# ALERT Geomaterials

**Alliance of laboratories in Europe for Research and Technology**
Aussois, 27/09 – 02/10, 2021

## 32nd ALERT Workshop / POSTER SESSION

*Booklet of abstracts*


**Editors: Nadia Benahmed**
**Antoine Wautier**
(INRAE, France)

# ALERT Geomaterials

The Alliance of Laboratories in Europe for Education, Research and Technology

# 32nd ALERT Workshop

# Poster Session

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Antoine Wautier

(INRAE, Aix-en-Provence – France)

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*Dear colleagues,*

*We are pleased to welcome you to Aussois and to our 32nd ALERT Workshop and School.*

*As always, it is an exciting time for us to continue to meet and bring together inspired people for fruitful days with interesting, stimulating discussions, exchange of knowledge and experience on Geomechanics. Presentations of recent advances offer the chance to get up-to-date and to remain at the cutting edge.*

*This year, the workshop has a particularly sweet taste since it is one of the first opportunities to meet in person after the pandemic and the cancellation of ALERT workshop on 2020. Because our way of interacting will be changed on the long term, this workshop is also the right place to discuss and question our way of sharing and teaching science. For this reason, we have included in the poster session, two posters as a foreword to discuss the issue of remote teaching and use of online content.*

*We would like to express our thanks to all of you who contributed to the success of this poster session!*

*We wish you a good workshop and school experience and a pleasant stay in Aussois (or elsewhere if you attend the workshop remotely)!*

*Kind regards,*

*Nadia Benahmed and Antoine Wautier.*

# Good and bad with virtual teaching

***Wolfgang Fellin***
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***Keywords:*** flipped classroom, R/exams online tests, online teaching

***Abstract***

The Covid-19 pandemic was a huge challenge for university teaching, e.g. (Daumiller et al. 2021). Almost all lectures at the University of Innsbruck were converted to online-only courses. In the first lock-down in spring, this was possible for my courses within 2 weeks, as the courses were already based on the flipped classroom concept on a flipped classroom approach (Lage, Platt, and Treglia 2000), which recently turned out to have a statistically significant advantage compared to traditional settings (Låg and Sæle 2019; Cheng, Ritzhaupt, and Antonenko 2019; Hassan and Othman 2021). A good learning management system (The OpenOlat learning platform), a virtual meeting software (BigBlueButton) and the tool R/exams for automated exams generation (Zeileis, Umlauf, and Leisch 2014) made this possible from a technical point of view. However, the total loss of physical encounters in purely virtual teaching stayed problematic.

I performed an online survey in 2021 among students who had participated in three of my courses: one bachelor course Fellin (2021a) and two master courses. The students missed the face-to-face contact with their fellow students and the teacher a lot (Figs. 1 and 2) and felt that the virtual meetings were only a weak substitute. The only real advantage of virtual teaching is flexibility in terms of time and location. Home office is also perceived as pleasant by some. The bachelor students rated the course much worse than the master students. One reason for that difference may be that the face-to-face classrooms of the bachelor course were replaced with voluntary virtual meetings (consultation hours), which were rarely visited by students, whereas the face-to-face classrooms of the master courses are just moved to weekly virtual meetings with group work in breakout rooms.

The survey and the personal experience revealed (Fellin 2021b): Courses based on a flipped classroom approach are suitable for online lectures. However, hybrid forms (e.g. blended learning) are highly preferable to online-only settings. If you were forced to teach in a purely virtual setting: keep in touch with students by regular meetings in virtual classrooms and use breakout rooms for working in small groups.

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### Acknowledgement

W. Fellin is supported by Le Pôle interdisciplinaire d'études françaises de l'Université d'Innsbruck (Frankreich-Schwerpunkt der Universität Innsbruck).

### Figures

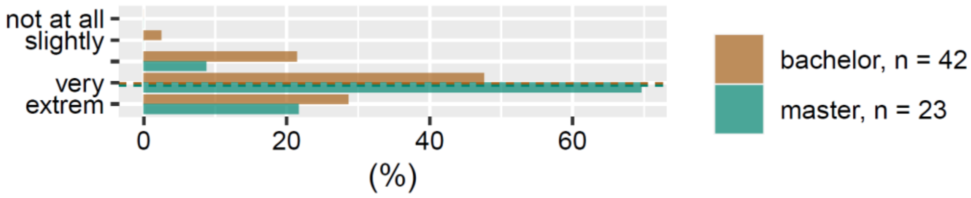


***Figure 1:*** *How much did you miss the face-to-face contact to your fellow student? 42 answers of 122 invited bachelor students and 23 answers 30 invited master students. The mean values are given as dashed line in the color of the group. This lines almost overlap.*

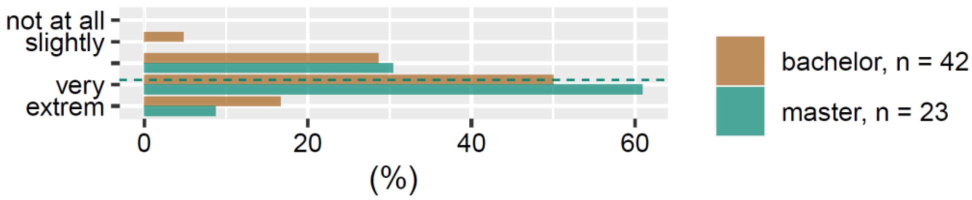


***Figure 2****: How much did you miss the face-to-face contact to the teacher?*

# ‘Animating Soil Models’ - Visualizations as teaching and learning material for constitutive modelling

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***Keywords***: open education, constitutive modelling, Hypoplasticity, Elastoplasticity

### *Abstract*

Constitutive modelling is a core subject in the field of computational geotechnics, as the quality of predictions made by finite element simulations depends on the quality of the used constitutive model. For many students, constitutive modelling in engineering education is perceived as an abstract and ’hard to grasp’ topic.

The here presented open education project *’Animating Soil Models’* aims to increase the understanding of constitutive modelling with the help of interactive graphics and animations by improving the visual aspect of teaching soil models. Amongst others, the following topics are visualized: yield surfaces, stress invariants, Critical State Soil Mechanics and some related models as the Modified Cam Clay model and clay hypoplasticity (*Mašín, 2013*).

The content of the project is shared under the open license CC BY as teaching and learning material: soilmodels.com/soilanim. The visualizations certainly do not replace studying the equations, computing or reading books. However, they can facilitate teaching and understanding concepts related to constitutive modelling.

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### *Acknowledgement*

Gertraud Medicus gratefully acknowledges financial support of the University of Innsbruck: ProLehre project, AURORA Challenge Domains. G. Medicus is further financed by the Austrian Science Fund (FWF) P 28934-N32. In addition, G. Medicus is supported by Le Pôle interdisciplinaire d’études françaises de l’Université d’Innsbruck (Frankreich-Schwerpunkt der Universität Innsbruck).

### *Figures*

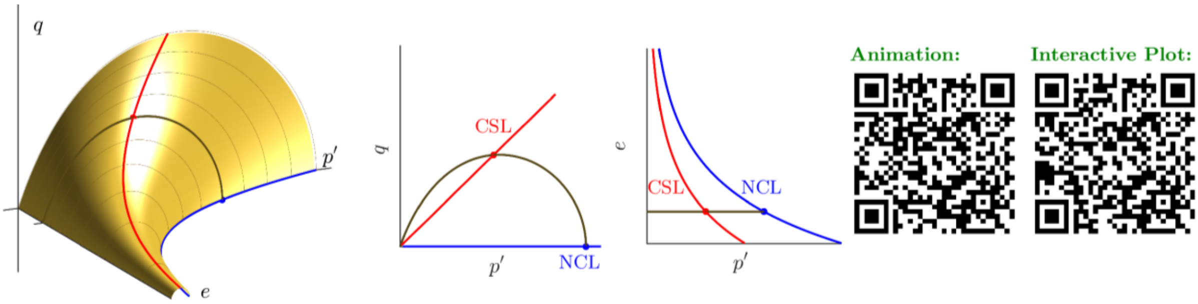


***Figure 1***: *3D view of NCL and CSL and Asymptotic State Boundary Surface of clay hypoplasticity (Mašín, 2013). A related animation and an interactive plot can be accessed via the QR codes.*

## *Table of contents*

# Comparison of two small-strain concepts: ISA and intergranular strain applied to barodesy

***Merita Tafili[1], Gertraud Medicus[2], Manuel Bode[2] & Wolfgang Fellin[2]***

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***Keywords***: constitutive modelling, small-strain, intergranular strain, ISA, barodesy


### *Abstract*

The intergranular strain concept (IGS, Niemunis & Herle, 1997) and the intergranular strain anisotropy formulation (ISA, Poblete et al. 2016) are state of the art extensions to describe small-strain effects.

In this work, barodesy (Medicus & Fellin, 2017) is enhanced with ISA to improve its predictions of the mechanical behaviour of soils at small-strain. The performance of the new model is compared with barodesy enhanced with IGS, by performing qualitative simulations as well as using experimental data. Thereby, the conceptual differences and similarities between ISA and IGS are discussed and some recommendations on the models' applicability are provided.

The main conceptual difference between ISA and IGS is the purely elastic strain range introduced by ISA. Furthermore, the used ISA formulation includes an additional state variable in order to reduce accumulation effects for cyclic loading with a larger number of repetitive cycles. However, for certain parameter values, the results of ISA and IGS are very similar: then for very small strain/stress cycles, also IGS provides a virtually vanishing stress or strain accumulation, even without a predefined purely elastic bubble (Tafili et al., 2021).


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### *Acknowledgement*

G. Medicus and M. Bode are financed by the Austrian Science Fund (FWF) P 28934-N32. G. Medicus and W. Fellin are supported by Le Pôle interdisciplinaire d'études françaises de l'Université d'Innsbruck (Frankreich-Schwerpunkt der Universität Innsbruck). M. Tafili acknowledges gratefully the financial support of the German Research Foundation (Deutsche Forschungsgemeinschaft DFG), Project TR 218-27-1.

***Figures***

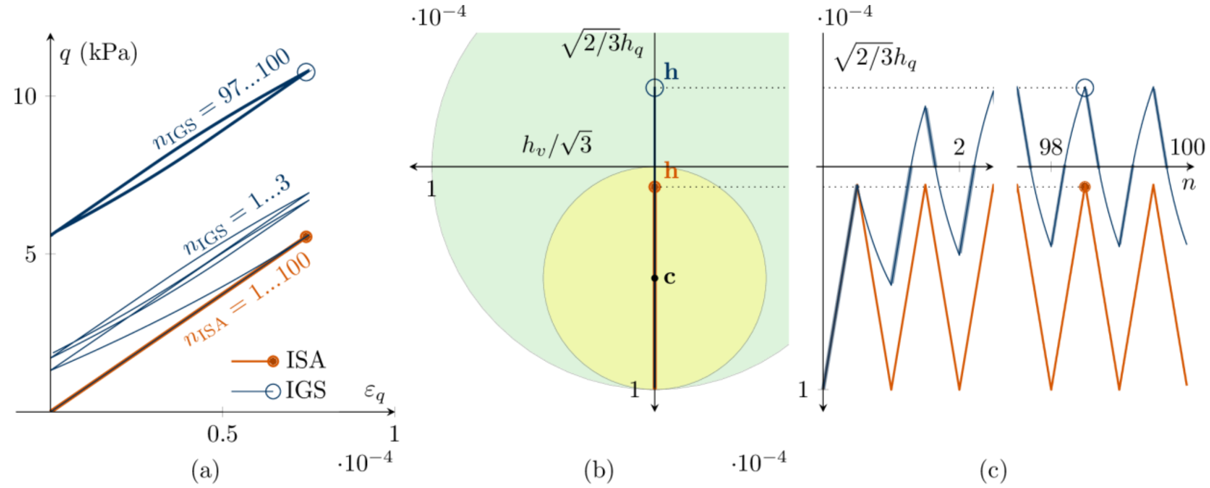


***Figure 1:*** *Undrained triaxial compression tests with 100 very small strain ($\Delta\varepsilon_q$=7.5 · $10^{-5}$) cycles. For barodesy with IGS, the bold line indicates elastic response, the thin line indicates transition from elasticity to barodesy. Barodesy with ISA behaves purely elastic. Figure from (Tafili et al., 2021)*

# Aggregate-size distribution using image analysis to investigate effects of pore-water chemistry and temperature on clay inter-particle forces

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***Keywords***: clay, sedimentations, inter-particle forces, image analysis

***Abstract***

Clay particles in suspension tend to come into contact and form aggregates. Physicochemical factors strongly influence the size of the aggregates as they affect the non-contact electrochemical forces arising between clay particles ([1]). Understanding particle association modes at the level of suspension may be the key to gain insight into the role of electrochemical forces driving clay macroscopic mechanical response.

Aggregate size can be investigated via the rate of sedimentation of aggregates in suspension ([2]) for the case where no dispersant is added to the clay suspension. Clay mineralogy, temperature and chemistry sedimentation fluid determine the mode of particle aggregation in suspension and thus the final sediment fabric. Studies on kaolin suspensions have shown that, by increasing the electrolyte concentration ([3]) and by decreasing the relative dielectric permittivity of the pore fluid ([4]), the size of clay flocs decreases, resulting in a longer sedimentation time and a more packed sediment fabric. Similarly, it has been observed that the final sediment obtained for alkaline solutions (high pore fluid pH) is around two times smaller in void ratio than the one obtained for acidic solutions ([5]).

In this research, sedimentation tests were performed to investigate modes of clay particle aggregation in different settling environment. Three main factors were analysed: the pH, the relative dielectric permittivity, and the temperature of the settling fluid.

A purely inferential image analysis technique is proposed to evaluate the aggregate size of the analysed suspensions. For each sedimentation tests, optical signals were captured by a Digital Single-Lens Reflex (DSLR) camera at regular intervals (see Figure 1) and the aggregate size distribution was computed by image analysis of the acquired 2D images.

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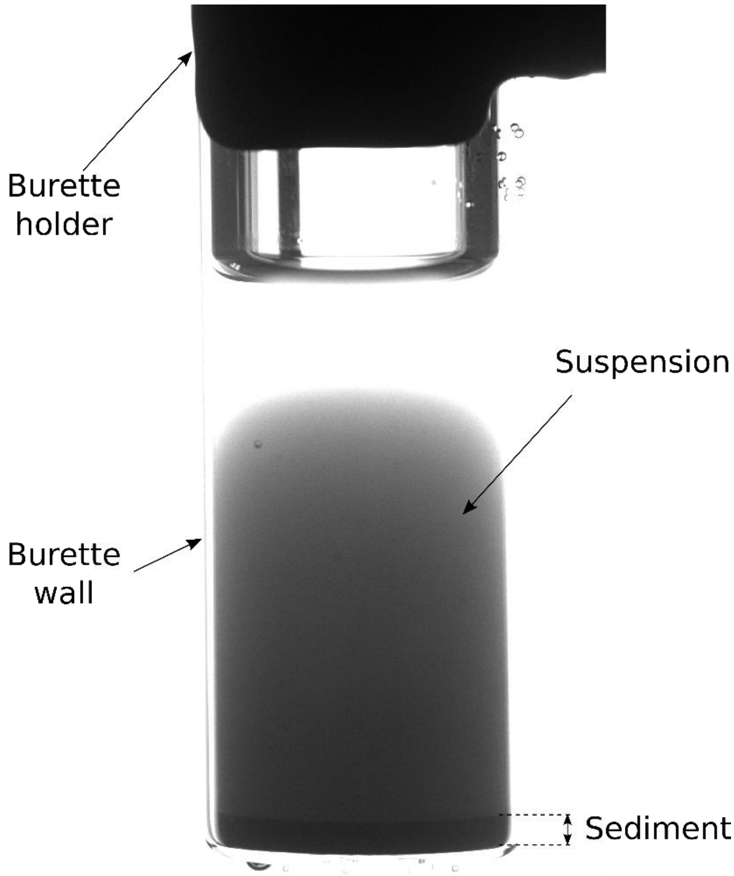


***Figure 1:*** *Optical signal captured by the DSLR camera after 17.5 hours from the beginning of the sedimentation test.*

# Microstructure-based modeling of snow mechanics, experimental evaluation on the cone penetration test

**Herny Clémence[1], Hagenmuller Pascal[1], Chambon Guillaume[2], Roulle Jacques[1], Peinke Isabel[1], Mede Tijan[2]**

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***Keywords***: snow; microstructure, DEM, tomography, CPT

### Abstract

Snow is a complex porous material existing on Earth close to its melting point, which makes it thermodynamically unstable and promotes a large variety of snow microstructural patterns. Although of primary importance for many applications such as avalanche forecasting, the link between snow mechanics and snow microstructure is still poorly understood. In particular, the failure mechanisms occurring at high shear rate (> $10^{-2}$ $s^{-1}$) during the release of an avalanche remain represented by very coarse empirical laws. In this brittle regime, the mechanical behaviour of snow is mainly controlled by bond failure/formation and grain rearrangements, which can be modelled by the discrete element method. Recent numerical developments based on 3D snow microstructures have provided new insights on the snow mechanical behaviour but lack of experimental evaluation so far. We present here an evaluation of these numerical models using experimental cone penetration test combining tomographic imaging and penetration strength measurements conducted in a cold room. On several centimetres snow samples spanning different snow types (recent snow, round grains, faceted crystals…), we measured the initial snow microstructure at a resolution of about 10 microns, performed a cone penetration test, and measured the deformed microstructure. The initial microstructure is used to feed the discrete element model reproducing the cone penetration test (Fig. 1) and the final microstructure is used to capture the deformation around the cone. We are performing a detailed comparison of numerical results with experimental measurements (Fig. 2) to better understand the link between the mechanical behaviour of snow and its microstructure. The cone penetration test implies a complex heterogeneous deformation field. Therefore, confrontation of numerical results to experimental measurements for this configuration gives strong insight on the validity of the DEM model, which could be further applied with different boundary conditions.

## *Figures*

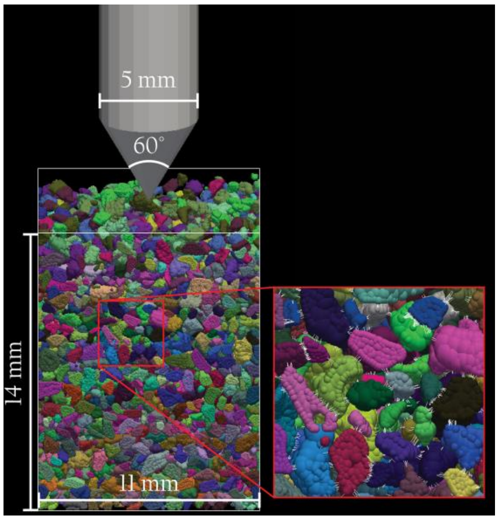


***Figure 1:*** *Visualization of the initial state of the DEM simulation of the Cone Penetration Test. The mesh is built from tomography images of a large rounded grain (RGlr) sample. Each grain (single color element) is represented by discrete spherical elements (mean radius = 0.1 mm) clumped in rigid aggregate. The white lines visible on the zoom are the cohesive interactions between spheres in contact. The sample is contained in a rigid box of dimensions 11 x 11 x 14 mm. The cone radius is 25 mm. The tip is moving downward at a constant velocity of 20 mm s-1. The forces applied on the tip while penetrating into the sample is recorded to compute force profiles at a resolution of 4 μm (Fig. 2).*

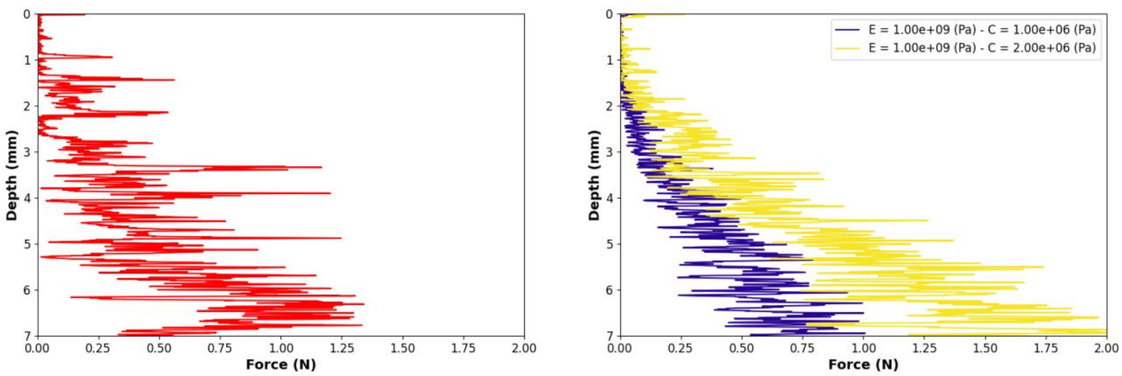


***Figure 2:*** *Comparison of force profiles obtained with experimental measurement (left panel, red curve) and numerical simulations (right panel, blue and yellow curves) of the Cone Penetration Test in snow sample (large rounded grain, RGlr). The depth 0 mm corresponds to the sample surface. The experimental profile has been acquired in a cold room with a SnowMicroPenetrometer. The physical parameters, Young's modulus (E) and cohesion (C), are tuned in the DEM simulations to match the experimental profile.*

# Experimental inspection of undrained Miner's rule on fine-grained soils under undrained cyclic conditions

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***Keywords***: cyclic loading, kaolin, Miner's rule, triaxial testing

### *Abstract*

For the development, improvement and calibration of constitutive models for fine-grained soils, different experimental databases on soils with different characteristics (e.g. plasticity, structure, mineralogical composition, among others) are necessary. This article comprises some relevant results of an extensive experimental investigation on Malaysian kaolin under monotonic and cyclic loading. In the tests, a wide range of initial conditions was varied in order to investigate their influence on the mechanical behavior of the kaolin. In particular, the influence of the initial stress ratio, deviator stress amplitude, drained cyclic preloading and sequence of packages of cycles with different deviator stress amplitudes has been investigated.

The so-called Miner's rule [1], states that the application of packages of cycles of different magnitudes in different sequences does not affect the final accumulation of strains. The validity of Miner's rule is convenient for the simplification of complex loading scenarios in simple groups of packages with constant loading amplitude in any sequence, as presented in Figure 1. However, the experimental results suggest that if the packages of cycles are applied under undrained cyclic conditions, its sequence does affect the final accumulation of strains and pore water pressure, as presented in presented in Figure 2. To account for the pore water pressure accumulation, a Modified Steward's Approach (MSA) has been proposed to estimate the accumulated strains and pore water pressures based on known results of single-amplitude cyclic tests (see Figure 3). Readers are referred to [2] for more details on the experimental database and the proposed approach.

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## *Figures*

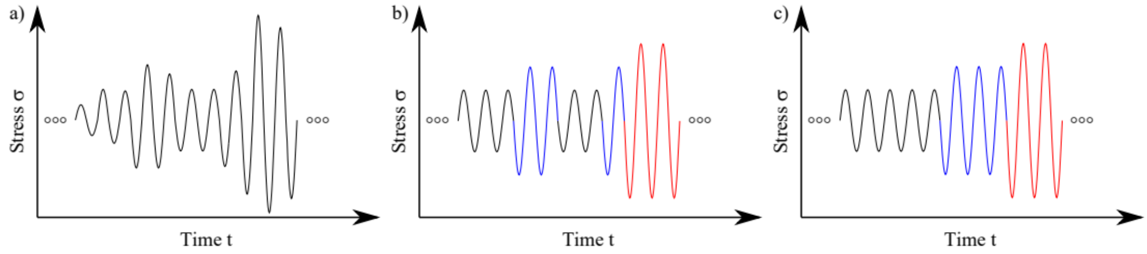


***Figure 1:*** *Typical simplification of complex loading scenarios based on the Miner's rule postulate*

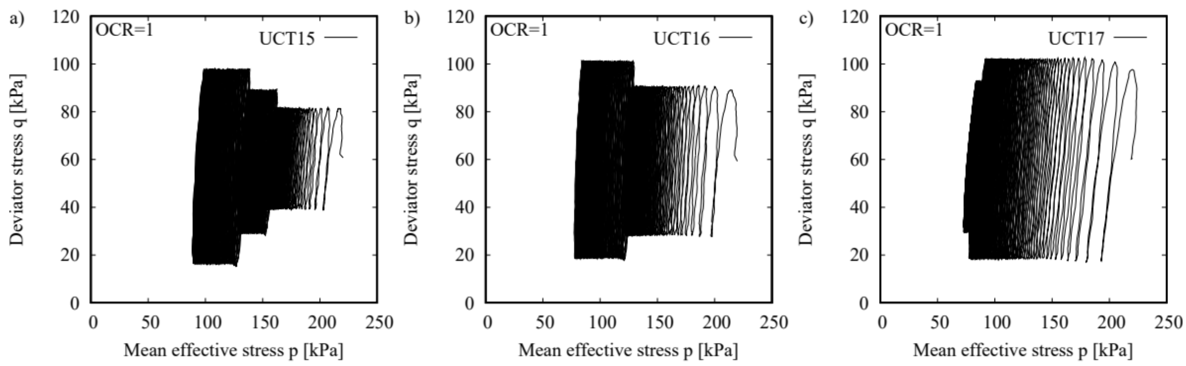


***Figure 2:*** *Typical results of undrained cyclic triaxial tests with packages of cycles in different sequences*

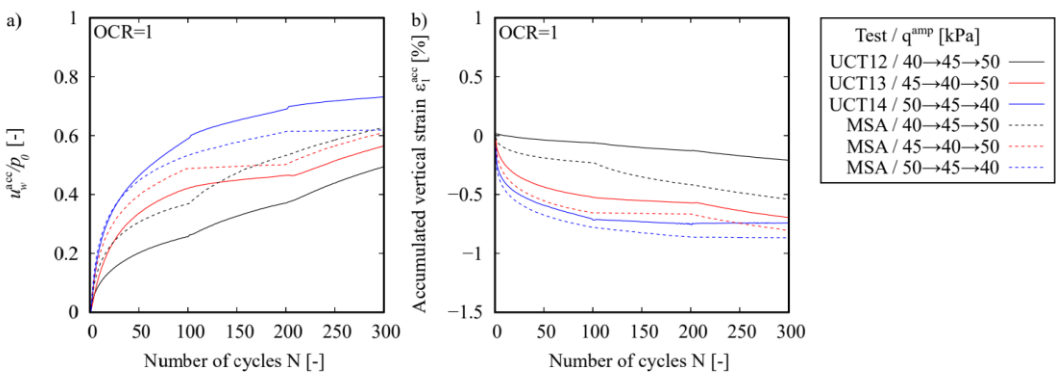


***Figure 3:*** *Comparison between tests UCT12-UCT14 with packages of undrained cycles and the predictions using the Modified Stewart's Approach (MSA) based on single amplitude tests: a) normalized accumulated pore water pressure $u_w^{acc}/p_0$ against the number of cycles N, b) accumulated vertical strain $\varepsilon_1^{acc}$ against the number of cycles N*

# Thermodynamics-based Neural Networks: a general framework for modeling microstructured materials displaying path-dependency

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***Keywords***: Deep Learning; Artificial Neural Networks; Thermodynamics; Constitutive model; Multiscale.

### *Abstract*

Many problems in science and engineering involve complex material systems (e.g. heterogeneous and multiscale in nature) displaying path-dependent behaviors, such as geo-, bio-, and meta-materials. Existing constitutive laws can account for several of these phenomena, but may fail to capture response of complex material systems, limiting the possible technological applications. A remedy is to rely on micro-mechanical simulations and multiscale approaches (see e.g. Nitka et al, 2011). Nevertheless, the calculation cost of these methods is prohibitive for real scale (industrial) applications.

A promising solution is to rely on data-driven approaches based on Artificial Intelligence and, in particular, Deep Learning. During the last decades, these techniques have been extensively used to retrieve the constitutive behavior of materials (see e.g. Ghaboussi et al. 1991; Mozaffar et al. 2019; Huang et al. 2020). However, the main drawbacks of such approaches are the lack of a rigorous frame based on the laws of physics and the generalization to complex materials.

Here, we propose new data-driven, physics-based, deep networks, which we define as Thermodynamics-based Artificial Neural Networks (TANN), see Masi et al. 2021a,b.

Our approach integrate, for the first time, thermodynamics-aware dimensionality reduction techniques and thermodynamics-based deep networks to identify, in an autonomous way, the constitutive laws of inelastic materials with microstructure. The physic framework of TANN results in a reduced need of large data-sets, high-fidelity, physically consistent predictions, and robustness.

The advantages of TANN with respect to state-of-the-art approaches and their performances are presented via several applications both at the microscopic and macroscopic scale.

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# Rock strength evaluation on a coastal cliff by infrared thermography

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***Keywords***: compressive strength, infrared thermography, rebound hammer, cooling rate index

### *Abstract*

The direct acquisition of geomechanical data in the field is often made difficult by the inaccessibility of the rock slopes, especially on coastal cliffs. Therefore, remote sensing approaches have become extensively utilised in research. In particular, InfraRed Thermography (IRT) has proven useful for mechanical characterisations, including in slope stability analysis (Melis et al., 2020). Strength is a fundamental parameter of rock masses that can be used to empirically estimate a number of properties and predict the likelihood of instability phenomena (Bieniawski, 1989).

After a detailed survey on naturally heated granitoids and phylonian rocks in a coastal cliff in southeast Sardinia, Italy, characterised by different degrees of fracturing (Figure 1), we propose a procedure for the evaluation of the rock strength through remote sensing analysis by studying the cooling behaviour of rock blocks during a 24-hour period (Loche et al., 2021).

The results show that the cooling trend of the rock blocks can be related with rock strength values via a cooling rate index (CRI). The latter can be used to obtain quantitative strength predictions through regression analysis (Pappalardo et al., 2016; Mineo and Pappalardo, 2016). A linear correlation between CRI and rock strength is pointed out by the analysis, which is particularly strong during the first five hours after the temperature peak ($CRI_{5h}$; Figure 2; Loche et al., 2021).

The analysis suggests the applicability of IRT techniques at various spatial scales, highlighting the possibility to characterise the strength of unreachable blocks using repeated flights of a drone equipped with a thermal camera. Further validations are needed in different settings and geomaterials to explore multi-variate correlations applicable over larger areas and support the formulation / validation of thermo-hydro-mechanical models.

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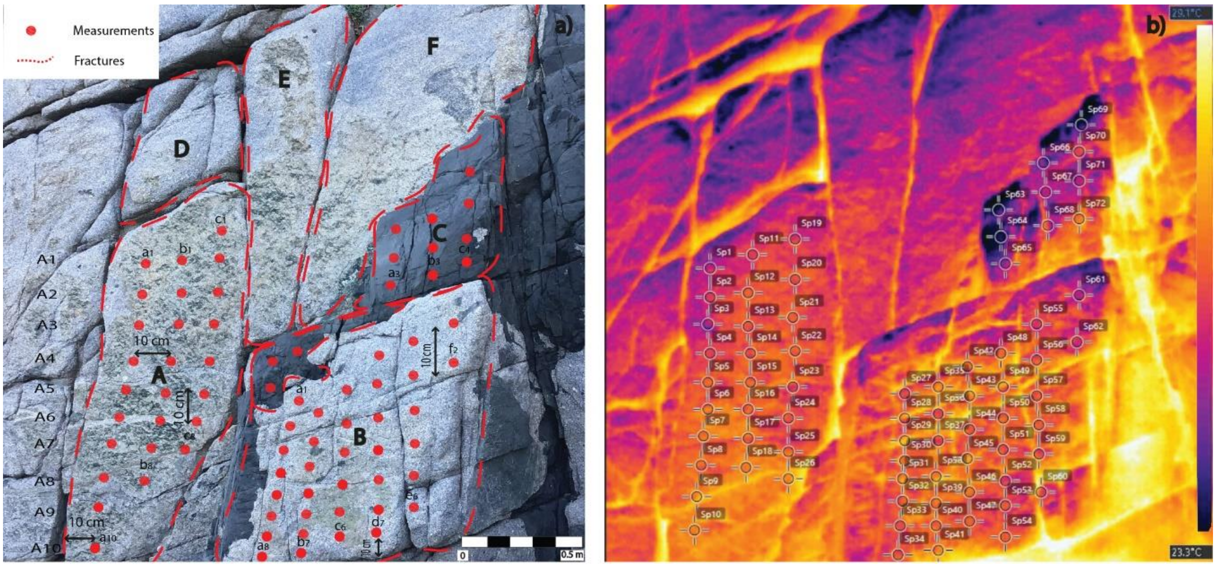


***Figure 1 :*** *(a) Acquisition scheme in the field where each point corresponds to 10 measurements through Schmidt hammer test; (b) in FLIR Tools software thermograms recorded at midnight where each point corresponds to a spot measurement (Loche et al., 2021).*

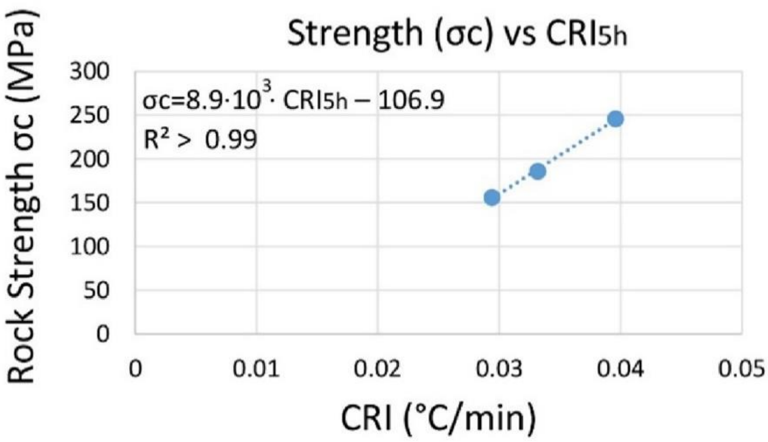


***Figure 2 :*** *Linear regression analysis between rock strength (σc) and CRI5h. The three dots represent the different blocks A, B and C in Figure 1 (mod. from Loche et al., 2021).*

# Exploring the role of Land Surface Temperature on post-earthquake landslide patterns

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***Keywords***: land surface temperature, thermo-mechanical coupling, controlling factor, landslide.

### *Abstract*

The direct role of temperature on landslide patterns and trends has not been investigated at a regional scale thus far (Reichenbach et al., 2018), even though some cases of temperature-related landslide activity have been reported (e.g., Shibasaki et al., 2016), and numerous laboratory results highlighted important thermo-hydro-mechanical effects in a variety of geomaterials (e.g., Hueckel and Baldi, 1990; Villar and Lloret, 2004; Romero et al., 2005).

Here, we propose a landslide susceptibility analysis based on remotely-sensed land surface temperature (LST) data, available in Google Earth Engine (Ermida et al., 2020), which we apply on a multi-temporal landslide inventory (2008–2015) covering the epicentral area of the $M_w$ 7.9 Wenchuan earthquake in China (Fan et al., 2018). We use a generalised additive model to explore landslide susceptibility through a nonparametric smoothing function (Petschko et al., 2014) applied to a slope unit (SU) based spatial subdivision (Alvioli et al., 2016). We opt for a minimalistic set of covariates: LST, peak ground acceleration (PGA), and SU morphological characteristics. We exclude information on lithology and precipitation, even though their control is undeniable, because they would provide little constraint to the model owing to their small spatial variation at the available data resolution.

Our results show a reasonable model performance despite the small set of covariates, with the susceptibility decreasing with time as the post-earthquake landslide activity fades (Figure 1). Notably, while the significance of the morphological covariates remains essentially unchanged, that of PGA and LST evolves with time: PGA dominates the coseismic and early-postseismic picture whereas the role of LST progressively emerges as the landscape heals (Figure 2).

Our study suggests that LST could be used to capture possible thermo-hydro-mechanical controls on landslides at a large scale. However, further study is needed to confirm our hypothesis in other climates, lithologies, and landscapes, also in non-seismic regions.

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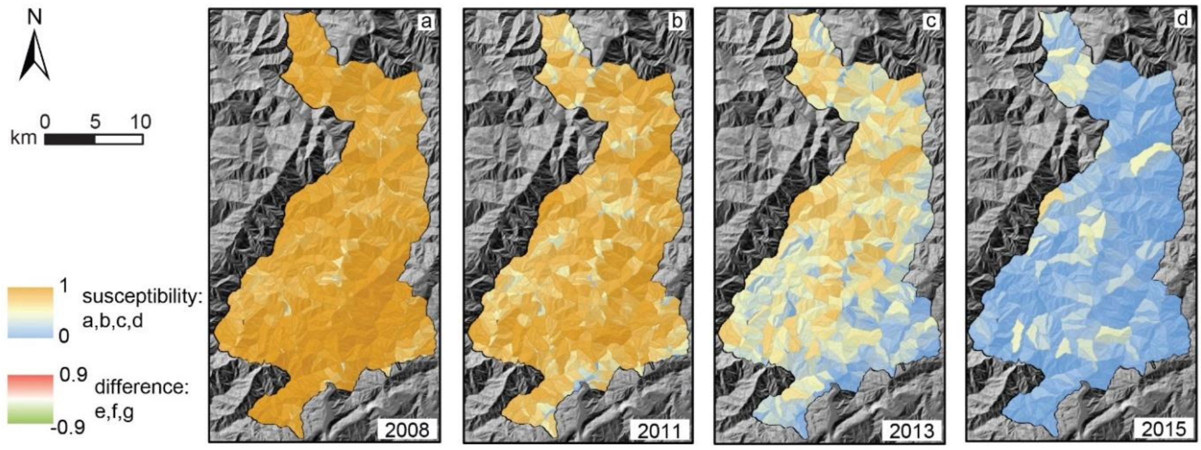


***Figure 1 :*** *Landslide susceptibility maps across the years (a–d) in the Wenchuan earthquake epicentral area.*

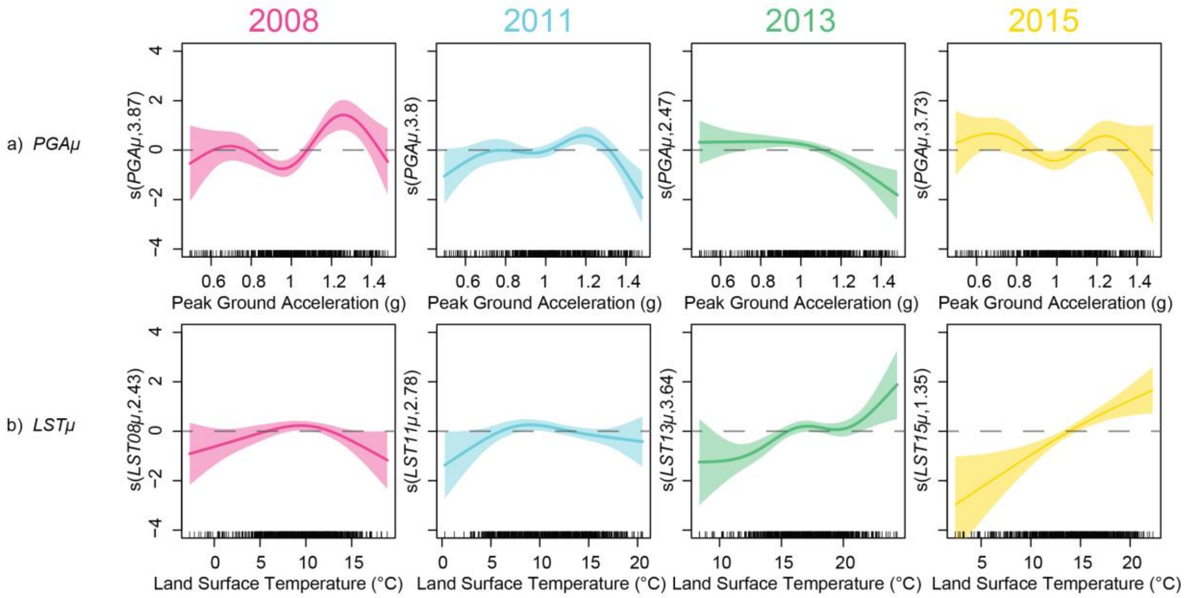


***Figure 2 :*** *Variable effects of (a) PGA and (b) LST displayed with confidence bands of 95% during the years.*

# Ship Wave induced Excess Pore Water Pressure in River Beds and Banks – An Investigation on Silty Sands

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***Keywords***: bank protection, excess pore water pressure, silty sands, riverbed, wave loading

### *Abstract*

Passing ships in navigable rivers and canals lead to hydraulic loads on the river banks and bed. Impacts of ship induced waves and water-level drawdown can lead to damage, which should be avoided both for economically and safety reasons. Therefore, bank protection measures like rip-rap are designed, regularly checked and improved. Reason for the slope destabilization and a possible trigger for e.g. near surface sliding is, among others, the excess pore water pressure in the subsoil beneath the bank protection. With large-scale model tests in the alternating flow apparatus (Figure 1), the processes that take place in quasi-saturated sediments under the described hydraulic conditions, can be investigated. Quasi-saturated sediment samples (approx. 88 – 95 % water saturation) can be observed under pressure changes representing the ship induced waves. The soil sample is hermetically sealed, approximately 80 cm high and has a diameter of 30 cm. The test cell containing the sample is connected to two pressure vessels, which generate the pressure changes.

In the past, experiments on the origin of these excess pore water pressures in fine sands have been conducted (Ewers 2016). These tests showed on which parameters the generation of excess pore water pressure depends on and that these parameters can be determined in the alternating flow apparatus (e.g. permeability, degree of saturation, porosity, descend speed of waves). Now, further tests were carried out, using various silty-sand mixtures (from fine sand to sand with up to 20 % silt) and wave characteristics that occur in navigable rivers and canals (Figure 2). The results of the tests will be presented and the strong dependence on the hydraulic permeability of the soil and the wave characteristics (e.g. drawdown velocity) will be highlighted.

Further insights into the development of excess pore water pressure for the sand-silt mixtures are still to be investigated. Based on the tests, future work will be to check procedures and assumptions as used for the bank protection design base in Germany. Therefore, the test results will be used to validate analytical and numerical models.

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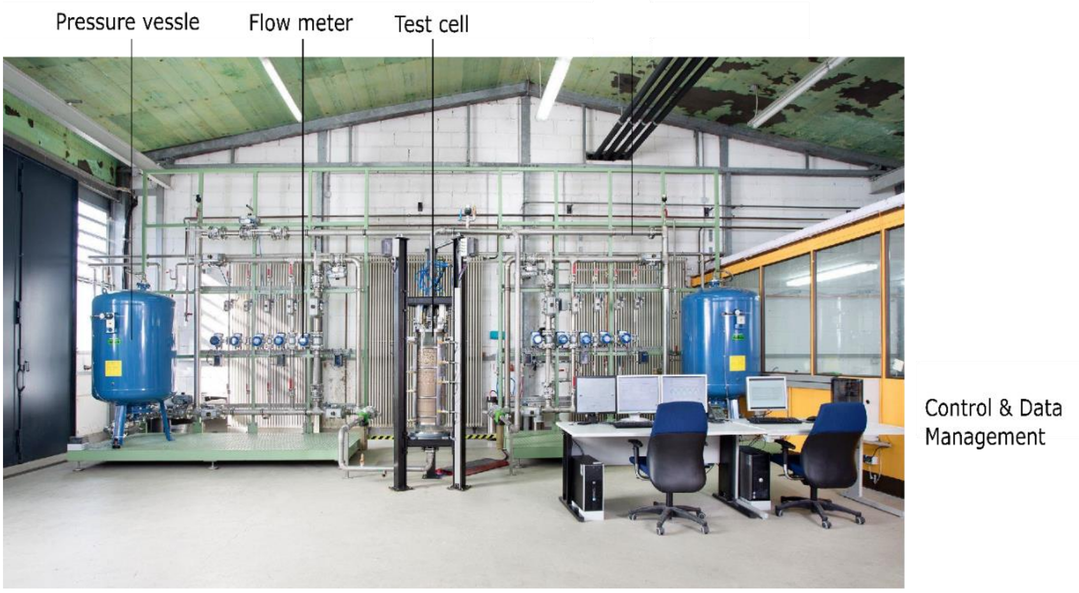


***Figure 1:*** *Alternating Flow Apparatus with test cell, pressure vessels and flow meters*

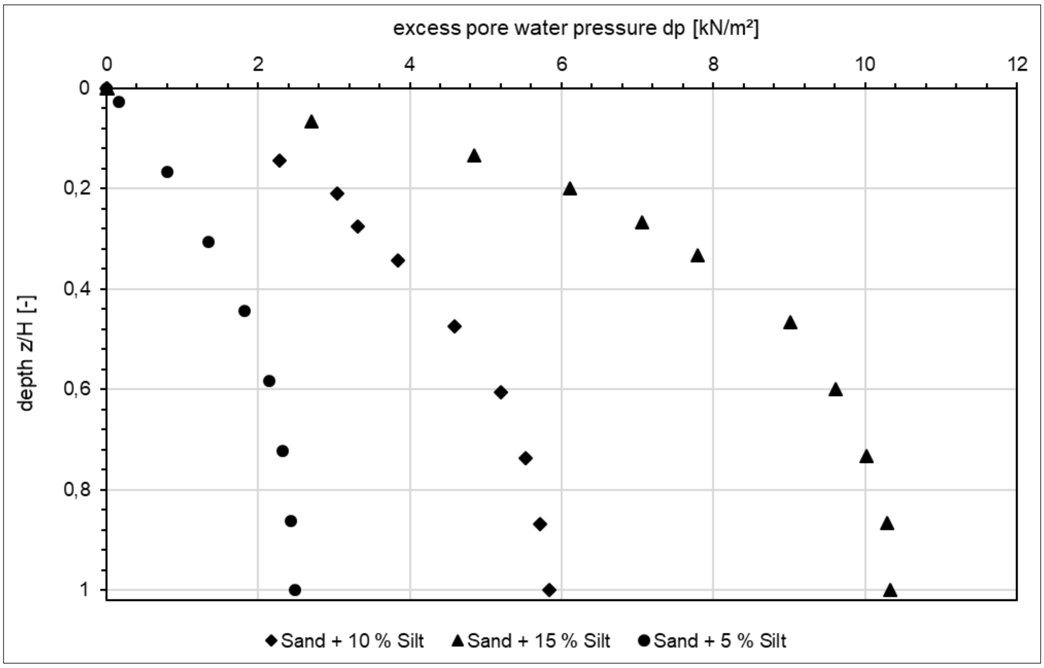


***Figure 2:*** *Excess pore water pressure responses to a wave (1,0 m in 55 s) in sands with various silt admixtures.*

# The geotechnical analysis of a subaerial landslide in Taan Fiord, Alaska

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***Keywords***: subaerial landslide, 2D limit equilibrium method, triggering factor

***Abstract***

Stability analysis for natural slopes under complicated geological conditions is still an appealing and challenging topic in the field of geotechnical engineering. On 17 October 2015, a large-scale subaerial landslide event occurred in Taan Fiord, Alaska, which released about 150 to 180 million tons [2,3,5] of rock entering the water body and triggering a tsunami with a runup up to 193 m, see Figure 1. The total volume involved in the final collapse is estimated by Franco et al. [1] to be approximately 50 Mm$^3$. The maximum depth of the sliding surface is around 100 m.

No one observed this event directly. Although some field surveys have been conducted and some related research works have been performed [2-5], the triggering mechanism of this landslide is still not finally elucidated. The geotechnical parameters (e.g. soil cohesion or friction angle) are unavailable for the slope, which brings a huge challenge for geotechnical analysis. As the surface of this slope is severely affected by weathering, its strength parameters should be close to the parameters of weathered sandstone or mudstone.

This contribution aims to simulate the possible evolution of this mountainous slope until the collapse and to analyze the possible triggering factors of this landslide event from a perspective of geotechnical engineering so that a deeper understanding of this large landslide event can be gained. We employ a 2D limit equilibrium method in this study to calculate the factor of safety and compare the location of the associated sliding surface with the assumed actual location when this landslide occurred. The calculation results reflect the evolution of this slope collapse, see Figure 2.

In this case study, past earthquakes very likely influenced the stability of this slope and enhanced the formation of a shear zone with weakened material. The glacial retreat in combination with rainfall before this landslide event is likely to be the most significant direct triggering factor for this slope failure along the predefined shear zone. This study also illustrates the applicability of a 2D limit equilibrium analysis in the investigation of large-scale slope stability under complex conditions.

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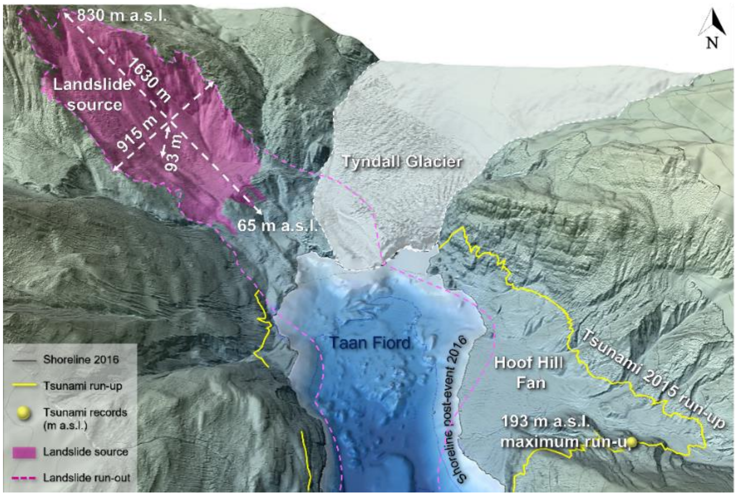


***Figure 1 :*** *Landslide source and corresponding impact area (modified from Franco et al. [1]).*

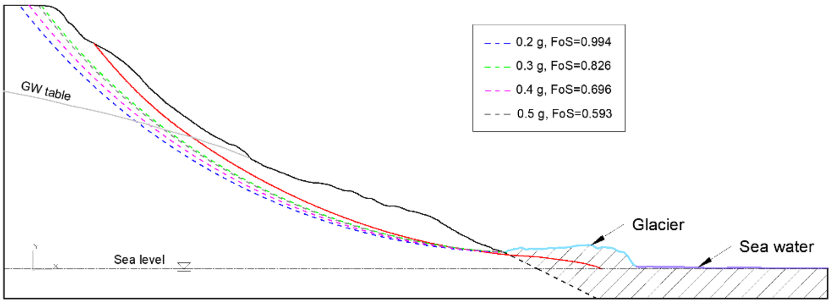


***Figure 2 :*** *Sliding surfaces in intact sandstone under different seismic acceleration conditions with Mohr-Coulomb failure criterion obtained by 2D limit equilibrium method compared to the geologically assumed shear zone with weaker material before the final slope failure (red line).*

## Acknowledgement


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# Immersed granular column collapse: role of the grain size distribution on the deposit runout

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***Keywords***: Polydispersity, Granular column, immersed

### *Abstract*

The granular column collapse is a simplified version of flows occurring in highly varying scales, ranging from natural debris flows to industrial handling purposes [1, 2]. A characteristic among them is their occasional submergence in a viscous fluid, resulting in a strong grain-fluid interaction. This interaction is amplified in the presence of particles of different sizes, a property termed polydispersity [3, 4, 5]. This work studies the effect of polydispersity in the runout of dry and immersed granular columns, simulating a series of two-dimensional granular columns. We study granular systems with different grain size distributions (GSD), varying the ratio between the biggest and smallest particle between $\lambda$ = [1.2: 19]. We show that the collapse mechanism and duration strongly depend on polydispersity in immersed cases (see Fig. 1(a)), but they are independent of polydispersity for dry cases. Increasing polydispersity reduces the collapse velocity (U) and the final runout ($L_f$) of immersed cases [6].

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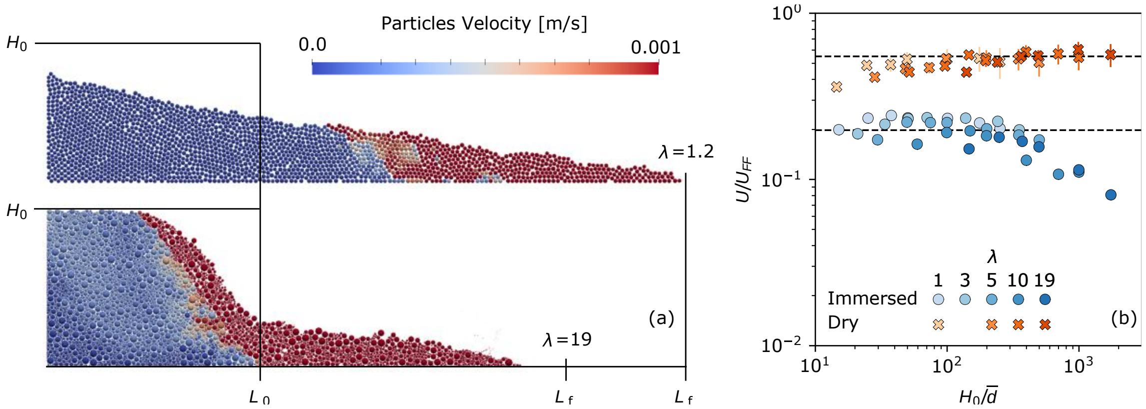


***Figure 1:*** *Snapshot of immersed column collapse with different GSD (top and bottom have $\lambda = 1.2$ and $\lambda = 19$, respectively) for the same instant (a). Variation of the collapse velocity (U) normalized by the characteristic free fall velocity ($U_{FF}$) as a function of the ratio between $H_0$ and the median particle diameter $\overline{d}$ (b)*

# The release of elastic unloading waves in nonlinear soil

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***Keywords***: wave propagation, finite element modelling, advanced constitutive modelling, high frequency motion, shear stack experiments

## *Abstract*

High frequency motion is often observed in free field response of soil in experimental works in laminar boxes even if simple sinusoidal input motions are applied at base of the soil specimen (e.g. Kutter et al., 2019). This high frequency motion is often attributed to the imperfections of experimental setups (e.g. Brennan et al., 2005). On the other hand, the most recent numerical studies (Kowalczyk, 2020; Kowalczyk & Gajo, 2021) suggest that the origin of high frequency motion observed in free field response can be a result of the release of elastic unloading waves in nonlinear soil. This poster will present introductory evidence to such a novel way of thinking regarding wave propagation in nonlinear hysteretic material. In detail, the numerical results comprise of using simplified and advanced constitutive approaches. The latter, represented by the most updated version of the Severn-Trent model (Gajo, 2010), are compared with relevant experimental data from the past (e.g. Durante, 2015) in terms of measured and computed horizontal accelerations (example on Figure 1) and evaluated corresponding spectral responses (example on Figure 2) for harmonic input motions. In addition, a part of the numerical computations focuses also on scaled earthquake input motions, soil-structure interaction and discusses the relevance of the findings on soil elastic waves on real earthquakes and structural response.

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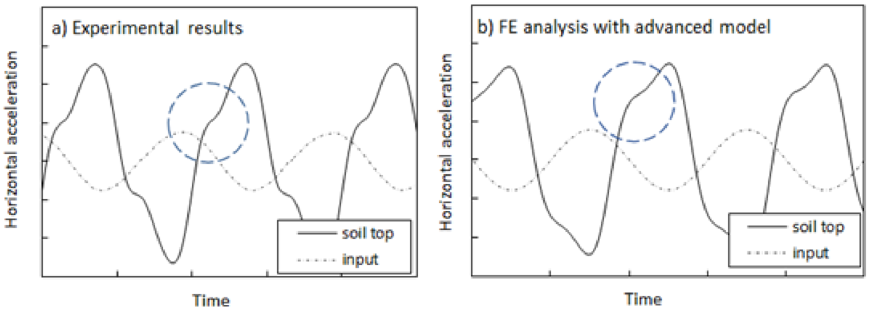


***Figure 1 :*** *Horizontal acceleration in free field: a) measured in experiment, b) computed in numerical study (presence of high frequency motion highlighted in dotted circles).*

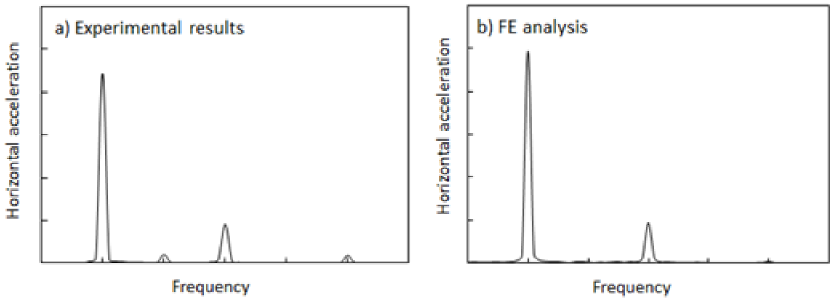


***Figure 2 :*** *Corresponding spectral response at soil top evaluated from: a) experimental data, b) numerical study.*

# From continuum to fractured quasi-fragile matters: modelling high compression with particle-based method

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***Keywords***: Discrete Element Method, long-range forces/horizon, particle bonding, oedometer test, highly porous geometry

***Abstract***

This work consists of a numerical development of particle-based model applicable to a continuum material undergoing mechanical failure. The model has been designed for an industrial application dedicated to the perforated bricks designed in a way that these perforations, of various positions and geometries, generate a highly compressible structure ( Figure 1). Such material with void is studied by Andra (the French agency of nuclear waste management) in the framework of its research and technological demonstration program in order to develop compressible structures.

The main challenge in designing the model comes from the globally changing characteristics at different damage levels. Under compression, the material is first elastically loaded until damage occurs in the form of localized micro- and macro-cracking. When the network of cracks develops enough to subdivide the brick into smaller blocks, the pockets of void gradually collapse, leading to the formation of an assembly of distinct units. Most of the modelling needs could be successfully met using the continuum method known as Peridynamics [1]. However, it is also necessary to handle the detection of newly occurring contacts. Thus, the numerical model was built upon Discrete Element Method [2] with some additional features borrowed from Peridynamics.

Due to a particle bonding technique, the model is capable to represent the continuum characteristics as well as its fracture process and the development of the complete network of cracks up to the fragmentation into pieces. The 2D representation of the material is essentially a disc packing as shown in Figure 1, and the constituent discs are bonded through cohesive centre-to-centre bonds. Those links can appear within a finite zone of interaction, referred to as a horizon – a concept clearly inspired by the Peridynamics. Horizon must be of a suitable size to provide the discs to interact with not only physical neighbours but also with the disks neighbouring in a long-range. Thanks to the occurrence of long-range bonding forces, the model avoids the local physical behaviour, and thus, make this discrete model more appropriate for homogeneous-like materials (e.g. ceramic or concrete). Horizon appears in the model as a parameter in addition to classic DEM parameters. The interactions involved in the closure of cracks or between the distinct blocks of quasi-fragile material are operated by the frictional contacts acting uniquely in the short distance, *i.e.*, between the adjacent neighbours.

Seeking the understanding of the model as well as its appropriate calibration, an extensive and prolific sensitivity analysis has been conducted addressing the influence of numerous

parameters. Those study included also the energy damping strategies as well as the variability of the microstructure. Essentially, the numerical model was applied to actual concrete structures previously tested in the experiments (Figure 2). The numerical campaign focused uniquely on oedometeric compression. Figure 3 presents an example of compression curves for one of the considered brick structures. This numerical investigation of the influence of the void distribution and size served Andra's objective to estimate easier the perforation's geometry of the bricks suitable for their needs.

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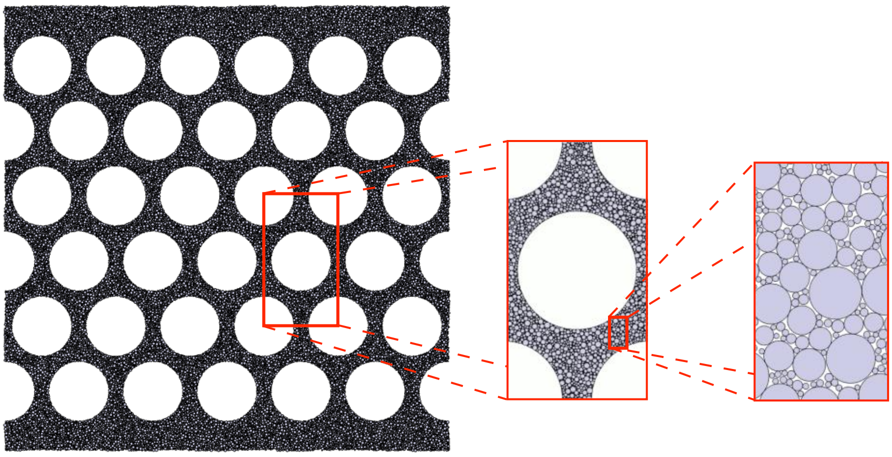

***Figure 1 :*** *Tested material. Representation of the bulk.*

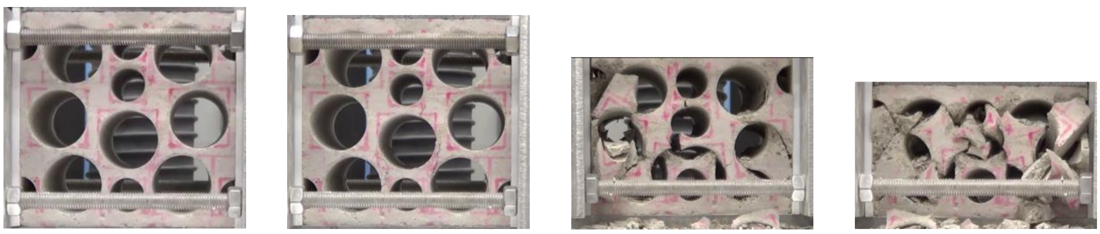

***Figure 2 :*** *Oedometer test on a block (Andra VAP solution) conducted by LamCube laboratory (Lille).*

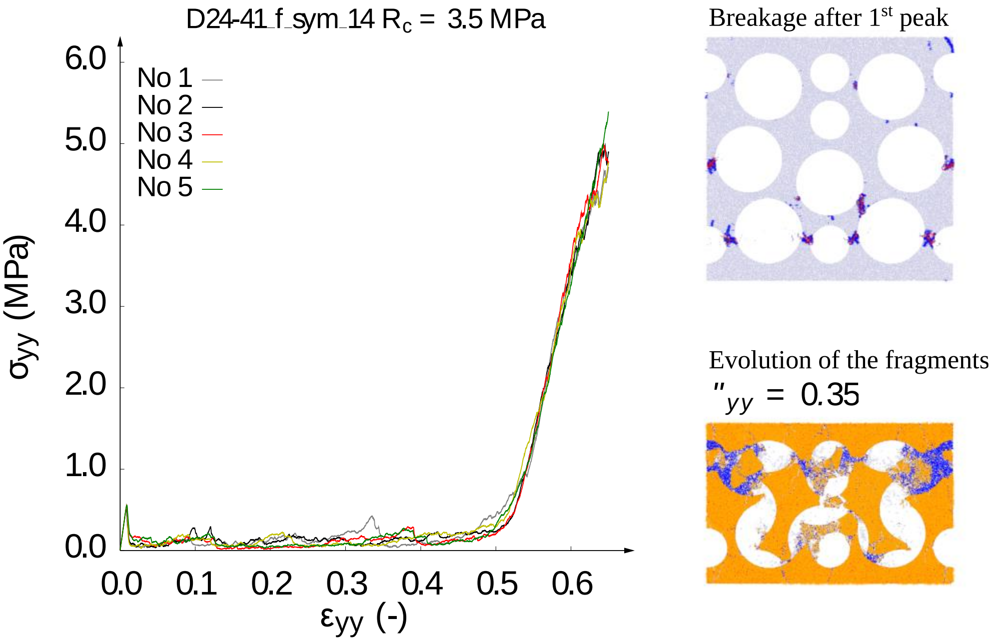


***Figure 3 :*** *Set of mechanical responses to oedometric compression of the brittle perforated brick (left). Breakage pattern for the primary pore collapse and fragmentation at the advanced compression state (right).*

# Sand flows within a split-bottom Couette cell: formation of radial heaps

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***Keywords***: Couette cell, angular particles, heap.

### Abstract

In a split-bottom Couette cell, it is possible to study steady flows of granular materials [1]. During shear, grains move in collective flow fields that form a heap on the free-surface [2, 3]. We study the formation of radial heaps with sand, exploring flows in a wide range of inertia. The height profile that captures the heap morphology is measured with digital image analysis and is linked with the flow velocity field. The heap morphology is amplified by the flow inertia, with a partial collapse when the cell comes to a halt. Our results complement the observation of free-surface deformations of flows of non-spherical grains [5] and provide a reference for the formation of natural levees in natural granular flows.

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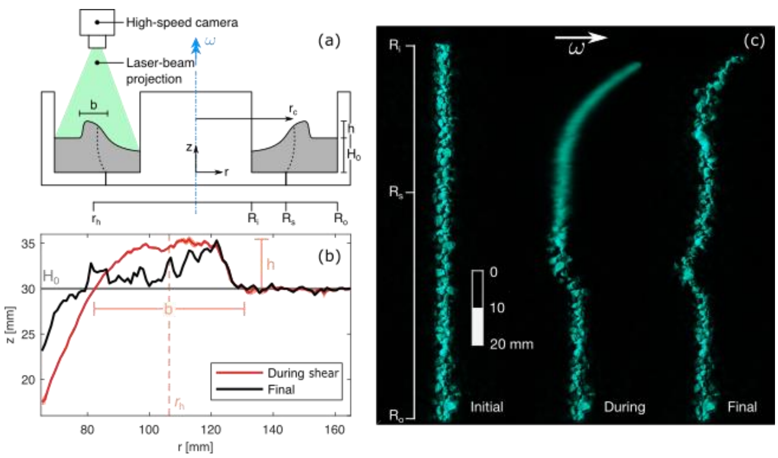


***Figure 1:*** *Sketch representation of the experimental set-up (a). Height profile of the sand flow during and after shear (b). Digital images of the laser-beam projection over the sand before, during and after shear (c). Adapted from [4].*

# Formulation and applications of a modified Cam-Clay model, with nonlinear deviatoric hardening

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***Keywords***: granular geomaterials, critical state soil models, generalized standard materials, modified Cam-Clay, nonlinear hardening.

### *Abstract*

The analysis of soil materials represents a major interest in the safety evaluations of engineering structures. One seeks to characterize their experimental behavior and to use finite element simulations to evaluate the response of geotechnical structures up to the ruin, for instance to assess the settlement under static or seismic loads. As a result, advances on both theoretical and numerical levels are required to propose efficient and numerically robust models of geomaterials.

For the class of granular geomaterials, we propose to establish a new formulation based on the thermodynamics of irreversible processes. We rely on the modified Cam-Clay model [1] (MCC) describing a parametrization of hardening or softening with the evolution of the volumetric plastic strain. We propose an enrichment of the MCC model through the introduction of a nonlinear deviatoric hardening in the energy potential, which involves another dissipative state variable, coupled by a unique yield criterion with the plastic deformation in the spirit of multi-mechanism models for crystal plasticity [2]. We end up with a new critical state soil model (CSSM), so called Deviatoric Bounded Hardening – modified Cam-Clay (DBH-MCC), allowing asymptotically to restore the MCC model with a possible linear deviatoric hardening.

DBH-MCC requires 7 parameters with a physical meaning allowing to propose a reduced and easy calibration procedure. The relevance of our model is validated by the comparison with previous experimental results of monotonic triaxial compressions on Karlsruhe sands [3] and cyclic isotropic torsions on Toyoura ones [4].

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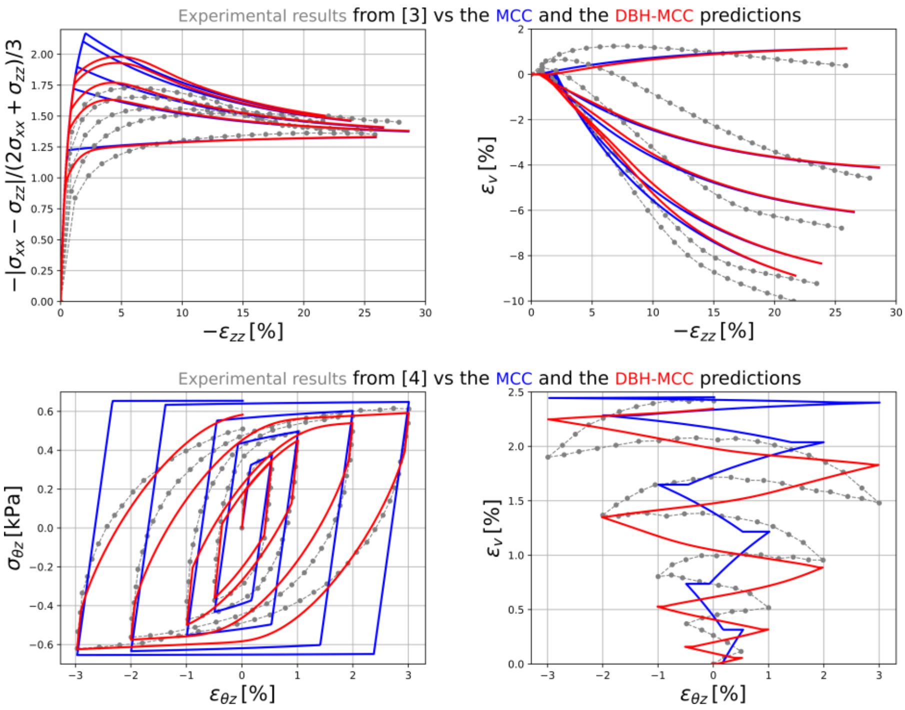


***Figure 1:*** *Experimental results [3, 4] compared to the predictions from the MCC model and our DBH-MCC new one.*

# Performance of tripod suction bucket foundations for offshore wind turbines: a numerical study

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***Keywords***: Numerical modelling, tripod, offshore engineering

## *Abstract*

Large diameter monopiles represent the most common type of foundation for offshore wind turbines. However, the use of tripod suction bucket foundations is rising due to its cost-effective benefits. Among them, the tripod suction bucket foundations deformation mechanism in sands reveals a "self-healing" effect induced during cyclic lateral loading. This effect leads to a dynamic stiffness recovery of the foundation after large number of cycles and consequently, the tilt of the foundation is reduced. Former studies found that this "self-healing" effect is caused by the uneven change in soil fabric and density among the buckets. Nevertheless, there is still a lack of precise and clear explanation on the ground flow around the caissons. This work investigated this deformation mechanism through the back-analysis of a series of centrifuge tests performed at Zhejiang University with an advanced three-dimensional finite element model, see Figure 1. The soil mechanical behaviour was reproduced through an advanced rate-independent hypoplastic model for sands by Von Wolffersdorff [1] coupled with the conventional intergranular strain theory by Niemunis and Herle [2]. The simulations results showed that the model was capable to precisely capture the magnitude of the peak and residual cumulative rotations and the "self-healing" effect.

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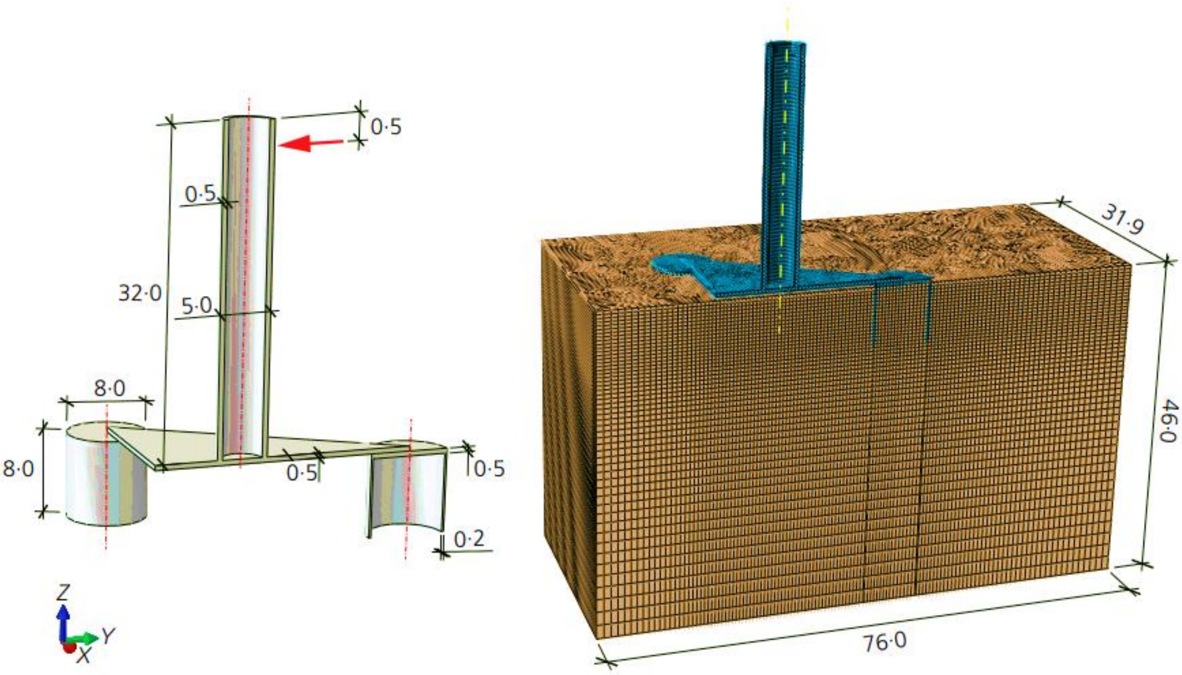


***Figure 1:*** *Geometry of the computational finite element model. Units in meters.*

# Preventing lab-quakes using advanced control theory

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***Keywords***: CoQuake, double-direct shear apparatus, control theory, earthquake control, induced seismicity, lab-quake

### *Abstract*

In this study, we perform double direct-shear experiments of decametric scale using a novel triplet apparatus that allows (a) to reproduce earthquake-like instabilities in the laboratory and (b) to prevent them by active fluid pressure adjustment. The dynamic earthquake-like events are prevented using the mathematical theory of control [1-3] by designing advanced controllers in both the discrete and the continuous domains.

Two scenarios are investigated experimentally using discrete control design (slow sampling rate). In the first scenario, the system is loaded close to its instability point and then fluid is injected in order to provoke a seismic event. We observe how the controller automatically adjusts the fluid pressure in order to prevent such instabilities and immobilize the system. In the second scenario, the controller adjusts the fluid pressure automatically in order to drive the system in a new stable equilibrium of lower energy in an aseismic manner. Despite the inherent (a) unstable behavior of the system, uncertainties related to (b) friction, (c) elasticity and (d) multi-physical couplings, the earthquake-like events are avoided and controlled.

Finally, by allowing a faster sampling rate, we are able to design two kinds of continuous-time robust controllers: one based on (a) Continuous Higher-Order Sliding-Modes (CHOSM) [4-5] and another on (b) Linear Quadratic Regulator (LQR) [2]. By conducting tracking experiments (second scenario), we observe that the response of the system is comparable among the different controllers, always driving the system aseismically to its new equilibrium point.

We expect our methodology to inspire earthquake mitigation strategies regarding anthropogenic and/or natural seismicity.

### *Acknowledgment*

This work was supported by the European Research Council (ERC) under the European Union Horizon 2020 research and innovation program (Grant agreement no. 757848 CoQuake), http://coquake.com.

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# Design of analogue fault gouges with custom frictional properties using 3D-printing with sand particles

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***Keywords***: CoQuake, 3D-printing, analogue rock-like material, direct-shear experiments, friction

### *Abstract*

Laboratory experiments with surrogate materials play an important role in fault mechanics. Analogue rock-like materials can effectively substitute in-situ rock and gouge materials [1-2] if they are appropriately selected and calibrated. Here, we investigate the utility of sand-based, 3D-printed specimens as a rock-analogue in experimental fault mechanics and geomechanics [3]. We perform uniaxial compression tests, direct shear, and inclined plane tests to obtain the mechanical and frictional properties of the proposed material and also to study the influence of some of its printing parameters.

Going a step further, we print rock-like interfaces of custom frictional properties based on a simple analytical model. More specifically, we design the a) maximum, minimum, and residual apparent frictional properties, b) characteristic slip distance, c) evolution of the friction coefficient in terms of slip, and d) dilatancy of the printed interfaces. This model is experimentally validated using interfaces following a sinusoidal pattern, which leads to an oscillating evolution of the apparent friction coefficient with slip. Our approach could be used for simulating earthquake-like instabilities in the laboratory and mimic the periodical rupture and healing of fault sections.

### *Acknowledgment*

This work was supported by the European Research Council (ERC) under the European Union Horizon 2020 research and innovation program (Grant agreement no. 757848 CoQuake), http://coquake.com.

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***Figures***

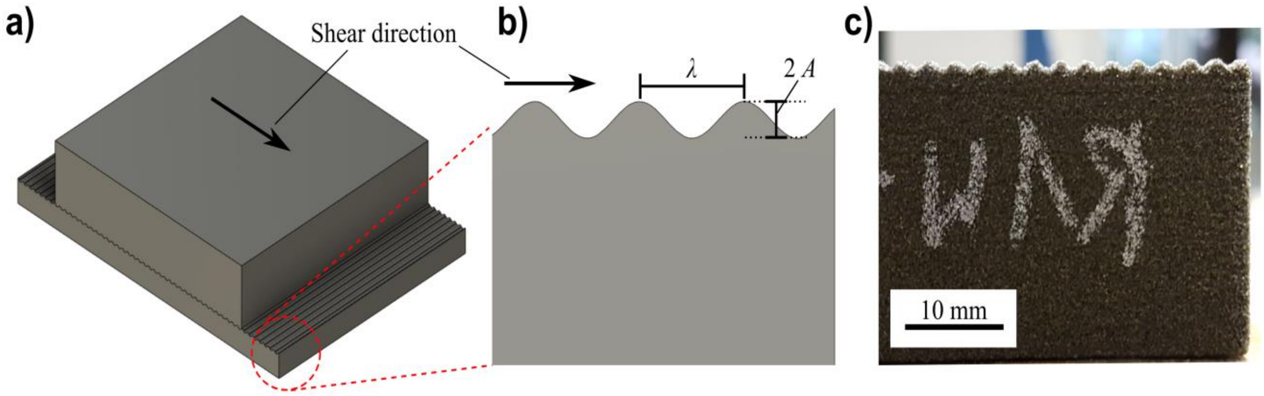


***Figure 1 :*** *a) Sketch of the direct-shear configuration used in laboratory experiments consisting of two sand-based 3D-printed samples with sine-wave frictional interfaces. b) Zoom in the sheared interface. c) Photograph of the actual specimen, where λ = 2.80 mm and 2A = 0.84*

# Design of analogue fault interfaces with custom rate-and-state frictional properties

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***Keywords***: Analogue material design, rate-and-state friction, friction evolution control, slip-weakening friction.

***Abstract***

Designing the surface roughness of analogue materials plays an important role in simulating earthquake-like instabilities in the laboratory [1]. The constitutive law that is widely used in the literature to describe the frictional behavior of these instabilities is the rate-and-state friction (RSF) law [2-3]. In order to estimate the RSF properties of a material, velocity-step direct-shear experiments have to be performed. Despite the need of experimental characterization, though, this friction law adds also one state variable to the system with debatable physical interpretation and, on top of that, it consists of unmanageable (potentially singular) logarithmic functions.

Here, we study the possibility of addressing the rate-and-state dependency of the faults to the geometry and the roughness of the fault interfaces [1] and ultimately derive an adequate friction law which depends only on slip.

Numerical simulations have been conducted using the analogue single-degree-of-freedom spring slider model [4] coupled with RSF. We evaluated the influence of the different parameters of the system on the characteristic response of an isolated (reference) seismic event. The frictional response in terms of slip of all these analyses is approximated using a linear fitting, the parameters of which are tabulated. Using the methodology proposed in [1], the resulted slip-dependent friction evolution is associated to the roughness of the frictional interfaces. As a result, it is possible to design laboratory specimens with custom rate-and-state frictional properties. Further study is needed, though, to validate the aforementioned strategy experimentally.

This work was supported by the European Research Council (ERC) under the European Union Horizon 2020 research and innovation program (Grand agreement no. 757848).

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# Thermodynamics-based Artificial Neural Networks for Nonlinear Seismic Analysis of High-rise Buildings

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***Keywords***: High-rise building; Structural system; Nonlinear seismic analysis; Machine learning; Artificial neural network; Finite Element modelling.

### *Abstract*

The assessment of structural seismic vulnerability is critical to credible high-rise engineering design. As is the case, a considerable share of operational high-rise buildings predates seismic codes and fails to adhere to construction standards. Although current Finite Element methods for seismic modelling successfully predict structural seismic response, such models remain quite complex and require access to a vast amount of high-quality data.

In recent years, Machine Learning techniques, particularly Artificial Neural Networks, have shown promise in addressing the computational limitations of structural seismic analysis tools (e.g. [1], [2], [3], [4], [8], [9], etc.). However, general Artificial Neural Networks lack a framework that respects the laws of physics.

Here, the seismic response analysis of a multiple-degree-of-freedom structural system is predicted with the aid of a Finite Element code incorporating a 'Thermodynamics-based Artificial Neural Network' - class material. The integration of a physics - aware neural network in the wiring of the Finite Element code can provide constraints to the network outputs, therefore reducing the need of large training datasets, solving overfitting issues, and thus improving the robustness of the code for more reliable seismic response prediction. To this date, successful applications of thermodynamics-based artificial networks include material response prediction at material point level and constitutive modelling of inelastic micro-structured materials (refer to [5], [6], [7]).

### *Acknowledgment*

The authors would like to acknowledge the support of the European Research Council (ERC) under the European Union Horizon 2020 research and innovation program (Grant agreement ID 757848 CoQuake). This work was presented in a Master's thesis completed by Farah Rabie at *Ecole Centrale de Nantes* under the supervision of Prof. Ioannis Stefanou and Dr. Filippo Masi.

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# Microbial-induced calcium carbonate precipitation method (MICP) used for liquefaction mitigation in various soil gradations

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***Keywords***: Liquefaction, MICP, soil gradations

### *Abstract*

Liquefaction is a life-threatening hazard that can bring large damage to constructions. Microbial induced calcium carbonate precipitation (MICP) method, a sustainable technique with less carbon emission, has proved its efficiency in mitigating liquefaction [1]. However, in most of the current studies that used MICP to improve soil qualities, the soil used was restricted to relatively fine sands with diameter smaller than 1 mm, like Ottawa 50-70 sand used in [2], [3], [4], [5]. And the conclusions were usually drawn qualitatively. Moreover, few cyclic tests were made on different gradations of sand up to now.

In this study, we applied MICP treatment to a series of loose sands (Dr=0.3) with different percentages of fine grains (0, 20, 40, 60 and 100%) and the maximum diameter of used sand was extended to 5 mm. Different numbers of treatment were used for each kind of soil to obtain different cementation levels (light, moderate and heavy treatment). For untreated samples, both loose (Dr=0.3) and dense (Dr=0.9) samples were prepared for mechanical tests. Consolidated undrained cyclic triaxial tests were carried out on both treated and untreated soil samples. Results showed that all the untreated samples liquefied within 50 cycles at 0.25 cyclic stress ratio. However, the treated sample needed more cycles to liquefy, especially the heavily treated samples. In **Figure 1**, cyclic stress ratio was raised to 0.5 to induce liquefaction. For different gradations of sand, $CaCO_3$ needed for having effectiveness varied a lot, from around 9% for soil without fines to 2% for soil with 100% fines. Density played a vital role in the liquefaction mitigation of soil with no fines (**Figure 1**). For soils with more fines (**Figure 2**), liquefaction mitigation of soil was mainly due to the effectiveness of MICP treatment

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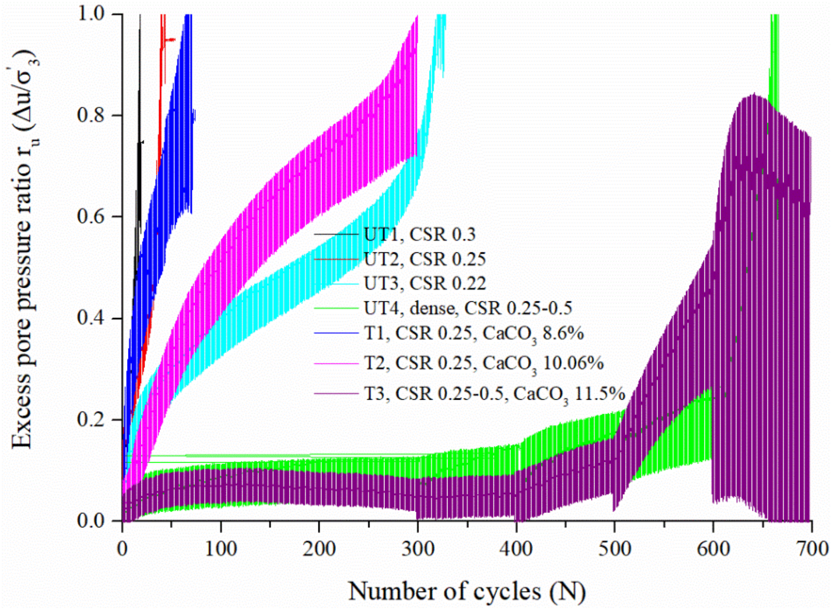


***Figure 1 :*** *Excess pore pressure ratio ru as a function of number of cycles N for soil with no fines*

# Numerical investigation of the role of thermal pressurization in the fault's frictional response under large coseismic slip

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***Keywords***: strain localization; THM-Couplings; traveling instability; Cosserat; bifurcation; finite elements; Lyapunov stability

### *Abstract*

We study the role of thermal pressurization in the frictional response of a fault under large coseismic slip. We investigate the role of the seismic slip velocity, mixture compressibility, characteristic grain size and viscosity parameter in the frictional response of the coupled Thermo-Hydro Mechanical problem, taking into account the fault's microstructure (see also Rattez et al. (2018a,b)). Starting from the mass, energy and momentum balance for Cosserat continua we derive the equations of our model, which are completed by introducing perfect plasticity and Perzyna viscoplasticity. We take into account large displacements with the help of an updated Lagrangian Eulerian method (ALE). We investigate both the rate independent and the rate dependent frictional response and compare with the rate and state friction law (Dieterich (1992)).

Our model is capable of predicting strain rate hardening and velocity softening without the assumption of a state variable. We observe traveling instabilities inside the layer that lead to oscillations in the fault's frictional response see the left part of Figure 1. We note that our model predicts partial regain of the fault's strength during seismic slip, which depends on the seismic slip velocity (see right part of Figure 1). This behavior is not captured by the existing model of uniform shear (Lachenbruch (1980)) and shear on a mathematical plane (Lee and Delaney (1987); Mase and Smith (1987); Rice (2006)), which predict a strictly monotonous behavior during shearing.

We investigate the role of the instability mode under isothermal drained boundary conditions in the fault's friction. For a stationary mode on a bounded domain, thermal pressurization ceases and the fault regains its strength in full before the slip stops (see left part of Figure 2). For a traveling instability on the unbounded domain, the fault develops a non zero residual friction (see right part of Figure 2). These results indicate a reappraisal of the role of thermal pressurization as a frictional weakening mechanism and its role in earthquake nucleation.

### *Acknowledgements*

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## Figures

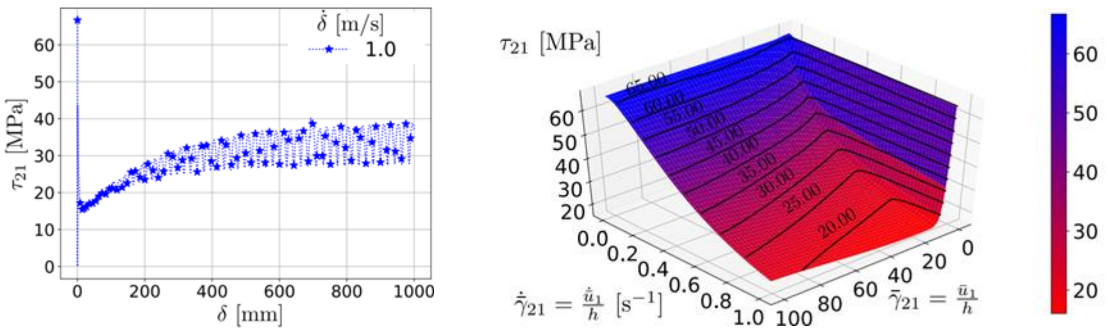


***Figure 1 :*** *Left: Evolution of τ 21 with slip δ. Right: 3D fitted surface of τ 21 with slip δ and slip velocity δ̇.*

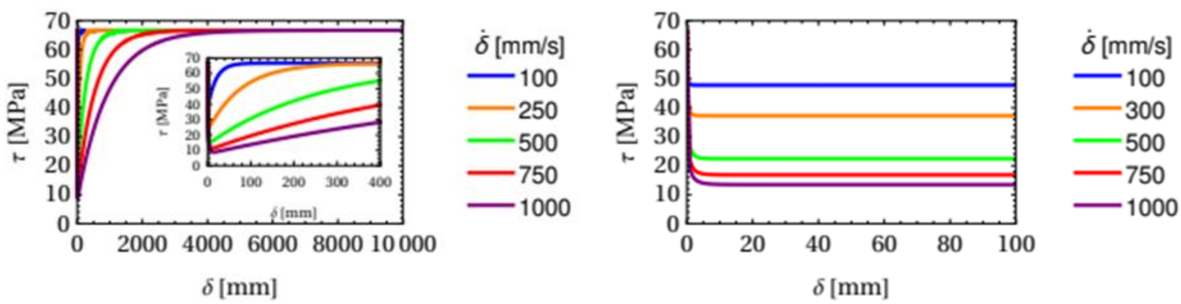


***Figure 2****:Frictional response of the fault. Left: Stationary strain localization mode on a bounded domain. Right: Traveling instability on an unbounded domain. Different values of seismic slip δ̇ were examined.*

# Viscous regularization in dynamical problems, does not regularize strain localization on a mathematical plane and mesh dependency!

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***Keywords***: strain localization; Perzyna, Consistency elastoviscoplasticity; traveling waves; mesh dependency; bifurcation; finite elements; Lyapunov stability

### *Abstract*

Strain softening is responsible for mesh dependence in numerical analyses concerning a vast variety of fields such as solid mechanics, dynamics, biomechanics and geomechanics. Therefore, numerical methods that regularize strain localization are paramount in the analysis and design of engineering products and systems. We revisit the elasto-viscoplastic, strain-softening, strain-rate hardening model as a means to avoid strain localization on a mathematical plane ("wave trapping") in the case of a Cauchy continuum. Going beyond previous works (de Borst and Duretz (2020); Loret and Prevost (1990); Needleman (1988); Sluys and de Borst (1992); Wang et al. (1996, 1997)), we assume that both the frequency ω and the wave number k belong to the complex plane (see Brown et al. (2009)). Applying the first method of Lyapunov for investigating stability (see Chambon et al. (2004); Lyapunov (1992)), we derive a different expression for the dispersion relation. The dispersion relation indicates the existence of a pole $\omega^{P1}$ on the positive imaginary axis of the complex plane (see Figure 1). Thus, we have proved that the waves of infinitesimal wavelength are present in the elasto-viscoplastic medium and their amplitude increases faster than all possible perturbations. Under these conditions strain localization on a mathematical plane is possible.

The above theoretical results are corroborated by extensive numerical analyses. At first, the linearized partial differential equation for the determination of stability under continuous plastic loading was solved numerically for a variety of initial conditions. We performed fully non linear analyses taking into account possible unloading near the yielding area, based on the available examples in literature (see de Borst and Duretz (2020); Wang et al. (1997)). We show that strain softening in the presence of strain rate hardening leads to strain localization on a mathematical plane and mesh dependency.

### *Acknowledgements*

The authors would like to acknowledge the support of the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (Grant agreement no. 757848 Coquake).

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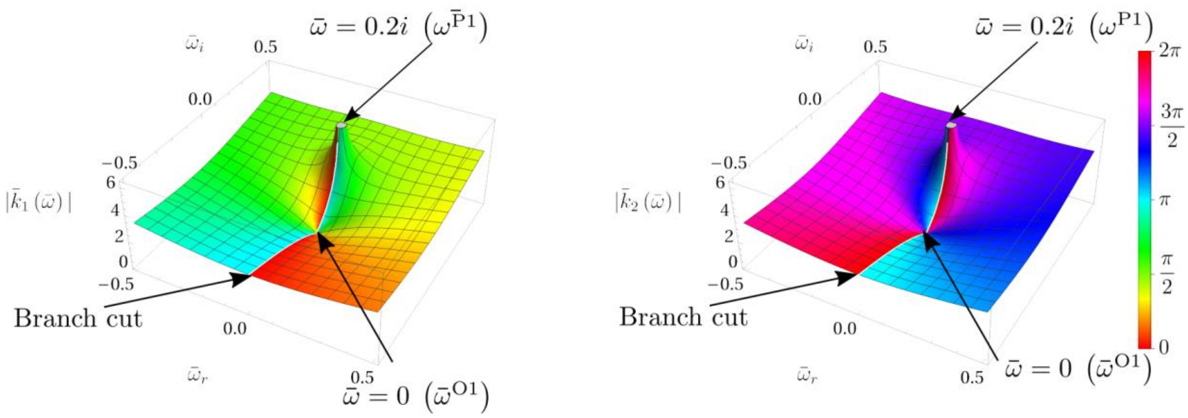


***Figure 1 :*** *Figure on the left: Detail near the pole $\omega^{\bar{P}1}$ for the first solution of the dispersion equation. Figure on the right: Detail near the pole $\omega^{\bar{P}1}$ for the second solution of the dispersion equation.*

# Assessment of the open-cast coal mine landfill stability with the hypoplastic clay strength reduction method

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***Keywords***: Hypoplasticity, strength reduction, slope stability

### Abstract

Production of a large quantity of lumpy soil is often an inseparable part of mining operations in the open-cast coal mines. This soil is often dumped without any artificial compaction and thus forms a large loose deposits of double porous material. Initially highly porous material is gradually transformed into impermeable soil with intergranular pores filled with a reconstituted material due to the lumps disintegration. Example of such a coal mine can be found in Bilina in Czech Republic which stretches over 18 $km^2$. The deposit of the double porous material created during its operation have risen to 200 m in height and its stability is of high concern.

In this poster, the stability of the landfill is investigated with the strength reduction method for the hypoplastic clay model (Kadlíček 2020) and compared with the prediction of the Mohr-Coulomb model. The strength reduction method employs the radial mapping rule when returning an inadmissible stress to the state boundary surface. Thus the mean stress $p$ is preserved while the deviatoric stress $J_2$ is reduced along a constant Lode's angle $\theta$, see Fig. 1. The hypoplastic model (Mašín 2013) was calibrated on the reconstituted samples and on samples of a material with a reduced granulometry curve, which represents the lumpy soil. The accuracy of the calibration was assessed with respect to the observed landfill settlement.

The crucial section of the landfill is represented by the slurry pits which served for gathering and drainage of the underground water at the toe of the landfill. As the landfill expanded and the toe of the land fill was about to move ahead, the existing slurry pits were covered with the deposited material and a new pit was excavated in a short distance. The slurry pits have not been excavated in a straight line and they form two distinct areas of irregular *s-shapes* which emphasises the spatial characteristics of the stability analysis, see Fig. 2a. The slurry pits are modelled with a separate layer of the same parameters as the body of the landfill. However, undrained and normally consolidated conditions were assigned to this layer.

To limit local failures, a surface of the landfill was strengthened with the elastic surface layer which was interrupted in various shapes to predetermine different locations of failure with different factors of safety, see Fig. 2b. Eleven failure locations were tested in total in search for the most unstable location. In the most unstable case, both hypoplastic clay and Mohr-Coulomb predicted stable state of the landfill.

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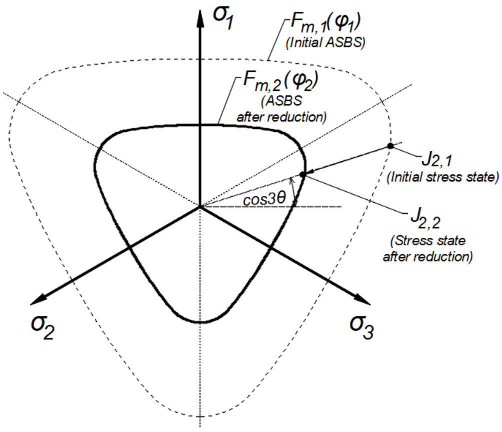
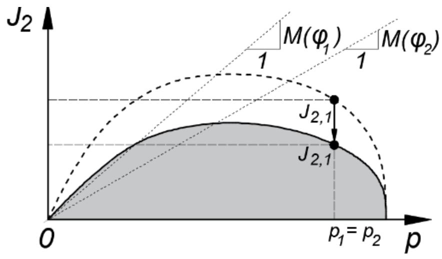


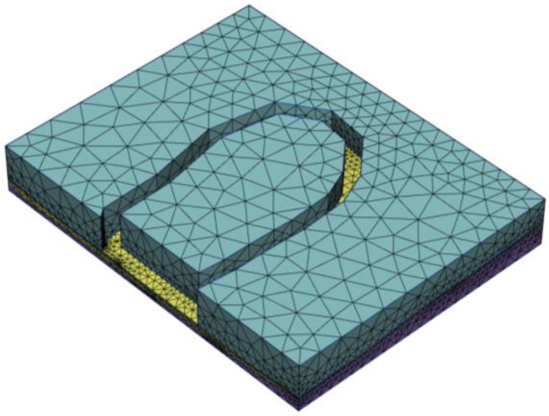

*a) Deviatoric plane*




*b) Meridian plane*

***Figure 1:*** *Mapping rule of the hypoplastic clay strength reduction method*

*a) Base layer with slurry pits. Purple-elastic base; Black-hypoplastic slurry pits*



*b) Elastic surface layer predefined to predetermine the shape of slope failure. Yellow-hypoplastic landfill; Blue-elastic surface layer*

*Figure 2: Geometry of two selected layers of the numerical model*

# Multi-scale analysis of deformation, localization and damage of carbonate rocks under triaxial loading

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***Keywords***: Localization bands, Porous carbonate rocks, Multi-scale

### *Abstract*

Understanding inelastic compaction in carbonate rocks is of key importance to assess the performance of geosystems. The formation of deformation bands as observed in laboratory tests and *in situ* is associated with intense porosity reduction due to pore collapse, grain crushing, grain rearrangement, pressure solution etc. These bands can form a barrier for fluid flow and affect permanently the transport properties and the performance of geosystem operations such as $CO_2$ storage. Complex sedimentation processes and variable depositional environments can induce a large heterogeneity of the rock microstructure at various scales, resulting in a great diversity of micromechanical processes involved at different scales to accommodate deformation processes.

A model limestone chosen for its large and heterogeneous porosity, the Saint-Maximin Limestone, is studied in an experimental program of triaxial tests conducted at mesoscale (standard laboratory sample) and at microscale (sample size of few millimeters). Triaxial compression tests are combined with Digital Volume Correlation performed on X-Ray Computed Tomography images, in order to identify the micromechanisms involved in deformation bands development and patterning. For mesoscale samples these images are recorded before and after several axisymmetric triaxial loading stages performed at different stress state conditions (Abdallah, 2019; Abdallah *et al*., 2020-2021). For microscale samples, a new testing device permitting *in situ* full field measurements has been developed which will allow a better quantification of strain localization at a micrometric scale.

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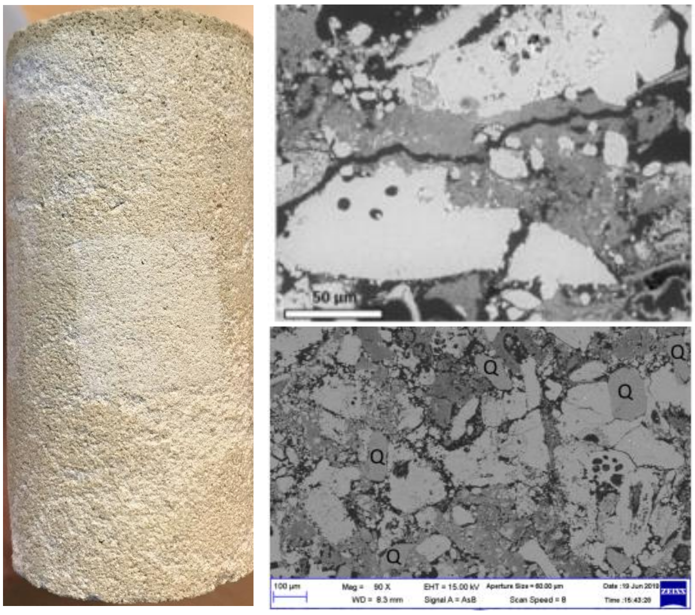


***Figure 1****: a) Saint-Maximin Limestone tested at a confining pressure of 13 MPa. Subparallel deformation bands are visible on the sample. b) Identified micromechanisms at meso-scale in the Saint-Maximin Limestone in deformation bands: intergranular fracturing in a shear band and c) grain fracturing in a compaction band (From Abdallah, 2019)*

# Effect of anisotropic creep on the mechanical response of drift excavated in the Callovo-Oxfordian claystone

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***Keywords***: creep anisotropy, deep tunnel, convergence, COx claystone

### *Abstract*

The long term behaviour of the lining support in deep drifts is a crucial issue for nuclear waste underground repository project. In order to demonstrate the feasibility of the project, the French Radioactive Waste Management Agency (Andra) has built an Underground Research Laboratory at Bure (MHM URL). The underground structure is composed of a network of galleries whose drilling generates stress redistribution, damage and fracture in the surrounding medium. The damage and fracturing of this excavation damaged zone has a direct effect on the displacement field and on the interaction between the formation and the lining support. Moreover, the development of the fractured zone depends on the direction along which the drifts are excavated. The design of the support system request, in order to be as efficient as possible, a precise knowledge of the stress and displacement fields around the drift. For viscoplastic rock formation, the stress field around the drift and its effect on the support system must be determined for at least a couple of hundreds of years. This is why we have studied the long term behaviour of drifts using an elasto-viscoplastic constitutive law. The laboratory test data and field observations have shown that the Callovo-Oxfordian claystone has a slightly anisotropic behaviour for its elasticity, failure criterion and also creep properties. Its anisotropy, is mainly due to development of a fractured zone, whose effects on the convergence can be represented by transverse isotropic models.

2D plane strain numerical simulations were performed in the code Disroc [1] with the model called ANELVIP and which consists of an anisotropic elasto-viscoplastic material with transverse isotropic elasticity, anisotropic Mohr Coulomb plasticity and anisotropic Lemaitre creep law. The anisotropic constitutive law will thus represent the global behavior of the rock mass around the drifts, which is made of both sound rock and fractured rock in the fractured zone. Many research teams have been modelling the convergence of the drifts of the MHM URL [2]. While the simplicity of the model does not permit to explain the creation of the fractured zone around the drifts itself, our goal is to enable a trustworthy reproduction of the rock formation after the excavation, and especially the time-dependent convergences due to the creep. This is essential to be able to provide a tool for the design of the lining supports based on the long term behavior of the drifts. The presented modeling approach allows us to take the fractured zone into account in a reasonably simple manner, without needing a precise knowledge of the fracture density or orientations in the fractured zones around the drifts to calibrate the parameters. By considering vertical fractures in the case of GCS drift and horizontal fractures in the case of GED drift we are able to reproduce the convergences of both

drifts with two transverse isotropic materials. The advantage of this approach is that in order to switch from the model of GCS drift to the model of GED drift, we only need to rotate the anisotropy plane by 90 degrees and change the anisotropy parameters.

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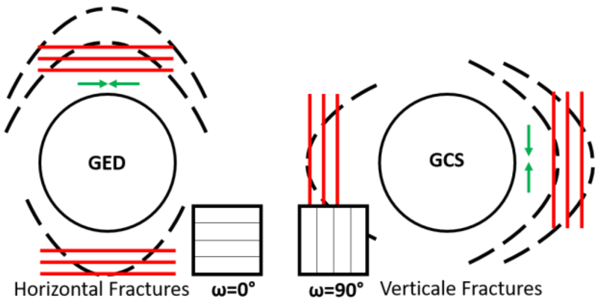


***Figure 1:*** *Representation of reference, dynamic and yield surfaces*

# Strength and deformation behaviour of bio-inspired blade like surfaces sliding along a soil-structure interface

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***Keywords***: soil-structure interface behavior, bio-inspiration, shear behavior, sliding

### *Abstract*

Studies about the soil-structure interface behaviour are important for the mechanism of understanding the bearing capacity behaviour of geotechnical structures. Recently, bio-inspiration have been applied more and more in geotechnical engineering [1]. The first initial research on the usage of bio-inspiration at the soil structure interface is from Martinez & Palumbo [2] and newer research show the potential of snake-skin inspired anisotropic surfaces [3].

Based on this work, an experimental program regarding the application of flexible and non-flexible blade like surfaces on a soil-structure interface have been performed. The tests were done in a direct-shear interface device to test the performance of flexibility and inclination of the bio-inspired surface (see Figure 1).

These initial results indicate that the flexibility have a minor role compared to the inclination angle of the blades. Based on the results, a clear trend is that the order of shearing direction have a larger consequence, as it have been demonstrated before by [2,3]. Figure 2 indicatesdifferent shear-stress to shear-displacement response, in which it is evident that the shearing direction and blade inclination are important.

These results in general show the potential for the usage of generally anisotropic surface and the overall great potential of bio-inspiration in the future geotechnical implications.

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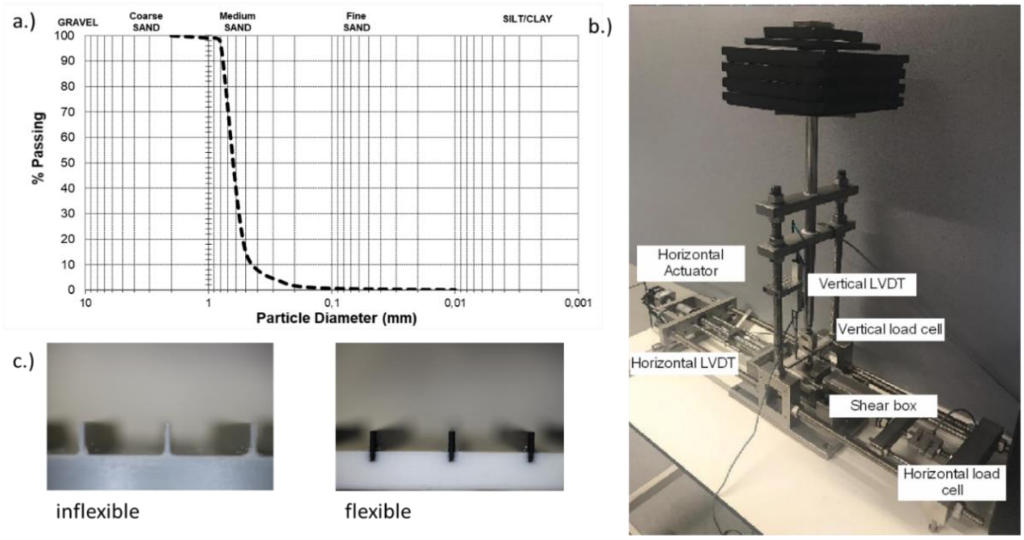


***Figure 1:*** *a.) Grain size distribution of the tested material, b.) Direct interface shear test, c.) Flexible and non-flexible 3d printed surfaces*

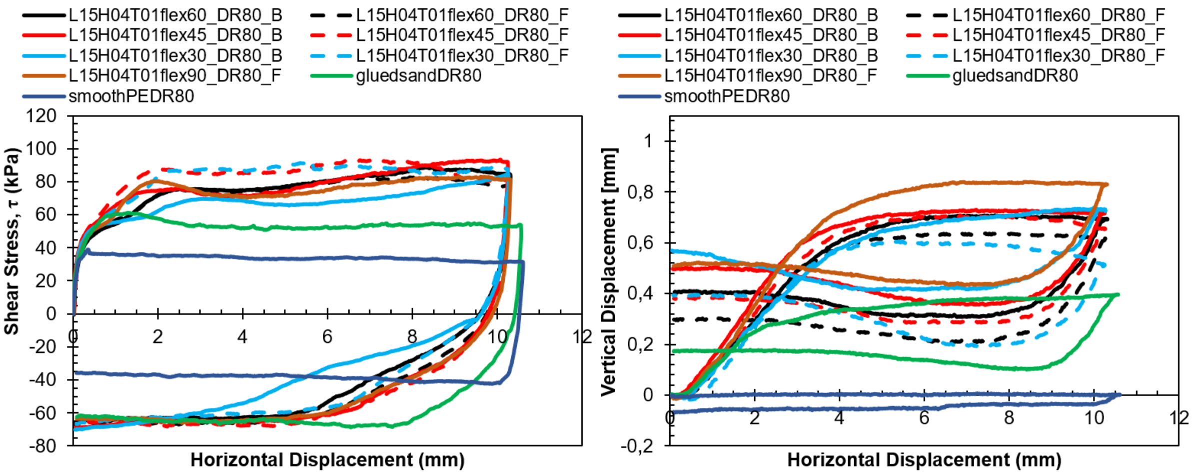


***Figure 2:*** *Shear stress vs. shear displacement plot and vertical displacement vs shear displacements of different surfaces*

# Investigations on the erasing of the cyclic preloading history by monotonic deformations in granular soils

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***Keywords***: high-cyclic loading, cyclic preloading history, granular soils

### *Abstract*

This work summarizes the experimental program regarding the influence of large monotonic strains on the cyclic preloading history in context of the high-cycle accumulation Model (HCA-Model) by Niemunis et al. [1]. In the HCA-Model, the cyclic preloading history is taken into account by the cyclic preloading history function $\dot{f}_N$ depending on the number of cycles $N$ and the intensity of cycles. In tests with packages of cycles interrupted by monotonic loading phases, Wichtmann and Knittel [2] performed cyclic triaxial tests on Cuxhaven fine sand and observed an effect not captured by the current HCA-Model (Fig. 1). After the monotonic loading, a loss of the cyclic preloading memory was assumed. This resulted to an increase of the rate of strain accumulation in the next bundle of cycles.

In this research, 21 drained cyclic triaxial test on saturated, cylindrical fine sand samples ($h$ = $d$ = *10* cm) were performed. Throughout the tests, the packages of cycles were applied on the sample one after another. Between the packages, either the mean average stress $p^{\mathrm{av}}$ or the average stress ratio $\eta^{\mathrm{av}}$were changed. Simultaneous changes of the $p^{\mathrm{av}}$ and $\eta^{\mathrm{av}}$ were also applied. Two exemplary test procedures in the $p$-$q$-space are shown in Fig. 2.

In order to examine the reduction of the cyclic preloading history, the tests were analysed regarding the accumulated strain throughout the packages of cycles in each test. To quantify the erasing of the cyclic preloading history, all tests were simulated with the HCA-Model. Wichtmann [3] introduced a scaling factor $r$ to scale the initial value of the cyclic preloading variable $g^A$ at the beginning of each package $g^A \cdot r$. In this context, $r$ = 0 corresponds to the total loss of the cyclic preloading memory, while $r$ = 1 means that the cyclic preloading remains unchanged. Fig. 3 shows three exemplary simulations of one element test. For $r$ = 0, one obtains an overestimation of the accumulated strain, while $r$ = 1 leads to an underestimation of the accumulated strain. Therefore, one needs to find the right scaling factor $r$ for each package of cycles.

Subsequently, all tests were simulated to find the optimum scaling factor $r$ for each package of cycles. To investigate the reduction of cyclic preloading history by the monotonic loading phases, the monotonic strain before each bundle of cycles were correlated with the respective scaling factor used. This correlation is shown in Fig. 4.

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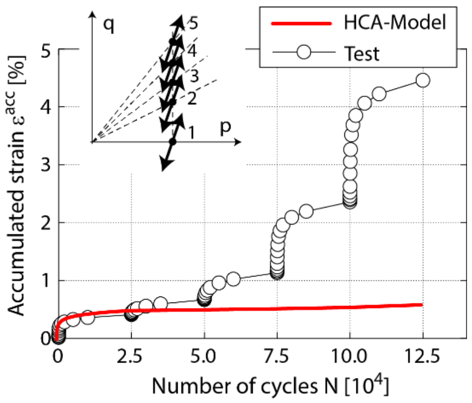


***Figure 1:*** *Packages of cycles applied one after another with increasing average stress ratio revealing an effect not captured by the current HCA-Model [2]*

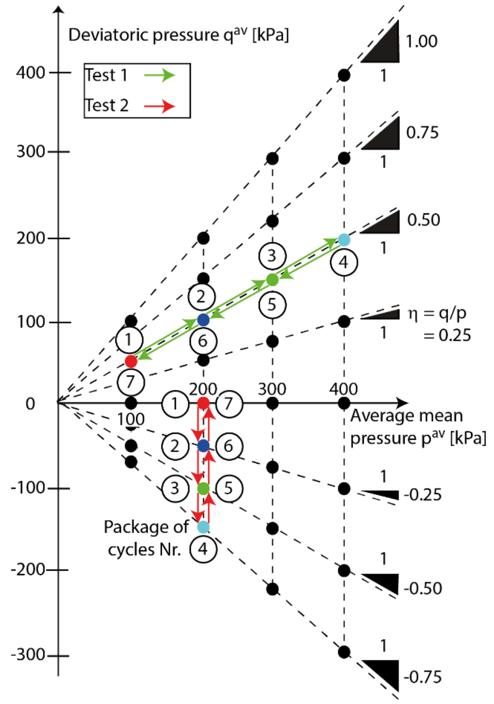


***Figure 2:*** *Two exemplary test procedures in the p-q-space*

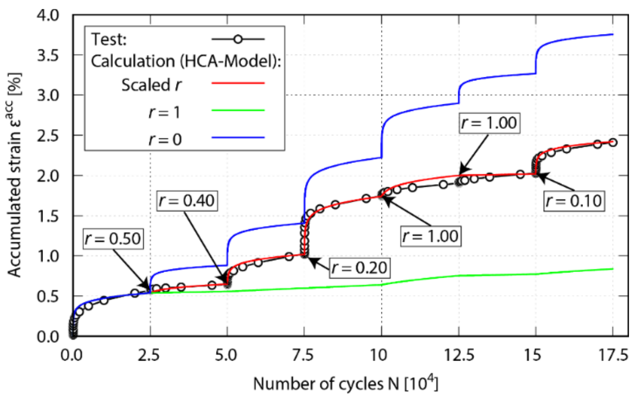


***Figure 3:*** *Simulation of the accumulated strain with different scaling factors r*

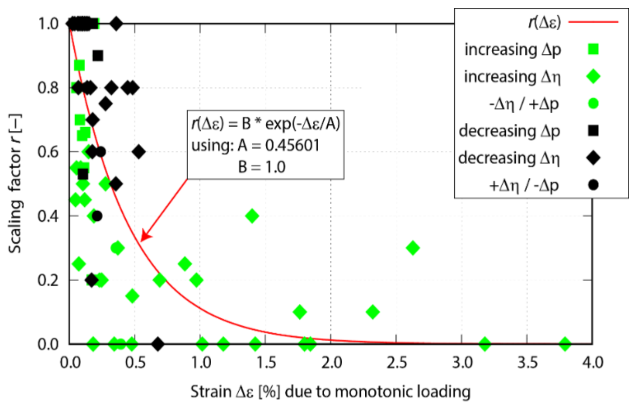


***Figure 4:*** *Correlation between monotonic strain and the scaling factor r used to find the best possible simulation of the test results*

# On the hyperelasticity of fine-grained soils: Element tests and modelling

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***Keywords***: hyperelasticity, fine-grained soils, elastic stiffness, small-strain stiffness

### *Abstract*

In geotechnical engineering, the accurate estimation of deformations is of practical importance. For this purpose, the finite element method (FEM) is commonly used. In order to achieve the most reliable results, the FE-simulation is based on an advanced constitutive description of the soil. A constitutive model should take into account the increased stiffness at small strains to reproduce the realistic deformation. Comparisons with measurements show, that models which do not consider the increased stiffness (e.g. HS model) produce too big deformations (see Fig 1a). Commonly used approaches for the elastic stiffness are often thermodynamically inconsistent and therefore lead to possible dissipation of energy and accumulation of deformations.

The stiffness of the soil depends on the deformation range. For fine-grained soils the stiffness is constant up to the shear strain amplitude of $\gamma^{\mathrm{ampl}} \approx 10^{-4}$, restricting the elastic range (Jardine, 1992). With increasing deformations, the stiffness decreases rapidly, see Fig. 1b. To describe the elastic stiffness depending on the stress state, a complementary potential function $\bar{\psi}(\sigma_{ij})$ can be used. The potential ensures the derivation of a thermodynamic compliant and a hyperelastic stiffness. Knittel et al. (2020) found a suitable potential function for sand and calibrated it for Karlsruhe fine sand. Due to different properties of fine- and coarse-grained soils the potential by Knittel et al. (2020) can not be directly applied for fine-grained soils. One of the differences is the inherent anisotropic behaviour, see Fig. 1c, which influences also the hyperelasticity.

In this contribution, element tests on kaolin are conducted to determine the pure elastic stiffness in different stress states and stress ratios. The test results are used to calibrate a hyperelastic potential for fine-grained soils. In the proposed constitutive description, the inherent anisotropy is additionally taken into account, see Fig. 1d.

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## Figures

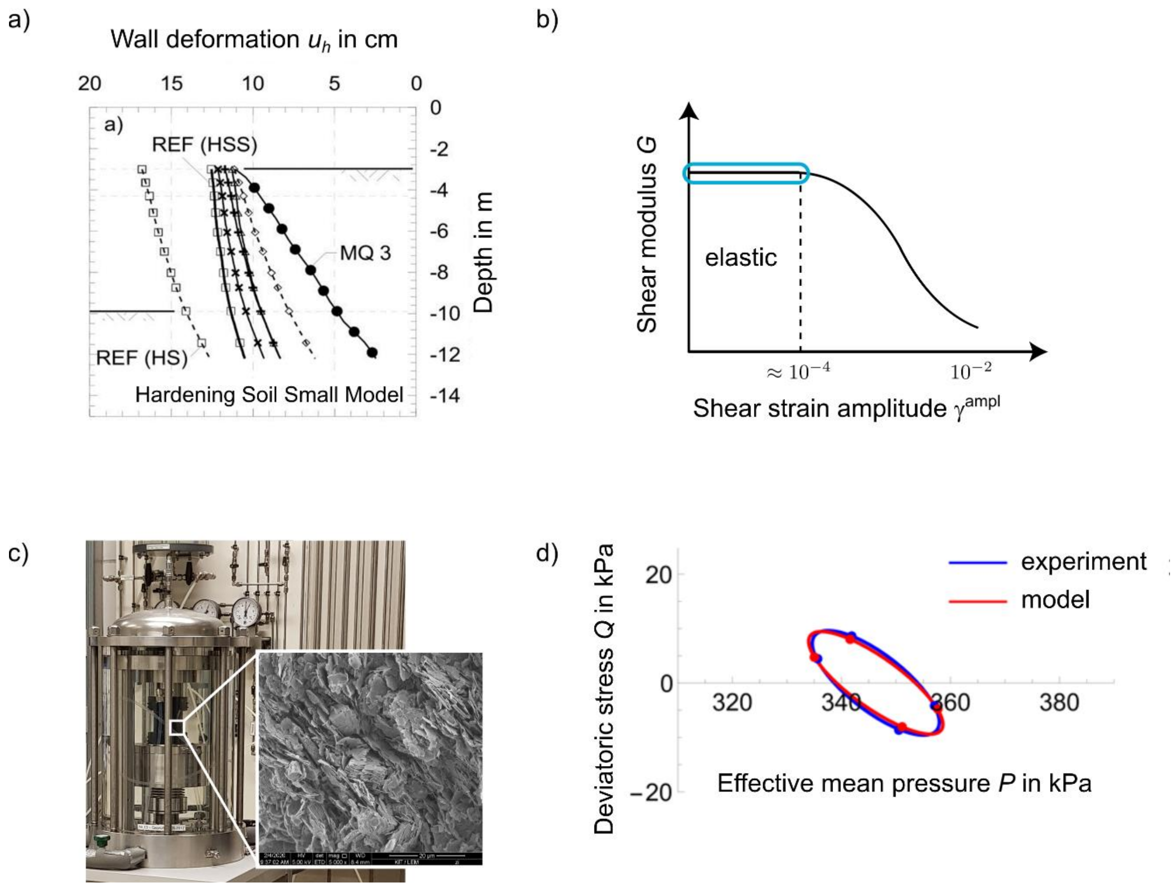


***Figure 1:*** *a) Wall deformation: Measurements (MQ 3) and forecast with the Hardening Soil model (HS) and the Hardening Soil Small model (HSS). (Becker & Kempfert, 2010); b) Shear modulus degradation; c) Test device and microscopy of the test material kaolin; d) Experimental and simulated response envelope for kaolin in an isotropic stress state*

# Constitutive modelling of bio-cemented soils: effect of cement spatial distribution

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***Keywords***: MICP, constitutive modelling, cement spatial distribution, bond degradation

### Abstract

Microbially induced carbonate precipitation (MICP) has great potential to be an eco-friendly ground improvement technique. Bio-cemented soils usually exhibit higher stiffness, higher peak strength, larger dilatancy and stronger strain softening. This poster highlights the effect of carbonate spatial distribution on the parameters of a constitutive model for bio-cemented soils. An elastoplastic model for bio--cemented soils was proposed in [1], which contains a scaling constant $a$ (kPa/%) quantifying the cementation improvement and a degradation rate $\mu$ controlling the degradation process.

Four types of $CaCO_3$ spatial distribution are evidenced in experiments (Figure 1). These types of distribution were created in DEM to investigate their effects on mechanical behaviour of bio-cemented soils. Results show that bridging and contact cementing lead to higher strength than grain coating and pore filling. In addition bridging has the highest bond degradation rate (Figure 2). The DEM results were used to calibrate the constitutive model [1]. The scaling constant $a$ and degradation rate $\mu$ vary with the spatial distribution of carbonate (Figure 3). The modelling bond degradation decreases faster and approaches zero, which deviates from the DEM results (Figure 4). The reasons are associated, among others, with bond efficiency and anisotropic bond breakage in DEM, which retains bonds in certain directions. In the future, Further investigation into effective $CaCO_3$ content is required to evaluate the improvement by MICP.

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### Figures

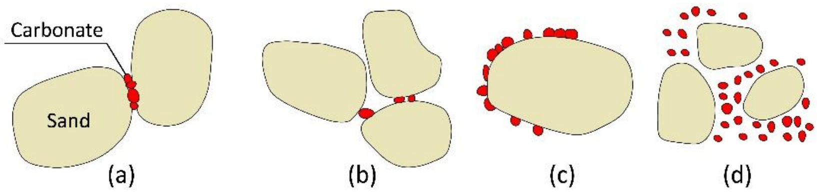


***Figure 1:*** *Spatial distribution of $CaCO_3$: (a) contact cementing, (b) bridging, (c) grain coating, (d) pore filling.*

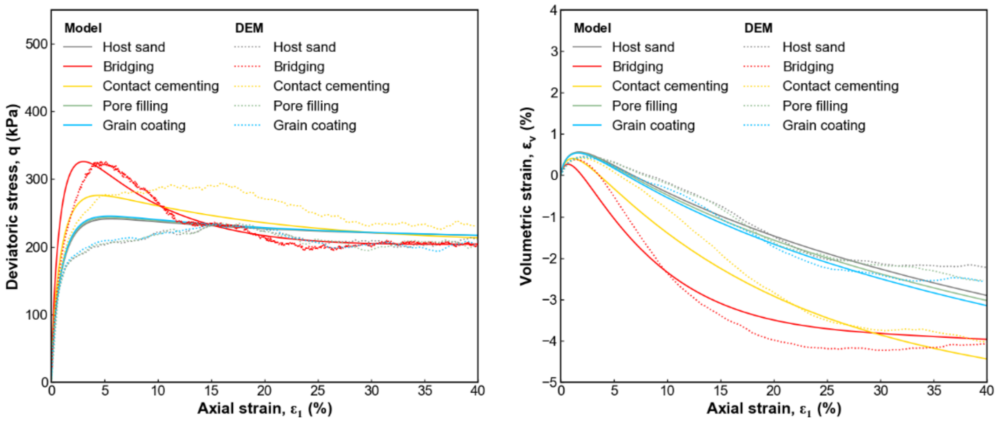


***Figure 2:*** *Results of constitutive modelling and DEM ($CaCO_3$ content = 1%).*

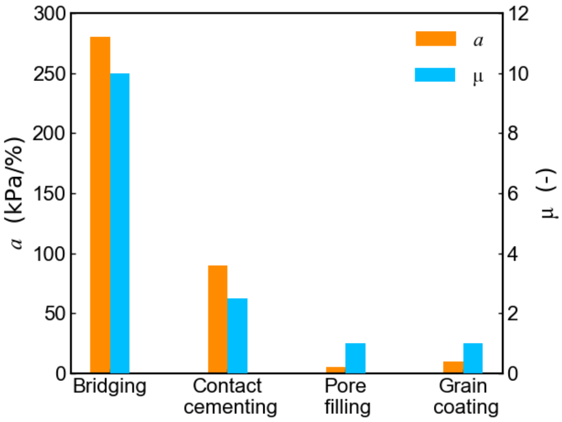


***Figure 3:*** *Model parameters for four types of spatial distribution.*

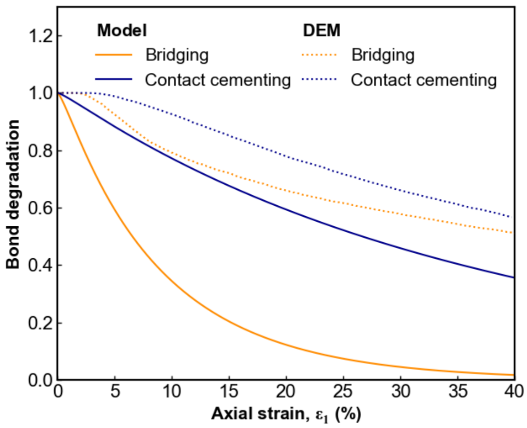


***Figure 4:*** *Bond degradation upon triaxial shearing.*

# On the possibility of Earthquake Prevention using Artificial Intelligence and Reduced Order Modelling

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***Keywords***: Earthquake Prevention, Artificial Intelligence, Reinforcement Learning, Control, Instabilities

### *Abstract*

Earthquakes, are widely acknowledged as major phenomena responsible for human life loss, infrastructure damage, economical depression and serious risks in energy related industrial projects. In this work we propose a novel method that uses reinforcement learning to avoid these catastrophic events through the application of retrieved injection policies. The rapid growth of artificial intelligence over the last years allows such prediction-control problems to be all the more tackled by function approximation models. These models learn how to control a specific task, even for systems with unmodeled/unknown dynamics and important uncertainties. We show for the first time the possibility of controlling earthquake-like instabilities using deep reinforcement learning techniques. A reduced model of the physical system is used for the training of the A.I. controller. The reduced model embodies the main dynamics of the physical problem and it offers simplicity and flexibility. After the controller is trained, the response of the uncontrolled system is compared to the controlled case, highlighting the key points of earthquake-like events mitigation. The model's robustness to unmodeled dynamics and mechanical uncertainties (variations of the mechanical properties of the fault zone) is explored. The proposed method may serve, first, as a solution towards minimizing seismicity in industrial projects (geothermal energy, hydrocarbons production, $CO_2$ sequestration). In a second step, it could pave the way for techniques that control and prevent natural earthquakes.

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