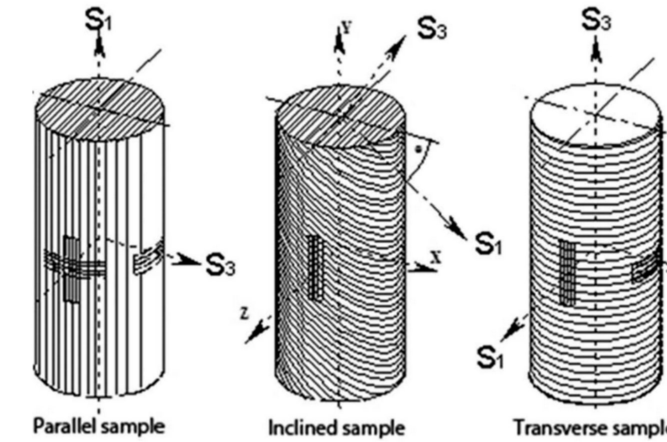
How does anisotropy control rock slope deformation?
A discrete element modelling investigation

EGU General Assembly 2022

Marius Huber
Doctorate in supervision of Jérôme Lavé and Luc Scholtès

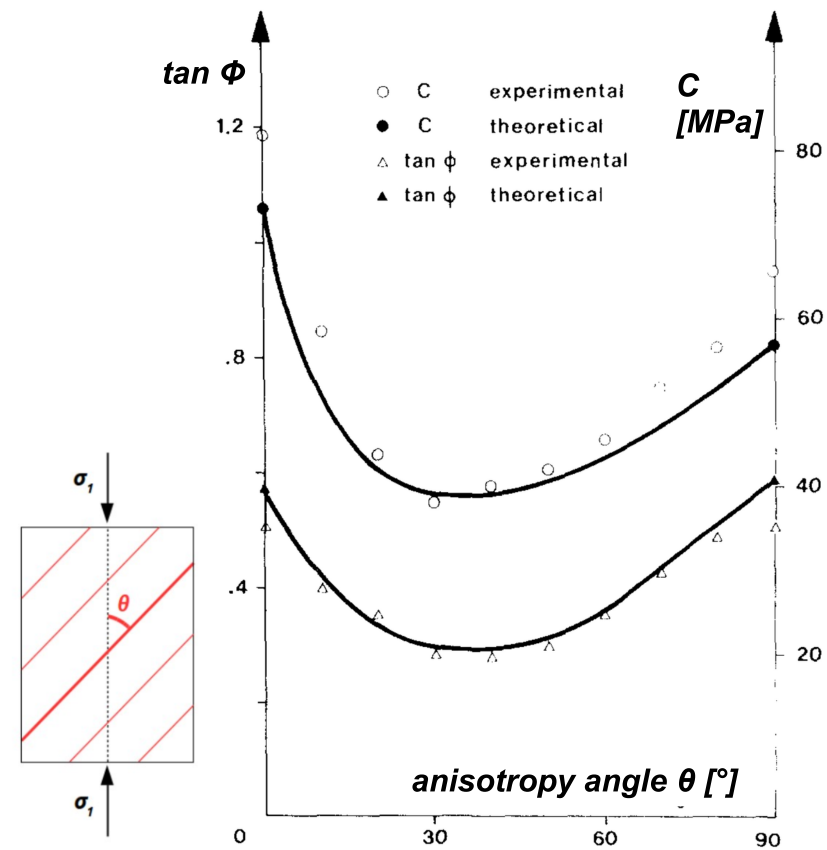
May 2022



Giot et al. (2018)

Anisotropy in rocks

- Rock masses anisotropy results from **lithology** (layering and foliation) and **structures** (joints)
- The mechanical properties (stiffness and strength) of most rock materials is direction dependent
- Sedimentary and metamorphic rocks exhibit transverse isotropy



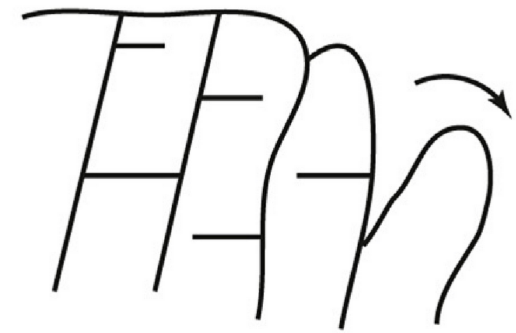
Nova (1980): "Dependence of overall friction angle and cohesion on the inclination of the plane of least resistance" for transversely isotropic rocks

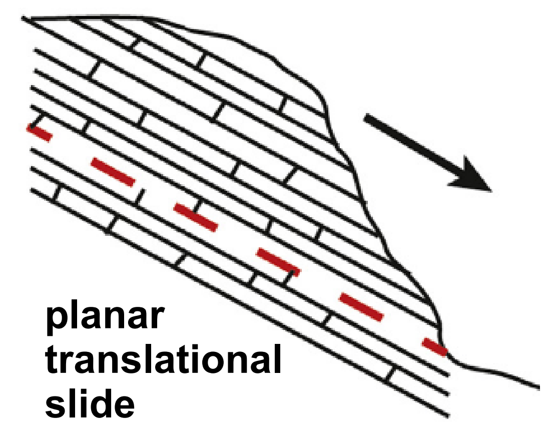
wikipedia.org, "Joint (geology)"

nationalgeographic.com

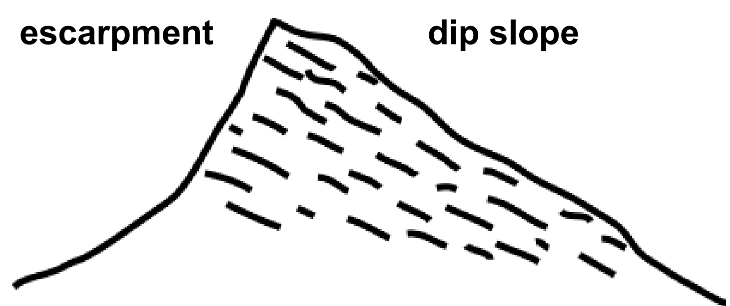
Anisotropic slopes fail and form landscapes

- Rock fabric controls slope deformation and drives failures, their **mechanics and geometry**
- Anisotropy is often described qualitatively for all types of deep-seated failures, but there is a **lack of systematic understanding** of the effects of anisotropy orientation
- Implications for **natural hazards and risks**, as well as **landscape evolution**





sketches by Stead and Wolter (2015)



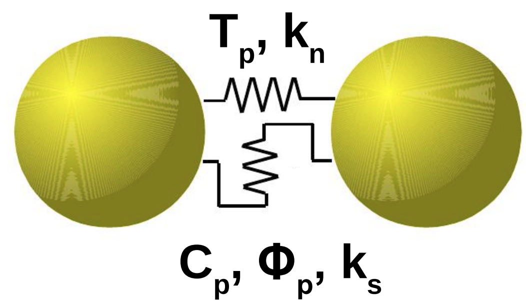
→ Crête des Rochers de la Balme, Massif du Vercors, France; Association Amitié-Evasion, http://amieva.eklablog.com

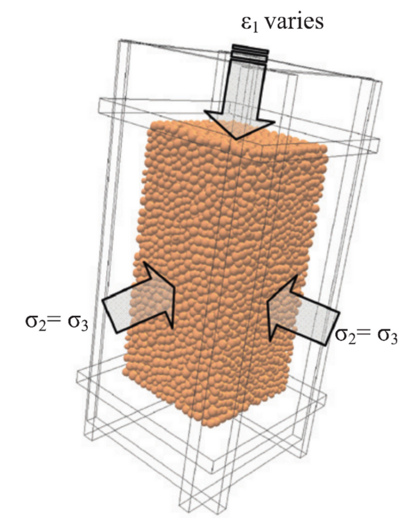
Modelling approach

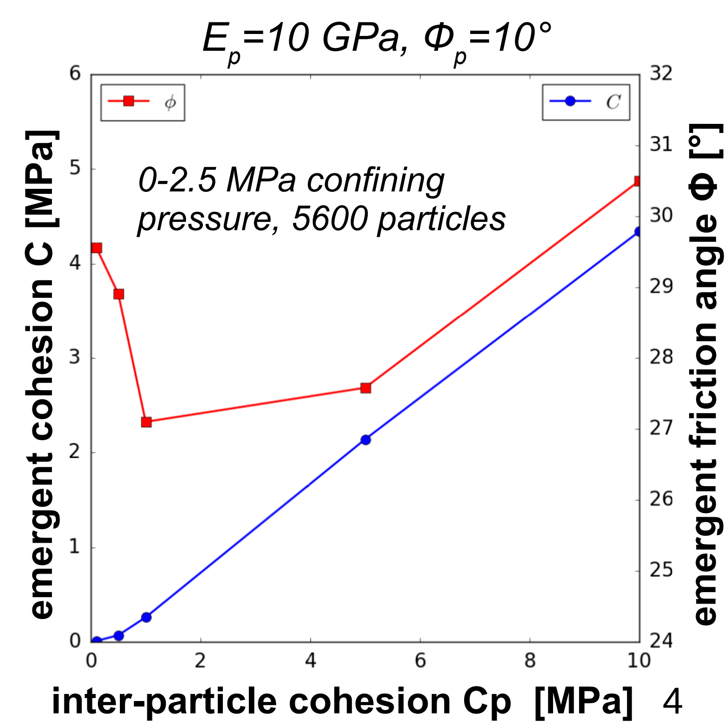
Discrete element modelling with Yade

- Rock material imitated by bonded particles
- **Inter-particle properties ≠ emergent properties,**
  → calibration needed (triaxial testing)
- Investigation on 2D slices in “slope step geometry”

TRIAXIAL TESTING
(with DEM)



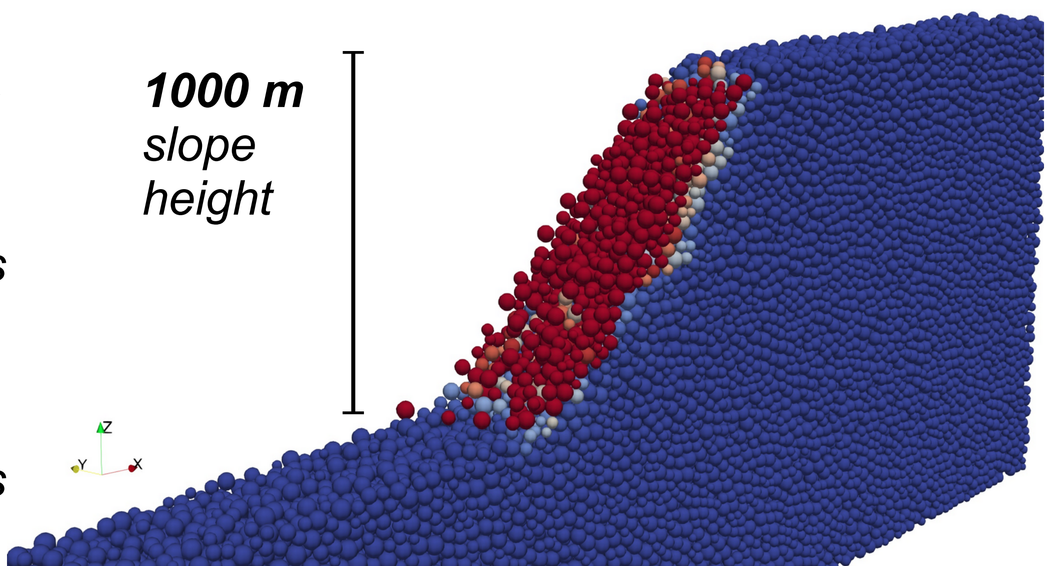




velocity:

red *particles* ***move****,*

blue *particles* ***stay***



Modelling approach

TRIAXIAL TESTING
(with DEM)

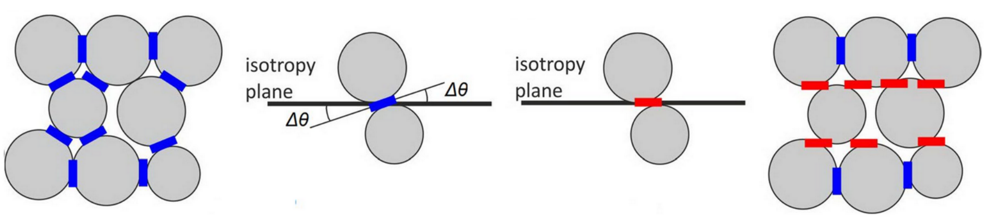
How to set anisotropy in the model ?

Introduction of **weakness plane**, following an approach by Dinç and Scholtès (2018)

1) **Detection of bonds** dipping subparallel to the weakness plane, angle range ± Δθ

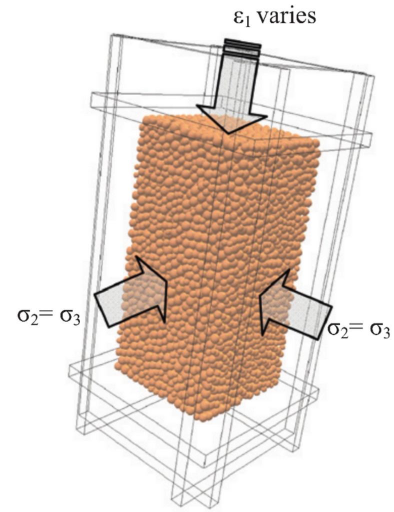
2) **Re-orientation of bonds** along the weakness plane

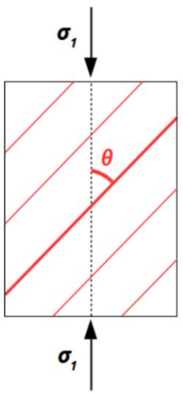
3) **New inter-particle properties are introduced** for the re-oriented bonds (low stiffness, low strength)
   → calibration needed (triaxial testing)



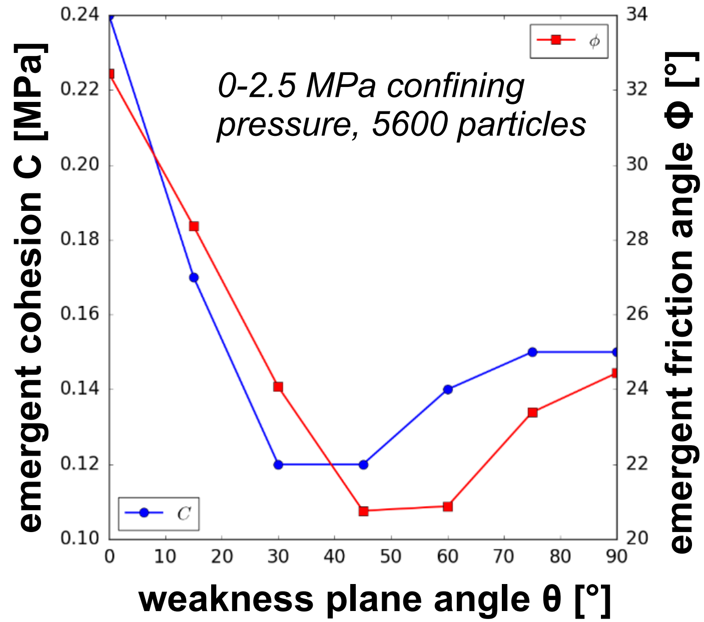
1) 2) 3)

Dinç and Scholtès (2018)



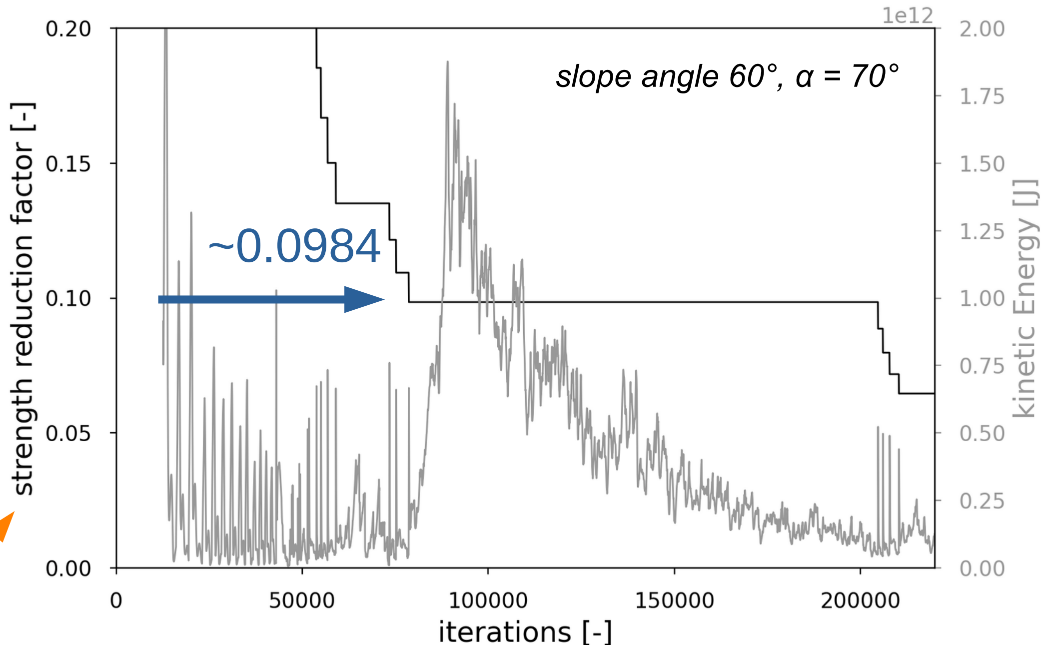


E_p= 10 GPa, $Φ_p$= 10°, T_p= C_p= 1 MPa, Δθ = 55°



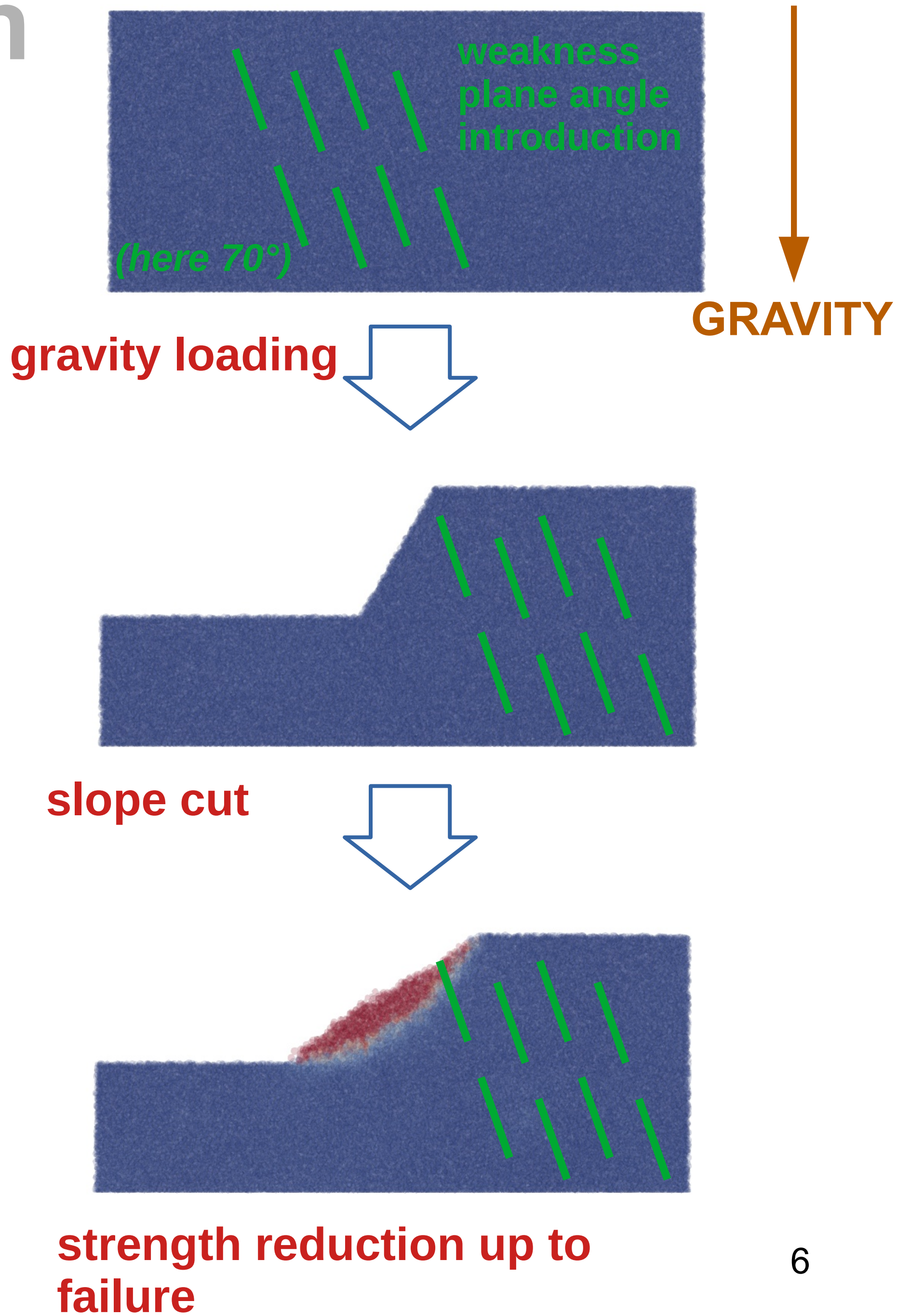
Modelling approach

Strength reduction method

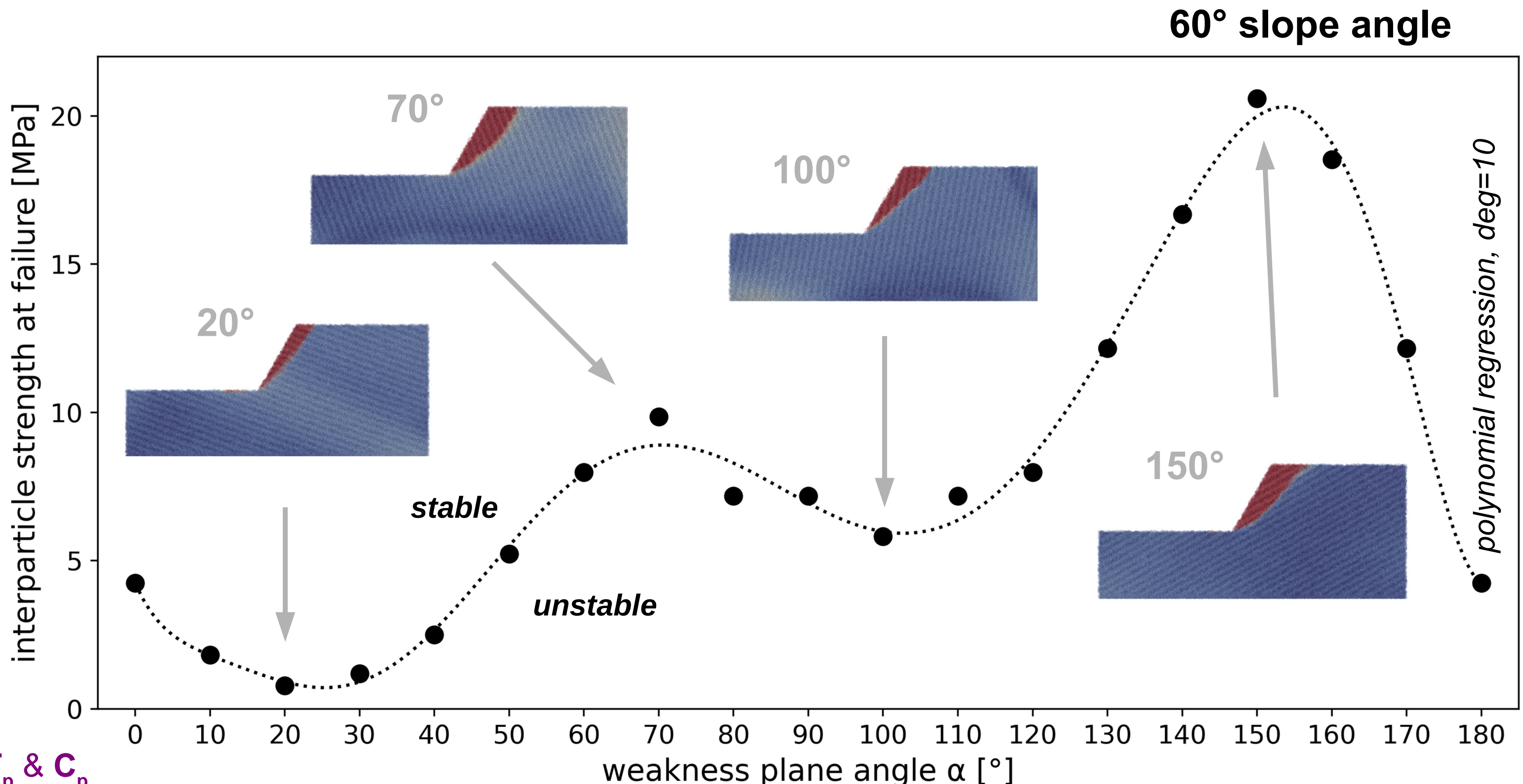


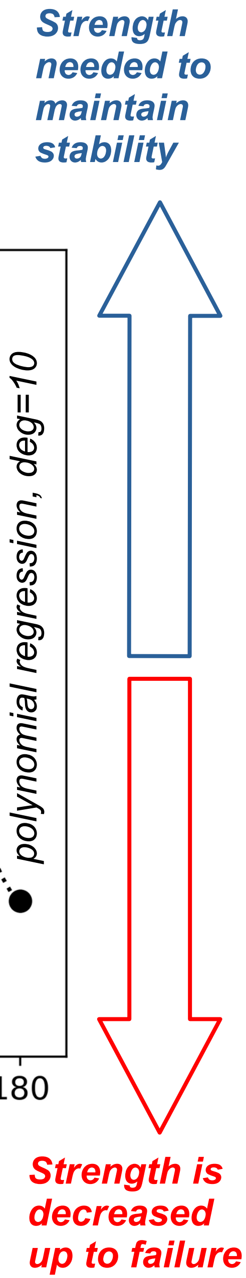
applied on inter-particle strength (Cp and Tp) !

- **strength is reduced stepwise** when the **slope is considered stable**
- **stability is assessed** through the **kinetic energy**
- failure is identified by the **rise of the kinetic energy**



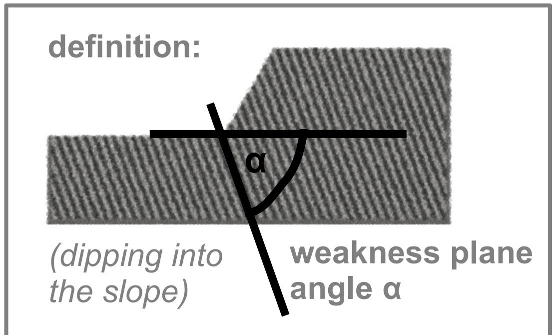
Results – failure plot





T_p & C_p

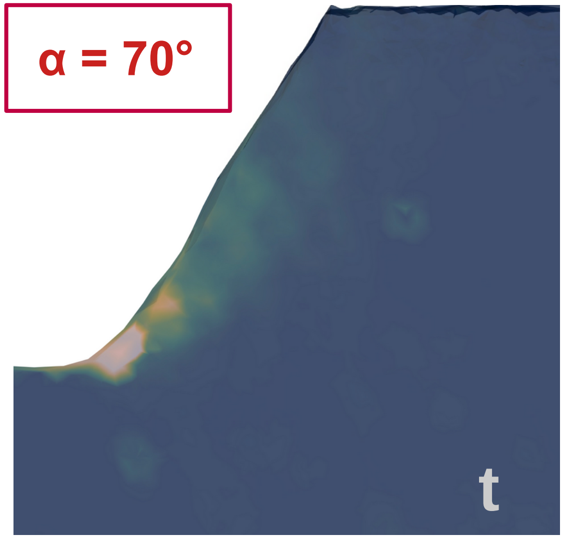
=> **two minima** and **two maxima** of slope stability for weakness plane angle range 180°

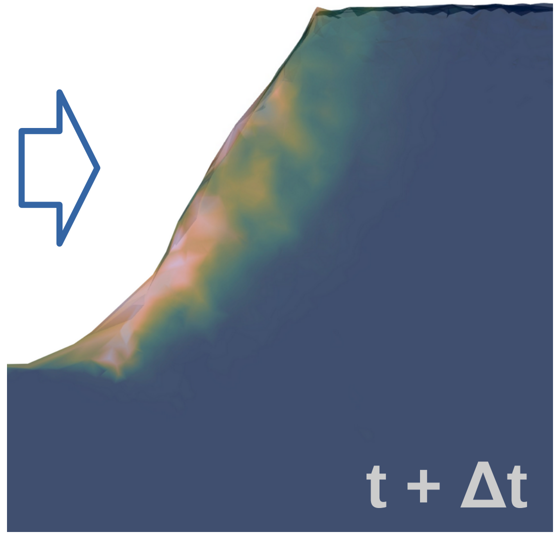


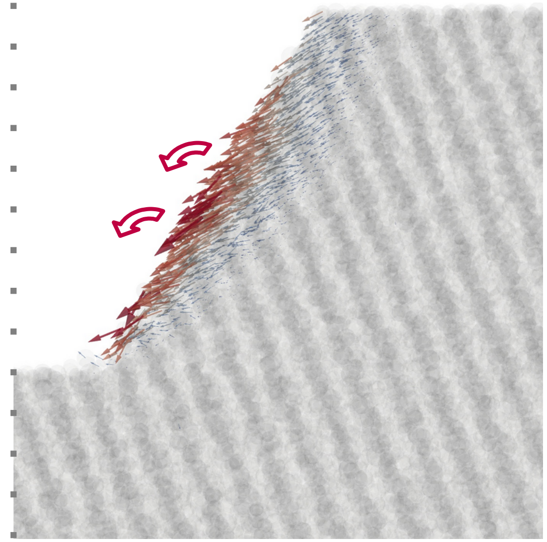
Different failure modes

60° slope angle !!

α = 70°





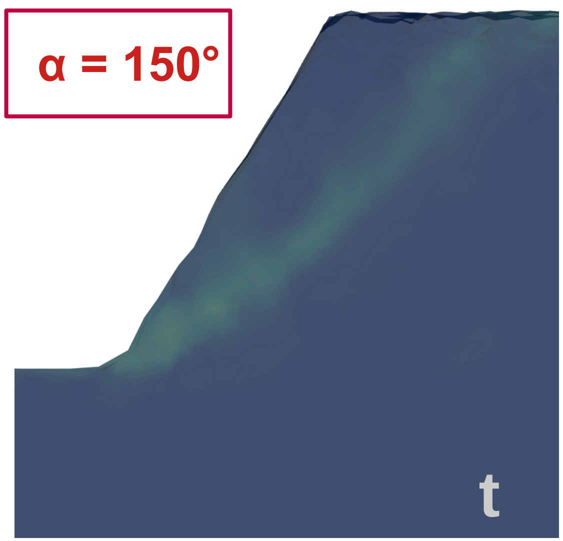


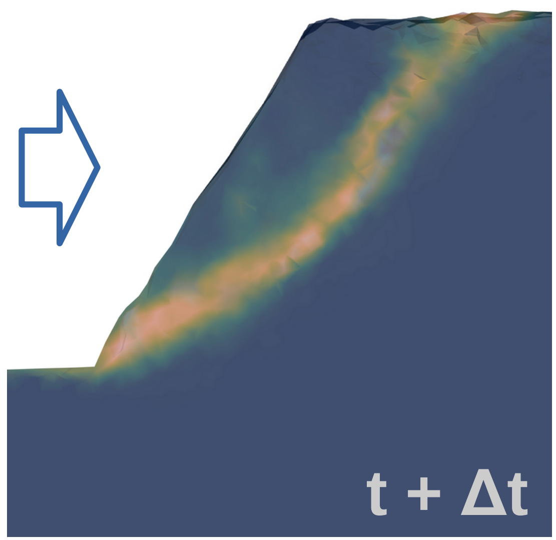
Stability minima 70°:

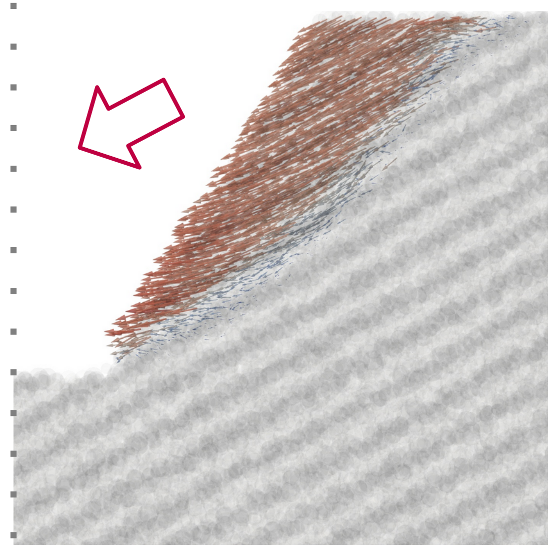
Toppling
(rotation)

- disintegration from surface into the slope

α = 150°







Stability minima 150°:

Sliding
(translation)

- coherent block on well-established rupture surface

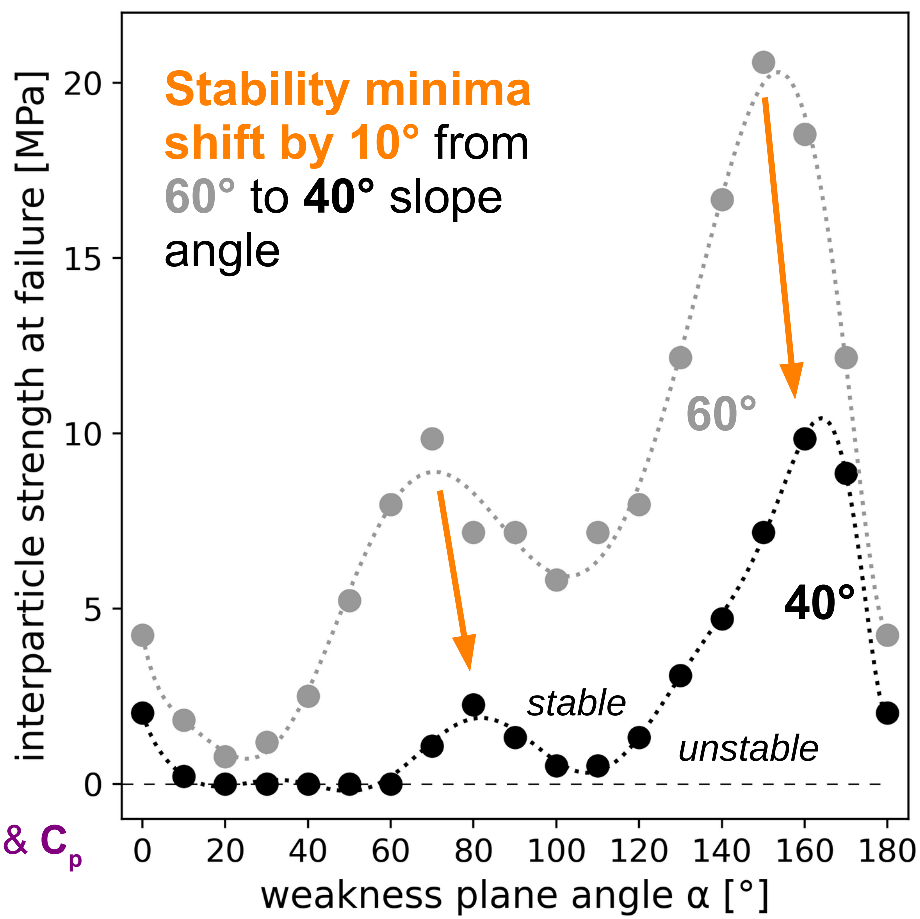
strain deviator map

displacement vectors
(over 10 000 iterations at failure)

More results

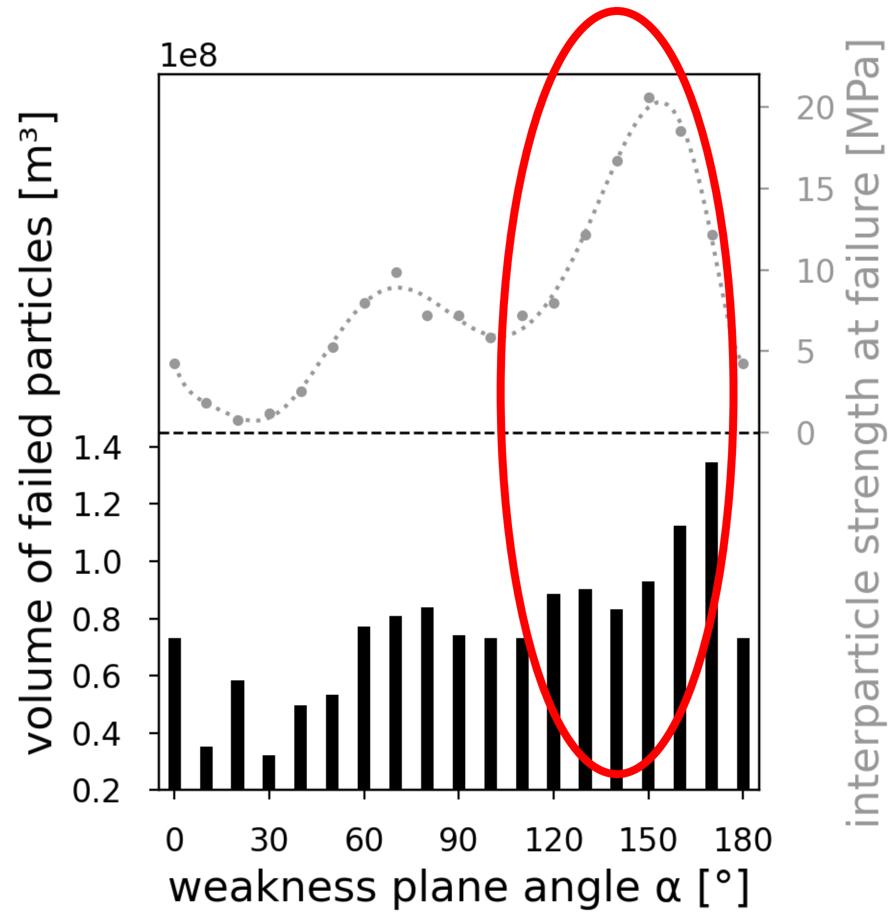
60° slope angle !!

Slope angle 40°



T_p & C_p

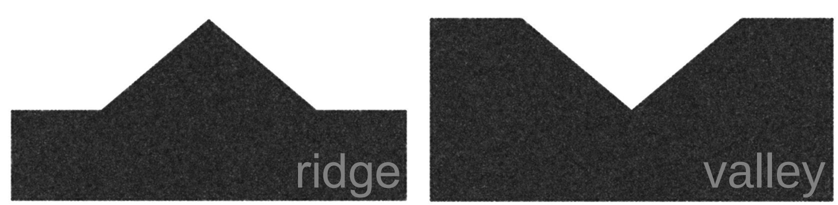
Volume of failed particles



Divergence for low-rising weakness plane angles

Conclusions

- Discrete element models can be used to study the effects of anisotropy on the deformation of rock slopes
- When applying the 180° range of possible anisotropy-orientations we observe two stability maxima and two stability minima
- Two stability minima represent two different modes of failure, toppling and sliding respectively, they shift with slope angle
- Some correlation of failed volume and slope stability, but not for low rising weakness plane angles
- Where to go from here with the model ?
  optimize model setup, study different slope scale properties and different geometries, analyse the kinetics of failure, stress inside the slope



Thank you for your attention !

If you like our research or have questions please come and talk to me in person or contact me via e-mail

marius.huber@univ-lorraine.fr .

This presentation participates in **OSPP**

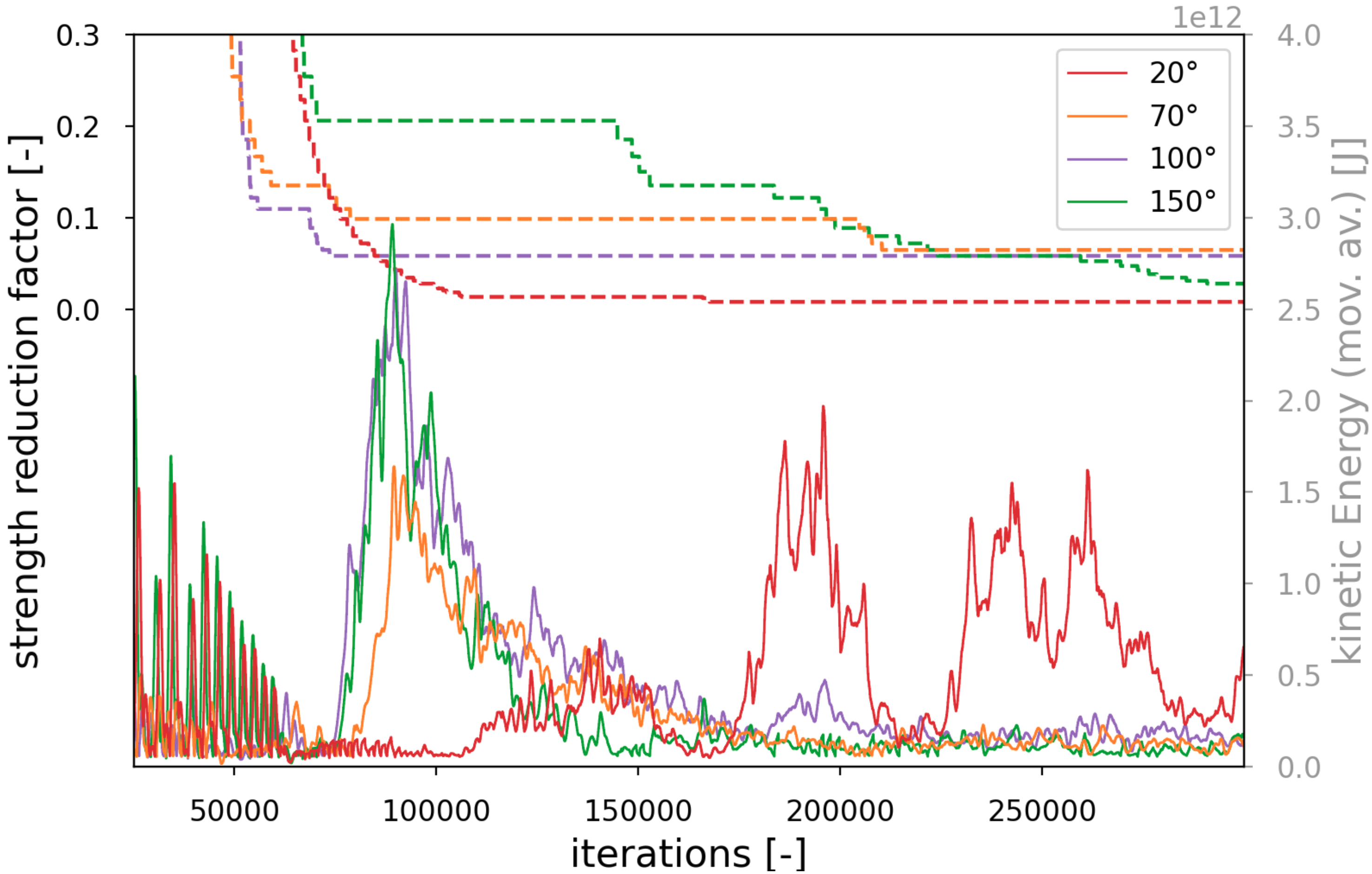
Outstanding Student & PhD candidate Presentation contest

I am looking for postdoc opportunities !

Results

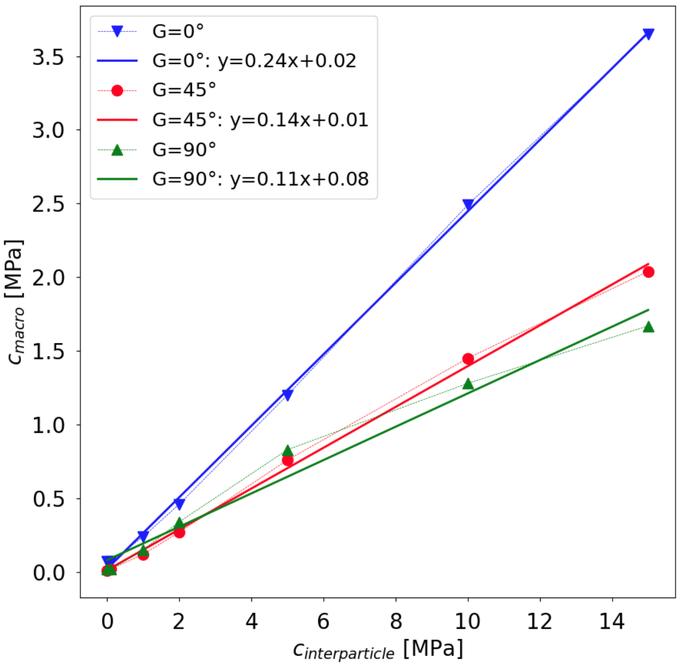
60° slope angle !!

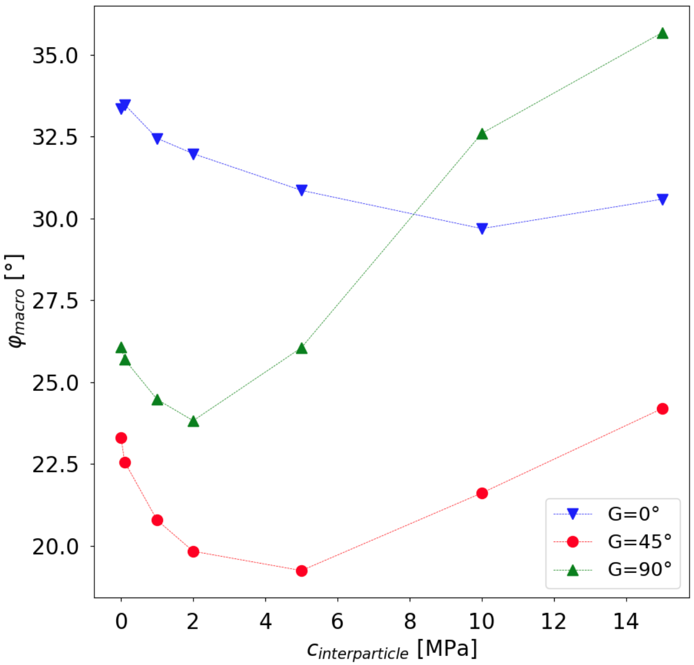
Kinetic Energy (moving average) of the two stability maxima and two stability minima (20°, 70°, 100°, 150°)



Emergent slope properties

Estimation of **emergent properties of the anisotropic slopes** at failure from inter-particle properties (triaxial testing)



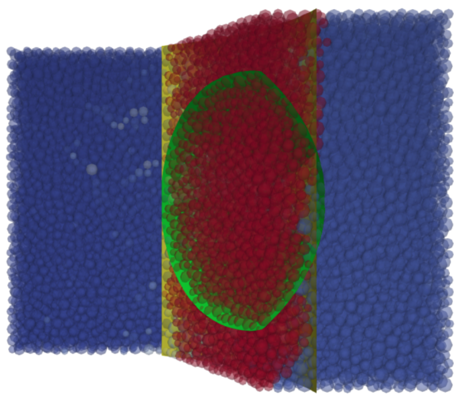


Work in progress

Initial validation of DEM

Validation of isotropic DEM with **analytical slope stability solution** provided by **Leshchinsky et al. (1985)** based on Limit Equilibrium Method (LEM)

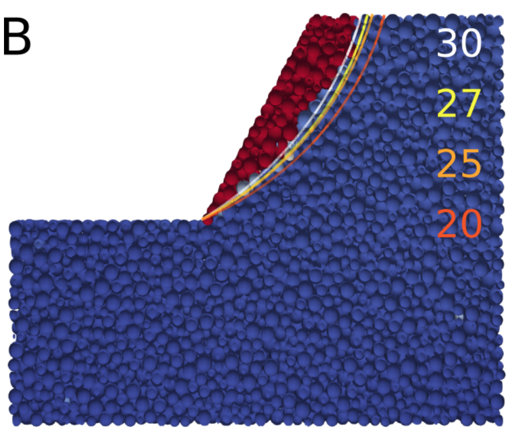
A



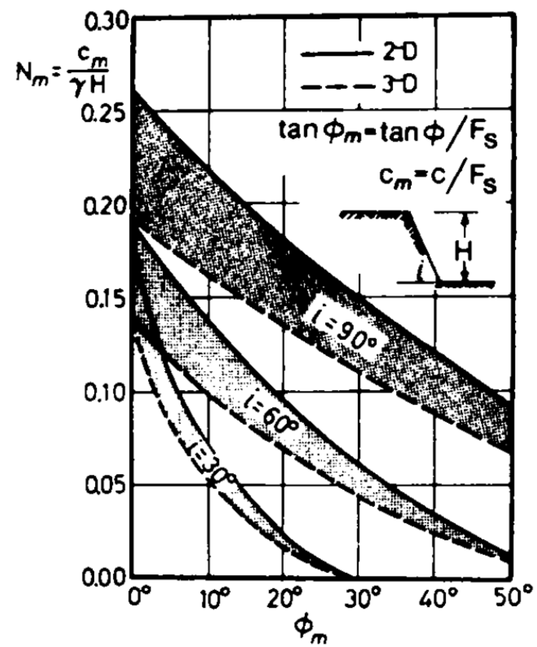
2D failure plain

3D failure plain

B



2D failure plains of four different friction angles



$N_m = c_m/\gamma H$

N_m = "stability number", normalized; c_m = normalized cohesion; γ = average unit weight of the material above the slip surface; H = slope height

References

Dinç, Ö., Scholtès, L., 2018. Discrete Analysis of Damage and Shear Banding in Argillaceous Rocks. Rock Mech Rock Eng 51, 1521–1538. https://doi.org/10.1007/s00603-017-1397-6

Giot, R., Granet, S., Faivre, M., Massoussi, N., Huang, J., 2018. A transversely isotropic thermo-poroelastic model for claystone: parameter identification and application to a 3D underground structure. Geomechanics and Geoengineering 13, 246–263. https://doi.org/10.1080/17486025.2018.1445874

Leshchinsky, D., Baker, R., Silver, M.L., 1985. Three dimensional analysis of slope stability. Int. J. Numer. Anal. Methods Geomech. 9, 199–223. https://doi.org/10.1002/nag.1610090302

Nova, R., 1980. The failure of transversely isotropic rocks in triaxial compression. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts 17, 325–332. https://doi.org/10.1016/0148-9062(80)90515-X

Smilauer, V., Angelidakis, V., Catalano, E., Caulk, R., Chareyre, B., Chèvremont, W., Dorofeenko, S., Duriez, J., Dyck, N., Elias, J., Er, B., Eulitz, A., Gladky, A., Guo, N., Jakob, C., Kneib, F., Kozicki, J., Marzougui, D., Maurin, R., Modenese, C., Pekmezi, G., Scholtès, L., Sibille, L., Stransky, J., Sweijen, T., Thoeni, K., Yuan, C., 2021. Yade documentation. The Yade Project. https://doi.org/10.5281/zenodo.5705394

Stead, D., Wolter, A., 2015. A critical review of rock slope failure mechanisms: The importance of structural geology. Journal of Structural Geology 74, 1–23. https://doi.org/10.1016/j.jsg.2015.02.002