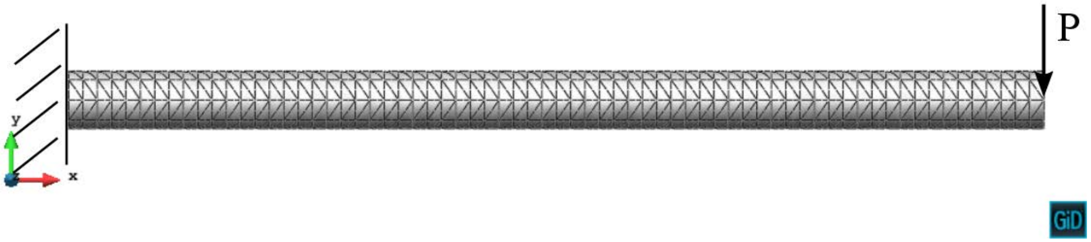

1 rock discretized with
cohesive DEM (rolling)
1 single layer of
cohesive DEM

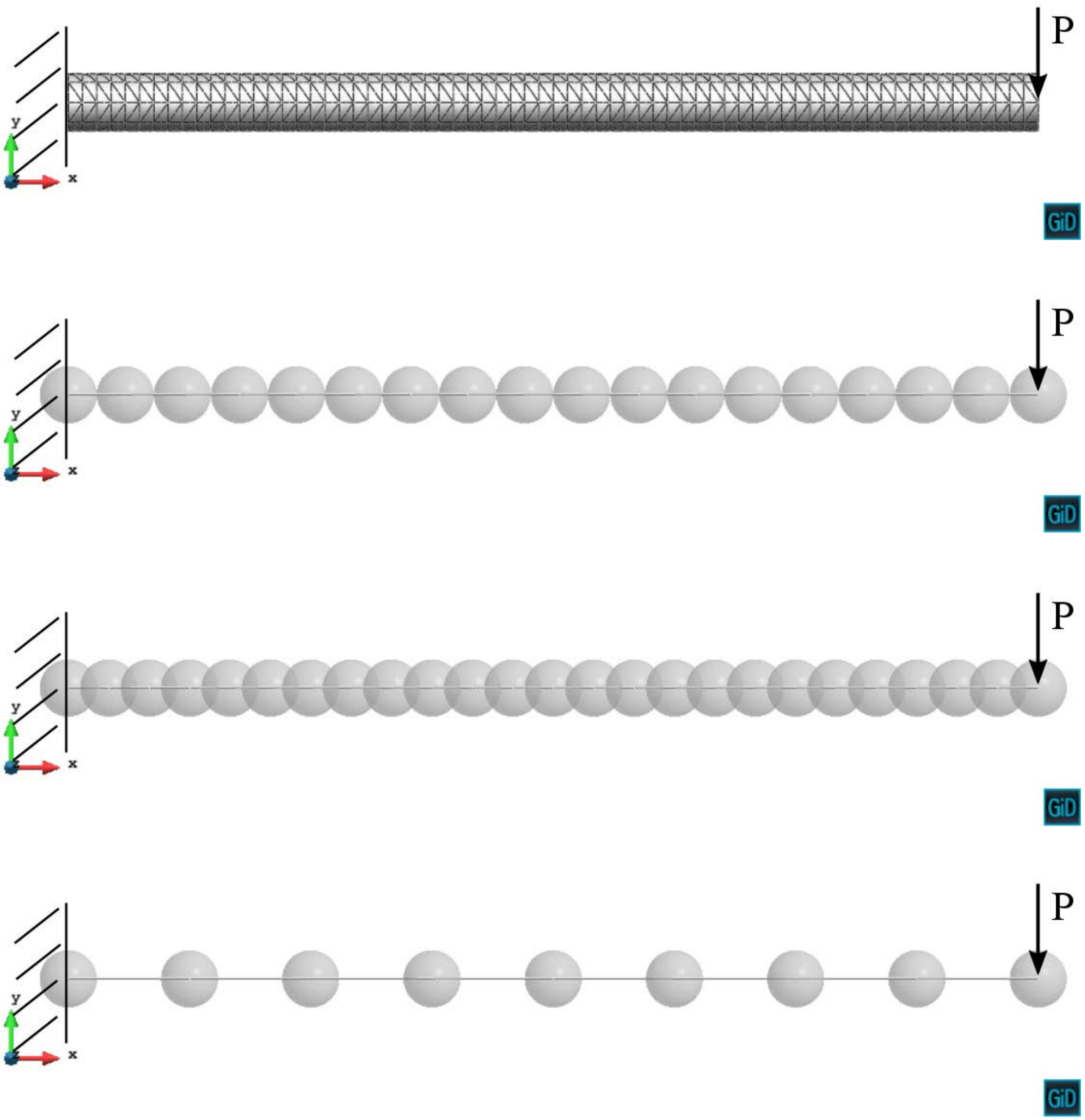
Validation

Cantilever beam



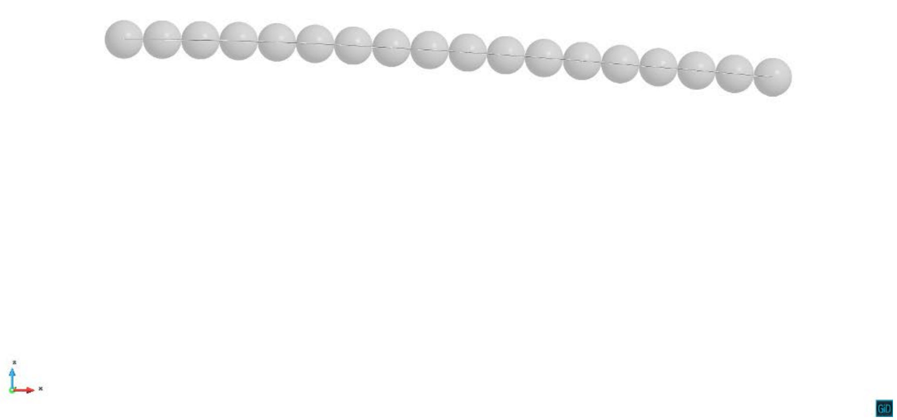
Large deformations
Non-linear problem } Analytical solution unknown ⇨ FEM


P
y
x
GiD

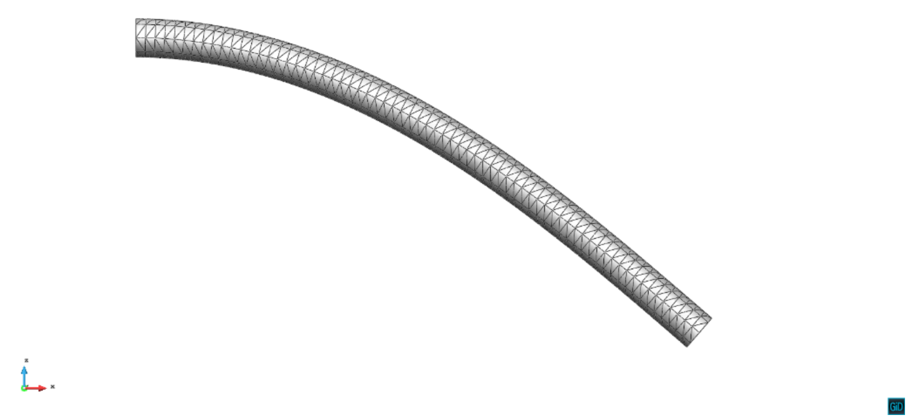

P
y
x
GiD
P
y
x
GiD
P
y
x
GiD
P
y
x
GiD

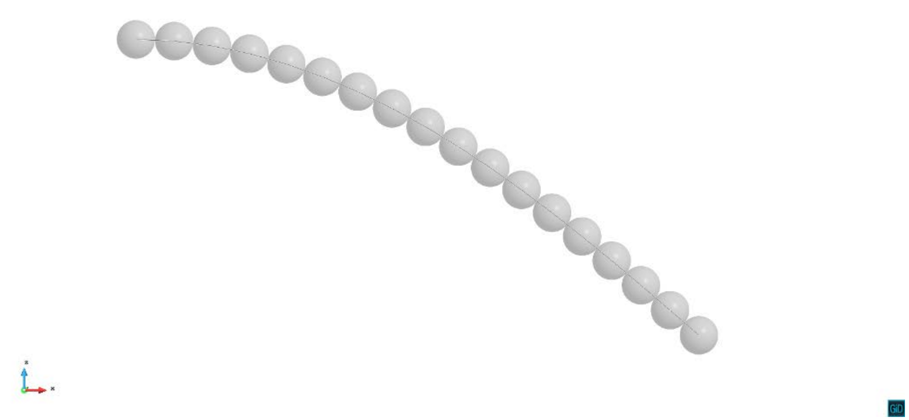
E = 117.21 Gpa, ν = 0.35, L = 0.204 m and R = 0.006 m

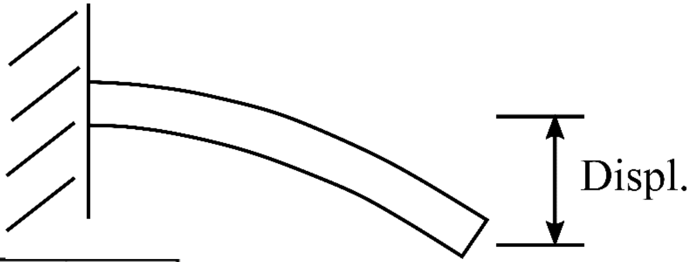
P = 500 N

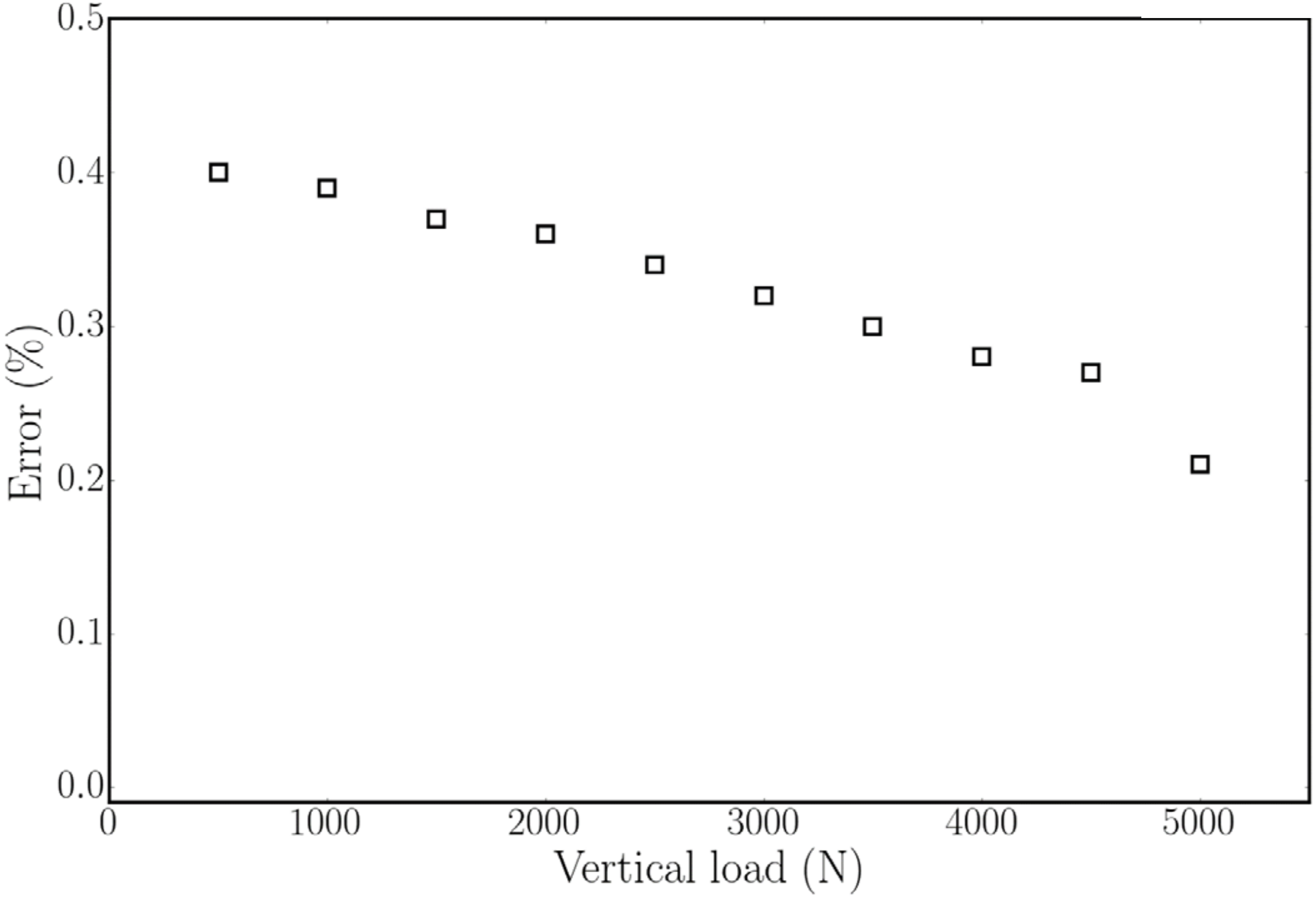


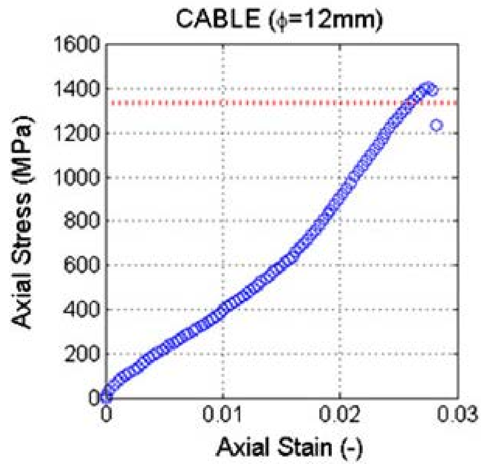
P = 5000 N

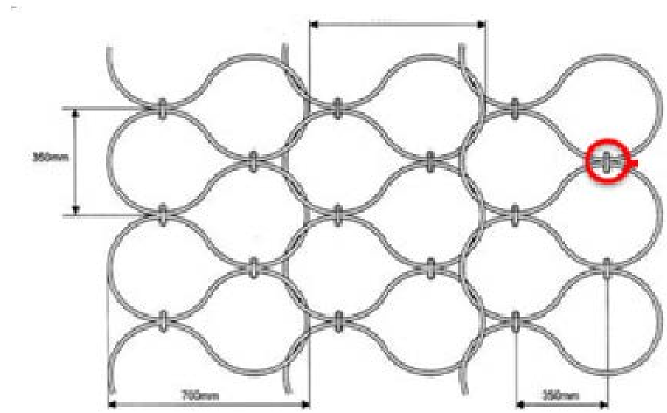


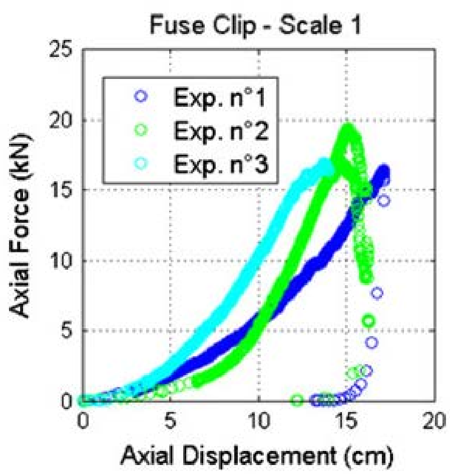



Displ.


0.5
0.4
0.3
0.2
0.1
0.0
Error (%)
0
1000
2000
3000
4000
5000
Vertical load (N)

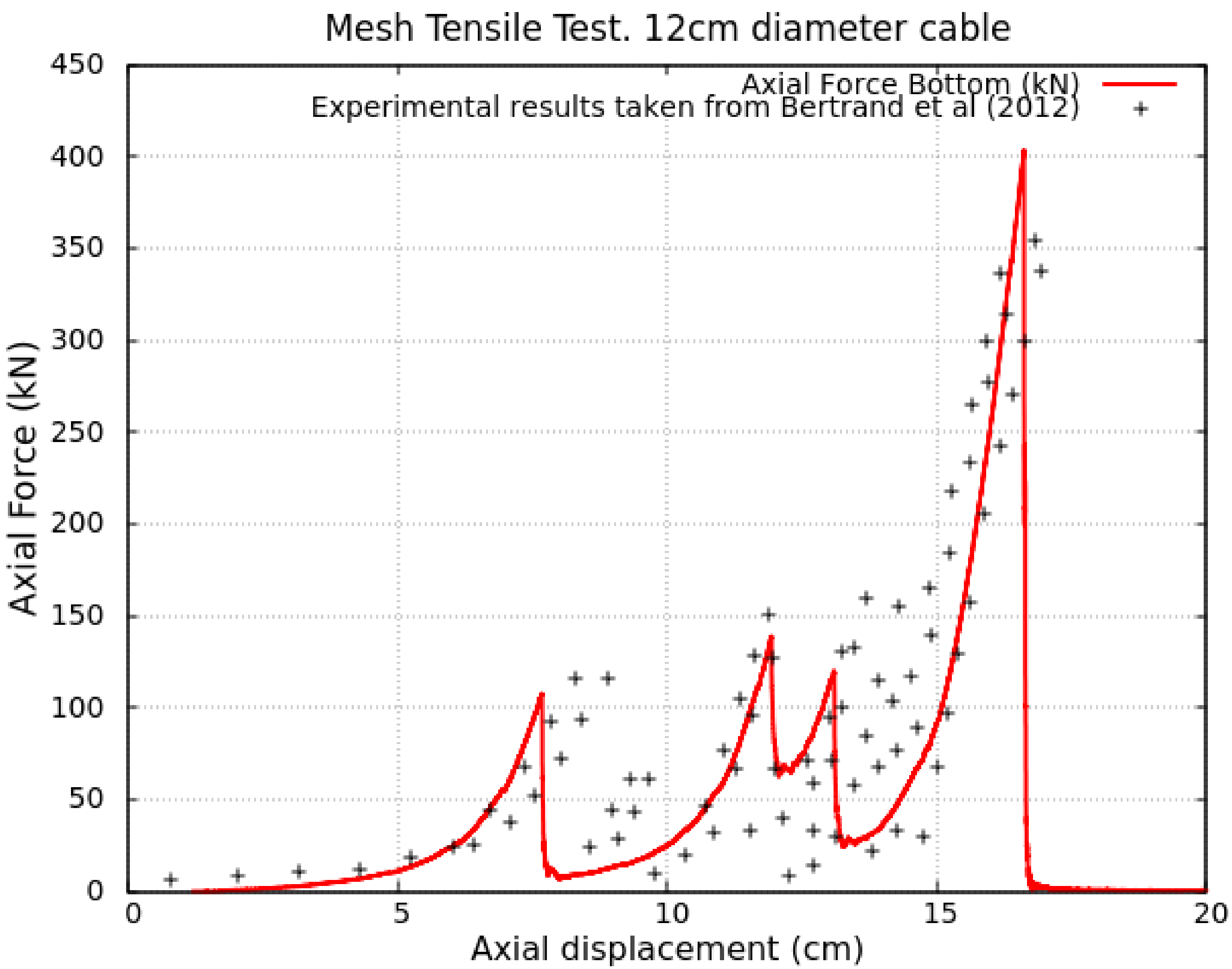






Tensile test

Bertrand, D., Trad, A., Limam, A. and Silvani, C., 2012. Full-scale dynamic analysis of an innovative rockfall fence under impact using the discrete element method: from the local scale to the structure scale. *Rock mech rock eng*, 45(5), pp.885-900.


Mesh Tensile Test. 12cm diameter cable
Axial Force Bottom (kN)
Experimental results taken from Bertrand et al (2012)
Axial Force (kN)
Axial displacement (cm)
0
50
100
150
200
250
300
350
400
450
0
5
10
15
20

Ongoing work

Punching test

fence under impact using the discrete element method: from the local scale to the structure scale. *Rock mech rock eng*, 45(5), pp.885-900.

Conclusions

The discrete element method seems to be appropriate for evaluating rockfall protection nets behaviour

PROS:

- Allows an efficient calculation of contacts
- For different geometries of the net
- Net junctions can be properly represent

CONS:

- Very high E -> small time step
- Very dynamic phenomenon -> small time step
- Costly simulations (Parallelization helps…)

Thank you for your attention

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