ALERT Geomaterials

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Booklet of abstracts

Editors: Nadia Benahmed

Antoine Wautier

(IRSTEA, France)

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Dear colleagues,

We are pleased to welcome you to Aussois and to our 29th 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.

We would like to express our thanks to all of you who came to Aussois to present and share your own work!

We wish you a good workshop and school experience and a pleasant stay in Aussois!

Kind regards,

Nadia Benahmed and Antoine Wautier.

Table of contents

Influence of different sample preparation on sand-clay mixtures' multi scale structure for interface direct shear test: from the cm- to µm-scale

K. Yin*, K. Othmani, G. Sciarra, P. Kotronis, A-L. Fauchille

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Keywords: Sample preparation; sand-clay mixtures; multi scale structure; SEM; ESEM; X-ray tomography; porosimetry; interface; direct shear test

Abstract

Shear stresses along the interfaces between piles and soil often affect structural stability, such as in marine energy piles and geothermal piles. Natural soils are generally classified as sandy or clayey soils based on the fine content classification systems. However, both in-situ and in the laboratory, natural soils are complex partially due to a geological history and their components are characterized by different mechanical behaviors, heterogeneous mineralogies, and anisotropies. In this study, sand clay mixtures were used as "simplified" soils in the laboratory to investigate the shear behaviour of soils along piles.

This poster focuses on the influence of the sample preparation on the multi scale structure of sand-clay mixtures, using different qualitative and quantitative methods. The goal of this study is to find the most homogeneous preparation to perform future direct shear tests along piles at the laboratory scale.

Sand-clay mixtures with different proportions of silica and kaolinite were used. Three different protocols to mix silica and kaolinite were tested in the laboratory to identify the one providing the most homogeneous microstructure. From the macroscopic to the microscopic scales, optical observation, 3D x-ray tomography, 2D scanning electron microscopy (SEM), 2D environmental scanning electron microscopy (ESEM) and mercury intrusion porosimetry (MIP) tests were carried out on wet and dry samples.

This poster provides a first insight on the mechanisms of sand-clay mixing from the cm to µm scale. Preliminary results demonstrate that the microstructures of the samples prepared by the three different procedures have similar porosities. However, the preparation which mixing the sample with the order of sand-water-clay provides a more homogeneous microstructure with silica grains well-surrounded by an oriented clay layering, this probably due to a geometrical effect. Understanding the formation of the oriented clay layering brings microstructural features that will help to formulate sand clay microstructure models and to better explain the grain displacements and rotations during direct shear tests.

Experimental study on lunar surface soil properties using simulants FJS-1 and SS-1

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Keywords: lunar soil surface, simulant, density profile

Abstract

Recently, for the purpose of deep space exploration [1], lunar exploration and base development missions have once again drawn considerable attention. When these missions are carried out, as practical matters, it is essential to know the ground properties of the lunar surface. To remotely conduct various kinds of operations on the lunar surface such as banking, compaction, excavation, and sampling, development of proper simulant (**Figure 1**) and simulations which are held in advance on Earth is significant. Thus, in this study, we used two types of simulants, FJS-1[2], well studied previously [3, 4] in Japan, and a newly-developed light soil simulant, SS-1, which can reproduce low-gravity environments on Earth. We conducted three different experiments (**Figure 2**): The first one is a sedimentation experiment [5] to estimate the density profile of the lunar soil surface layer, the second is a one-dimensional compression test, and the last one is a penetration test. These test results are basically consistent with the previous results as well as the in-situ observation in the Apollo mission [6].

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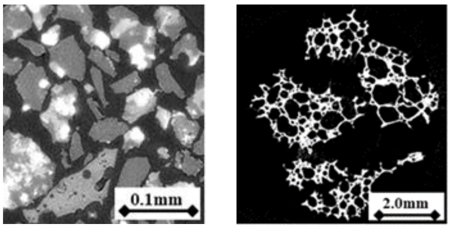
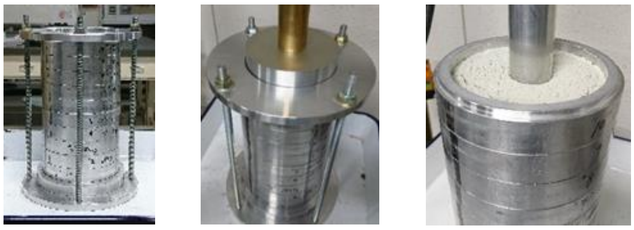
Figures



(a) FJS-1 *(b) SS-1*

Figure 1: *X-ray CT images of materials*



(a)sedimentation *(b)1D compression* *(c) rod penetration*

Figure 2: *Setup of three types of experiments*

Granular free-surface flow: Comparison between DEM and μ(I)-rheology

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Keywords: granular flow, free-surface flow, gravity-driven flow, μ(I)-rheology, DEM

Abstract

We have performed a systematic simulation study of dry, granular, gravity-driven, free-surface steady flow in two dimension, investigating the rheology of cohesionless granular particles in rough inclined plane geometries by discrete element method (DEM). DEM simulation results are compared to a widely accepted μ(I)-rheology model. Microscopic parameters such as coefficient of inter-granular friction and particle size distribution are changed to investigate the influence on macroscopic.

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Figures

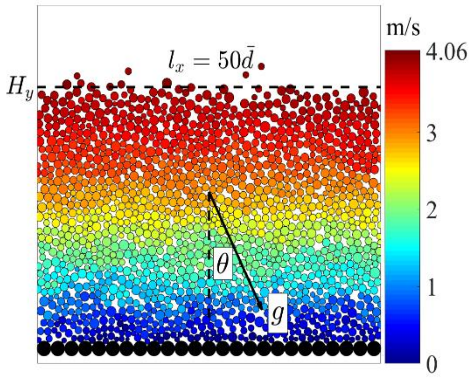

Figure.1 Snapshot in DEM simulation with 1500 free particles ($\mathbf{3\Sigma = 0.5}$) and inclination $\boldsymbol{\theta = 26}^\circ$ in steady state. The simulation cell is periodic in x-direction. Fixed particles (black) form a supporting base. Colors indicate the particle velocity magnitude, from blue to red (slow to rapid)

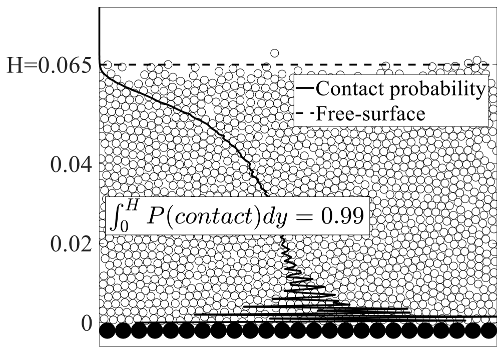

Figure.2 Definition of free-surface: solid line shows the particles' contact probability at the height y and is added up from base (y=0) to some height (y=H). We define the height H where the sum reaches 0.99 as the position of the free-surface (dash line).

$$\mu(I) = \mu_s + \frac{\mu_2 - \mu_s}{I_0/I + 1} \qquad (1)$$

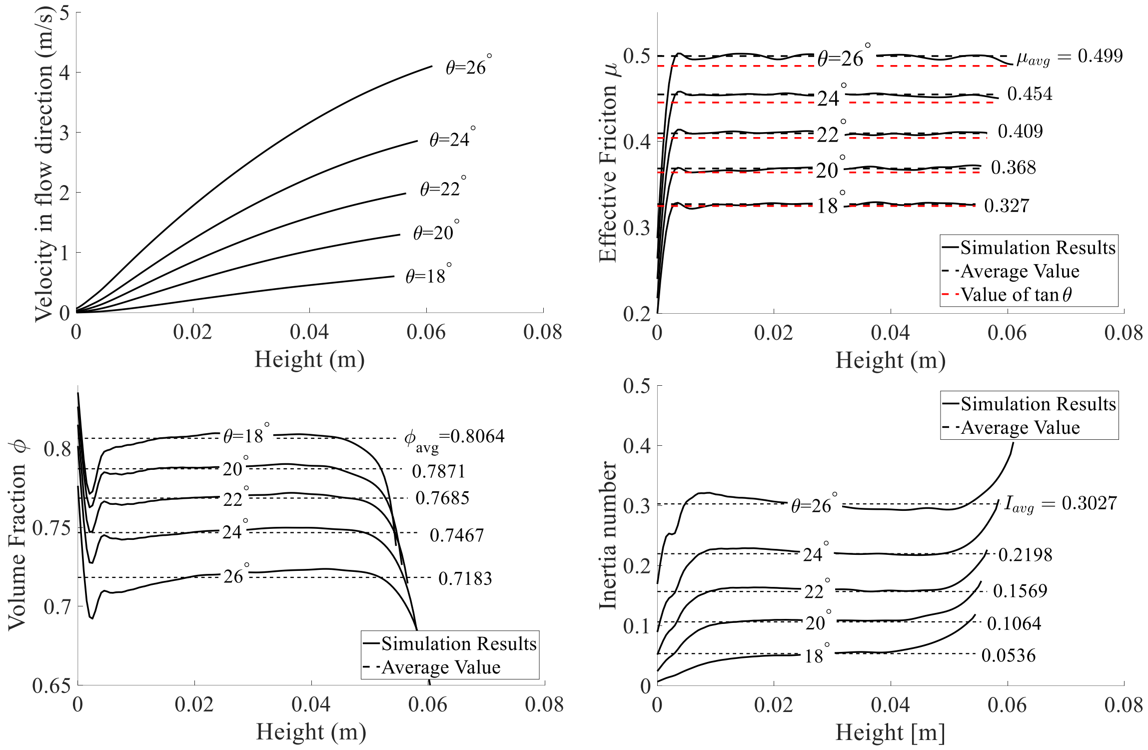

Figure.3 *Depth-profiles of velocity field, volume fraction, effective friction and inertial number of different slope angle.*

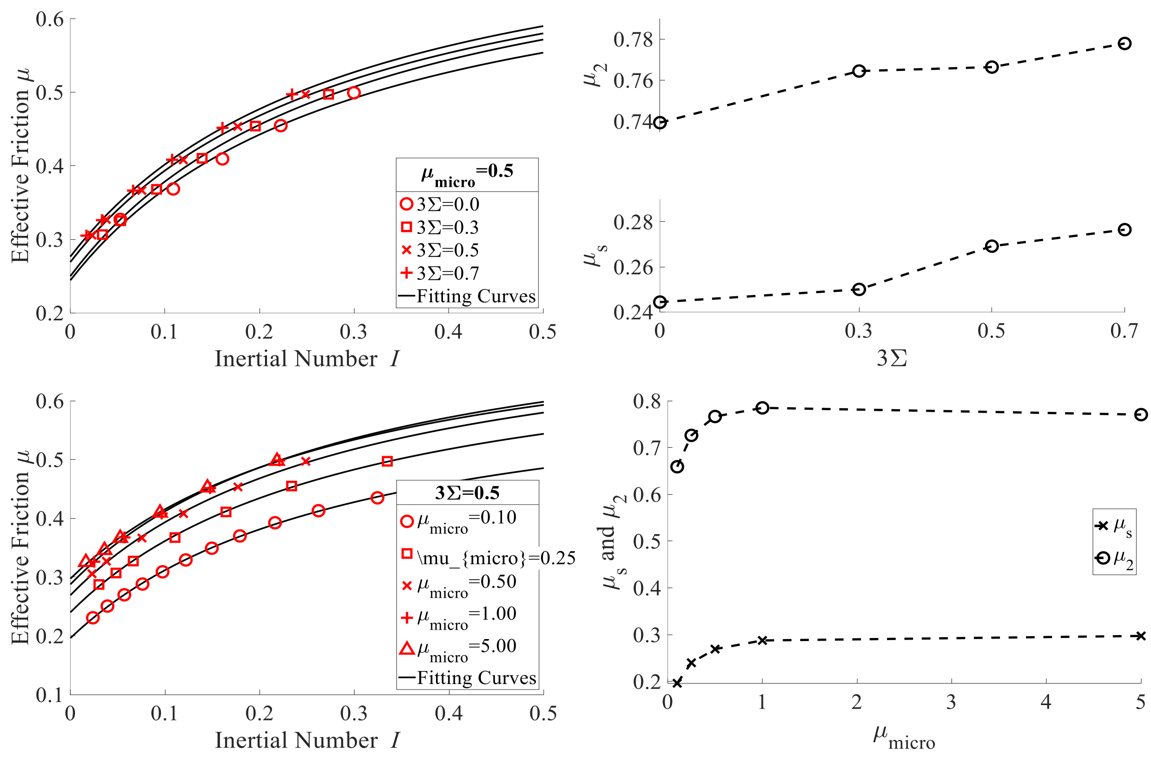

Figure.4 (left) Fitting results of effective friction $\boldsymbol{\mu}$ vs. inertial number I according to Eq.1. (right) Relation between particle size distribution 3$\boldsymbol{\Sigma}$, inter-particle friciton $\boldsymbol{\mu_{micro}}$and $\boldsymbol{\mu_s}$, $\boldsymbol{\mu_2}$

Experimental Contact Mechanics During Uniaxial and Triaxial Granular Compaction

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Keywords: granular materials, inter-particle force, energy dissipation, tomography, diffraction

Abstract

Particle rotations, contact slip, twist and roll, and contact energy dissipation play fundamental roles in the mechanics, stability, and inelastic behavior of granular materials. Despite their importance, these quantities have not yet been fully characterized in 3D granular materials because they involve processes occurring at micro- and nano-scales that are challenging to measure. In this work, we present new results from two experiments that provided access to these particle- and contact-level quantities. In particular, we combined *in-situ* X-ray computed tomography (XRCT) and 3D X-ray diffraction (3DXRD) to determine particle kinematics and contact fabric during uniaxial and triaxial compaction of approximately 900 nearly-spherical 150µm diameter sapphire particles. By combining XRCT and 3DXRD data sets, we calculated inter-particle forces using the method of Hurley *et al.* (2016), contact slip and roll distances (with <1µm resolution), contact twist angles (with 0.05° resolution), and contact energy dissipation (with nJ resolution) for all contacts during more than 10 macroscopic strain increments in each experiment. We found that inter-particle normal forces, contact slip and roll distances, contact twist angles, and contact energy dissipation each obeyed a power law distribution below their mean values and an exponential distribution above their mean. The power law distributions were stress-independent for both experiments, while the exponential distributions exhibited variation with applied load for the uniaxial experiment only. We found that energy dissipation calculated by combining slip, roll, and twist calculations with inter-particle forces agreed with a macroscopic energy balance. Dissipation due to slip at particle contacts was responsible for the majority of energy dissipated during compression of both systems. Although contacts exhibiting greater than the mean inter-particle force constituted less than half of the contacts in both experiments, these contacts were responsible for 70-80% of the total energy dissipated. This work demonstrates a new application of combined XRCT and 3DXRD measurements and provides access to important processes occurring at sub-millimeter length scales in stiff, frictional granular media.

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Soil-Structure interaction for shearing problems

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Keywords: interface, material model, shearing phenomena

Abstract

The structural performance of many geotechnical systems (e.g. axially-loaded deep foundations), depends on a shearing effect at the soil interface, which may govern the whole soil-structure interaction. Experimental investigations have shown that this interaction is mainly localized within a narrow soil layer next to the structure. If the loads are cyclic, a contraction of the soil at the interface may arise (net volume loss), possibly leading to a stress relaxation and thus to a loss in bearing capacity. This complex phenomenon, which may take place for instance along axially loaded offshore piles, is related to different factors such as roughness of the contact body, normal pressure at the interface, soil density and soil grading, just to name a few.

In this work, a constitutive model in the framework of Generalized Plasticity [1] for sandy soils has been chosen to be adapted for the interface zone. From the direct shear experiments [2] a sandy soil at loose and dense states under different normal pressures is considered. The adapted constitutive model is able to reproduce contraction and dilatation of the soil according to its relative density and it shows a good agreement with the experimental data.

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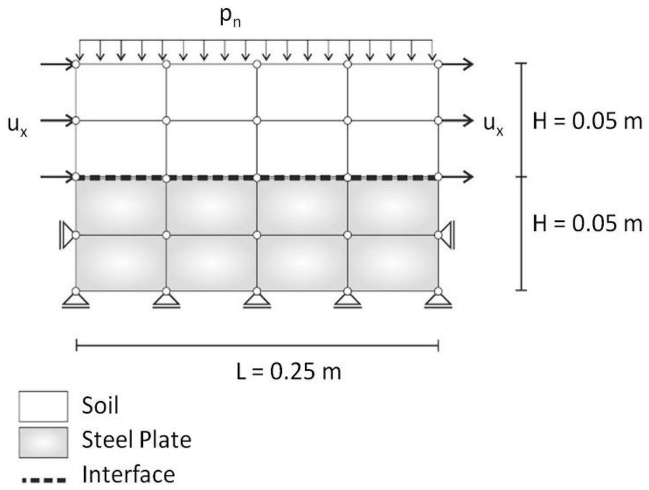

Figure 1: Boundary value problem of direct shear test

Multiscale model of partially saturated media based on a pore-network approach and lattice Boltzmann method

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Keywords: Liquid morphology, lattice Boltzmann, multiphase flow, pore-network, unsaturated media.

Abstract

Multiphase flows through porous media are widespread in many natural and industrial processes. Some examples include infiltrated rainwater into soil, storage in underground reservoirs, riser reactors, gas-liquid flows in evaporators and condensers, fluidized beds, etc [1-2].

Flow through porous media is simulated using the multicomponent Shan-Chen lattice Boltzmann method [3-4] (see figure 1). The evolution of capillary forces, fluid morphology and water content are evaluated during the drainage of a granular assembly with a relatively uniform distribution of spheres.

In order to optimize the computation resources, we present a hybrid model that combines the efficiency of the pore-network approach and the accuracy of the lattice Boltzmann method at the pore scale [5]. The granular assembly is decomposed into small subsets (see figure 2), in which lattice Boltzmann simulations are performed to determine the entry pressure p_e, the primary drainage curve and the liquid morphology for each pore throat. In each elementary problem that is solved with the LBM, both phases (typically water and air) are initially in equilibrium. Then, the fluid-fluid interface is displaced as the capillary pressure increases (see figure 2c). When the capillary pressure reaches the entry pressure p_e, the non-wetting phase (air) invades the pore body. p_e is determined for all the subsets and the global problem is assembled and solved at the network scale [5].

This technique enhances a full analysis without simulating all the pore throats of the granular assembly (empty pores and isolated cluster with no flux are excluded in the LBM simulations). Thus, the multiscale coupling takes advantage of both Pore-Network and LBM reducing the computational cost.

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Figures

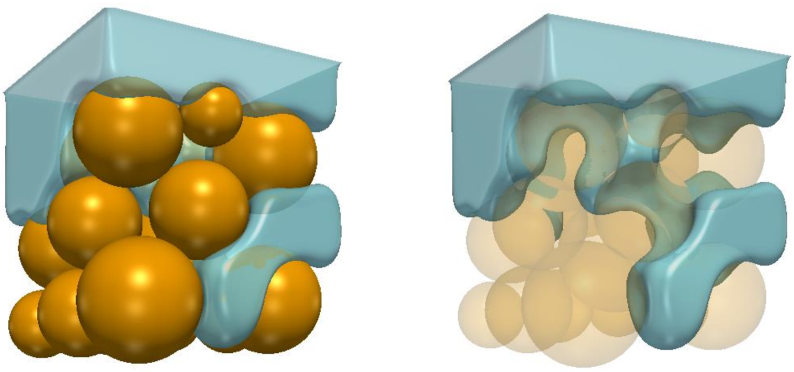

Figure 1: *Distribution of wetting phase during a drainage simulation of a 20 sphere packing. The blue isosurface indicates the interface between the two fluids. For the sake of clarity, the right part of the figure includes translucent spheres.*

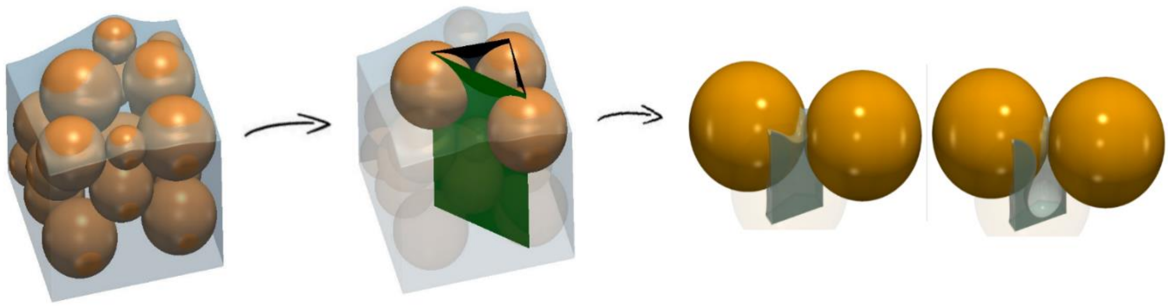

Figure 2: *Decomposition of the granular assembly (a) into small subsets (b). Each subset is made up of 3 spheres (c). By increasing the capillary pressure, the interface is displaced towards the bottom. When the entry pressure is achieved, the non-wetting phase penetrates the pore body. Notice the translucent third sphere in figure c.*

Local organisation of clay particles and its relation to volume change of remoulded clays

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Keywords: Multiscale investigation; Kaolin; Triaxial tests; Microstructure; Scanning Electron Microscopy; X-ray Microtomography

Abstract

This experimental work aimed to identify the local mechanisms of remoulded clays under consolidated drained triaxial compression tests. Both the normally consolidated and the overconsolidated saturated specimens of a remoulded kaolin clay were considered. The mechanical behaviour at a given stress level reached by following two different stress paths (i.e., the conventional constant σ'_3 stress path and the purely deviatoric stress path), as well as the mechanical behaviour along a given stress path to two different stress levels (i.e., one is below the critical state and the other is at the critical state) were investigated (Figure 1a and c). The microstructural states of the clay specimens induced by different triaxial loading paths were examined at two different scales using the scanning electron microscopy (SEM) and the X-ray microtomography (XR-μCT), respectively. Subsequently, the clay particle orientation, pore orientation and local cracks were identified by means of image processing methods. The microscopic results revealed different particle-orientation modes that could be activated during triaxial loading (Figure 1b and d). These modes seem to be highly dependent on the stress level, the overconsolidation ratio, and the stress path. Mesoscopic cracks were found to develop within the strongly overconsolidated specimen accompanied by the occurrence of dilatancy (Figure 2). The proposed conceptual modes provide an interesting approach to understand the local mechanisms particularly the dilatancy phenomenon of remoulded clays.

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Figures

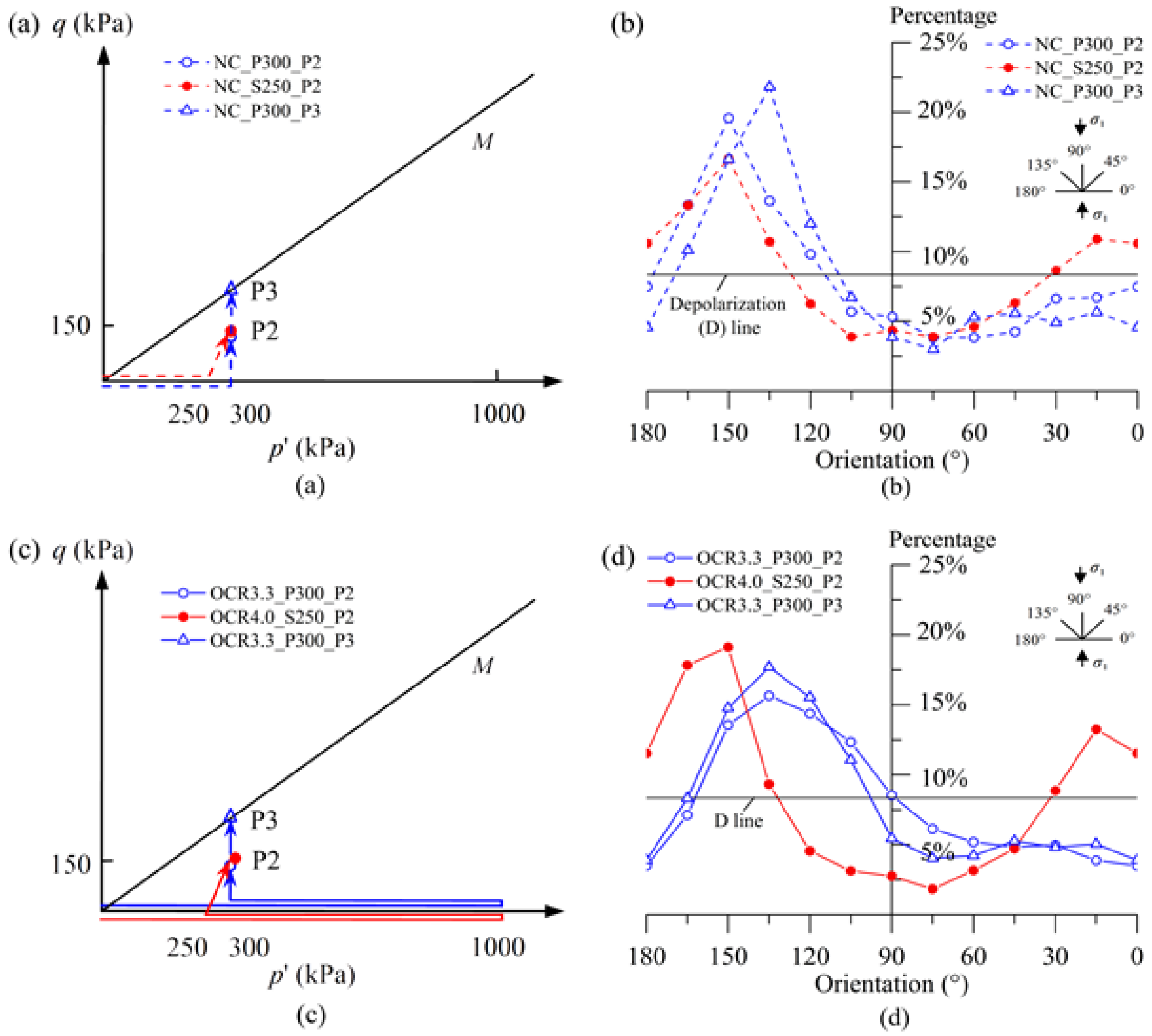

Figure 1: *Clay particle orientation of remoulded clays under various loading conditions*

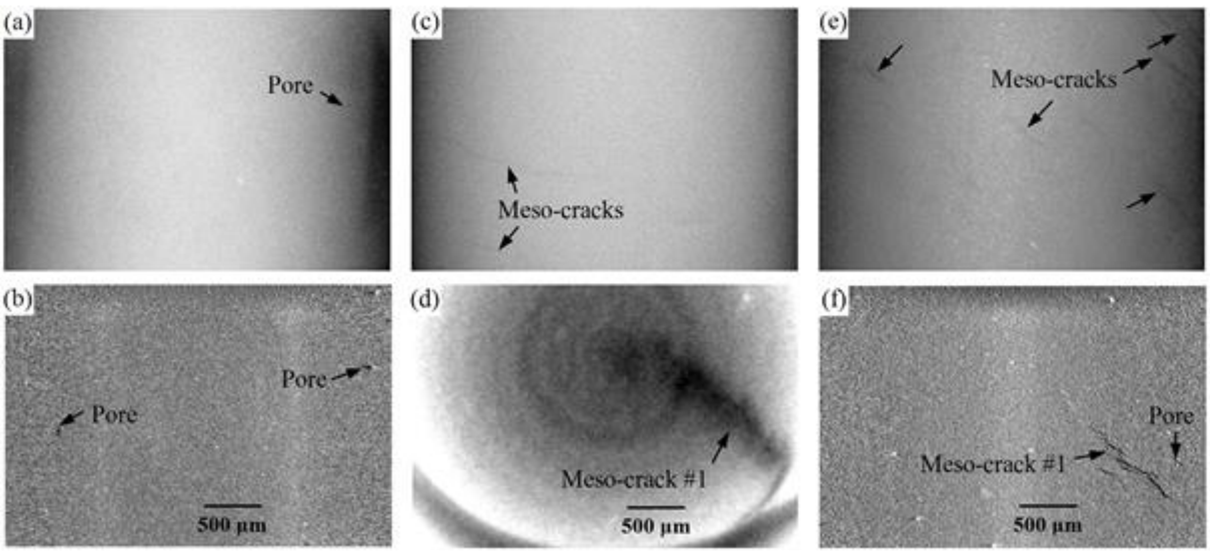

Figure 2: *XR-µCT projections and slices: (a-b) NC_P300_P2; (c-d) OCR4.0_S250_P2; (e-f) OCR3.3_P300_P2*

Anatomy of Critical State Theory: Incompleteness and its Remedy

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Keywords: Critical State, Critical State Theory, Fabric, Discrete Element Method, Anisotropic Critical State Theory

Abstract

According to classical Critical State Theory (CST) of granular mechanics, two conditions on the ratio of stress invariants and the void ratio are postulated to be necessary and sufficient for reaching and maintaining Critical State (CS). The present work challenges the sufficiency of these two conditions based on the results of a virtual Discrete Element Method experiment, which imposes rotation of the principal axes of stress with fixed stress principal values at CS. The rotation does not affect the stress invariants but induces contraction and, thus, abandonment of CS, despite the satisfaction of the two CST conditions at the initiation of rotation. The recently proposed Anisotropic Critical State Theory (ACST) remedies this lack of sufficiency by enhancing the two CST conditions by a third, related to the CS value of a fabric anisotropy variable defined in terms of a fabric tensor in conjunction with the plastic strain rate direction. Violation of this third condition by the stress principal axes rotation explains the aforementioned abandonment of CS, and the subsequent response of the virtual sample upon resumption of radial loading till reaching CS again. Thus, the three conditions of ACST are both necessary and sufficient for reaching and maintaining CS.

Scan-line void fabric tensors: importance, shortcomings and modifications

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Keywords: Void fabric, Anisotropy, Scan line

Abstract

The fabric of granular materials is related to the statistical distribution of orientation of different microstructural vector-like entities associated with the solid or the void phase. Contact normal-based fabric is the most prevalent type but it is very challenging to measure in physical experiments due to difficulties associated with the accurate determination of the contact normal vectors. Thus, void fabric appears of particular interest today as it is simpler to quantify within the current laboratory techniques for granular media, such as X-ray CT. The corresponding void fabric tensors can be determined by image-based quantification methods of voids, which are well defined and easy to apply to both physical and numerical experiments. Such a promising void fabric characterization approach is based on the scan line method originally proposed by Oda et al. [1] and modified in Ghedia and O'Sullivan [2]. In this work, existing scan line void fabric anisotropy tensors definitions are proven analytically to inherit serious shortcomings and as a result they should be modified for future use; such modifications are proposed and verified in Theocharis et al. [3].

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X-CLAY triaxial apparatus: Advanced stress paths and full field observations for hydro-mechanical probing of clays.

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Keywords: triaxial cell, clay, X-ray tomography

Abstract

A bespoke miniature triaxial apparatus designed for non-standard hydro-mechanical stress and strain controlled probing is presented. The apparatus is a hydraulically operated Bishop-Wesley triaxial cell (Bishop & Wesley, 1975) with special modifications required for testing of fine-grained soft soils in various non-standard stress paths. The shortened drainage path associated to the miniature sample size, 10 mm diameter and 20 mm in height, reduces radically the test duration. Further adjustments are the membraneless configuration (Iversen & Moum, 1974) and the corresponding sample mounting procedure that both assure minimum sample disturbance. The shorter test duration and compact size enables the execution of in-situ experiments with drained load paths on low-permeability clays in an X-ray tomograph. Quantifiable measures on the deformation characteristics of the sample will be extracted by Digital Volume Correlation of obtained tomography images. The objective of this apparatus is to combine advanced stress path probing with the corresponding internal deformation fields to reveal the complex mechanics of saturated (natural) fine-grained soils.

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Figure

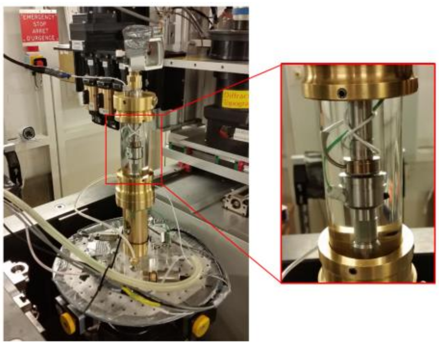

Figure 1: *The XCLAY triaxial apparatus inside the ID19 hutch of ESRF microtomography beamline (left) and a magnification of the mounted sample (right).*

Experimental research of the evolution of desiccation cracks

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Keywords: Clays; Kaolin; Digital Image Correlation (DIC); Cracking; Desiccation; Shrinkage; Suction; Void Ratio; Soil-Water Characteristic Curves.

Abstract

The objective of this experimental work was to try to understand the crack initiation and propagation phenomenon during drying. The studied clayey material is the Kaolin K13, which contains high percentage of kaolinite particles. The initial state of the tested sample, before dying, was saturated at about 1.2 w_L, the tests have been performed under controlled desiccation.

Digital Image Correlation (DIC) analysis using Vic-2D allowed to characterize first the shrinkage phenomenon, and then, the initiation and propagation of cracking network operated during the desiccation. Thanks to ImageJ software, influence zones, of large strains development all around the cracks, were precisely characterized. On the other side, to identify the unsaturated properties of the clayey material, volume change measurements of specimens were achieved using the Kerdane-liquid replacement method. Subsequently, the method permits to deduce parameters such as: gravimetric water content w, shrinkage limit w_{SL}, degree of saturation S_r and void ratio e.

The results show that propagation of cracking might be divided into three phases: (i) the initiation and propagation of primary cracks; (ii) the connection of primary cracks (initiation of secondary cracks); (iii) the formation of cracking network. The propagation of the cracks and shrinkage seem to develop under a constant relative humidity rate. The cracks propagation appears thus as independent of the *RH* rate, until a given water content value is reached. From this point the propagation velocity of cracks decreases to zero.

Finally, the study highlighted that the influence zones area appears before the initiation of cracks. At the end of desiccation, the cracks form a network associated to zones of maximum strains.

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Figures

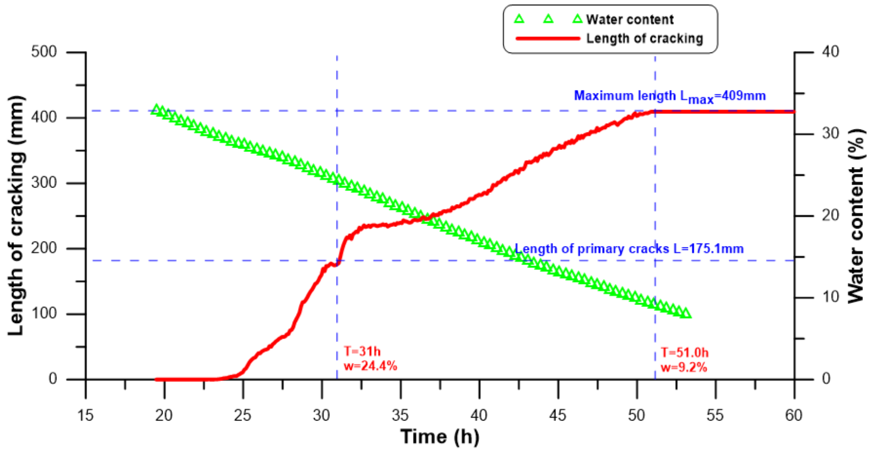

Figure 1: *Initiation and propagation of the crack*

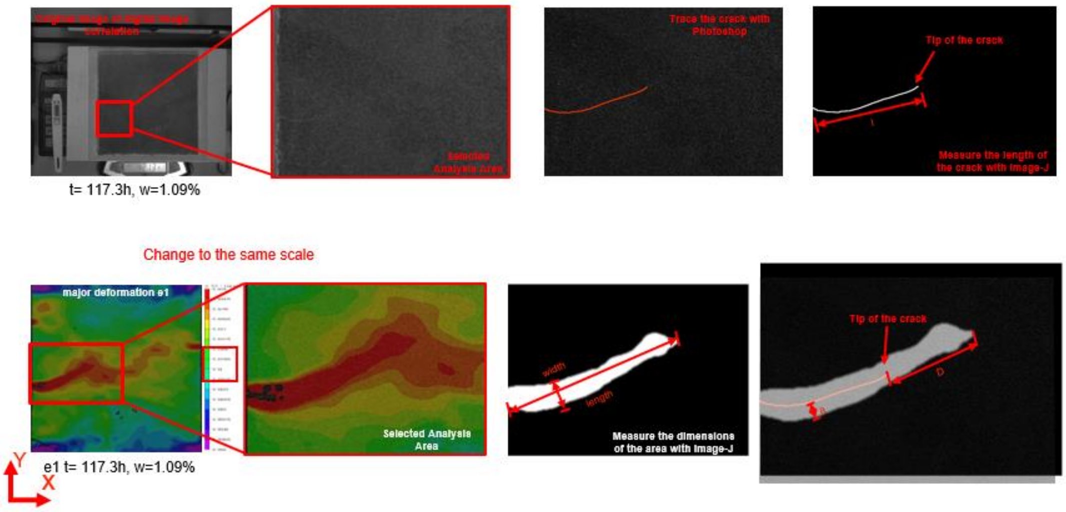

Figure 2: *Analysis of the influence zones around the crack*

Experimental and numerical study of the drying process of a clay soil

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Keywords: Kaolin; Unsaturated soil; Capillary pressure; Hydromechanics; Simulation

Abstract

The clay soil is composed of solid skeleton and porous, and can be studied in the framework of porous media. During the drying process, the initial saturated clay soil deforms mainly due to the changes of water content and capillary pressure. With the further increase in capillary pressure, the soil cracks. In fact, the deformation and the stress in clay soil tightly related with the water content and capillary pressure. Therefore, it is of great interest to understand the changes in capillary pressure and water content within the clay soil during the drying process. However, it is difficult to obtain these field variables by experiments alone. Therefore, the numerical simulation could be good choice for deeper understanding of the dry process in clay soil. In current research, the combined numerical simulation and laboratory experiments research were conducted for investigating the drying process of a remolded clay soil composed of Kaolin. The current article is organized as following: firstly, the laboratory experiment research on the drying test of an initial saturated remolded kaolin clay is presented. The experimental results, such as the humidity, temperature in the drying container, the weight of the specimen etc. were analyzed. Then, according the laboratory experiment, the numerical model was created and the model parameters were characterized according the experimental results. Finally, the numerical results were comparing with the laboratory observation. This research is the basis for the further study of the cracking process of clay soil due to drying.

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Figures

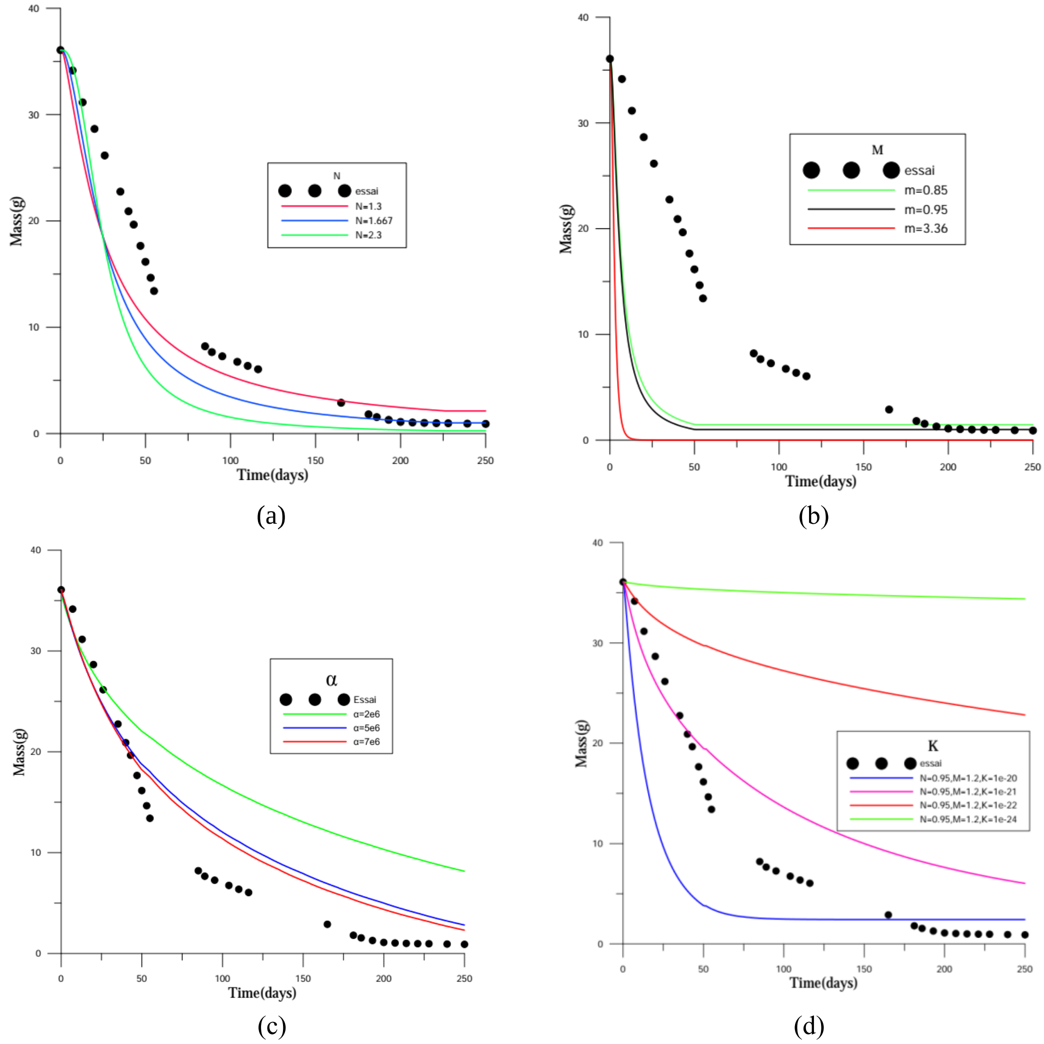

Figure 1: *Influence of experimental parameters on numerical results*

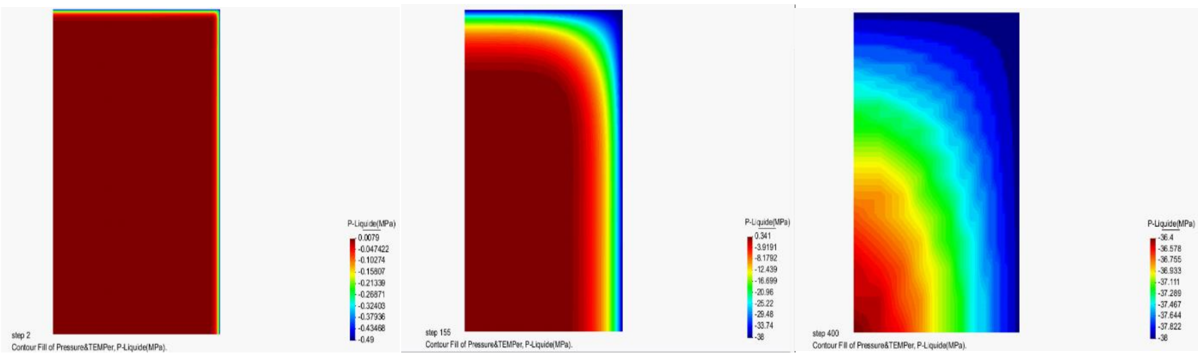

Figure 2: *Distribution of capillary pressure at different times in soil specimen*

Standing granular jumps in flows down a slope

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Keywords: numerical DEM, X-ray experiments, granular flows, jumps,

Abstract

The rapid transition between a fast shallow flow and a thick slow flow is called a jump. The jumps during free-surface flows have been widely studied in hydraulics but were also observed in granular media [1,2].

We present a detailed study of standing granular jumps following three main axes of research:

i) A theoretical study [3] established a general relation based on mass and momentum equations to predict the height after the jump and was carefully checked against existing experimental data. However, this equation highlighted the need of further investigation on the length of the jump, the effective friction, or the density evolution, in order to become fully predictive.

ii) Discrete Element Method simulations have been developed [4] to recreate the standing jumps observed in the laboratory tests. All the parameters of the jumps were accessible, so it was possible to study the influence of a number of microcospic and macroscopic parameters on the jump features and highlight the existence of several jump patterns.

iii) Laboratory tests have been performed using an innovative non-invasive dynamic technique using X-ray radiography [5], which allowed us to measure the density field within the flows of spherical particles (glass beads) and elongated particles (rice). In addition to confirming some of the results obtained from the discrete element method simulations for spherical particles, another type of jump pattern was evidenced with the elongated particles.

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Experimental study on runout distance of dry granular flow

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Keywords: Dry granular flow, grain properties, runout distance

Abstract

Rock/soil avalanches are common geo-disasters, and their risk evaluation for the structures in the deposition area is an urgent issue. Being different from soil-water mixture flow, dry granular flow causes discrete grains being scattered in front of mass flow. Such discrete grains are sometimes rocks of several meters in size, and damage the structure by their impact force. Therefore, it is important to evaluate not only mass runout distance but also “particle” runout distance which must be a function of slope height, total sliding mass, grain size and so on. The previous studies on rock/soil avalanches seem to focus mainly on the mass runout distance 1-3) and the effect of grain properties on those runout is not clarified yet. Therefore, in the present study, we carried out a series of laboratory experiments on inclined chute flow (Figure 1) using various types of sands and gravels (Figure 2) 4). Note that K1, K2, K3A and K3B are all Kashima sand sieved in different size. An example of the final deposition is shown in Figure 3. Here the mass runout distance is defined by the distance from the end of the chute to the furthest edge of the continuous deposition of the grains. Figure 4 summarizes the mass runout for different sands and gravels. It was found that the mass runout has a local peak around the grain size of 1 to 2 mm for all grain volumes (0.5, 1.0 and 2.0 liters), and this tendency is not fluctuated by the difference of grain shape (Kashima sands are round, while other sands are much more angular). The mechanism of this tendency is not very clear including the effect of system size. Regarding the particle runout, an image analysis was adopted to compute the distribution of scattered grains, and the results for Kashima sands are shown in Figure 5. The figure shows that the resulting distributions can be fitted as power-law distribution, and the exponent (the inclination of the plots) seems to decrease with increasing grain size. Note that the distribution for K3A is affected by the edge wall of the deposition plate whose length is 1.8 m. The mechanism of this observation is also under investigation. The mass runout and the particle runout should be correlated, and the energy distribution mechanism should be a key issue.

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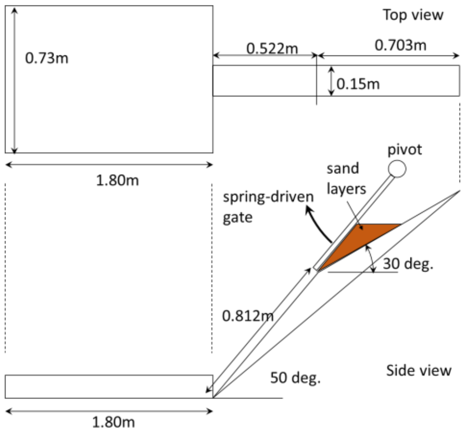

***Figure 1:** Experimental setup*

***Figure 2** Materials used in this study*

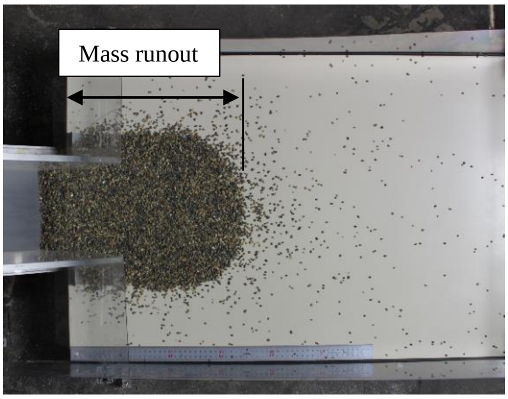

***Figure 3:** An example of final deposition*

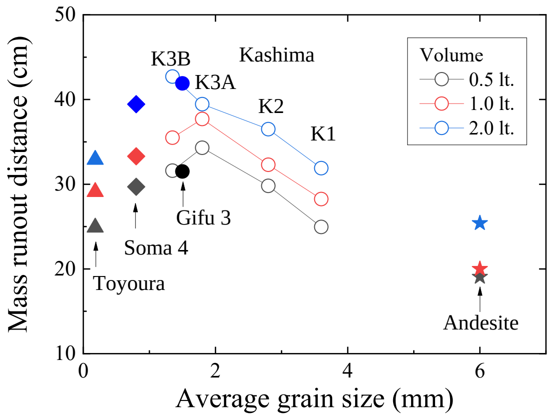

***Figure 4** Mass runout distance for various materials*

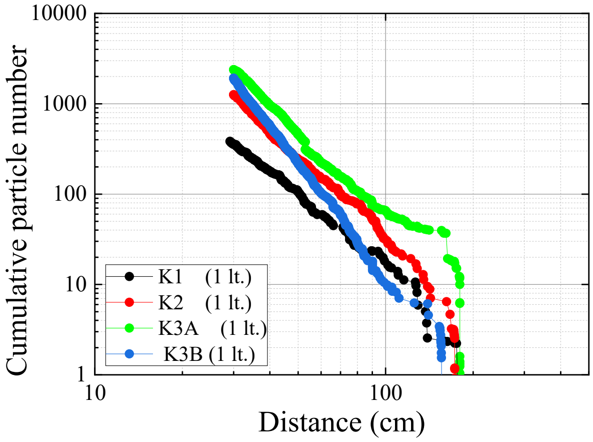

***Figure 5:** Distribution of scattered grains for Kashima sands*

A DEM investigation of the micromechanics of non-active clays

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Keywords: DEM, clay, micromechanics

Abstract

The micromechanical behaviour of clays cannot be investigated experimentally in a direct fashion as opposed to granular materials, due to the small particle size. A suitable approach for understanding the mechanical processes occurring at the microscale would consist of selecting possible inter-particle interactions on the basis of indirect experimental evidence at the particle scale, and translating them into a DEM framework. In this work, a simple two-dimensional DEM framework is presented. The contact laws are inferred from existing indirect experimental evidence regarding the mechanical interactions at the edge-to-face contact and the electro-chemical repulsion between particle faces (i.e. particle-to-particle interactions were modified experimentally by varying the pore-fluid chemistry). The simple DEM framework is successfully challanged against its ability to reproduce qualitatively the main features of the macroscopic response of non-active clays during one-dimensional compression for different pore-fluid chemistry, this confirming the validity of the micromechanical concept underlying the proposed contact laws.

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Figures

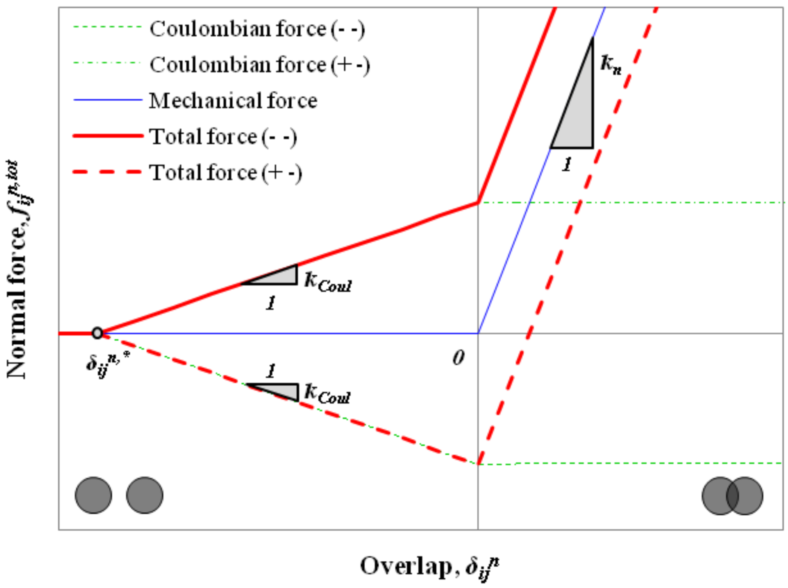

Figure 1: *Normal contact law*

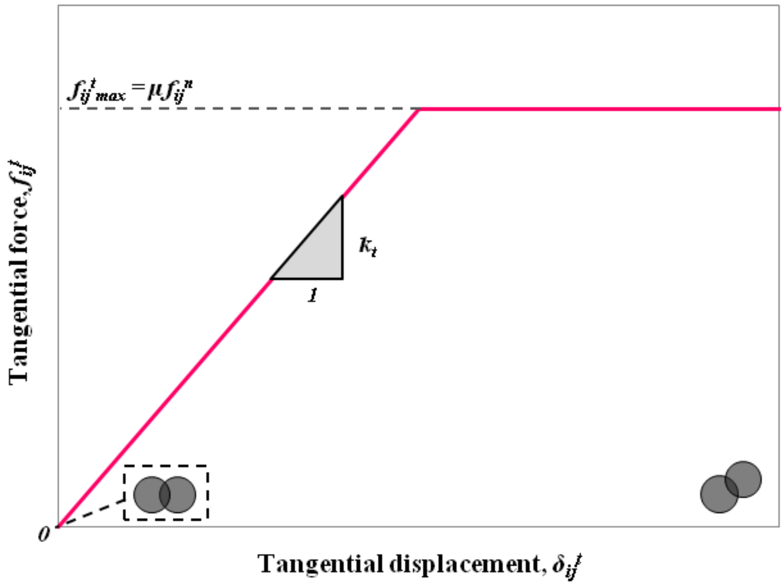

Figure 2: *Tangential contact law*

Why does geomechanics need tube-shaped grains? DEM insight into grain crushing

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Keywords: DEM, cluster model, grain strength, grain crushing, void ratio, 3D simulations, oedometric and isotropic compressions.

Abstract

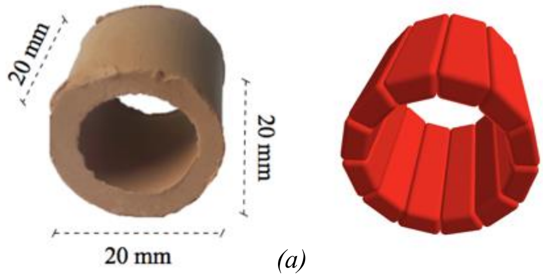
A number of studies, both numerical and experimental, are dedicated to grain crushing in the various granular materials. Those investigations concern both a particle with extensive breakage capability and an assembly of highly crushable grains. However, most of the research engage either a natural soil or a granular material with analogous features like a grain shape.

The study presented herein concerns an innovative granular material composed of brittle, tube-shaped grains that are backed from clay (Figure 1a); hereafter called shells. On account of the established geometry, a value of void ratio e_{grain} for the individual grain is 1,06. Therefore, the void ratio e of the material is increased up to high value of around 2,5. These grains are integrated into the precast concrete linings for the underground constructions such that its compressible behavior is activated (Andra's & CMC patent). This technology called VMC (Voussoir Monobloc Compressible) will enable an optimization of tunnel dimensions such that one can construct resistant and effectively working tunnel.

In case of the brittle material such as baked clay, that shows itself low ability of being compressed, the high compressibility of the granular structure originates mainly from grains breakage. The internal voids of tube-shaped gains guarantee significant amount of free space and therefore allow high densification of such granular assemblies. When a shell crushes, the internal void is released and a high compressibility of the sample is observed. A numerical study of the mechanical behavior of an assembly is possible only with a micro-scale model of a single shell capable of reflecting its fragmentation. To this end, the first step in this work was to model a brittle fracture of the shell by means of a discrete element method (DEM) proceeded with a tool named Rockable, developed in the 3SR group (Univ. Grenoble Alpes, France) by Vincent RICHEFEU. The strategy consists in modelling the shell shape as an assembly of sectors that are joined where the shell is expected to break in case of radial compression [1]. For that reason, the shell is composed of 12 sphero-polyhedral prisms adjoined so that the pre-defined discontinuities are radial plans (Figure 1b). The sectors are connected through 4 points located in each of their corners. To prevent the opening of the crack (mode I fracture), an elastic cohesive force acts up to a threshold force value, in the normal direction of each contact point. For the in-plane shear force (mode II fracture), the same solution is used in the sliding direction. To break the links loaded in both directions, a yield criterion is defined by accounting the two force thresholds. This cluster model was calibrated using a radial compression test on single shell (Brazilian test) [1].

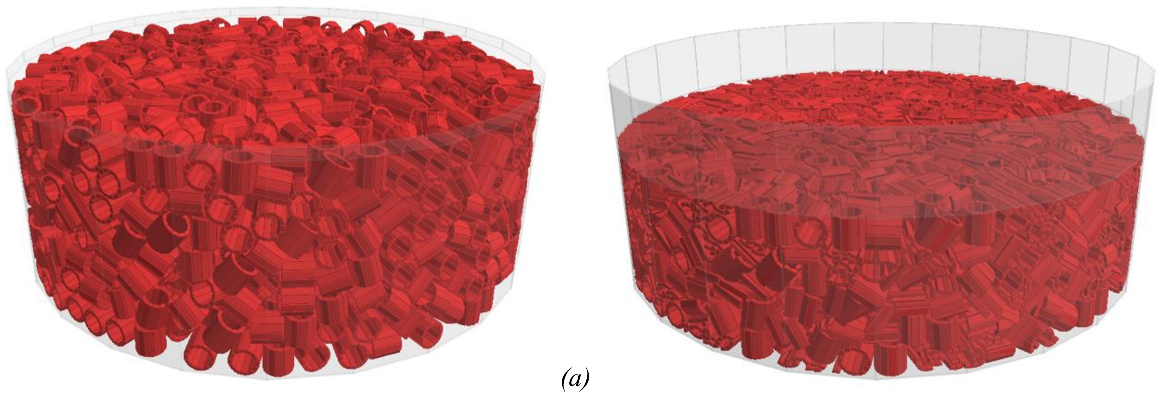
This discrete model of the brittle grain was then used for the simulations of high pressure oedometric and isotropic compressions on the assemblies of shells (Figure 2). The analysis of the mechanical behavior was performed, paying special attention to grain crushing. Along each simulation we quantified the shells breakage and we followed the evolution of the grading. The analysis of void ratio $e = V_V/V_S$ according to classic division for void (V_V) and solid (V_S) phase showed standard relationship – decrease of void ratio with increase of the stress. This evolution was checked with an existing model [2]. Furthermore, we adapted the perception of the void and solid volumes for tube-shaped grains due to a large amount of internal void locked inside intact shells. This drove us to suggest a new definition of the void ratio e^{*}. Then, one can observe an increase of e^{*} till all grains are broken. The grain strength varies due to change of the geometry (more material) or increase of the strength (change of the material). A parametric study characterizes how grain strength influence the mechanical behavior and compressibility of this granular material. Finally, this analysis and the observations will result with a model relating e^{*} with stress, incorporating a prediction of breakage based on the strength of grain.

Figures



(a) *(b)*

Figure 1: *A tube-shaped grain: (a) – backed from clay, (b) – numerical representation with cluster model.*



(a) *(b)*

Figure 2: *A simulation of an oedometer test: (a) – an initial cylindrical sample with a geometry decbribed by a diameter 35 cm and a height 12 cm composed of around 2000 shells, (b) – the sample during the oedometric test for the strain equal to 30%.*

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Use of advanced soil constitutive models and finite element analysis to replicate soil-structure seismic interaction

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Keywords: soil-structure interaction, finite element analysis, advanced soil constitutive models, shaking table testing, earthquake engineering, pile foundation

Abstract:

Soil-structure interaction under seismic loading conditions has been receiving increased attention in recent years. A common observation is that taking into account the soil-structure interaction affects the response of the structural system when compared to the fixed conditions. Therefore, a detailed comprehension of seismic soil-structure is required to improve the understanding of the behavior of structures under earthquake events.

This work presents initial results of a use of two advanced constitutive models, namely Severn Trent model [2] and Hypoplastic model for granular material [4]. A finite element analysis of shaking table tests [2], [4] has been carried out in Abaqus. Calibration of the two models is briefly presented followed by the results of the shaking table tests. Firstly, a single pile in a single-layer soil profile has been modelled, free pile head condition, no rotation pile head condition and a case with a single degree of freedom oscillator have been analyzed under the real earthquake time history [4]. Secondly, a pile group of five piles in a two-layer soil profile will be simulated under harmonic excitation [2]. The results are presented in the form of the pile bending moments and soil displacement fields (vertical and horizontal).

Further studies to be carried out during the PhD work course will be suggested in order to improve the prediction of the models.

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Figures

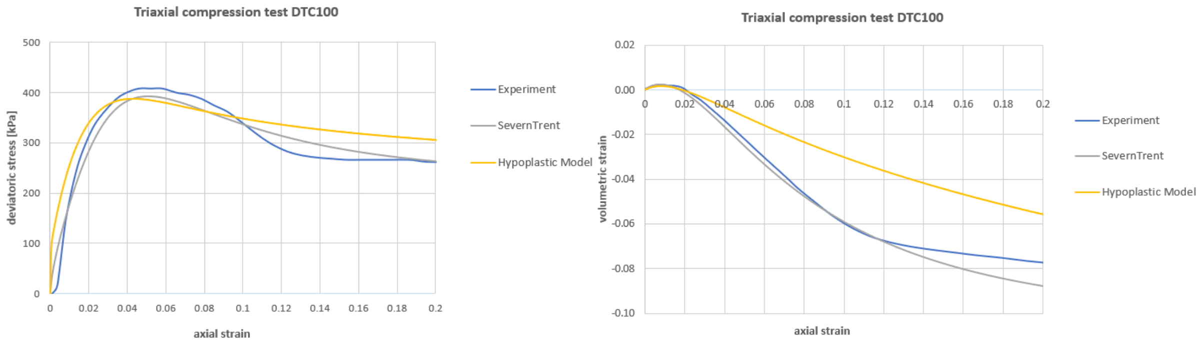

Figure 1: *Calibration of the two models for Leighton Buzzard Sand, fraction E.*

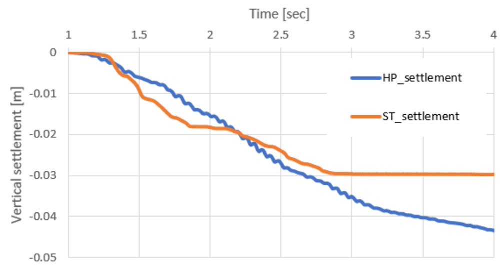

Figure 2: *Development of vertical displacement in 4sec time history.*

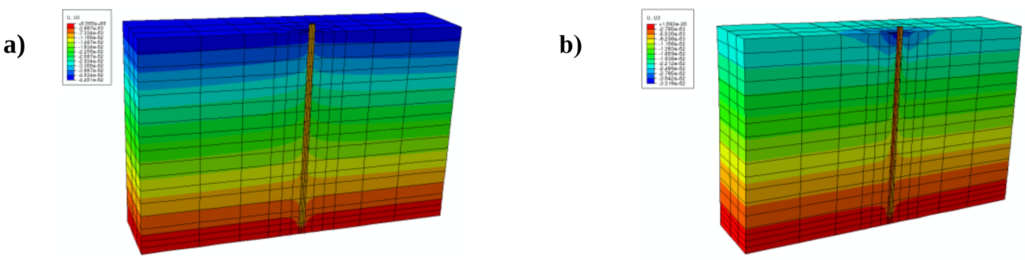

Figure 3: *Total settlement profile after 4sec time history:* ***a)*** *Hypoplastic Model;* ***b)*** *SevernTrent Model.*

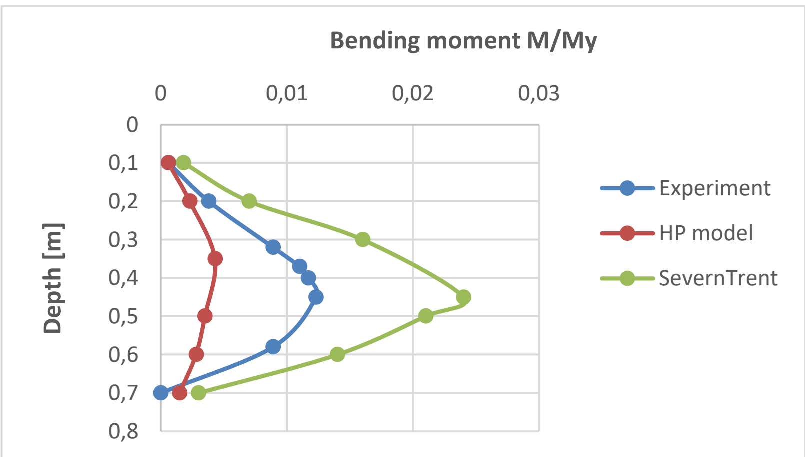

Figure 4: *Comparison of the maximum pile bending moments for single layer soil profile, free head pile condition and Tolmezzo earthquake input time history (2-scale).*

Tensile and compressive failure of micro-concrete: from mechanical tests to FE meso-model with the help of x-ray tomography

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Keywords: meso-scale FE modelling, micro-concrete failure, local failure mechanisms, morphological description, x-ray tomography, *in-situ* evolution, Digital Volume Correlation

Abstract

In this work, concrete is studied at meso-scale (aggregates, macro-pores and mortar matrix), where the local failure mechanisms are known to drive the macroscopic behaviour of the material. In order to highlight the impact of the mechanical and morphological properties of each phase (along with their interfaces), micro-concrete specimens are prepared with rather small dimensions (11 mm diameter and 23 mm height) compared to the size of the largest heterogeneities (macro-pores reaching 2 mm and aggregates reaching 3 mm).

X-ray tomography is used to reliably obtain the morphology of the heterogeneous meso-structure [3], which is then given as an input to a 3D FE meso-model with enhanced discontinuities [2] and uniaxial tensile and compressive tests are simulated. In parallel, a suitable experimental set-up compatible with the x-ray scanner of Laboratoire 3SR is developed, allowing the micro-concrete specimen to be scanned while it is under load. This permits a direct validation of the meso-model. Meanwhile, a valuable insight of the 3D fracture mechanisms while the load progresses is also achieved, with a DVC analysis [1] based on a developed software called 'SPAM'.

After identification of the numerical parameters, it is shown that starting from an x-ray scan in meso-scale, the 3D meso-model is capable to predict the macroscopic behaviour and the failure patterns of the material in tension. As for the more complex failure patterns observed in compression, the meso-model is capable to follow the macroscopic response.

As an illustrative example, Fig.1 shows the response of a micro-concrete specimen under uniaxial tension. Fig. 1a shows the morphology of the micro-structure in the final loading step, where in red colour the formed macro-crack is extracted. Fig.1b shows the numerically computed crack patterns having as an input the morphology taken from the first scan, before loading. A very good agreement between the two responses is shown, where a typical macro-crack for fracture mode I is formed, crossing the cylindrical specimen, indicating that the explicit representation of the meso-scale heterogeneities seems to be the key feature of the presented meso-model.

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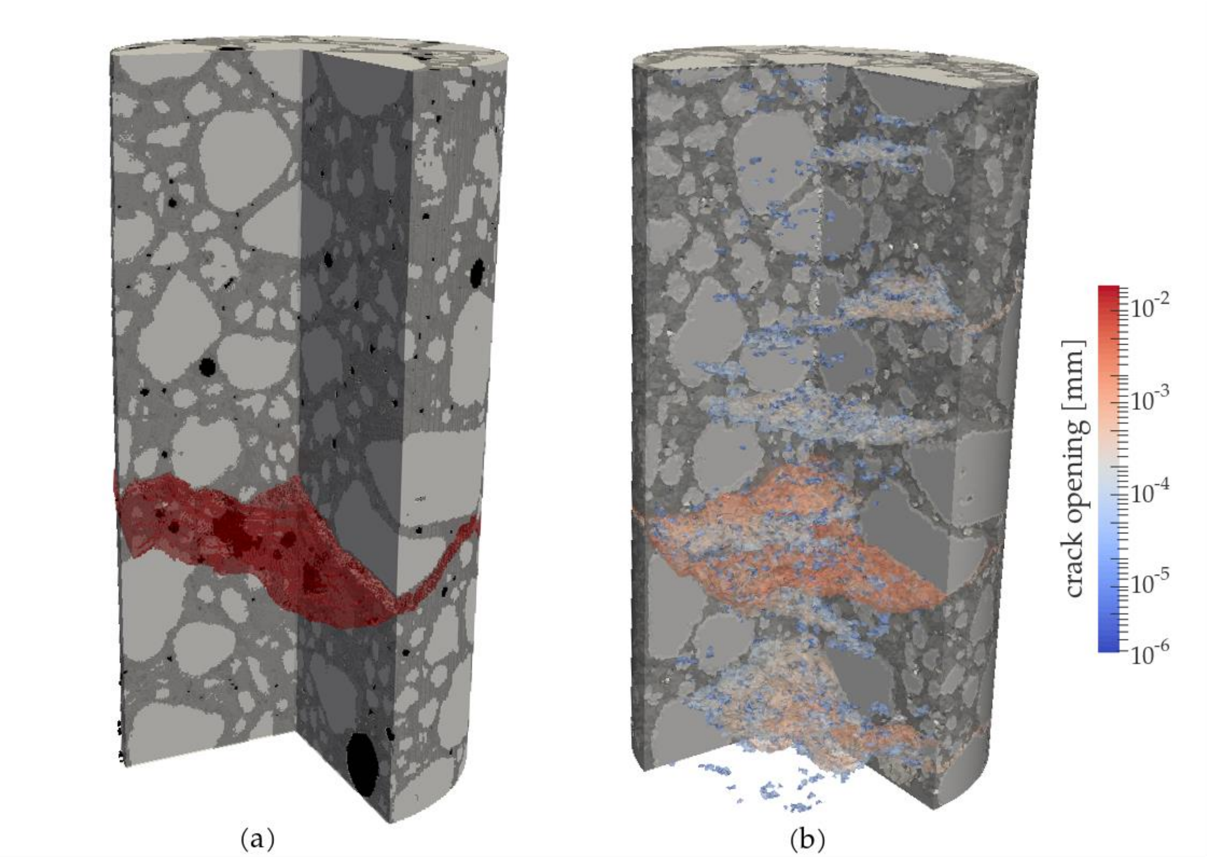

Figure 1: *Comparison between: (a) experimental macro-crack (coming from the segmented 3D image of the post-peak x-ray scan) and (b) numerical crack patterns (at the end of simulation)*

Characterization of Diffuse and Localized Deformation in a Porous Sandstone: A True-Triaxial Experimental Study

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Keywords : Strain Localization, True Triaxial Testing, Digital Image Correlation

Abstract

In the past 50 years, following the development of several true triaxial apparatus (TTA), a number of studies using polyaxial compression tests have demonstrated the effect of the intermediate principal stress on deformation and failure mechanisms in mechanically isotropic rocks [1]. While the effort of these experimental campaigns have been to explore alternative stress paths, the role of stress tensor invariants on diffuse and localized deformation have been scantly studied and only in a limited number of recent publications [2,3].

The purpose of this work is to explore the independent effect of the mean stress (first invariant) and the lode angle (third invariant) and its influence on deformation in a high porosity (20%) Vosges sandstone (Eastern France). The experimental work consisted of a series of ten experiments, at five different lode angles and on two deviatoric planes, using a high pressure TTA located at laboratoire 3SR [4,5].

Incremental digital image correlation (DIC) was performed on high resolution full field images acquired during the deviatoric loading phase to capture changes from homogeneous to localized deformation. It was thus possible to observe pre-peak localization and the development of deformation bands during mechanical failure of the sample and into the softening regime. The study provides a framework to evaluate and expend bifurcation theory as a way to predict failure and failure modes in porous rocks.

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Multiscale Analysis of Sand Under Load: A Novel Neutron Diffraction Based Experimental Approach

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Keywords: Granular mechanics; Full-field measurements; Grain-strain; Stress distribution; Neutron Strain Scanning; Digital Image Correlation; Plane strain.

Abstract

The theoretical enrichment of continuum models for granular materials that take into account strain localisation processes down to the microscale level (i.e., grain scale) is still ongoing and has always been highly dependent on the available experimental data and its quality. To this end, over the past few years there has been a great effort to develop new experimental approaches to provide missing information on the state of strain and stress deep inside granular media.

Neutron Strain Scanning (NSS) is a diffraction–based technique that has been successfully used to determine the force/stress distribution in granular materials under load (e.g., [1-3]), by measuring the variations in interplanar distances of crystals (i.e., the crystallographic – or grain – strains). The work presented here is part of a PhD research project that involves the development of a specially designed plane strain loading apparatus for the realisation of NSS experiments on granular geomaterials, in combination with other material testing full-field measurement methods, such as Digital Image Correlation (DIC) and Ultrasonic Tomography (UT).

Herein, a review of representative results from the first NSS – DIC experiments on quartz sand under load are presented, focusing on the potential of the suggested experimental approach. These experiments were realised at the ENGIN-X time-of-flight neutron strain scanner [4], at the ISIS spallation source in the UK, and the monochromatic stress diffractometer SALSA [5], at the reactor–based neutron source of ILL in France. The main objective is to use spatially resolved neutron diffraction to map out the evolution of grain strains under loading, so as to infer the stress distribution throughout the material, from a continuum point of view (i.e., force chains between grains cannot be visualised), and its evolution with – localised – deformation. Associating the stress distribution determined from NSS with the simultaneous measurement of the total strain field, through DIC, and traditional boundary measurements, will enable a completely novel multiscale analysis of granular (geo-) materials. In addition, the future development of the apparatus, to incorporate simultaneous UT measurements for the investigation of the evolution of the elastic properties of the material, is discussed.

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Numerical investigation of the Quicksand phenomenon using a Coupled Discrete Element - Lattice Boltzmann hydromechanical model

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Keywords: Discrete Element Method, Lattice Boltzmann, quicksand

Abstract

We present a numerical investigation of the quicksand phenomenon using a coupled Discrete Elements - Lattice Boltzmann hydromechanical model. Simulations of ascending water flows through granular deposits are performed for two cases namely under a gradually increasing hydraulic gradient and under different constant volumetric flow rates. In the first case i.e. under the increasing hydraulic gradient, the simulations show that the quicksand condition is actually reached for a hydraulic gradient very close to the critical hydraulic gradient calculated from the macroscopic analysis of classical soil mechanics, i.e. when the resultant of the applied external pressure balances submerged weight of the deposit. The simulations point out moreover that the quicksand phenomenon could be produced locally under slightly lower gradients. In the second case i.e. under controlled volumetric flow rates, the simulations show that there are three levels of flow; low flow rates that allow seepage without any destabilization, medium flow rates that cause expansion of the deposit to increase its permeability and high flow rates which may cause the formation continuous tunnel between the upstream and the downstream sides as well as sand boils.

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Figures

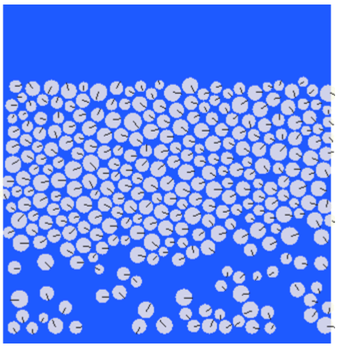

Figure 1: *Quicksand with fixed hydraulic gradient*

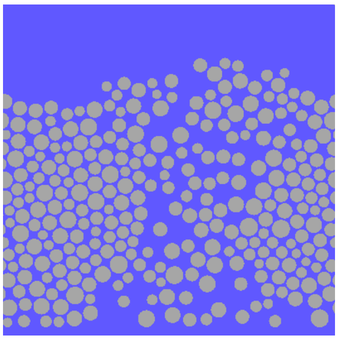

Figure 2: *Quicksand with fixed flow rate*

A depth average sph model including μ *(I)* rheology and crushing for rock avalanches

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Keywords: Rock avalanches; SPH; depth integrated models; rheology; inertia number; rock fragmentation; Frank rock avalanche.

Abstract

Rock avalanches are a particular case of landslides with a very high capacity of destruction.

In many cases blocks break while falling downhill, resulting in finer materials. In this case, avalanche material can be described as a frictional fluid. It is important to notice that friction observed in real event modelling are in general smaller than the internal friction coefficient of a granualar material. This is the result of high mobilty shown by this type of phenomena.

Among the various explanations of high mobility one is the changing in grain size of the granular particle due to fragmentation of the mass of the landslide. According to Davies (Davies and McSaveney, 2008) and to Crosta and coworkers (Crosta, Frattini and Fusi 2007) rock fragmentation is a very important phenomenon in large rock avalanches. High stresses lead to fragmentation of particles, increasing the mobility and expanding runout distances. It is shown that material that break down to finer particle tends to a self-similar fractal distribution (Casini et al. 2013).

The rheological model proposed, following the work of Pouliquen and co-workers (Pouliquen, 2002), Hatano (2007) and Gray (2014), is a combination of a frictional model based on the inertia number I , often referred to as $\mu(I)-$rheology with two crushinbg laws. As the variation of grain diameter might change the inertia number I and also the basal friction, a fragmentation law is included, following the work of Douadji and Hicher (2010) and Casini et al (2013). Pouliquen and co-workers conducted a series of experiments on laboratory flumes. For an intermediate range of inclination angle on a rough bed configuration, steady state can be observed. Therefore, in this range, frictional force is able to balance the gravity force indicating a shear rate. In this case with the hypothesis of shallow flow it is possible to recast the rheological law in terms of Froude number defined with medium velocity of the flow $\bar{u}$ and *h* the height of the flow.

The rheological law is completed with two law of crushing. The first law is based on the idea that the reduction of the grain size due to crushing follow the same hyperbolic law of the one of strength parameter of the material (Critical state line). Moreover, an alternative law based

on the concept of fractal GSD (Casini et al 2013) is considered. Both laws permit to obtain reduction of the diameter depending on the work of the basal shear stress.

The laws proposed permit, first to take into account reduction of diameter with a proper laws of crushing depending on two parameters, secondly to take into account the reduction of basal friction due to the reduction of diameter. First a sensitivity analysis was make to check the influence of the parameters on mobility. Then a real case application was proposed: Frank Slide.

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Figures

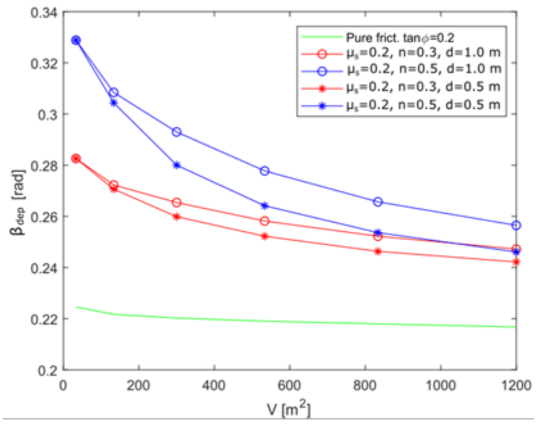

Figure 1: *Dependence of the final deposition angle β on volume of the landslide*

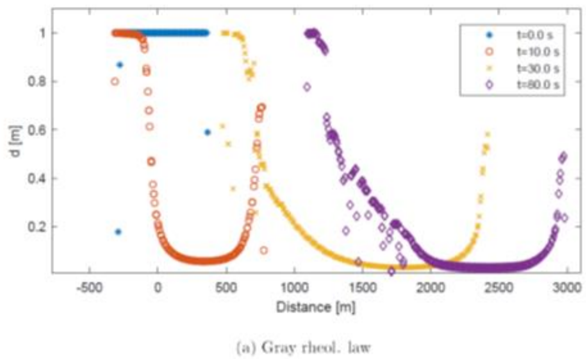

Figure 2: *Representative grain sizes along the central section at times 0, 10, 30 and 80s*

Study of one-dimensional multi-compression tests on sands

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Keywords: granular material, grain crushing, porosity, compressibility.

Abstract

This work presents the analysis of an experimental campaign carried out on three different sands (silica, carbonate and artificial). A single sample of each material is repeatedly compressed to 50 MPa under one-dimensional conditions. After each compression up to the target vertical stress of 50 MPa, the sample is sieved to quantify the evolution of grain size distribution and sampled again using the dry-pluviation technique. Figure 1 shows the typical results obtained in terms of a) grading curves and b) compressibility curves. The materials tested at multi-compression tests at high pressures change its mechanical behaviour. Several considerations have been made on the grain crushing phenomena, on the porosity state and on the compressibility.

Figures

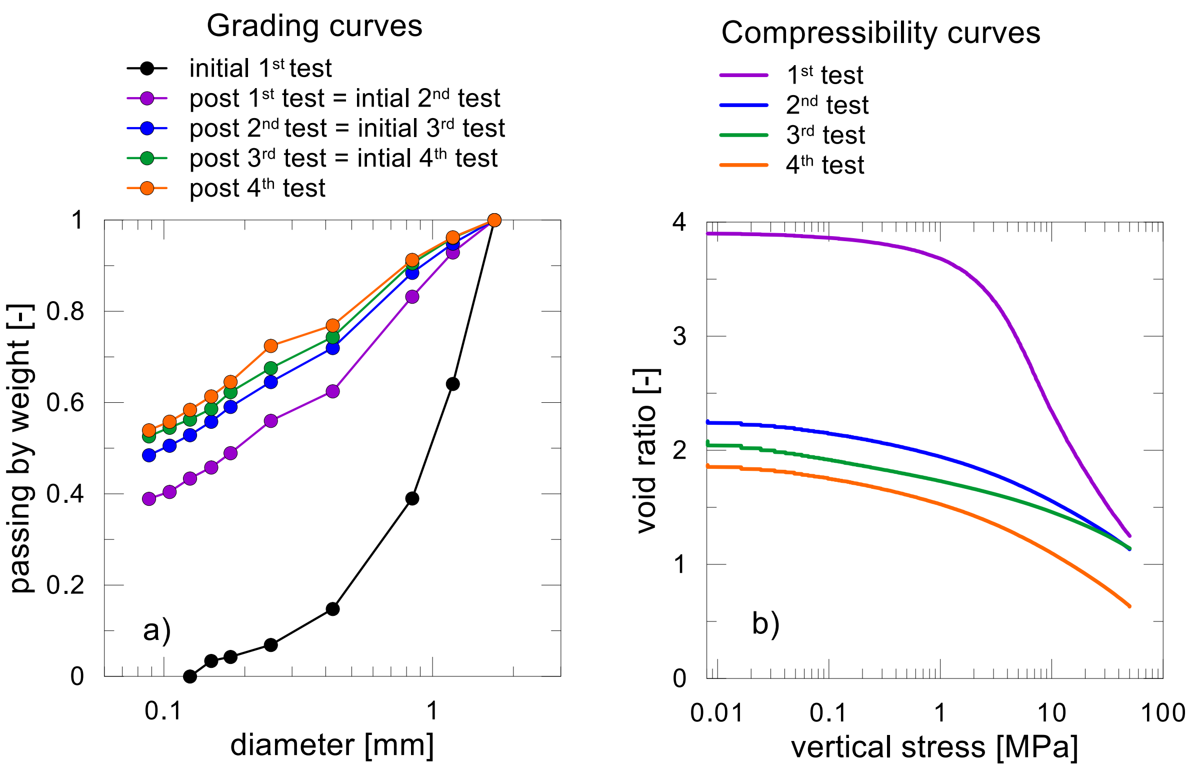

Figure 1: *Multi-compression results: a) Grading curves and b) Compressibility curves.*

Local macro-element model of rigid monopiles in sand

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Keywords: Macro-element, p-y curve, t-z curve, monopile foundation

Abstract: Macro-element modelling has gained significant importance over conventional finite element modelling in recent times, due to its computational ease and readily available information for numerical parametric studies and engineering concept design. This poster presents a 'local' macro-element for rigid open-ended monopile in sand, under cyclic loading for offshore wind turbine applications. It is inspired by the macro-element developed for deep foundations by Taciroglu et al., 2006. The local macro-element model is an assembly of a non-linear spring model representing pile-soil interface friction, combined p-y & t-z soil-pile interaction behavior along pile shaft; and q-z behavior at pile base of monopile. Simplified cyclic loading scenarios approximately representing the wind and wave loading has been utilized in the computations; with consideration to standard ultimate and serviceability limits criteria. The pile head response observed from the model under static monotonic and cyclic loading shows the qualitative potential of the macro-element model. The model response results are further utilized to report significant differences between the previously studied 'flexible pile' and our 'rigid pile' behaviors in sand under combined loading.

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Figures

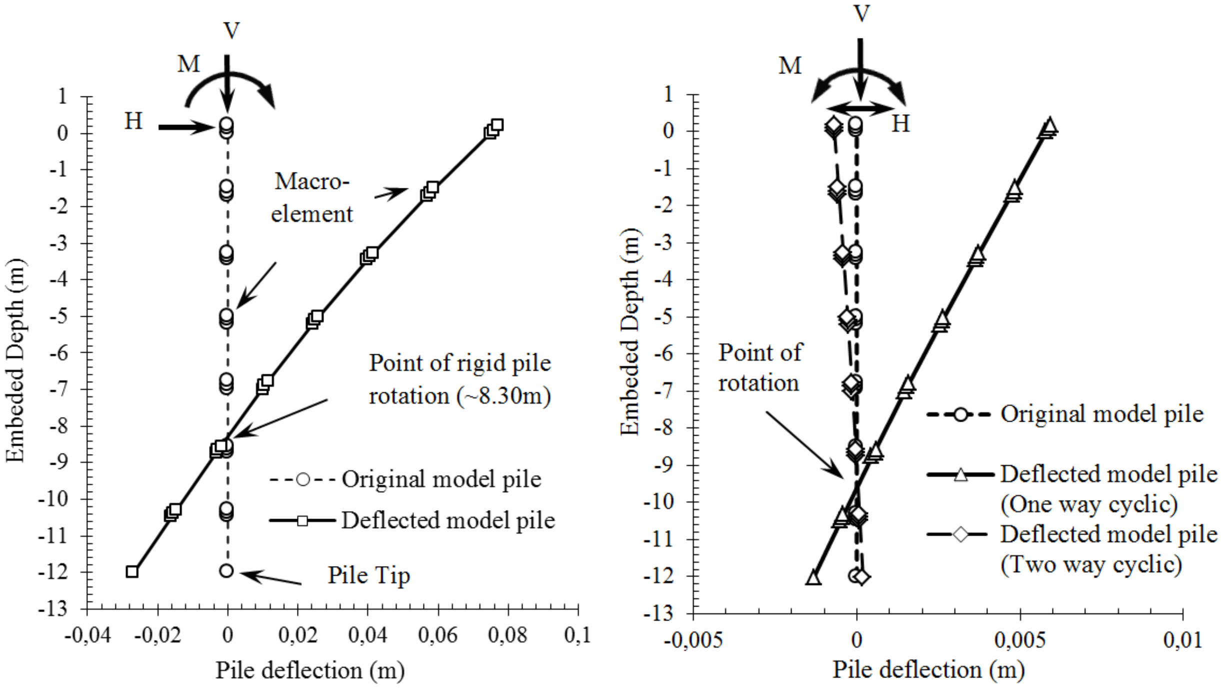

Figure 1: *Deflection profile of rigid monopile model for static(left) and cyclic horizontal (right) combined loading conditions*

NeXT-Grenoble: The Neutron and X-ray Tomograph in Grenoble

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Keywords: Neutrons, X-ray, Tomography, Bi-modal imaging

Abstract

Neutrons and x-rays interact differently with the atomic structure of materials, which means that in radiography techniques they can provide different information about the same material. Notably, neutrons interact with hydrogen-rich substances more readily than x-rays, simplifying the identification of water and hydrocarbons. The high complementarity of neutron and x-rays can be taken advantage of to explore a plethora of processes of great relevance to the geomechanical and engineering communities at large.

NeXT-Grenoble is the Neutron and X-ray Tomograph born in 2016 from the joint effort of Universitè Grenoble Alpes (UGA) and the Institut Laue-Langevin (ILL), and takes advantage of the world's highest cold neutron flux. A key feature of the instrument is the possibility to perform simultaneous x-ray and neutron tomography, in order to take advantage of the high complementarity of the attenuation coefficients of these two techniques.

The registration of the two volumes is made possible by recent mathematical developments which also provides phase identification, with much more ease than with either image individually.

The instrument relies on a suite of detectors ranging from fields of view above 170x[mm]x170[mm] to true resolutions below 7 µm. Thanks to the uniquely powerful flux, the instrument can perform high speed tomographies (below 10 seconds) at large fields of view as well as acquire high resolution tomographies in times comparable to those of microfocus x-ray setups.

A multi-million-euro upgrade of the instrument is foreseen in the forthcoming two years to further improve its performances as well as to add further options (e.g, monochromation, polarised neutrons, grating interferometry). This instrument is open for proposals through its dedicated website (https://next-grenoble.fr/).

This, together with the aforementioned performances has already allowed a range of high pressure, high temperature and hydro-mechanical in-situ tests to be performed at high speeds.

Figures

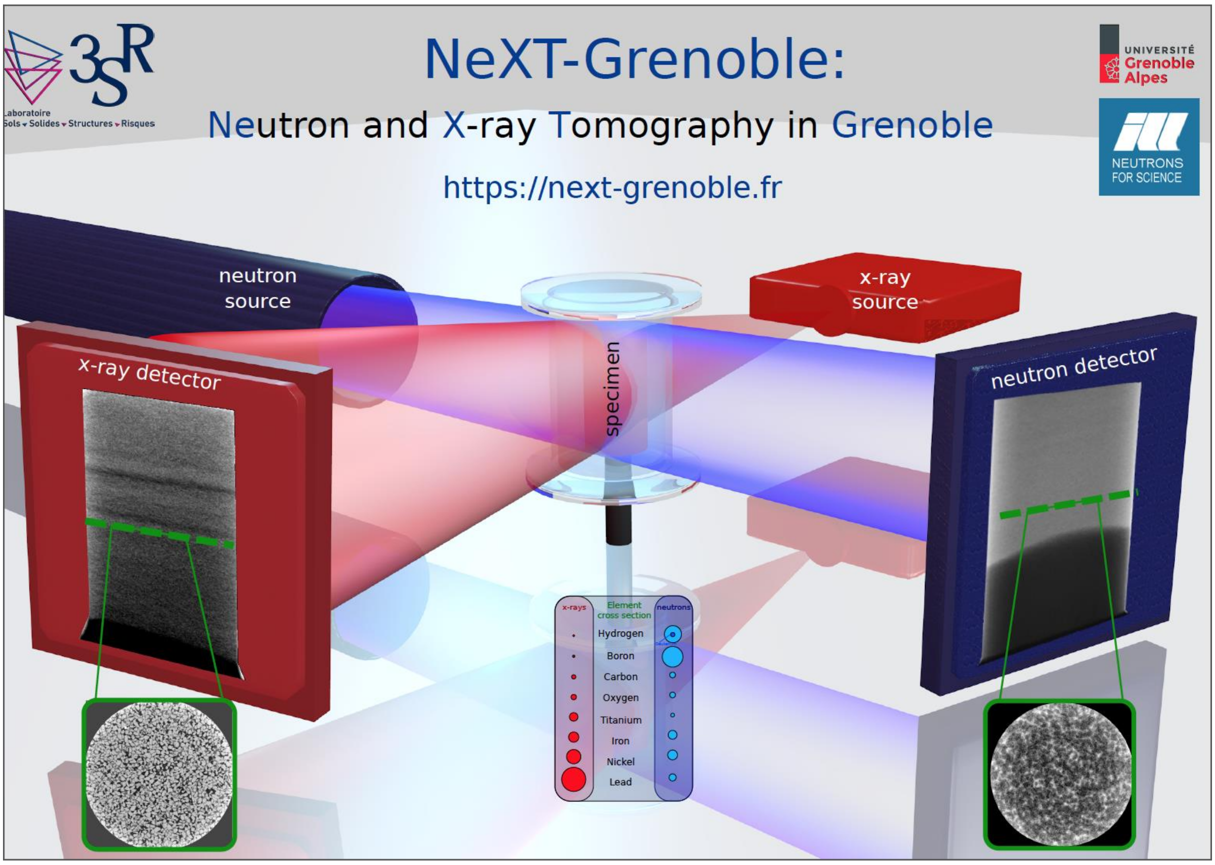

***Figure 1:** Conceptual scheme of NeXT, the Neutron and X-ray Tomograph in Grenoble*

Agglomerates of wet particles: effect of size distribution

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Keywords: agglomerates, granular matter, capillary force law, discrete element method, plastic strength, diametrical compression.

Abstract

We analyze the strength of agglomerates of wet frictional particles subjected to axial compression by means of particle dynamics simulations. The numerical model accounts for the cohesive and viscous effects of the binding liquid up to a debonding distance [1]. We show that wet agglomerates undergo plastic deformation due to the rearrangements of primary particles during compression [2]. The compressive strength is characterized by the plastic threshold before the onset of failure by the irreversible loss of wet contacts between primary particles [3]. The agglomerate plastic threshold is proportional to the characteristic cohesive stress defined from the liquid-vapor surface tension and the mean diameter of primary particles, with a pre-factor that is a nearly linear function of the debonding distance and increases with size span. We analyze the effect of particle size distribution and show that the plastic strength is an increasing function of the size ratio when the size of the particles in the largest size class is increased.

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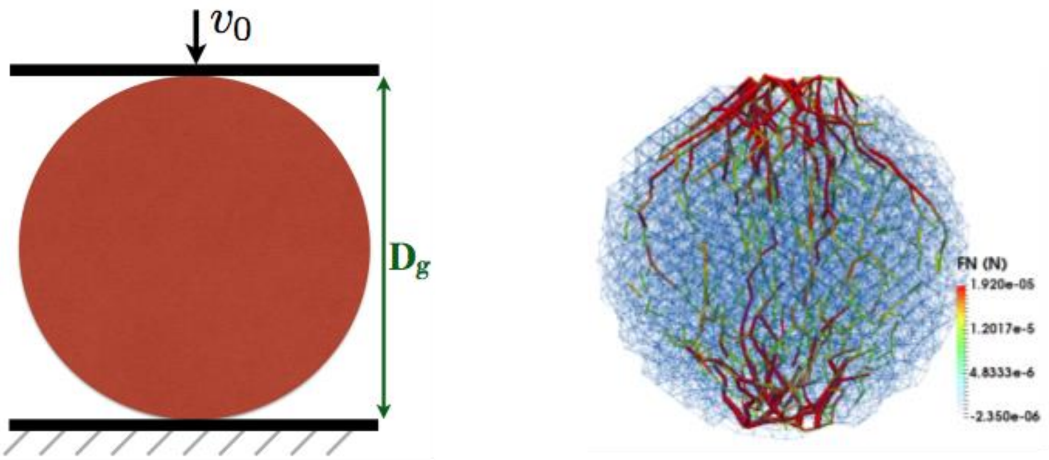

Figure 1: *Schematic representation of diametrical compression test and force chains distribution in the granule.*

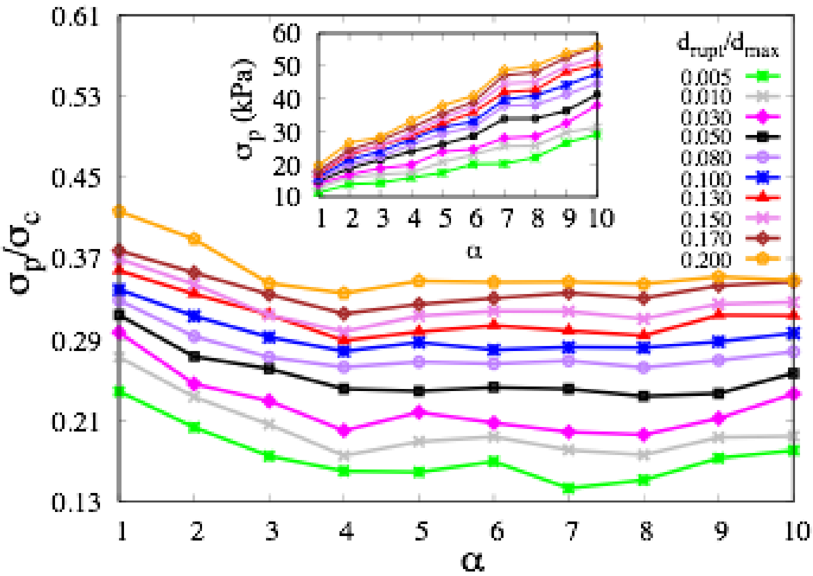

Figure 2: *Normalized plastic strength of the wet agglomerate for several values of the debonding distance as a function of the size ratio. The inset shows the non-normalized value of the strength as a function of the size distribution.*

Fire spalling of concrete: In-situ neutron tomography and 3D numerical modeling of moisture migration

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Keywords: spalling, drying, high temperature, neutron tomography, FE modeling, aggregates

Abstract

Concrete has been extensively used in the construction industry as a building material. A major drawback of this material is its instability at high temperature, expressed in the form of violent or non-violent detachment of layers or pieces of concrete from the surface of a structural element. This phenomenon, known as fire spalling, can lead to the failure of concrete structures such as tunnels, high rise buildings, nuclear power-plants, underground parkings etc. because the reinforcement steel is directly exposed to high temperature and the designed cross section of the concrete elements (e.g., columns, beams, slabs) is reduced. A lot of research has been dedicated on developing preventing methods for spalling and also on determining the parameters that have an influence on it. However, the physics behind this phenomenon is not yet fully understood. The objective of this work is to contribute to the understanding of spalling mechanisms through a combined experimental and numerical approach, i.e., neutron tomography coupled with advanced numerical modeling in an adequate scale [1].

In this work, the first 3D measurements of moisture content in heated concrete, which is believed to be one of the processes directly related to spalling, have been performed using in-situ neutron tomography [2]. In order to follow the fast dehydration process of concrete, one 3D scan (containing 500 radiographs) per minute was captured thanks to the world leading flux at the Institute Laue Langevin (ILL) in Grenoble. This acquisition speed, which is ten times faster than any other experiment reported in the literature, was sufficient to follow the dehydration process. A dedicated setup (see Figure 1), adapted to neutron imaging and high temperature, has been developed for performing such kind of experiments. Concrete samples with different aggregate size have been tested. Quantitative analysis showing the effect of the aggregate size on the moisture distribution is presented. Results on the moisture accumulation behind the drying front, known as the moisture-clog, are also presented and discussed.

In parallel, a numerically-efficient coupled thermo-hydro-mechanical (THM) model has been implemented in the finite element software Cast3M for understanding and predicting the complex behaviour of concrete at high temperature in the context of spalling [3]. The newly implemented code is remarkably faster (20-30 times) than an existing one, on which it is based. A mesoscopic approach has been adapted to the model for taking into account the heterogeneity of concrete. First the model is applied to experiments from literature monitoring standard parameters such as temperature, gas pressure and mass loss. Then, 1D moisture profiles obtained from neutron radiography experiments are used for verifying and improving the model in terms of some critical constitutive laws such as dehydration and water retention curves. Finally, the model is employed for predicting the 3D moisture distribution measured in this

work via neutron tomography (see Figure 3). Among others, mesoscopic THM simulations are performed for investigating the influence of an aggregate on the drying front.

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Figures

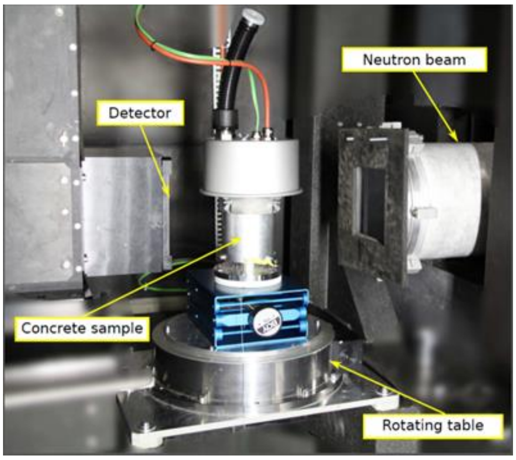

Figure 1: *Experimental setup in the NeXT (D50) beamline at Institute Laue Langevin (ILL*

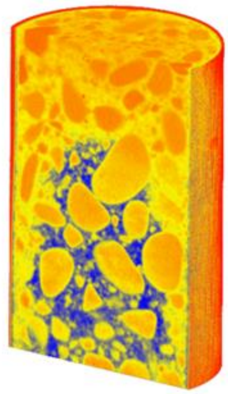

Figure 2: *Real-time observation of concrete drying using in-situ neutron tomography*

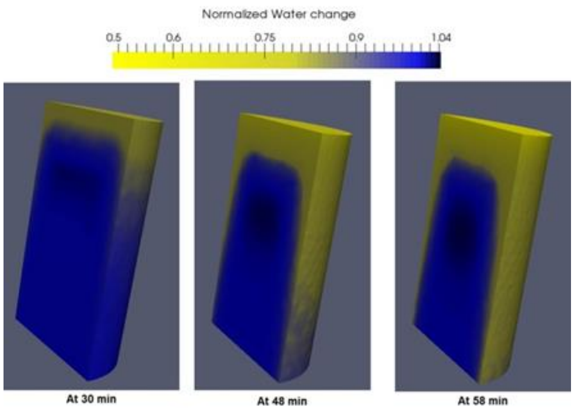

Figure 3: *3D simulations of the moisture migration in heated concrete*

Effect of desiccation cracking on the fluid transfer process in agricultural soil

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Keywords: agricultural soil, desiccation cracking, preferential flows, code LAGAMINE

Abstract

The natural soil structure can be strongly modified and generate heterogeneities during wetting and drying processes. This significantly affects the transfer of fluids and nutrients between the atmosphere, the subsoil, the hydrosphere and the biosphere. Experimental observations on a Cutanic Luvisol from agricultural field in Gembloux, Belgium, by using X-ray microtomography coupled with 3D image analysis have shown the cracking phenomenon occurring and leading to preferential flows in the soil sample during a drainage process. In order to better understand the impact of cracks on the behaviour of this soil type, in this study, we have proposed a numerical modelling of soil evaporation process by using the constitutive models implemented in the finite element code LAGAMINE. Considering that the soil we study is a loamy soil, we have chosen to fit the dual model of Durner [1] for the water retention capacity. The drying kinetics is modelled using the boundary layer model [2], assuming that the vapour and heat transfers take place in a boundary layer at the surface of the porous medium. The embedded fracture model is chosen to represent the development of the fractures in porous medium in which fracture opening is activated by a threshold strain parameter [3]. The results obtained have shown that an increase in permeability in the fracture zones makes the permeability tensor anisotropic up to one order and thus strongly modifies the drying kinetics of the soil core (e.g., evaporation rate). The results also have suggested that using a simple concept of cracking development, a continuum model is capable of modelling preferential flows developed in a fractured porous medium such as agricultural soil.

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Modeling of pile foundations under multi-directional cyclic lateral loading

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Keywords: piles, multi-directional loading, cyclic loading, p-y curves, piles

Abstract

The most commonly used procedure for prediction of the behavior of laterally loaded piles is the p-y curve formulation. The use of this approach cannot reproduce accumulation due to cyclic loading as usual p-y curves are considered reversible. Besides this approach is limited to a single direction of loading. However, there are several situations in which a pile is submitted to cyclic and multi-directional lateral loadings, such as piles for offshore wind turbines or offshore bridges because of wind and waves loads. We present here an extended framework for p-y curve modeling that enables account for cyclic and multi-directional loadings.

Even if cyclic loading effects are very well documented for various types of soils, there is a lack of specifications for the design of piles submitted to cyclic lateral loading. With regards to p-y curves, the only change in p-y curve expression proposed in DNV (2014) is a decrease of ultimate reaction independently of the number of cycles and the level of loading. Global recommendations are presented in Puech and Garnier (2017). Explicit relations are given as function of the number of cycles and the level of loading. A novel procedure is proposed here for the extension of the p-y curve approach to cyclic loading. The idea is to model cyclic accumulation as a creep phenomenon. Indeed, creep and fatigue phenomenon are shown to share similar features (Cerfontaine and Collin, 2018). The framework is schematically shown in Figure 1. The advantage of this framework is its simplicity as only two additional parameters are needed. Moreover, it permits fast computations for a high number of cycles.

Only few works can be found in the literature on the design of piles under lateral loading with varying directions. Among them, one can mention Levy et al. (2007) who present a method to take into account multi-directional loading using an energy-based variational approach. Besides, some experimental works exist in the context of seismic loading (Mayoral et al., 2014) and in the context of offshore wind turbines foundation (Peralta, 2010 and Rudolph et al., 2014). A procedure is proposed here for the extension of the uni-directional model to a multi-directional one (Figure 2). The framework consists in considering several springs in various directions around the pile perimeter at each depth. The advantage of this framework is that it remains simple and practical as the original p-y curve method, and does not need any further information or parameters. The model has been validated by comparison with the one proposed by Levy et al. (2007). The effects of multi-directional loading are discussed based on simulation results.

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Figures

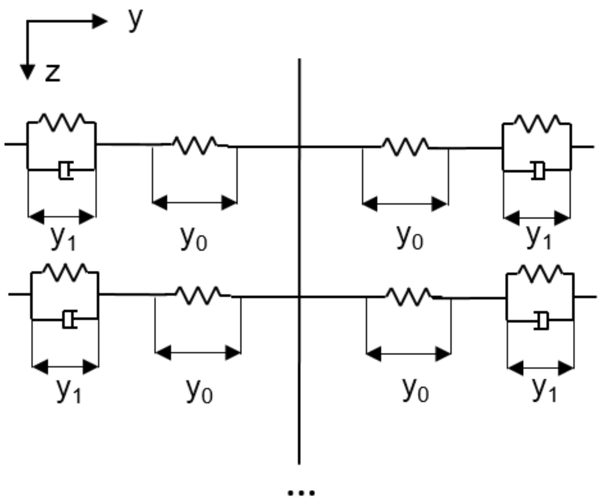

Figure 1: *Framework of extension of p-y curve approach for cyclic loading*

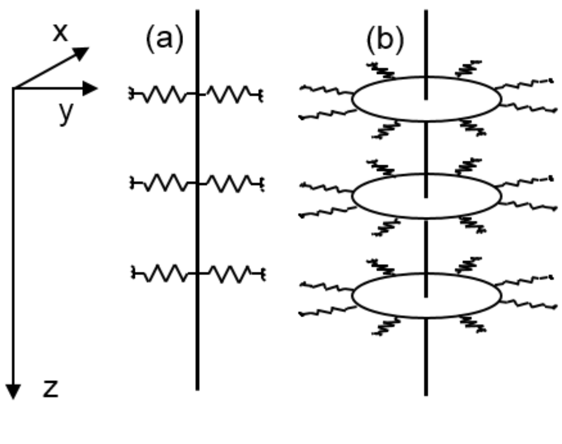

Figure 2: *Comparison of uni-directional (a) and multi-directional (b) models*

Modelling particle breakage inside rotating drums

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Keywords: Granular Materials, DEM, Contact Dynamics Method, Breakage, Rotating Drums

Rotating drums are widely used in industrial applications such as grinding, breakage, mixing. Processes in which the main objective is reducing particle size (i.e. particle breakage) depend on the mechanical efforts to which the particles are subjected. Most simulation tools present limitations and challenges in the case of very dynamic regimes. However, by choosing the adequate model and correct parameters, the results can provide new insights into the details of the process at the particle and contact scales. In this work, we study the fracture of granular materials composed of perfectly plastic particles using the bonded cell method (BCM). First, the fragmentation due to the impact of a single grain is studied focusing on energy dissipation. Then, the breakage of an assembly of polygonal particles inside a rotating drum is addressed. The simulations were performed using the Contact Dynamics method. In BCM the grains are assumed to be perfectly rigid but modelled as an assembly of glued polyhedral cells. An inter-cell contact loses its cohesion only when it is at a normal or tangential stress threshold, and it dissipates an amount of work equal to the fracture energy of the particle. For a single particle breakage, we analyze the fragmentation efficiency as a function of the impact energy and stress thresholds, as well as their scaling with fracture energy. In particular, we find that the fragmentation efficiency varies unmonotonically with the impact energy, with a maximum for a specific value of the normalized energy regardless of the fracture energy and stress thresholds. Finally, the evolution of the breakage inside a rotating drum as a function of rotation speed and filling degree is analyzed.

Figures

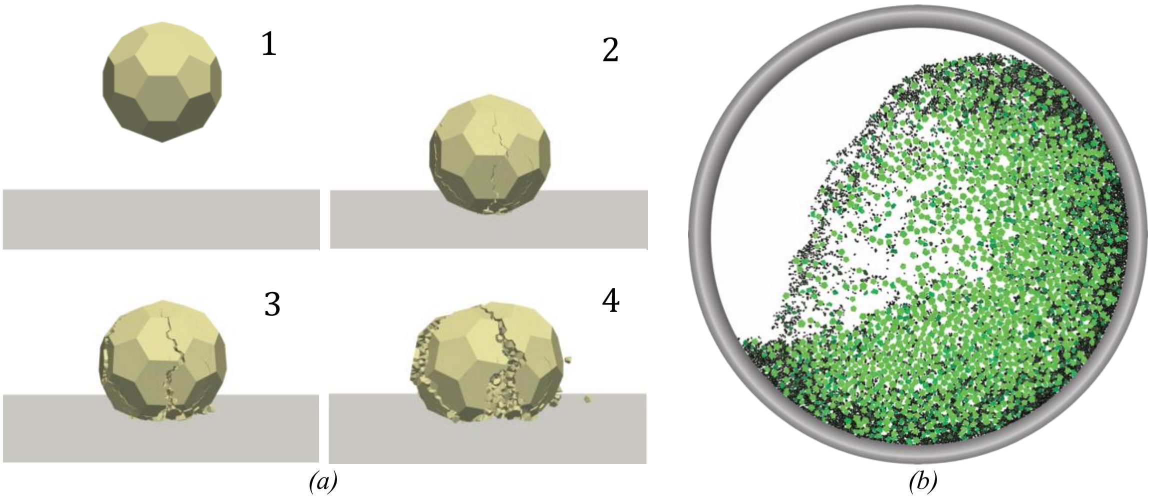

Figure 1: *(a) Sequential images of a single particle impact onto a rigid plane. (b) Snapshot of a rotating drum simulation. The broken and unbroken particles are shown in black and green colors, respectively.*

Elaboration of an experimental protocol for erosion behavior improvement of a coarse soil

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Keywords: *granular soil, erosion, hole, optimum dry density, hydraulic earthworks.*

Abstract

Internal erosion is the main cause of ruptures in hydraulic earthworks, such as dikes and dams. The consequences of such breaks are substantial and costly. This phenomenon occurs because of internal erosion. The objective of this study is to provide an experimental understanding of the parameters controlling the initiation and evolution of the erosion process in coarse soil.

In this study a granular soil reconstitution protocol is developed from a mixture of sandy materials. The tests are carried out using a developed device inspired from the Hole Erosion Test. It allows the measurement of parameters such as inflow and outflow, the mass of eroded particles. A parametric study is carried out on the influence of certain parameters, such as the percentage of soil compaction relative to the optimum dry density of the Proctor curve and the diameter of the hole. At the end of the test the specimen is extracted from the device and the melted paraffin is then poured into the eroded hole.

The obtained results have shown that the soil is unstable with respect to this phenomenon in view the considerable departure of particles. As well as the mass of eroded particles is inversely proportional to the compactness and diameter of the hole. The extracted candle takes the irregular shape of the eroded hole, the diameter of the latter measures approximately three times the initial diameter with an upstream diameter relatively a little larger than downstream.

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Figures

Figure 1: *the erosion cell*

Numerical modelling of triboelectric separation: application to vegetal powders

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Keywords: Triboelectric separation, Electrostatic process, triboelectric charging

Abstract

Electrostatic separation processes rely on the triboelectric properties of particles to sort them in an electrical field. One major benefit of these processes is that they produce no effluent and allow separation for various materials as for example separation of plastic grains from waste or for the removal of unburned carbon from fly ash. More recently the triboelectric separation was used for vegetal powders using and has proved to be well adapted for the purification of targeted compounds as Peeling and Gluten [1] or lignin in wheat straw [2]. To better understand the triboelectric separation, we developed a numerical model based on the Discrete Element Method (DEM). This model takes into account 1) the triboelectric charging during particles contacts and collisions, 2) the exchange of electric charges and 3) the collective effect of the electric fields generated by all particles and by electrodes. In this study, we first investigate the dynamics of charging of a vibrated packing of particles. The simulated evolution compares well with experimental data from the literature. This evolution allows to determine the so-called work function which is an intrinsic physical property characterizing charge transmission during collisions. Assuming that the effect of the air results only in a drag force applied to the center of mass of the grains, we were able to take into account the aerodynamic transport of particles. Finally, the real geometry of the experimental setup is considered and we highlight the capabilities of the model to simulate complex features as electrodes clogging, flow eddies resulting in dead zones or particles agglomeration.

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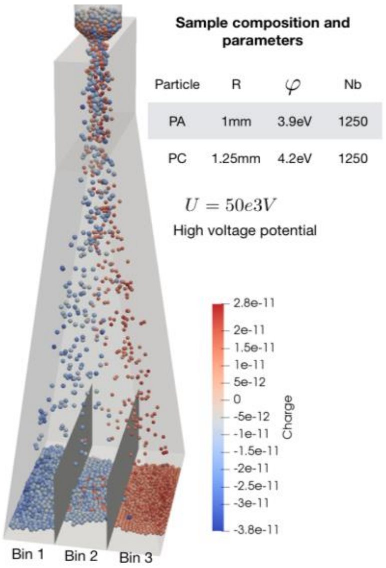

Figure 1: Particles in separation phase under electrostatic field

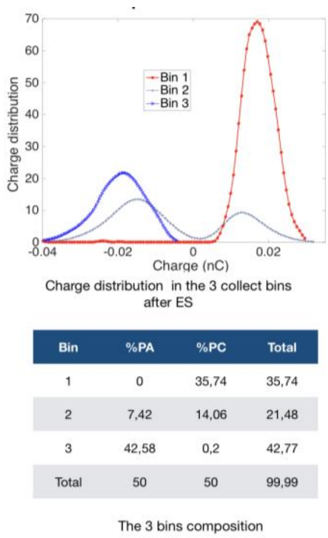

Figure 2: Charge distribution and the composition of the bins after separation

Drying of a Porous Medium due to Compressible Gas Flow

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Keywords: Flow-through drying, Porous medium, Gas compressibility

Abstract

The process of flow-through drying in a porous medium partially occupied by a water phase is examined, in order to identify the role of various parameters such as temperature, permeability of the medium, drawdown and depletion. In flow-through drying, gas flow causes evaporation of the water phase, due to the compressibility of the gas. A set of equations for the water saturation are developed and solved analytically for two cases. The one-dimensional and the axisymmetric gas flow. This work can be applied to the problem of drying of water in natural gas production. Evaporation in the near wellbore region leads to the removal of the trapped water, which decreases the skin, and thus increases production. Due to the complex nature of this problem, our findings confirmed that there is no single dominant mechanism in flow-through drying in terms of the aforementioned parameters.

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FFT-based Homogenization of Gas Hydrates Bearing Sediments

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Keywords: gas hydrates, sediments, inclusions, homogenization, Fast Fourier Transform

Abstract

The very inhomogeneous microstructure of gas hydrate bearing sediments and the difficulties encountered to test natural core samples [1] or synthesized specimens [2] led us to numerical methods. The macroscopic mechanical behaviour of gas hydrate bearing sediments is investigated through the numerical homogenization of a heterogeneous unit cell under periodic boundary conditions. The Fast Fourier Transform (FFT) is used in the resolution of the local mechanical problem with linear and non-linear elastic components but also with elasto-plastic components. Different microstructures of gas hydrate bearing sands and clays are modelled to study their homogenized mechanical behaviour and in particular the impact of hydrates on the overall response.

Moulinec and Suquet [3] first used the periodic Lippmann-Schwinger equation (LSE) to solve the local mechanical problem of a periodic unit cell defined by its stiffness distribution $C(x)$ and submitted to a global strain E. This equation reads, in real (a) and Fourier (b) space:

$$\begin{cases} \varepsilon(x) = -\left(\Gamma^0 * \left((C - C^0):\varepsilon\right)\right)(x) + E \quad \forall x & (a) \\ \hat{\varepsilon}(\xi) = -\hat{\Gamma}^0(\xi):\mathcal{F}\left((C(x) - C^0):\varepsilon(x)\right) \quad \forall \xi \neq 0, \qquad \hat{\varepsilon}(0) = E & (b) \end{cases}$$

with x being the spatial coordinate, Γ^0 the periodic Green operator associated to the reference stiffness C^0, $\mathcal{F}$ the Fourier transform, and '$*$' a convolution product. The LSE has a simpler expression in Fourier space, which is why many solvers were developed, based on the use of direct and inverse Fourier transforms. We chose one scheme in particular, from Gélébart and Mondon-Cancel [4], to compute the homogenized response of various simplified microstructures containing a sedimentary phase (grains for sandy sediments or a uniform matrix for clayey sediments), hydrate crystals, and voids. This method combines the Newton-Raphson algorithm and a Conjugate-Gradient based solver. We can use elasto-plastic behaviour for the constituents, such as the hydrate crystals, and have infinite stiffness contrasts, like the one between the voids and the sedimentary phase.

The prescribed loading can be a macroscopic strain or stress, and we can simulate standard laboratory tests. We compared the FFT-based results to a Finite Element Model (FEM) output to validate the method. FFT-based homogenization methods can help us develop a macroscopic mechanical behaviour to be subsequently implemented in coupled models.

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Figures

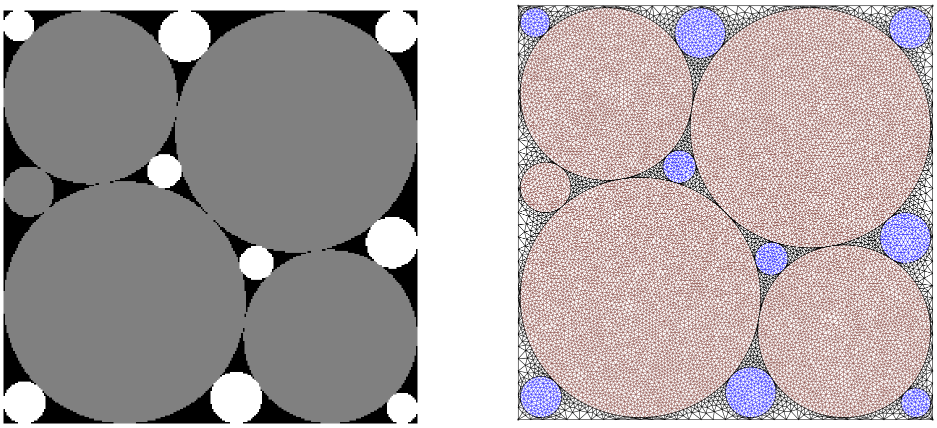

Figure 1: *Unit-cell of 256x256 pixels (left) and finite-element mesh (right) of a heterogeneous microstructure containing: solid grains (left: grey, right: brown), hydrates (left: white, right: blue), and voids (black).*

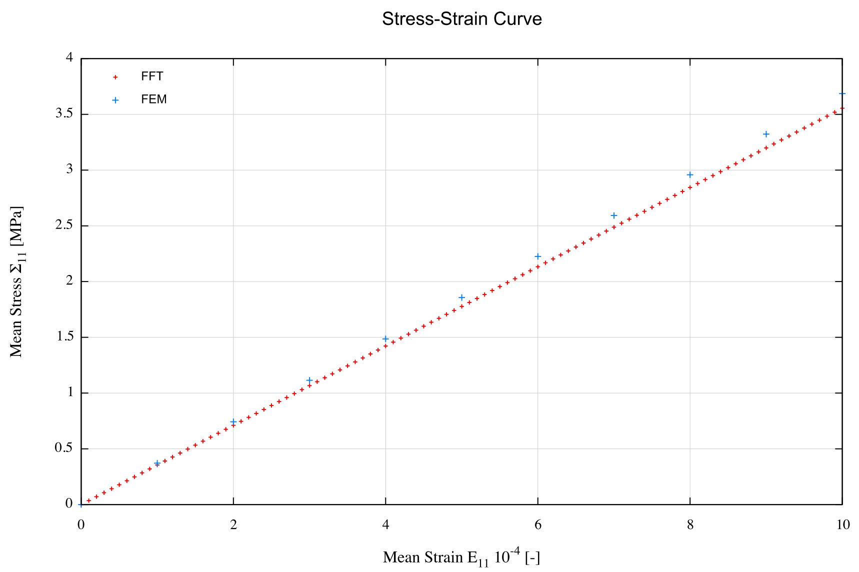

Figure 2: *Macroscopic stress-strain response to a macro-strain load $E_{11}=E_{22}=0.001$ of the structures presented in figure 1 (in plane strain configuration).*

An analytical solution for the one-dimensional consolidation under a general time-dependent loading profile

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Keywords: Consolidation, analytical solution, eigenfunction expansion.

Abstract

A new approach to derive an analytical solution to the well-known one dimensional consolidation equation under a general time dependent loading is described. The approach is based on the eigenfunction expansion method. While most existing solutions in the specialized literature are developed for a particular loading type, the proposed strategy can be easily applied to obtain an accurate response for a general loading, independently of whether this external load is smooth or piecewise smooth. The proposed strategy is applied to a constant, single ramp, cyclic square and cyclic haversine loading profiles. The results are in agreement with analytical solution previously obtained by other researchers.

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Figures

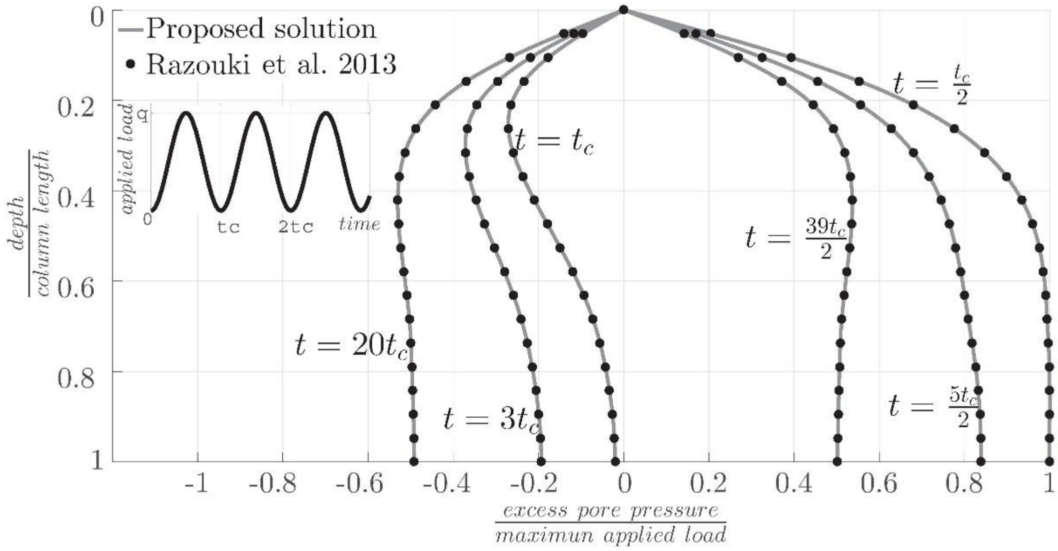

Figure 1: *Comparison of the proposed solution with Razouki et al. 2013. Isochrones for different values of time t. Cyclic haversine loading*

A two phase SPH-FD model for debris flow propagation-consolidation

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Keywords: Debris flow, Pore water pressure, Two phase.

Abstract

Many of the most interesting fast catastrophic landslides such as debris flows, involve more than one phase where the coupling between solid and pore fluid plays a fundamental role and due to the strong coupling between phases, pore pressures can be generated. The principal objective of this paper is to develop mathematical and numerical modelling for simulating two-phase landslides in which considering the effect of pore water dissipation is essential for risk analysis. For these reasons the models have to take into account the changing of pore water pressure in each time-step.

The approach is based on the mathematical model proposed by Zienkiewicz and Shiomi (1984), which is similar to those of Le and Pitman (2005) and Pudasaini (2012). Pastor (2017) proposed to use a double set of nodes for soil and water phases, in which the interaction between them being described by a suitable drag law. This work is extended here to consider excess pore pressures in the mathematical model and also an improved method for pore pressure dissipation based on combining the SPH nodes with finite difference 1D meshes is proposed based on the propagation-consolidation model proposed by Pastor (2015b). The Smoothed Particle Hydrodynamics (SPH) numerical method is used for problems that are basically in the form of partial differential equations.

The model is applied to a dam break problem on a horizontal plane with a frictional soil phase, and a debris flow which happened in Hong Kong. After considering the benchmarks presented here, we can conclude that the model is suitable tool to simulate different cases with a good combination of accuracy and computation cost.

References

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Figures

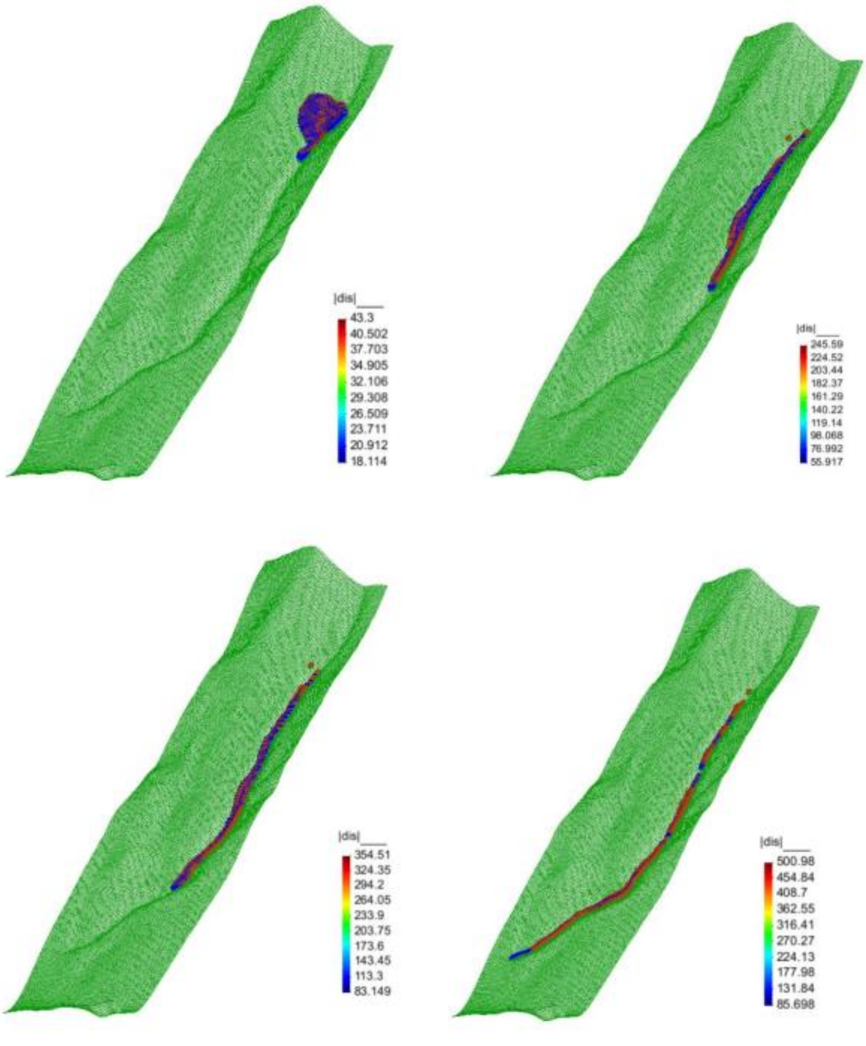

Figure 1 : *Results sequence of the debris flow simulation at different positions.*

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