ALERT Geomaterials

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POSTER SESSION

Booklet of abstracts

Editor : Nadia Benahmed

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ALERT Geomaterials

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Nadia Benahmed

(IRSTEA, Aix en Provence – France)

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Dear colleagues,

We are pleased to welcome you to Aussois and our 26th 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 and stimulating discussions and exchange of knowledge and experience on Geomechanics, and presentation of recent advances to 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.

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Mesoscale Modeling of C-S-H

Katerina Ioannidou[1,2], Emanuela Del Gado[3,4], Pierre Levitz[5], Roland Pellenq[1,2,6]

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Keywords: Cement, C-S-H, mesoscale, Molecular Dynamics, Monte Carlo

Abstract

Calcium-silicate hydrate (C-S-H) is the main binder in cement and concrete. It starts forming from the early stages of cement hydration and it progressively densifies as cement sets. C-S-H nanoscale building blocks form a cohesive gel, whose structure and mechanics are still poorly understood, in spite of its practical importance. Here we review a statistical physics approach recently developed, which allows us to investigate the C-S-H gel formation under the out-of-equilibrium conditions typical of cement hydration. Our approach is based on colloidal particles, precipitating in the pore solution and interacting with effective forces associated to the ionic environment. We present the evolution of the space filling of C-S-H with different particle interactions and compare them with experimental data at different lime concentrations. Moreover, we discuss the structural features of C-S-H in the mesoscale in terms of the scattering intensity. The comparison of our early stage C-S-H structures with small angle neutron scattering (SANS) experiments shows that long-range spatial correlations and structural heterogeneties that develop in that early stages of hydration persist also in the hardened paste.

References

K. Ioannidou, R.J.-M Pellenq and E. Del Gado, Soft Matter (2014)

E. Del Gado, K. Ioannidou, E. Masoero, A. Baronnet, R. J.-M. Pellenq, F.-J. Ulm, and S. Yip, European Physical Journal - Special Topics 223, 2285-2295 (2014)

Hydro-mechanical behavior of Boom clay host-rock in interaction with a deep excavated gallery's lining

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Keywords: Boom clay, Strain localization, Excavation Damaged Zone, Pore water pressure distribution, Interfaces

Abstract

In the framework of the long-term management of the high-level nuclear waste, storing them in deep stable geological formations is considered as an acceptable solution. Geological disposal facilities (GDFs) combine a suitable system of engineered barriers with an host rock with favourable confinement properties, among which is a low hydraulic conductivity, at a depth that ensures adequate isolation from man and the environment. Boom clay, plastic clay formation located in the north of Belgium, is a candidate host-rock [1] for this purpose.

Due to the underground excavation process, a damaged zone with significant irreversible deformations and important host rock's properties modifications is expected to be created around the openings resulting to the macro and microfracturing and a rearrangement of rock structures. This zone is called as Excavation Damaged Zone (EDZ). Our study is firstly focused on numerical modelling of this zone around a gallery excavated in Boom clay host-rock through the framework of a strain localization approach in shear band mode. The initial anisotropic stress and cross-anisotropy of the elasto-plastic properties of the material are considered for a more realistic simulation. Additionally, to properly model the localization phenomenon and post-peak shear strength behavior, the coupled second gradient method is applied [2]. The development of the shear strain localization and extension of EDZ is analyzed numerically in comparison with the in-situ evidences while the both consist in an eye-shape extension of EDZ (Fig. 1). Besides, with regard to the long-term coupled hydro-mechanical behaviour of the rock, the pore water pressure evolution measured through some in-situ boreholes are analyzed compared to the corresponding numerical predictions. A good agreement is found between the simulated results and site measurements (Fig. 2).

Moreover, given the essential need to a lining while excavating in the plastic Boom clay formation in order to minimize the extension of the damaged zone and the convergence of the rock [3,4], the interaction of the rock with the gallery' lining is analyzed. Our study demonstrates that there is a fundamental relation between the development pattern of strain localization within the clay in the galley's proximity, and the pressure excreted by the clay on its interface with the lining upon contact (Fig. 3) [5]. Furthermore, the long-term strain evolution in the gallery's lining recorded through some installed instrumentation is analyzed. To reproduce realistically the latter results in the lining, we propose modelling of a discontinuous lining, making of the concrete blocks (like the real case), while the interface elements are introduced between them to address their contact phenomena [3].

References

[1] Bernier F, Li XL, Bastiaens W. Twenty-five years' geotechnical observation and testing in the tertiary Boom clay formation. Géotechnique; 2007, 57(2):229–37.

[2] Collin F, Chambon R, Charlier R. A finite element method for poro mechanical modelling of geotechnical problems using local second gradient models. International journal for numerical methods in engineering; 2006, 65(11):1749–72.

[3] Salehnia F. From some obscurity to clarity in Boom clay behavior: Coupled hydro-mechanical analysis in the presence of strain localization, Ph.D. thesis; Université de Liège; prepared for submission in September 2015.

[4] Salehnia F, Charlier R, Sillen X, Dizier A. Modeling of excavation damaged zone through the strain localization approach in Boom clay. In: Computer methods and recent advances in geomechanics. CRC Press; 2014, p. 335.

[5] Salehnia, F, Collin, F, Li, XL, Dizier, A, Sillen, X, Charlier, R. Coupled modeling of excavation damaged zone in boom clay: Strain localization in rock and distribution of contact pressure on the gallery's lining. Computers and Geotechnics; 2015, 69:396–410. doi:10.1016/j.compgeo.2015.06.003.

Figures

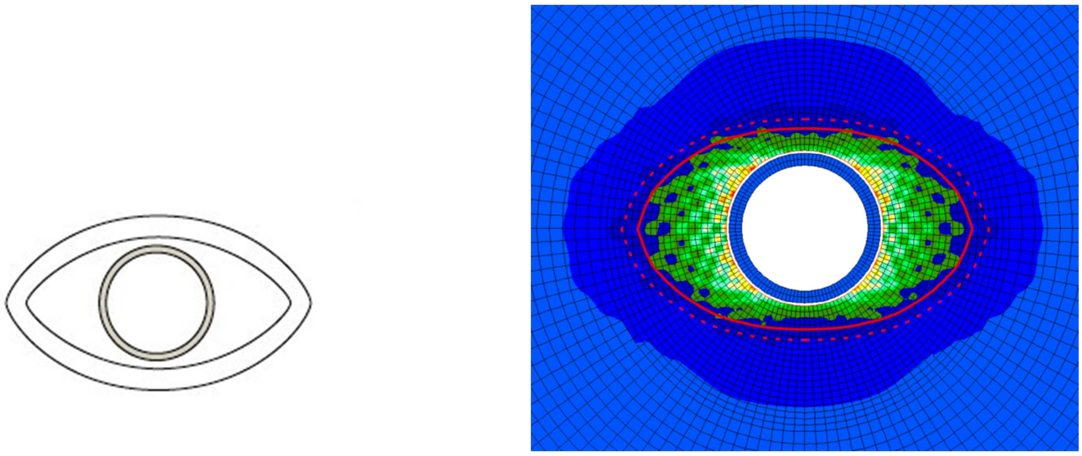

Figure 1 : *Schematic representation of the eye-shape fractures pattern observed around the gallery [1] (left side), and the similar numerical prediction of an eye-shape extension of the EDZ (right side) [3].*

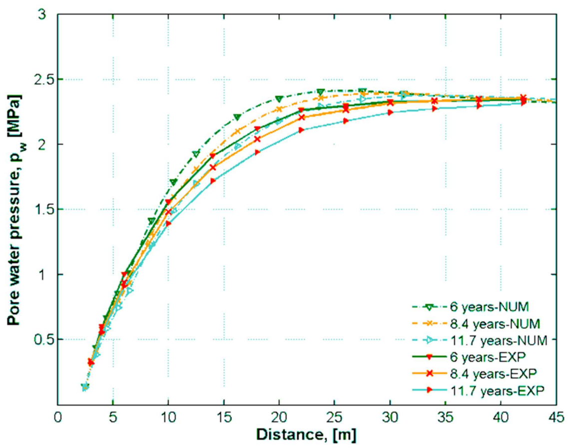

Figure 2 : *In-situ measurements through an eastward borehole R55E, compared to the numerical results [3].*

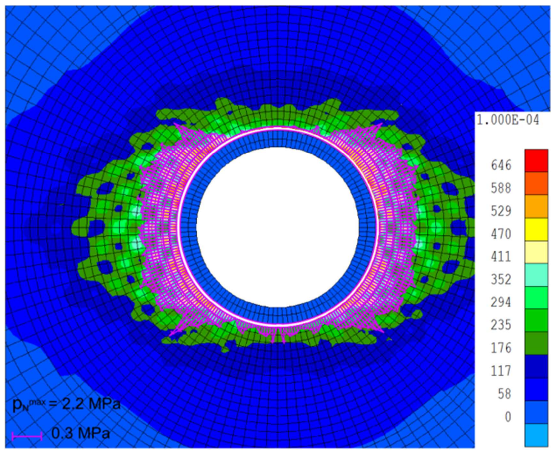

Figure 3 *: Superposition of the localized shear bands and normal contact pressure on the interface [5].*

Numerical modelling of bifurcation modes of deformation in buried soil-pipe interaction

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Keywords: localization, diffused instability, soil-pipe interaction

Abstract

Geohazards and associated ground deformations as well as varying operational conditions pose a substantial threat to the structural integrity of pipelines as they often involve large irrecoverable plastic deformations of soil. Both onshore and offshore pipelines should be designed to accommodate very large strains at the serviceability stage. Therefore, numerical modelling of large deformations in soil-pipe interaction is paramount to improve the current design guidelines.

Progressive failure of buried pipelines involves complex behaviour such as strain localization into shear bands, soil flowing into the cavity created by the displaced pipe and the volumetric behaviour of the compression zone in front of the pipe.

Although instability analysis of granular materials has been matured over past few decades, its practical application in modelling soil-structure interaction is scarce. This research focuses on numerical modelling of bifurcation modes of deformation such as strain localization into shear bands and diffused instability during lateral soil-pipe interaction using finite element software "ABAQUS". Nor-Sand constitutive model will be modified taking account of both geometrical and material non-linearities. Bifurcation analysis will be conducted to detect the onset and inclination of shear bands. Both dry (one phase) and submerged (coupled pore fluid and solid) soil behaviour will be explored under this instability analysis. Post-bifurcation behaviour: propagation of shear band will be simulated using a suitable regularisation technique such as second gradient theory.

The ultimate goal is to more accurately capture the salient features of soil-pipe interactions under large deformations.

Definition of a discrete numerical model to describe the mechanical response of soils subjected to suffusion

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Keywords: Internal erosion, suffusion, DEM, model calibration

Abstract

Internal erosion is a major cause of the failure of hydraulic earthen structures. Suffusion is a particular case of internal erosion constituting a strongly coupled fluid-solid interaction problem. It is a selective erosion of fine particles from an unstable soil structure leaving behind the granular skeleton which leads to the deformation of the soil matrix. Such a process causes modification in the mechanical behavior of the soil. To study this problem numerically, a model is established using the Discrete Element Method implemented in Yade[1]. Periodic boundary conditions were adopted and 3D spherical discrete elements were chosen. Such an oversimplified particle's shape leads to excessive rolling [3,4]. To overcome this obstacle, rolling resistance was taken into consideration in the contact law through the incorporation of the plastic (plastic rolling moment, η_r) and elastic (rolling stiffness,K_r) parameters. The influence of such parameters were studied and it was found that for sufficiently high rolling stiffness, the macroscopic plastic behavior is independent of the elastic ones (Figure 1). Therefore, the plastic macroscopic behavior of the granular assembly is governed only by its initial density, the plastic bending moment and the contact friction angle. Moreover, we are interested in studying a range of models varying between loose and dense states. However, in the literature, the creation of loose models in DEM are rarely presented. Thus, in this poster, we address this issue in which a creation method is presented. This method consists of developing a model by adding cohesion at the contact of particles, in such a way we mimic the experimental creation mode by moist tamping. Such a procedure succeeded by which we were able to define a range of porosities corresponding to very loose, loose, dense and very dense samples (Figure 2). We had succeeded in calibrating the elastic and plastic parameters to meet some experimental results obtained from drained triaxial tests done on sand [2]. However, we had faced some limitations in establishing the influence of the confining pressure. Also we confronted difficulties in validating the model on undrained tests.

References

[1] Yade documentation. The yade project (http://yade-dem org/doc/), 2010.

[2] N.T. Kien. Etude expérimentale du comportement instable d'un sable silteux: Application aux digues de protection. PhD thesis, Université d'Aix-Marseille, 2014.

[3] M. Oda and K. Iwashita. Study on couple stress and shear band development in granular media based on numerical simulation analyses. International Journal of Engineering Sciences, 38:1713–1740, 2000.

[4] M. Oda, J. Konishi, and S. Nemat-Nasser. Experimental micromechanical evaluation of strength of granular materials: Effects of particle rolling. Mechanics of Materials, 1:269–283, 1982.

Figures

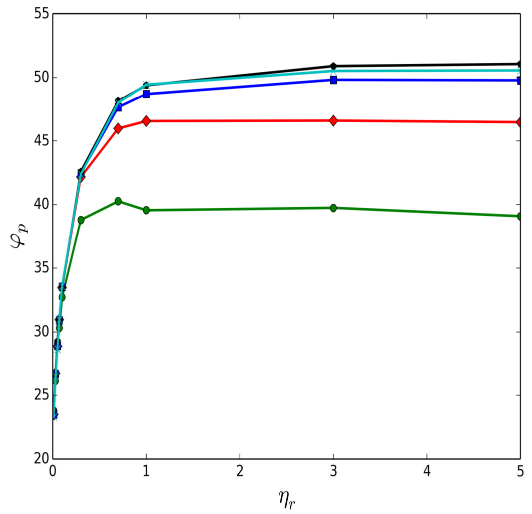

Figure 1: *The variation of peak friction angle with respect to ηr for different values of αr.(green: 0.025, red: 0.25, blue: 0.75, black: 1.25, cyan: 2.5) Note: αr and ηr are dimensionless parameters of rolling stiffness and plastic rolling moment respectively, used in Yade.*

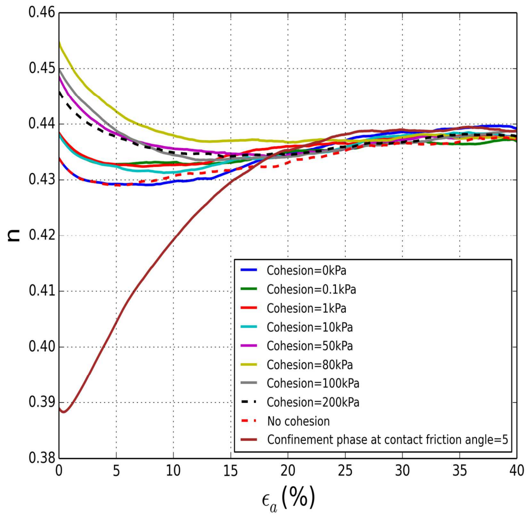

Figure 2: *The effect of contact cohesion, introduced during the compaction phase, on the initial porosity, and contractant or dilatant behavior along a drained compression path.*

Simulation of clay-interfaces under constant volume conditions using different constitutive interface models

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Keywords: Interface model, Clay, Hypoplasticity, Barodesy, Modified Cam-Clay

Abstract

The objective of this study is the constitutive modelling of fine-grained soil interfaces under constant-volume boundary condition. To this aim a recently developed approach [1] is used for adapting the standard continuum soil model as interface constitutive model. The idea is to use redefined tensorial operators with reduced stress and strain rate tensors. These are used with a 3-D constitutive model for the simulation of clay-structure interfaces. This approach is applied with different constitutive frameworks namely, the clay hypoplastic model with explicit defined state boundary surface [2], the Barodesy clay model [3] and the modified Cam-Clay model [4].

The three different models are used for simulation of two different clay-structure interfaces. The first simulation is done using London-Clay parameters. The second simulation show the comparison for Kaolin clay-structure interface. The comparison shows that new approach can simulate constitutive soil interface behaviour of fine-grained soil interfaces.

References

[1] Stutz, H., Mašín D. and Wuttke F. (2015): Enhancement of a hypoplastic model for granular soil-structure interface behaviour, (submitted)

[2] Mašín, D. (2013). Clay hypoplasticity with explicitly defined asymptotic states. Acta Geotechnica, 8, 481–496.

[3] Medicus, G. (2014). Barodesy and its application for clay. Ph.d. Thesis, University of Innsbruck.

[4] Roscoe, K. and Burland, J. (1968): On the generalized stress-strain behavior of wet-clay. In J.Heyman and F. Leckie (editors) Engineering Plasticity, pp. 535-609. Cambridge University Press

Figures

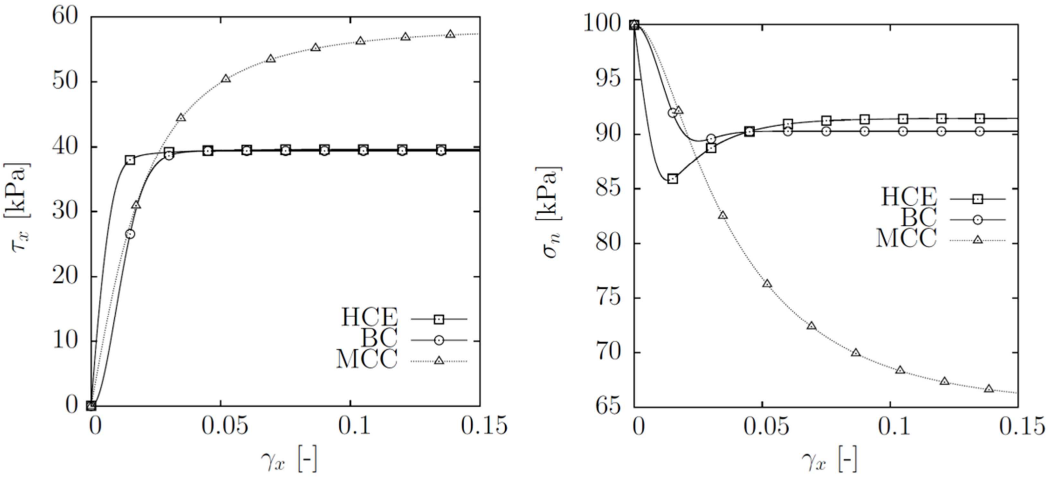

Figure 1 : *Shear and normal stress at the interface simulated by different constitutive models for London-Clay*

A numerical investigation with FEM on the behaviour of Suction Bucket foundations for wind energy turbines

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Keywords: offshore foundations, suction bucket, numerical model, pore water pressure, cycling loading

Abstract

Suction Bucket Jackets (SBJ) are found as a suitable alternative to driven piles for the support of jacket or tripod foundations for offshore wind energy converters. Offshore wind energy turbines are characterized by a small self weight and they can be subjected to different load combinations. The work presented here aims to show the numerical investigation on the behavior of suction bucket foundations under different kind of loads as well as load combinations. In order to do so, a suitable numerical model is much needed. The theoretical basis of the model lies on the Swansea formulation of Biot's equations of dynamic poroelasticity combined with a constitutive model that reproduces key aspects of cyclic soil behaviour in the frame of the theory of generalised plasticity. An adequate FE formulation, the representation of appropriate soil-structure interfaces and the computational efficiency are key aspects in order to successfully model such complex systems. The 3D numerical simulation allows a special insight into the fundamental behavior of the founding of Suction Bucket Jackets such as the evolution of the pore water pressure or the occurrence of the so called soil liquefaction.

References

1. Pablo Cuéllar, Pablo Mira, Manuel Pastor, José A. Fernández Merodo, Matthias Baeßler, Werner Rücker, *A numerical model for the transient analysis of offshore foundations under cyclic loading,* Computer and Geotechnics, Volume 59, June 2014, Pages 75–86.

2. Pastor, M., & Zienkiewicz, O. C. *A generalized plasticity, hierarchical model for sand under monotonic and cyclic loading*. In G. N. Pande & J. Middleton (Eds.), *2nd International Symposium on Numerical Models in Geomechanics* , 1986, Pages 131–150, Ghent, Belgium

3. Zienkiewicz, O. C., Best, B., Dullage, C. and Stagg K. G. (1970): *Analysis of non Linear Problems in Rock Mechanics with Particular Reference to Jointed Rock Systems*. Second Congress of the International Society for Rock Mechanics, Belgrad, Yugoslavia, 501-509

4. Cuéllar, P.: *Pile Foundations for Offshore Wind Turbines: Numerical and Experimental Investigations on the Behaviour under Short-Term and Long-Term Cyclic Loading*. Ph.D. Thesis, Technical University of Berlin, 2011

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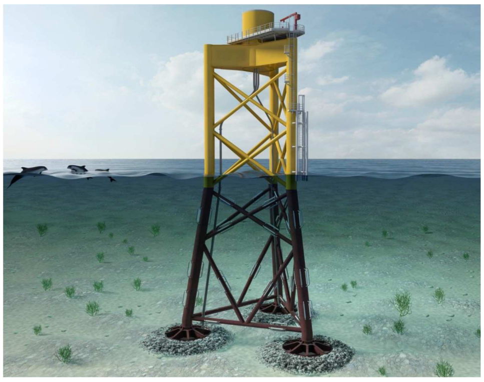

Figure 1 : *draft of the suction bucket jacket.*

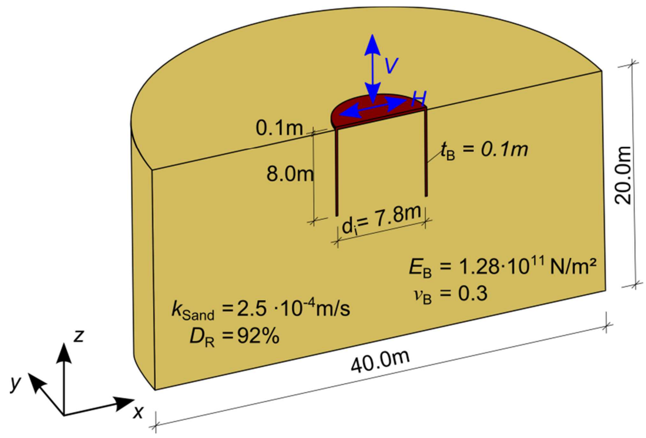

Figure 2 : *sketch of the model for the suction bucket jacket.*

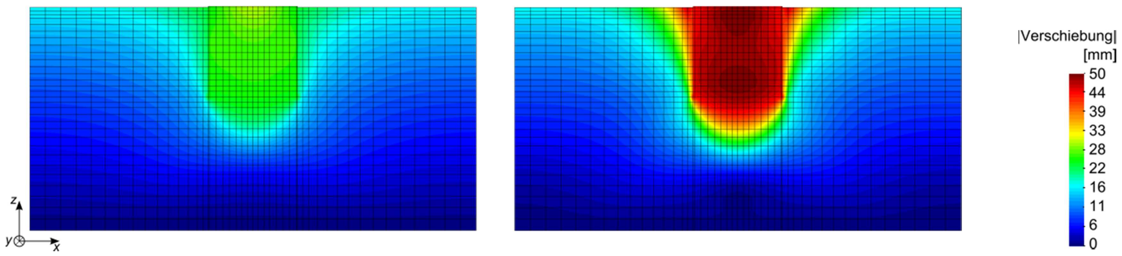

Figure 3 : *displacement results for a cycling load (left: at 2,6 s, right: at 22,1 s)*

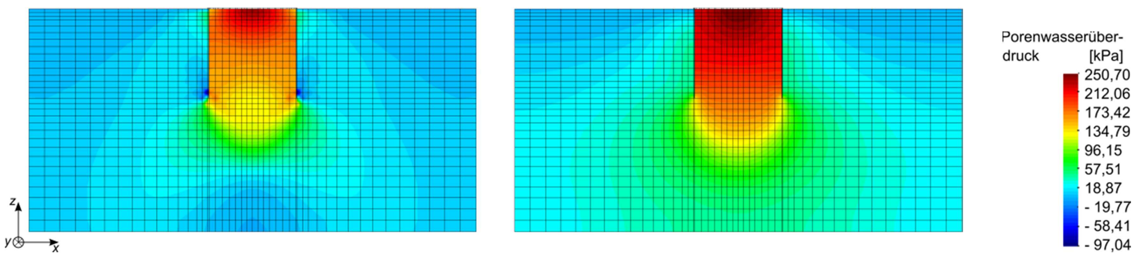

Figure 4 : *pore water pressure results for a cycling load (left: at 2,6 s, right:at 22,1 s)*

Comparative analysis of analytical and numerical solutions for one-, two- and three-dimensional reactive transport in porous media

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Keywords: analytical solutions, transport in porous media, numerical solution, software validation, reactive flow, COMSOL Multiphysics

Abstract

Mass transport is an essential process in the study of movement of fluids through porous media. Mass transport consists of three main phenomena: advection, diffusion-dispersion and reaction. Understanding of the reactive flows plays an important role in the design and treatment of various subsurface tasks such as the reservoir stimulation for oil and gas production and the CO_2 injection as part of the Carbon Capture and Storage processes. As a first part of the efforts to simulate the CO_2 storage reservoirs during the injection in the framework of the EU project "Thales-Geomecs", this study aims to validate the commercial software Comsol Multiphysics for the phenomena of mass transport in porous media. Literature in the field provides analytical solutions for one-, two- and three-dimensional solute transport in finite and semi-infinite length systems with first- or third-type boundary conditions in the inlet. Deep understanding of the analytical solutions provides a crucial view at the phenomena which will be very useful during the numerical simulations of the real situations. After solving various cases for one-, two- and three-dimensional transport analytically, models of these cases are imported into Comsol Multiphysics and solved numerically with the finite element method. Comparative diagrams of the solutions are presented to show the software validation and the convergence of the finite element method employed in Comsol Multiphysics and some central conclusions about the behavior of such flows are remarked. This study is the base for a series of future research tasks where non-conservative flows through porous media will be addressed with varying porosity, permeability and changes in the mechanical behavior of the reservoirs regarding the processes of acid stimulation (wormhole formation) and CO_2 injection and storage.

Teaching geomechanics of clay: a feedback from the International Master in Advanced Clay Science at Poitiers, France

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Keywords: geomechanics, clay, multi-disciplinary program, heterogeneous community of students.

Abstract

IMACS (International Master in Advanced Clay Science) is a program in Clay Science delivered by four Universities**:** the University of Poitiers (France), the Technical University of Crete (Chania - Greece), the University of Aveiro (Portugal) and the Federal University of Rio Grande Do Sul (Porto Alegre – Brazil)**.** Its objective is to form high level graduates by providing them a wide range of competences with applications in Environment, Earth Sciences and Materials (Geomaterials and Nanomaterials). Clay Science (i.e., the scientific study of clay) is a relatively young discipline which is extremely inter- and multidisciplinary as it includes geological, geotechnical, mineralogical, physico-chemical and bio-geochemical aspects. The IMACS is the first master course addressing analytical techniques and their recent developments, clay mineral properties as well as their main application domains.

Teaching geomechanics of clay is a challenging task in this context: the students come from different cursus and a large part of them are not familiar with the fundamentals of the mechanics and the geotechnical engineering. After five years of pedagogical experiment, we can make the following observations:

a. Most of the fundamental concepts used in the geomechanics of clay (swelling/shrinkage, primary and secondary consolidation) can be taught by simple laboratory experiments based on oedometer test. These simple experiments performed in the framework of practical works allow to transmit complex concepts to a heterogeneous community of students.

b. Swelling index and swelling pressure are employed in a wide range of empirical correlations in geotechnical engineering. These empirical correlations are used in practice with caution because most of them are site-dependent. However, in a pedagogical context, they are helpful to illustrate in a simple and quantitative way, huge geotechnical effects involving swelling clay soils.

c. Simple micro-macro models (e.g., Bolt, 1956) are efficient tools to link physico-chemical approaches (e.g., double layer theory) and geomechanical concepts associated with clay materials (e.g., swelling or osmotic pressure). They are essential in the context of a material-based and multi-disciplinary approach.

References

http://www.master-imacs.org/
Bolt, G. H. (1956). Physico-chemical analysis of the compressibility of pure clays. *Geotechnique, 6*(2), 86-93.

Experimental study of mechanical behavior of compacted bentonite from Czech Republic

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Keywords: compacted bentonite, swelling deformation, swelling pressure

Abstract

Compacted bentonite is often planned as an engineered barrier material between host rock and canister in nuclear waste disposal repositories thanks to its favourable swelling characteristics and low permeability. To design the repository, it is necessary to know the behaviour of compacted bentonite in unsaturated conditions and upon temperature changes[1-3]. For the design of one such repository planned in Czech Republic, a research program has been setup to assess the thermo-hydro-mechanical properties of compacted bentonite. In this poster, experimental results obtained within the project are presented for Czech bentonite 75 (B75) which was commercially available (crushed and sieved; Keramost Ltd)[4]. The material was tested at an initial dry density of 1.22-1.32g/cm^3. Wetting under constant load test and saturated oedometer test were performed in the laboratory. The results of swelling pressure tests (constant volume) and saturated oedometer unloading test showed a unique relationship when replotted in the effective stress vs dry density, which confirmed conclusions about effective stress in swelling soils presented by Mašín and Khalili(2015)[5].

References

1. Komine, H and Ogata, N. (1999) Experimental study on swelling characteristics of sand-bentonite mixture for nuclear waste disposal, Soils and Foundations, 39(2), 83-97.
2. Villar, M.V. and Lloret, A. (2004) Influence of temperature on the hydro-mechanical behavior of a compacted bentonite Appl. Clay Sci. 26, 337-350.
3. Komine H, Yasuhara K, Murakami S. (2009) Swelling characteristics of bentonites in artificial seawater[J]. Canadian Geotechnical Journal, 46(2): 177-189.
4. Hausmannova. L. & Vasicek. R. (2014) Measuring hydraulic conductivity and swelling pressure under high hydraulic gradients. Clays in natural and engineered barriers for radioactive waste confinement[B], 293-301.
5. Mašín D, Khalili N. (2015) Swelling phenomena and effective stress in compacted expansive clays[J]. Canadian Geotechnical Journal.

Figures

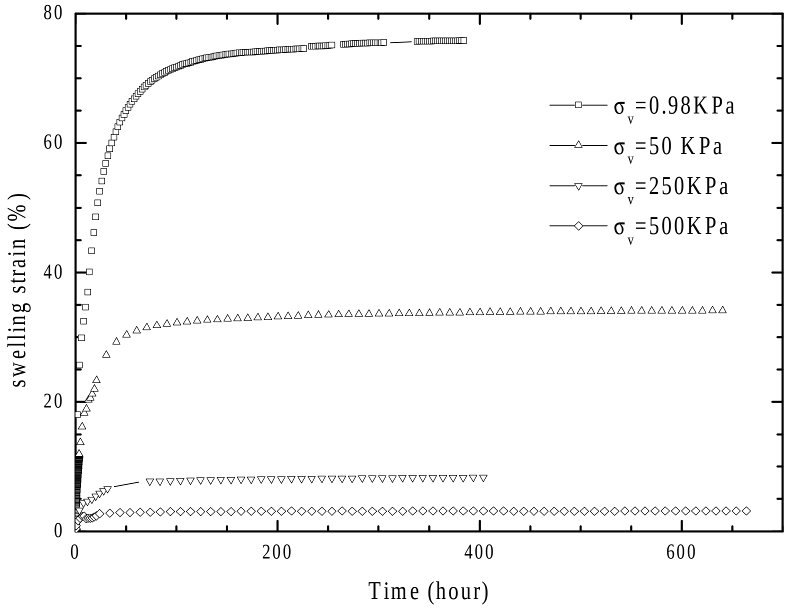

Figure 1 : *curves of swelling strain vs time at different constant load*

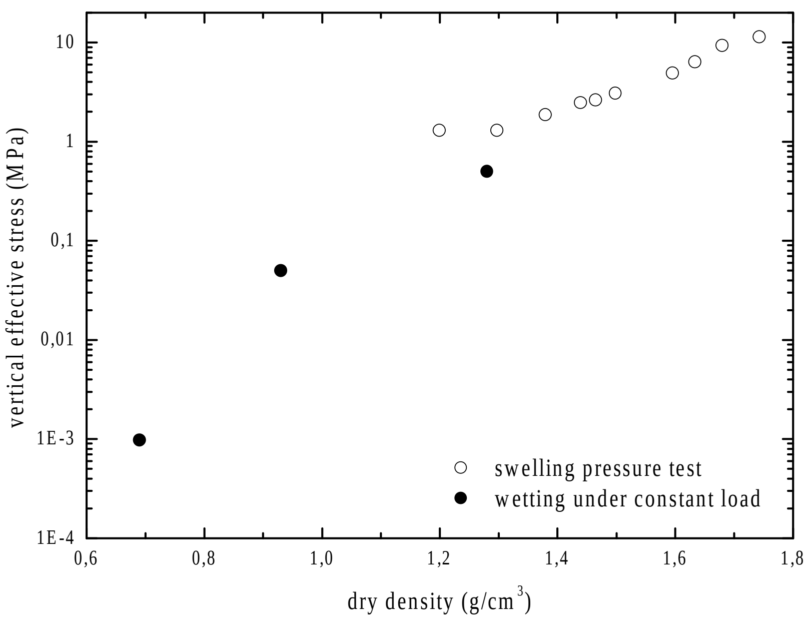

Figure 2 : *experimental data replotted in the effective stress vs dry density space (swelling pressure test data by Hausmannova&Vasicek(2014))*

A simplified method for estimating permanent earthquake-induced displacements in large mountain reservoirs

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Keywords: embankment, Earthquake, Sliding block model, Seismic displacement, Equivalent linear method

Abstract

In order to evaluate the seismic performance of large mountain reservoirs located in the Alpes, we propose a decoupled displacement-based method based on the sliding block model. A simplified procedure is performed by decoupling the dynamic response of the structures to actual recorded acceleration time histories, from a Newmark-type method. Based on dynamic analyses performed on 7 acceleration–time histories and applied to 33 geotechnical situations, we study the influence structure geometries and soil properties on the prediction of earthquake-induced displacements. We also discuss the relevance of our model by carrying out comparisons with often-used simplified models (Fig.1) and with observations on embankments performance during past earthquakes (Singh *et al.).* An elementary regression analysis using parameters of interest provides a semi-empirical equation, intended for use by practicing engineers within the scope of seismic risk assessments.

References

Hynes-Griffin, M.E., Franklin, A.G., 1984. Rationalizing thet seismic coefficient method. US Army Corps of Engineers Waterways Experiment Station. Miscellaneous Paper vol. GL-84-13.

Newmark, N.M., 1965. Effects of earthquakes on dams and embankments. Geotechnique 8, 133- 157.

Saygili, G., Rathje, E.M., 2008. Empirical predictive models for earthquake-induced sliding displacements of slopes. J. Geotech. Geoenviron. application in Southern California 109, 183-194.

Seed, H.B., Makdisi, I.F., De Alba, P., 1978. Performance of earthen dams during earthquakes. J. Geotech. Eng. 104, 967-994.

Singh, R., Roy, D., Das, D., 2007. A correlation for permanent earthquake-induced deformation of earth embankments. Engineering Geology 90, 174-185.

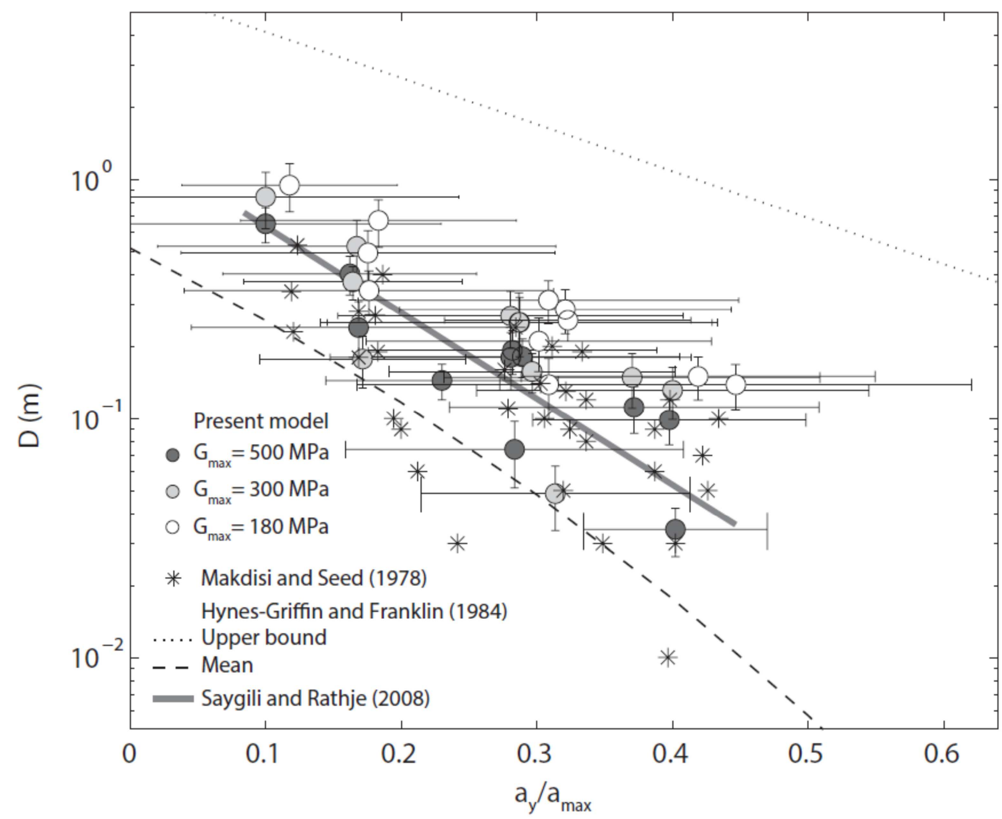

Figure 1 : *Displacements as a function of the critical acceleration ratio a_y/a_{max}, where a_y is the yield acceleration of the sliding block and a_{max}, is the peak value of the horizontal ground acceleration.*

Development of a hypoplastic model for soft clays incorporating rate effects and strength anisotropy

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Keywords: hypoplasticity, constitutive modelling, soft clay

Abstract

The stress-strain behavior of soft soils is complex. They exhibit: 1) significant degree of anisotropy of the fabric developed during deposition and one-dimensional consolidation; 2) bonding between particles, which can be progressively destroyed during straining; 3) and time dependent stress-strain behavior (creep and relaxation). One of the features – bonding between particles – has already been implemented into hypoplastic model for clays by Mašín (2007).

The main objective of the present research is to incorporate the other effects listed above into hypoplastic constitutive models. It is done by implementation of rate dependency and anisotropy (rotational hardening) into the latest version of hypoplastic model for clays (Mašín, 2014), which combines mathematical structure of hypoplastic models with the basic principles of the critical state soil mechanics and the Modified Cam clay model and allows for the explicit state boundary surface formulation. The explicit formulation enables us to incorporate rotated shape of the state boundary surface. The predictions of hypoplastic model (Mašín, 2014) for soft marine clays have shown not satisfactory results compared to experimental data, see Figure 2. The proposed changes to the hypoplastic model are expected to enhance the performance of the model for such soils. The rate-dependency will be included using similar approach as proposed by Niemunis et al. (2009). The poster presents the mathematical structure of the new model.

References

Fabianová, Klára. "Numerická analýza kolapsu stavební jámy Nicoll Highway v Singapuru." (*in Czech*) Charles University in Prague, (2014)

Niemunis, Andrzej, Carlos Eduardo Grandas-Tavera, and Luis Felipe Prada-Sarmiento. "Anisotropic visco-hypoplasticity." *Acta Geotechnica* 4.4 (2009): 293-314.

Mašín, David. "Clay hypoplasticity model including stiffness anisotropy." *Géotechnique* 64, No. 3, (2014): 232-238.

Mašín, David. "A hypoplastic constitutive model for clays with meta-stable structure." *Canadian Geotechnical Journal* 44, No. 3, (2007): 363-375.

Figures

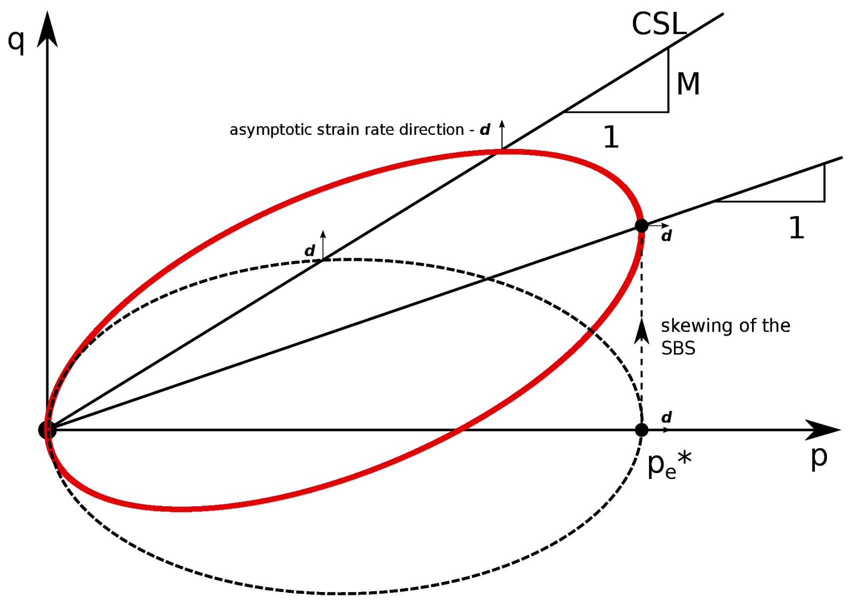

Figure 1: *Proposed approach for skewing of the SBS. Asymptotic strain rate direction (d) is assumed to be normal to the SBS for original and for skewed SBS, respectively.*

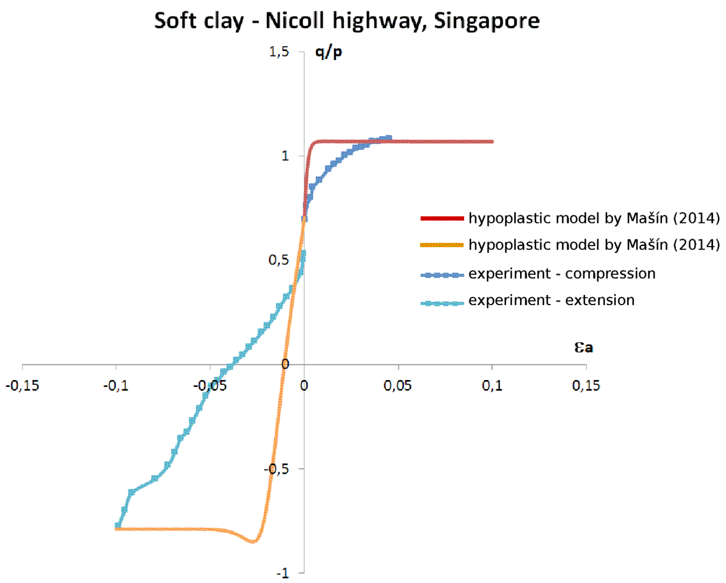

Figure 2: *Results of calibration of the latest version of the hypoplastic model (Mašín, 2014) for soft marine clays (Fabianová, 2014).*

Evaluation of Drucker-Prager plasticity using Isogeometric Analysis

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Keywords: isogeometric analysis, numerical methods, soil plasticity, NURBS

Abstract

Numerical simulation using finite element analysis, FEA, is today a common tool used during the design and performance analysis for geotechnical applications. The interaction between soil and structure often plays a decisive role for the performance of the analysis of geotechnical simulations. Unfortunately contact problems that include sliding and large displacements, which is often the case for soil-structure interaction problems, often leads to convergence problem due to the C^0 -continuous basis functions of the finite element method [1], and special treatment of the interacting surfaces is often required.

During resent years isogeometric analysis, or IGA, first introduced by Hughes et al. [2] have shown promising results for a broad number of engineering problems in resent years, ranging from analysis of unsaturated flow [3] and fluid-structure interaction [4] to analysis of shells [5].

IGA is a computational mechanics technology that utilizes the high order basis functions used in computer aided geometry design (CAGD), for analysis. Hughes et. al. suggested in [2], that the higher order continuity of the IGA basis functions leads to numerical advantages in certain areas. One of the areas suggested in [2] and that is also of great interest for geotechnical applications, is contact simulations where large displacements and sliding takes place and a thorough review of the current available contact formulations within the isogeometric framework can be found in [6]. The promising results for sliding contact problems and unsaturated flow simulations gives cause to evaluate the performance of IGA for analysis of soil behavior. The objective of the present work has therefor been to evaluate the performance of NURBS-based isogeometric analysis for soil plasticity using the Drucker-Prager criterion.

To assess how isogeometric analysis preforms for soil plasticity a NURBS-based Galerkin formulation have been implemented, as well as a non-associative Drucker-Prager model including hardening/softening behavior. To evaluate the performance of the IGA formulation in comparison to FEA, numerical examples have been studied using IGA and FEA. The first numerical example consists of a two-dimensional plane strain model of a smooth flexible footing placed on a sandy-silt. For this model a number of structured meshes have been studied where the displacement at a number of selected points have been compared.

The second model that has been studied consists of a three-dimensional cylinder subjected to a constant confining pressure and an increasing pressure at one of the ends. A final third numerical example simulates a shear fracture in brea sandstone presented in [7].

References

[1] I. Temizer, P. Wriggers, T. J. R. Hughes, Contact treatment in isogeometric analysis with nurbs, Computer Methods in Applied Mechanics and Engineering 200 (9-12) (2011) 1100–1112.

[2] T. J. R. Hughes, J. A. Cottrell, Y. Bazilevs, Isogeometric analysis: Cad, finite elements, nurbs, exact geometry and mesh refinement, Computer Methods in Applied Mechanics and Engineering 194 (39-41) (2005) 4135– 4195.

[3] M. N. Nguyen, T. Q. Bui, T. Yu, S. Hirose, Isogeometric analysis for unsaturated flow problems,Computers and Geotechnics 62 (2014) 257–267.

[4] Y. Bazilevs, J. R. Gohean, T. J. R. Hughes, Patient-specific isogeometric fluid–structure interaction analysis of thoracic aortic blood flow due to implantation of the jarvik 2000 left ventricula assist device, Computer Methods in Applied Mechanics and Engineering 198 (45-46) (2009) 3534– 3550.

[5] D. J. Benson, Y. Bazilevs, M. C. Hsu, T. J. R. Hughes, Isogeometric shell analysis: The reissner–mindlin shell, Computer Methods in Applied Mechanics and Engineering 199 (5-8) (2010) 276–289.

[6] L. D. Lorenzis, P. Wriggers, T. J. R. Hughes, Isogeometric contact: a review, GAMM-Mittellungen 37 (1) (2014) 85–23.

[7] J. F. Labuz, J. J. Riedel, S. T. Dai, Shear fracture in sandstone under plane-strain compression, Engineering Fracture Mechanics 73 (2006) 820–828.

Figures

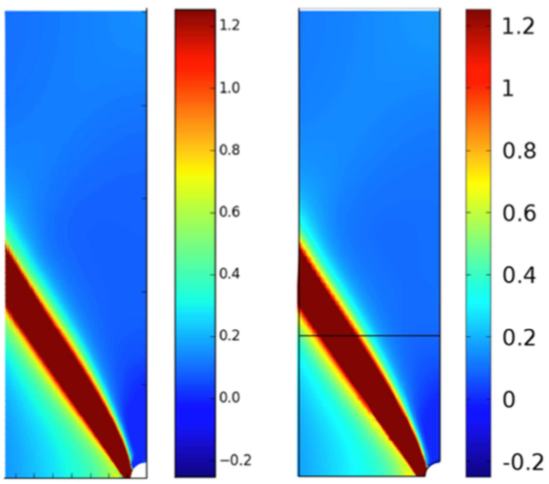

Figure 12: The current plastic strain $||\varepsilon^{pl}||$.

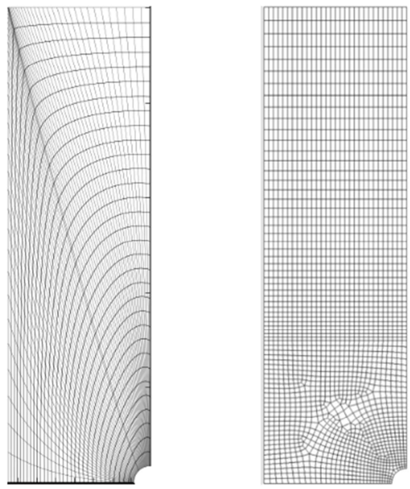

Figure 11: To the left, the mesh used in IGA and to the right the FEA mesh, used to model the shear fracture in the brea sandstone.

Seismic cross-hole method as a useful tool for estimation of inherent stiffness anisotropy of overconsolidated clay

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Keywords: stiffness anisotropy, shear modulus, very-small strains, cross-hole method, bender element, degree of anisotropy

Abstract

Field test using geophysical approach is one of the least disturbing ways to obtain material characteristics. We investigated the degree of Brno clay inherent stiffness anisotropy α_G' in very small strain range [3] by means of seismic cross-hole measurements [1]. α_G' stands for the ratio of square of shear wave velocities in-situ V_{pp}^I and V_{pt}^I and its value lies in the interval 1,20 – 1,30. For evaluation of times of shear wave arrivals, we used 3-component seismogram (Fig. 1) and particle motion tracking (Fig. 2) from the REFLEX software tool. A comparative triaxial laboratory testing of shear wave velocities V_{pp}^L and V_{tp}^L using bender elements was carried out [4]. The obtained ratio of $\alpha_G = (V_{pp}^L)^2/(V_{tp}^L)^2$ yields 1,45 whereas the theoretical condition $V_{tp} = V_{pt}$ is valid only for homogenous soils [2]. Despite the aspects influencing the laboratory testing (scale effect, sample disturbance, possible presence of stiffer intrusions, different unit weight) and field testing (subjective evaluation of the output signal) the difference between α_G' and α_G is acceptable.

References

[1] Filipský, D. (2012). Měření rychlostí seismických vln ve dvojici vrtaných sond. Závěrečná zpráva, INSET, s.r.o.

[2] M. L. Lings, D. S. Pennington, and D. F. T. Nash (2000). Anisotropic stiffness parameters and

12 their measurement in a stiff natural clay. G´eotechnique, 50(2):109–125.

[3] Mašín, D. and Rott, J. (2014). Small strain stiffness anisotropy of natural sedimentary clays: review and a model. Acta Geotechnica 9, No. 2, 299-312.

[4] Rott, J.; Mašín, D.; Boháč, J.; Mohyla, T.; Krupička, M. (2015). Evaluation of K0 in stiff clay by back-analysis of convergence measurements from unsupported cylindrical cavity. Acta Geotechnica (in print).

Figures

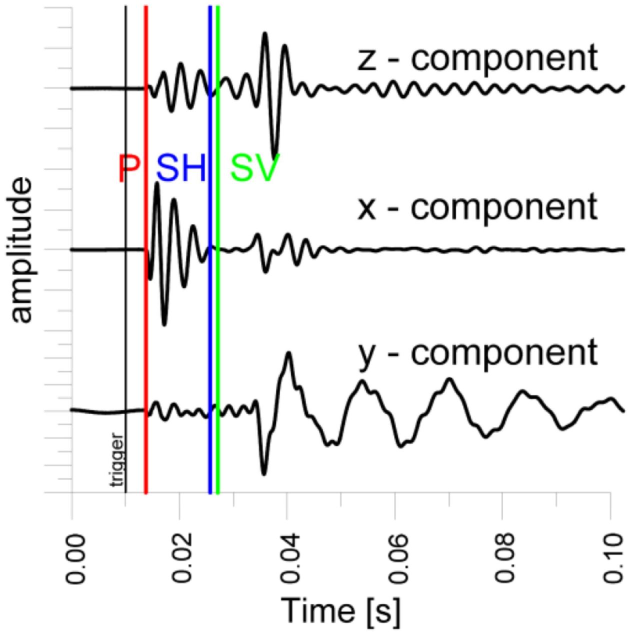

Figure 1. The components of 3-component seismogram in the depth of 8 m. The color lines indicate the time of arrival of P, SH and SV waves.

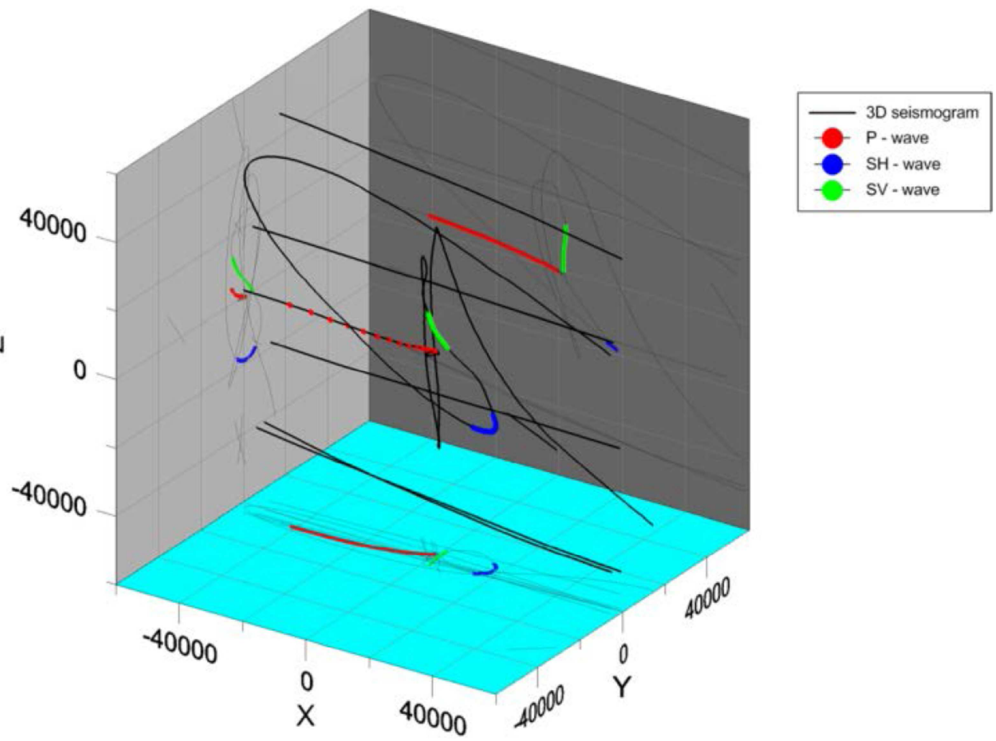

Figure 2. Particle motion diagram for the depth of 8 m. 3C seismogram is visualized by black curves. The grey curves show the projection of particle motion into coordinate planes. The color lines show the time of arrival of P, SH and SV waves.

A Biaxial Plane Strain Apparatus for Neutron Diffraction-based Experiments on Granular Rocks

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Keywords: Granular rocks, Plane-strain apparatus, Neutron diffraction, Grain-strain, Strain mapping

Abstract

This work considers the development of a new “plane-strain” biaxial loading device (Figure 1) for granular rocks through which the full-field investigation of strain evolution at different scales will be possible. Multiscale strain measurements will be accomplished by combining Neutron Diffraction with Digital Image Correlation (DIC) during plane-strain loading. The experimental set-up will also, in the future, include ultrasonic tomography to monitor the full-filed evolution of elastic properties.

Neutron Diffraction scanning has recently been successfully used to investigate force/stress distribution in granular materials under load. More specifically, Hall et al. (2011) showed that grain strains can be measured over a small gauge volume of a sample consisting of tens-of-thousands of sand grains. Further to that, Wensrich et al. (2012) produced in-situ mapping of the distribution of stress as an average over the volume of particles of a copper powder inside a solid die, excluding the voids. The key aim of this work is to extend the approach of Hall et al. (2011) to map spatial variations and evolutions of granular strains in rocks under loading, to investigate how forces are transmitted through the material and how this evolves with (localised) deformation. The simultaneous measurement of total strain fields (including porosity changes) through DIC and the use of samples with different cementations, will allow the characterisation of the mechanisms that act at different stages of deformation towards failure and how this is influenced by the degree of cementation.

Combining the different experimental techniques in a single apparatus requires certain constraints imposed by the different techniques and their combination to be addressed. A characteristic example relates to the combination of the design demands of the neutron measurements and of the high pressure needed to perform experiments under realistic in-situ conditions. The first requires the device walls to be as thin as possible to allow the maximum

number of neutrons to reach the sample, whereas the second requires the walls to be thick enough to sustain the required confining pressures. A first prototype of the device, without high pressure, has been tested (including for neutron penetration) at UK's neutron facility, ISIS. Results from this first proof-of-concept experiment, including 2D grain strain mappings for prismatic samples of sand loaded over a load-unload cycle, will be presented. Furthermore, the optimisation of the device, in terms of both mechanics and neutron scattering, for the construction of the second version, with confining pressure, will be presented and results of a first experiment with this device at the ILL neutron source in France will be discussed.

References

Hall S.A. et al., 2011, Granular Matter, 13, 251-254
Wensrich C.M. et al., 2012, Granular Matter, 14, 671-680

Figures

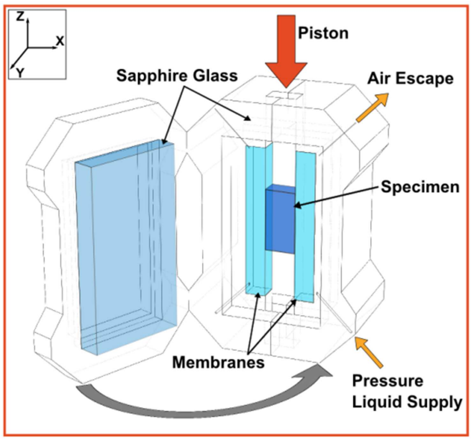

Figure 1 : *Initial schematic of the prototype þlane-strain'biaxial loading device.*

Small strain stiffness of unsaturated soil determined by triaxial testing

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Keywords: unsaturated soils, small strain stiffness

Abstract

The initial stiffness (shear modulus G_{max}, Young's modulus E_{max}) of saturated soil and its decrease with increasing strain was studied by various authors in the past decades. However, in case of unsaturated soils, there is not much data available in the literature, especially on the decrease of stiffness with strain. The proposed study is dealing with this phenomena and was inspired by the paper by Ng and Xu (2012).

The goal of this project is to study the effects of recent stress and suction history on the initial stiffness and shear modulus decay curve. A silty soil (loess) from Central Bohemia was chosen for the laboratory testing. The ongoing tests are carried out in a double wall cell triaxial system with high-air entry disk mounted in the base pedestal. The axis translation technique is used. The stiffness in the very small and small strain regions is measured by bender elements mounted in the pedestals and a pair of LVDTs (local axial displacements), respectively (Fig. 1). For controlling pore-water pressure, pore-air pressure and cell pressure the pressure/volume controllers are used. The measured values are going to be used for calibration of the hypoplastic model by Wong and Mašín (2014). The used stress paths are shown in Fig. 2.

References

Ng, C.W.W., Xu, J. (2012). Effects of current suction ration and recent suction history on small-strain behavior of an unsaturated soil. *Canadian Geotechnical Journal* 49, No. 2, 226-243.

Wong, K.S., Mašín, D. (2014). Coupled hydro-mechanical model for partially saturated soils predicting small strain stiffness. *Computers and Geotechnics* 61, 355-369.

Figures

Figure 1: *70 mm diameter triaxial specimen before test*

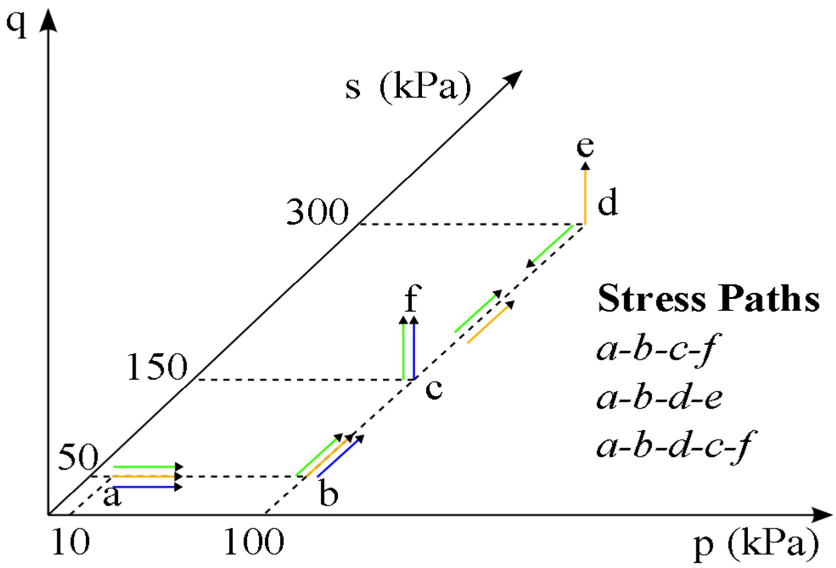

Figure 2: *An example of planned stress paths*

Identification of expansive minerals in foundation and pavement engineering practice

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Keywords: swelling index, swelling potential, smectite

Abstract

The purpose of this project is to find a simple method for determining expansive minerals in soils. Several commonly used methods, namely the X-Ray diffraction, clay activity and the swelling index were used to determine the swelling potential as one of the most representative properties in the estimation of swelling minerals. The swelling index was determined from oedometer test. X-Ray diffraction method was used to identify the smectite and its quantity. In addition, ethylene glycol (EG) test was used to confirm the presence of smectite (Fig. 1). The swelling potential was estimated as the swelling index correlated to qualitative ranges of potential volume change (PCV), and as the values of clay activity correlated to content of clay fraction.

Swelling pressure may be important a indicator of the expansive minerals in the soil. The measured samples show a wide range of swelling index (0 - 70 kPa) and smectite contents (0 - 21%). However, the values of swelling pressure are not consistent with the content of smectite. Some samples does not contain smectite but exhibit swelling pressure and vice versa. Moreover, X-ray diffraction analyses were time consuming and expansive and thorough a determination of clay minerals using this method requires a confirmation using the following methodology: microscopy, separation of clay fraction, Rietveld analysis, silicate analysis and cation exchange capacity (CEC). CEC is a common laboratory test and the value of CEC is related to clay mineralogy. Generally, the swelling potential increase as CEC increases. Cation exchange capacity (CEC) will be measured to determine the cation exchange activity (CEAc), and the coefficient of linear extensibility (COLE), respectively. Using these methods the mineralogical boundaries and smectite content of soil samples will be specified.

References

Mitchell, J. K., and Soga, K. (2005). *Fundamentals of soil behavior.* John Wiley and Sons, Inc. New York

Nelson, J. D., and Miller, D. J. (1992). *Expansive soils: problems and practice in foundation and pavement engineering.* John Wiley and Sons, Inc. New York

Figures

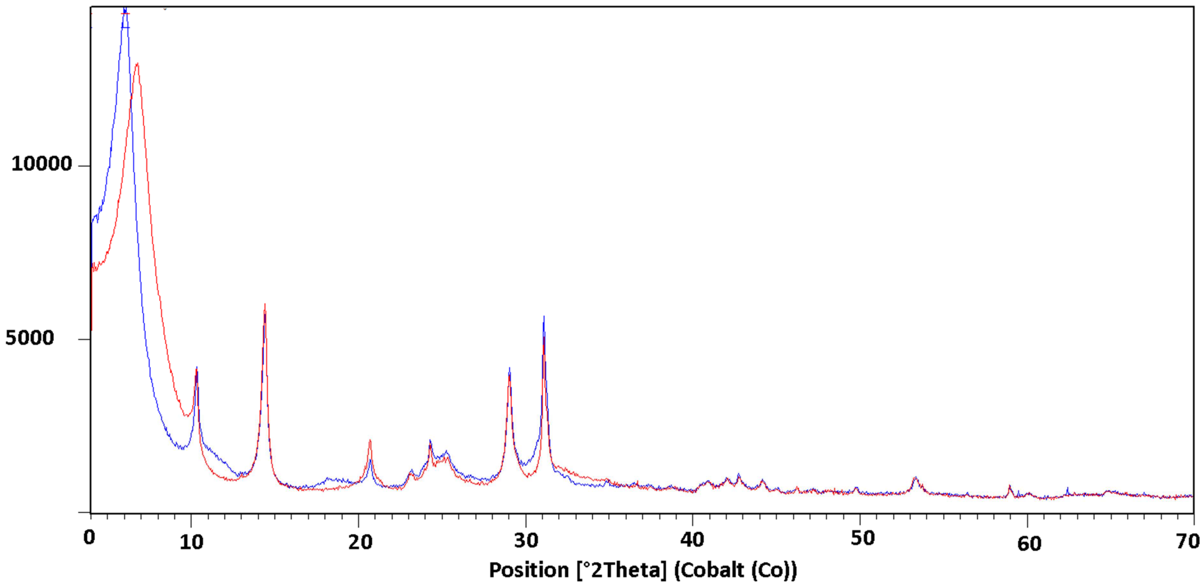

Figure 1: *Example of using EG test in identifying smectite mineral.*
(Shift to the left of the blue record indicates the presence of smectite.)

Local mechanisms of cohesive soil erosion

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***Keywords**:* erosion, model soil, impinging jet, turbulent flow

Abstract

Soil's erosion is a natural phenomenon described by the removing and transport of elementary soil particles under the action of air or water. The issue of hydraulic erosion of earth embankment dams and levees is responsible, on average, for one failure per year in France. In this context, a better understanding of the underlying mechanisms during erosion processes at the surface of a soil sample can help to improve the safety of such flood protection structures. In practice, the state of the art in modeling erosion of a cohesive granular media exposed to a water flow is still poorly understood and should necessarily be improved. Most of the empirical local erosion laws proposed in the literature involve two erosion parameters: the erosion threshold stress and the erosion coefficient. Both parameters are usually estimated experimentally with several different erosion tests: the Hole Erosion Test, the Erosion Function Apparatus, the Jet Erosion Test... However, there is generally no clear correlation between those erosion parameters and other commonly used soil properties.

In the present study, a parametric analysis is carried out to better comprehend the erosion mechanisms through an experimental approach based on the use of specially developed model materials. Interestingly, specific properties of these model soils, as cohesion and inter-granular forces, can be continuously modified and quantified by appropriate mechanical tests. In parallel, estimating the erosion parameters of the model material by a Jet Erosion Test [Hanson and Cook, 2004] allows to identify and analyze the soil's mechanical properties showing a strong influence on erosion resistance. Finally, these properties could be implemented in an efficient erosion model.

For instance, a useful model materials made out of glass beads with viscous cohesive bonds has been developed for its transparency. Then, combining the refractive index matched technique and the planar laser-induced fluorescence, as already used by Philippe and Badiane (2013), allows to image and monitor the local erosion processes as we can see in the *figure 1*(left). Experimentally, it is necessary that the oil mixture used as eroding fluid, the glass beads and the cohesive matrix made of heavy oil have all approximately the same refractive index. This method makes possible to observe the mechanisms by which the fluid flow removes single particles from the cohesive material and to quantify the progressive scouring of the soil during an Jet Erosion Test as in *figure 1* (right).

References

Ariathurai R., Arulanandan K. (1978), Erosion rates of cohesive soils. Journal of Hydraulics Division, ASCE, Vol. 104(2): 279-283

Hanson G. J. and Cook K. R. (2004), Apparatus, Test Procedures, and Analytical Methods to Measure Soil Erodibility In Situ. Applied Engineering in Agriculture, 20(4): 455-462.

Philippe P. and Badiane M. (2013), Localized fluidization in a granular medium. Physical Review E 87.

Figures

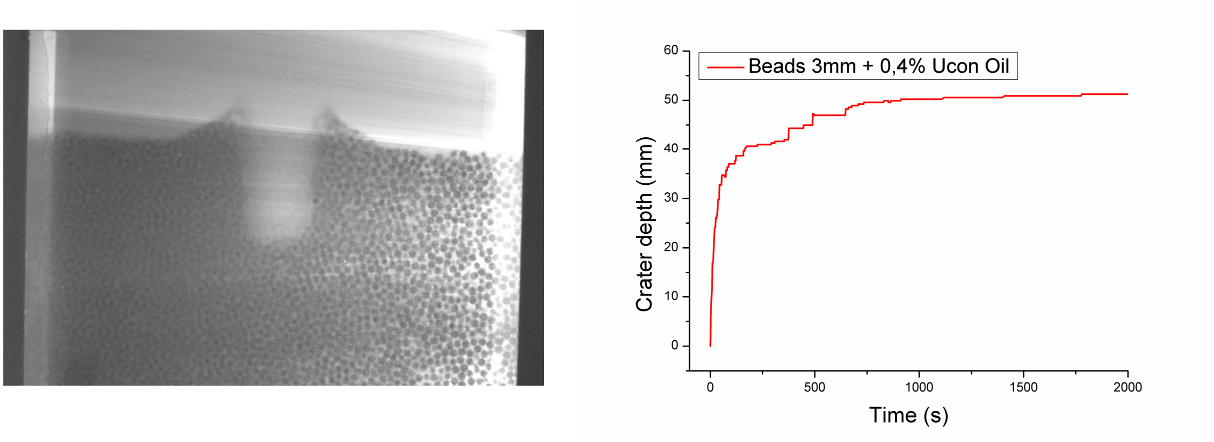

Figure 1: *Transparent Jet Erosion Test and crater depth variation for glass beads with a diameter of 3mm and bonded by Ucon Oil with 0.4% volume fraction.*

Localization of deformation of undrained adiabatic shearing of a rock layer with Cosserat microstructure

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Keywords: Earthquakes, Cosserat continuum, undrained adiabatic shearing, Pseudo-spectral methods.

Abstract

Shear bands is one of the major modes of failure in geomaterials. They constitute the cause of catastrophic landslides [1] and seismic faults [2] involving mechanisms that occur at several length and time scales. A fault that accommodates tectonic motion can be tens of kilometers long. Yet, the width of the band where the shear deformation localizes is very narrow, i.e. of millimetric scale or even thinner. Strain localization in narrow bands can be seen as a bifurcation from the homogeneous deformation solution of the underlying mathematical problem, which is favored by softening behavior [3]. Softening can be of mechanical origin (e.g. microcracking, grain crushing, reduction of internal friction etc.), of chemical reasons (e.g. dissolution, dehydration etc.) or it can be attributed to thermal effects. During seismic slip, a large amount of the accumulated deformation energy is converted into heat. For a saturated material this leads to pore-fluid pressurization induced mainly by thermal expansion of the fluid. Thermal pressurization is an additional destabilizing mechanism as it results to significant decrease of the effective mean stress and consequently to the reduction of its shear strength [4]. Additionally, temperature rise is related to the activation of endothermic or exothermic chemical reactions, which can further influence the energy budget of the system and the shear strength of a fault gouge [5], [6].

Here we present a model for the undrained, adiabatic shearing of a saturated rock layer under multiphysical couplings [7][8], [9]. Cosserat theory is used for the mathematical description of the mechanical behavior of the gouge. The reason for using Cosserat continuum is not only the well-known ill-posedness of the classical, Cauchy continuum [10], but also the fact that the shear band width is comparable to the size of the microstructure of the gouge material. Cosserat theory is particularly interesting as it can explicitly take into account the granular size.

Adopting an elastoplastic constitutive model for the Cosserat continuum, the mathematical system is integrated then numerically in order to study the post-bifurcation behavior of the problem. The numerical simulations were performed using pseudo-spectral methods with Chebyshev polynomials. The pseudo-spectral method used is a powerful alternative for solving nonlinear systems of partial differential equations [11]. The numerical analyses allowed to verify and to complete the theoretical predictions [7] in the post-bifurcation regime for a fault gouge under multiphysical couplings.

References

[1] I. Vardoulakis, “Dynamic thermo-poro-mechanical analysis of catastrophic landslides,” *Géotechnique*, vol. 52, no. 3, pp. 157–171, Jan. 2002.

[2] J. W. Rudnicki and J. R. Rice, “Conditions for the localization of deformation in pressure-sensitive dilatant materials,” *J. Mech. Phys. Solids*, vol. 23, no. 6, pp. 371–394, Dec. 1975.

[3] I. Vardoulakis and J. Sulem, *Bifurcation Analysis in Geomechanics*. Glascow: Blackie, 1995.

[4] J. R. Rice, J. W. Rudnicki, and J. D. Platt, “Stability and localization of rapid shear in fluid-saturated fault gouge : 1 . Linearized stability analysis,” *J. Geophys. Res.*, pp. 1–23, 2014.

[5] N. Brantut and J. Sulem, “Strain Localization and Slip Instability in a Strain-Rate Hardening, Chemically Weakening Material,” *J. Appl. Mech.*, vol. 79, no. 3, p. 031004, 2012.

[6] E. Veveakis, T. Poulet, and S. Alevizos, “Thermo-poro-mechanics of chemically active creeping faults: 2. Transient considerations,” *J. Geophys. Res. Solid Earth*, p. n/a–n/a, Jun. 2014.

[7] J. Sulem, I. Stefanou, and E. Veveakis, “Stability analysis of undrained adiabatic shearing of a rock layer with Cosserat microstructure,” *Granul. Matter*, vol. 13, no. 3, pp. 261–268, Feb. 2011.

[8] I. Stefanou and J. Sulem, “Chemically induced compaction bands: Triggering conditions and band thickness,” *J. Geophys. Res. Solid Earth*, vol. 119, no. 2, pp. 880–899, Feb. 2014.

[9] E. Veveakis, I. Stefanou, and J. Sulem, “Failure in shear bands for granular materials: thermo-hydro-chemo-mechanical effects,” *Géotechnique Lett.*, vol. 3, no. April-June, pp. 31–36, May 2013.

[10] I. Vardoulakis, “Stability and bifurcation of undrained, plane rectilinear deformations on water-saturated granular soils,” *Int. J. Numer. Anal. Methods Geomech.*, vol. 9, no. 5, pp. 399–414, Sep. 1985.

[11] J. P. Boyd, *Chebyshev and Fourier Spectral Methods: second edition*. 2000.

Figures

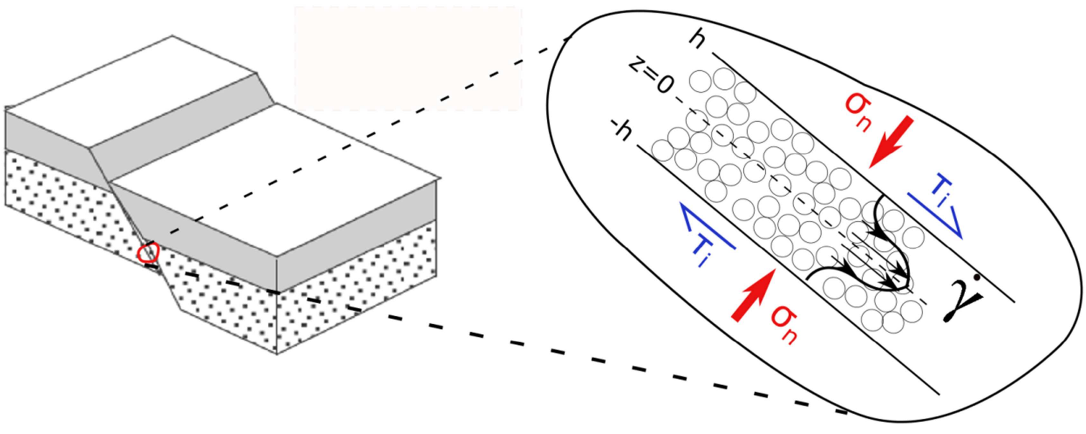

Figure 3 : *Sketch of a gouge layer which exhibits the localization of the shear strain rate*

Unsaturated Soil Behavior under Cyclic Loading

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Keywords: cyclic loading, small strain stiffness, unsaturated soil, accumulation of displacement, long-term cyclic loading

Abstract

The deformation of the granular material under the action of cyclic loading can be interpreted by unique soil properties. The various changes on the soil properties by the application of the cyclic loading create a unique response to the applied external forces. The study on the cyclic loading and unloading phenomenon has been undertaken by notable researchers like Nova and Hueckel (1981), from the microscopic level for single-phase soil. Furthermore, the study on the response of single phase soil under long term quasi static loading is undertaken by Whitmann et al. (2009).

As the existence of unsaturated soil is predominant, over the saturated or dry soil, the study on the cyclic response of footing over unsaturated soil is an imminent need to understand the response of the structure and to evaluate its performance in the long term. The deformation of the unsaturated granular material under the action of cyclic loading can be interpreted by unique intrinsic soil properties. The various changes on the soil properties by the application of the cyclic loading creates a unique response to the applied external forces. The response of the footing resting over unsaturated soil by the action of quasi static loading has been a least studied phenomenon. A Macroelement capable to predict the response of footing resting over multiphase granular material under the action of cyclic loading has been proposed lately by Kafle and Wuttke (2013).

In this study, experimental study on the response of the shallow footing resting over unsaturated granular geomaterial under the action of cyclic loading is presented. The influence of soil suction on the elastic and micro-plastic behavior of soil under cyclic loading is observed. Among the coupled elastic and micro-plastic part of displacement within a cyclic loop, the elastic part of displacement plays a dominant role at larger cycle for multiphase soil compared to dry and saturated soil. High values of slope of load-displacement for certain number of cycle including some negative values at large cycles is observed in unsaturated soil providing the evidence of complete elastic response of soil within those cycles. The complete elastic and the coupled elastic and micro-plastic soil response is observed with alternation at large cycle predominantly for unsaturated soil. The strong influence on the deformation behavior of soil by the soil suction is observed. A 3D boundary domain for the accumulation of displacement in the suction and cyclic history space is generated.

References

R. Nova and T. Hueckel, An engineering theory of soil behaviour in unloading and reloading, Meccanica, 16(2) (1981), 136-148,

T. Wichtmann, A. Niemunis, Th. Triantafyllidis, Validation and calibration of a high-cycle accumulation model based on cyclic triaxial tests on eight sands, Soils and Foundations, 49(5) (2009), 711-728

B. Kafle, and F. Wuttke, Cyclic macroelement for shallow footing over unsaturated soil, 1st Pan-American Conference on Unsaturated Soils, Cartagena, Colombia, (2013), 521-526

Figures

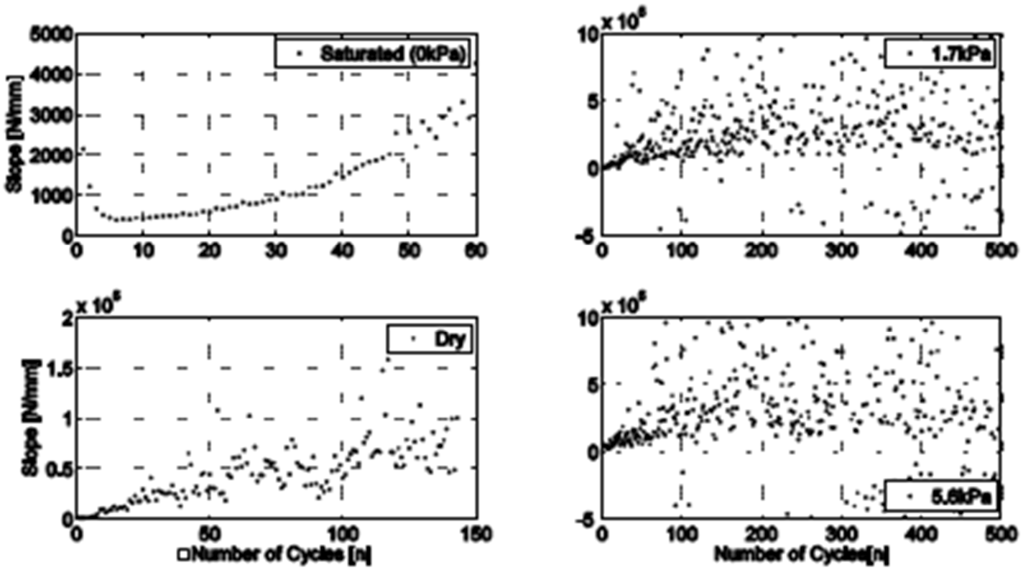

Figure 1 : *Change in the slope (df/dv) of each cycle with increasing number of cycle*

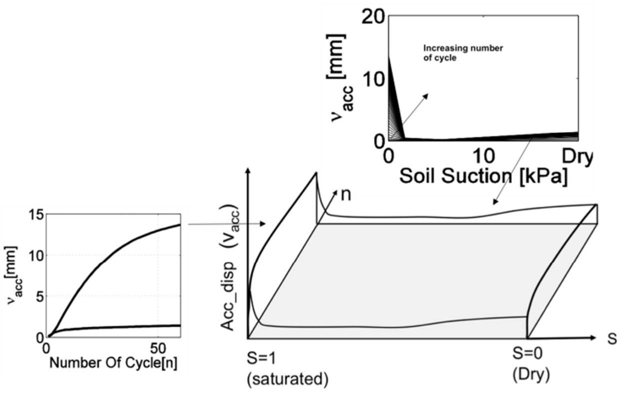

Figure 2 : *3D boundary of accumulation of displacement in the suction plane*

Experimental investigation of the mechanical behaviour of the Callovo Oxfordian clay-rock/concrete interface

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Keywords: clay-rock/concrete interfaces, shear test, instantaneous behaviour

Abstract

The French National Radioactive Waste Management Agency (ANDRA) is investigating the feasibility of a deep geological radioactive repository in Callovo Oxfordian clay-rock (known as COx) in Bure (France). The repository tunnels are lined with concrete, which will be pressurised after the installation of protective barriers. This overpressure, combined with the complex *in-situ* stress state and the presence of an Excavation-Damaged-Zone will load in shearing the concrete/clay-rock interface. Consequently, this experimental work aims to characterise the behaviour of this interface.

The instantaneous behaviour of the COx/concrete interface has been characterised in the BCR3D (a 3D shear box for rocks, see: *Boulon et al. 95*) on cylindrical samples (Ø=78mm) under a constant volume with imposing stresses up to 12MPa.

The Callovo Oxfordian clay-rock is a geomaterial with a very complex hydromechanical behaviour. Taking into account the possible influence of the water on the COx, samples prepared in two different ways were tested: fresh concrete/clay-rock and prefabricated concrete/clay-rock. The results in the mechanical response of the interface for both cases are compared.

References

Boulon M. (1995), *A 3D direct shear device for testing the mechanical behaviour and the hydraulic conductivity of rock joints*. Second Int. Conf. On Mechanics of Jointed and Faulted Rock MJFR-2, Vienne, Balkema ed., Rotterdam, Pays Bas, 407-413.

O. Buzzi, J. Hans, M. Boulon, F. Deleruyelle, F. Besnus, *Hydromechanical study of rock-mortar interfaces*, Physics and Chemistry of the Earth, Parts A/B/C, (2006).

Figures

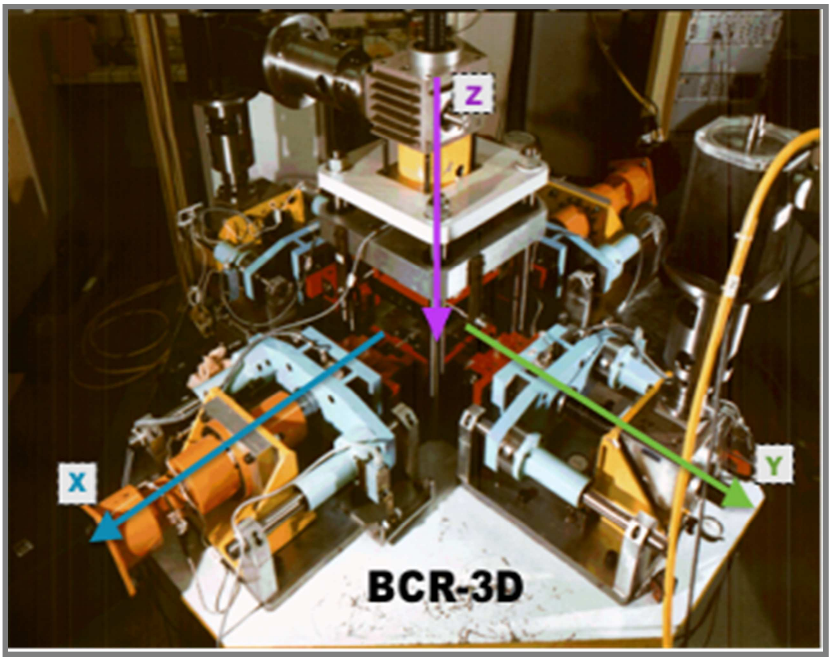

Figure 1 : *BCR3D, Shear box for rocks in 3 dimensions (Boulon et. al)*

A micro-mechanically based multi-scale model for granular soils

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Keywords: Granular material, Mesoscopic scale, Microstructure, Soil liquefaction, microdirectional model

Abstract

Microdirectional models involving a mesoscopic scale, constitute a good alternative to continuous models, defined at the macroscopic scale on phenomenological bases, and discrete models, poorly adapted for investigating the structure scale. In the H-microdirectional model, the granular assembly is modeled by a distribution of hexagonal patterns of grains in contact oriented in space. It is shown that the H-microdirectionnel is able to reproduce the main constitutive features of sands, including liquefaction. The influence of the distribution of orientation of the hexagones relative to the direction of loading and initial geometry is studied in terms of stress response. It is shown that the principal direction of anisotropy determines the liquefaction susceptibility of a soil, whereas the degree of anisotropy affects the amplitude of the post-peak loss of shear strength.

References

VEYLON, G., NICOT, F. (2015). *The role of microstructure in the liquefaction mechanism*. In: Bifurcation and Degradation of Geomaterials in the New Millennium - Proceedings of the 10th International Workshop on Bifurcation and Degradation in Geomaterials, 339-346.

NICOT F., HADDA N. & DARVE F. (2013). Second-order work analysis for granular materials using a multiscale approach. *International Journal for Numerical and Analytical Methods in Geomechanics*, 37, 2987-3007.

NICOT, F. & DARVE, F. (2011). The H-microdirectional model: Accounting for a mesoscopic scale. *Mechanics of Materials*, 43**,** 918-929.

Effect of hydration temperature on the porosity and microstructure of hardened cement paste

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Keywords: Cement microstructure, temperature, X-Ray diffraction, Rietveld method, Mercury Intrusion Porosimetry.

Abstract

In the structure of oil, geothermal and CO_2 injection wells, a cement sheath is placed between the casing and the rock for stability and sealing purpose. Due to the geothermal gradient, the cement sheath in a well is hydrated under different temperature conditions. This influences significantly the microstructure and poromechanical properties of the material, which are essential for predicting the well performances. The aim of this work is to investigate the effect of hydration temperature on the microstructure of a hardened class G oil-well cement paste [1].

The hydration of cement and the resultant microstructure, in terms of mineralogical composition and volume fraction are sensitive to temperature. Previous studies suggest a constant chemical composition of cement for hydration temperatures below 100°C [2]. Nevertheless, the resulting porous structure and hydrates distribution are highly controlled by the temperature. Increasing temperature is reported to change the C-S-H structure [3]. In fact, higher temperature results in a denser C-S-H [3] with a finer morphology, in a more heterogeneous distribution of hydrates and in a coarser porosity.

Through this study, we examine the influence of temperature on the microstructure of cement within the range of 7°C to 90°C. Combined X-Ray diffraction with the Rietveld method enables identifying and quantifying the major phases of cement microstructure. Mercury intrusion porosimetry helps capturing the variation of the porous structure with temperature. The powder diffraction patterns for the cement pastes cured at different temperatures are presented on Figure 1. The similarity of patterns shows that the chemistry of cement does not change significantly with the temperature. However, new phases appear with elevating temperature which may be explained by a change in the hydration behavior of aluminate and ferrite. Regarding the quantity of phases given by Rietveld calculation, the main crystalline phases, namely portlandite CH and calcite C, increase slightly with temperature, but it seems that the amorphous C-S-H content decreases beyond 40°C and another type of crystalline calcium silicate hydrate (Dellaite) is formed.

Apropos of the porous structure, from the results of mercury intrusion porosimetry (MIP), a coarsening of pores is markedly observed for higher temperatures on Figure 2. The porosity given by MIP presented in Figure 3, and which we suppose equivalent to capillary porosity, is increasing with the elevation of temperature. This has been reported before [3] and explained by the densification of the C-S-H which fraction was also reported to remain constant. However, the total porosity, measured by oven drying at 105°C, remains almost unchanged, suggesting that the porosity distribution is changing with temperature. These observations are compatible with the decrease in the C-S-H quantity, being replaced by a denser crystalline

product such as Dellaite.

References

[1] Ghabezloo, S., Sulem, J., Guédon, S., Martineau, F., & Saint-Marc, J. (2008). Poromechanical behaviour of hardened cement paste under isotropic loading. Cement and Concrete Research, 38(12), 1424–1437.

[2] Lothenbach, B., Winnefeld, F., Alder, C., Wieland, E., & Lunk, P. (2007). Effect of temperature on the pore solution, microstructure and hydration products of Portland cement pastes. Cement and Concrete Research, 37(4), 483–491.

[3] Gallucci, E., Zhang, X., & Scrivener, K. L. (2013). Effect of temperature on the microstructure of calcium silicate hydrate (C-S-H). Cement and Concrete Research, 53, 185–195.

Figures

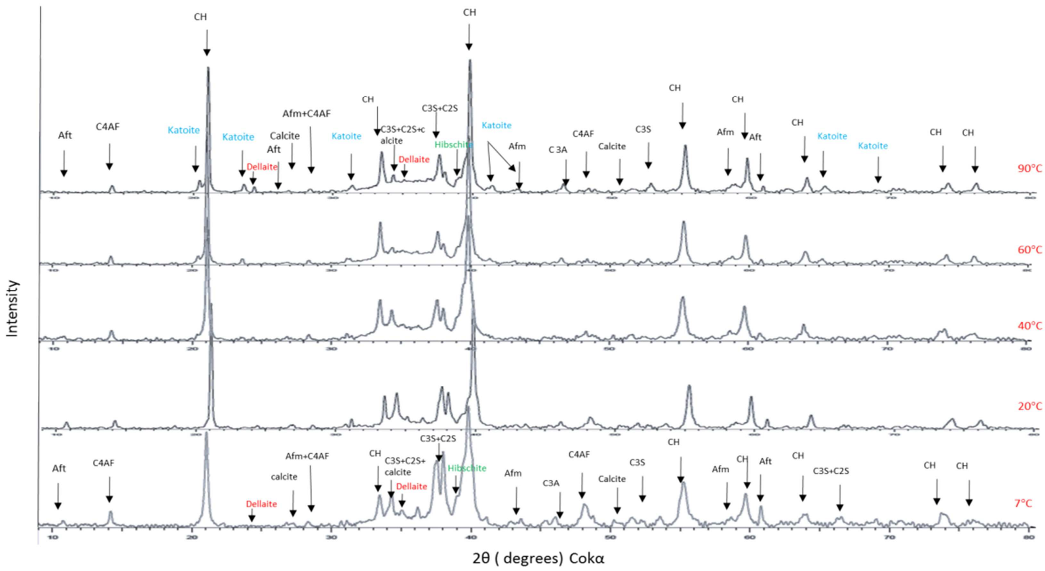

Figure 1: X-ray diffraction patterns for hardened cement pastes cured at different temperatures. The New phases that appear with higher temperatures are presented in colors.

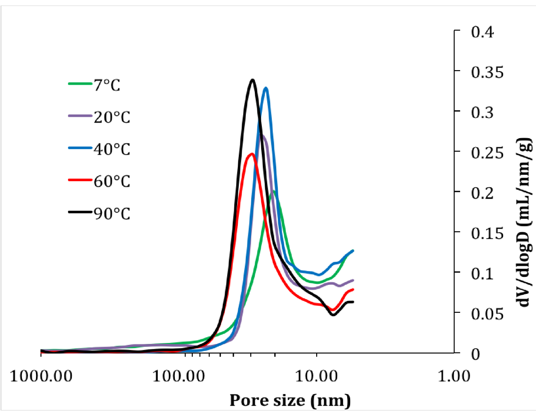

Figure 2: Influence of the curing temperature on the average size of the unique pore family as seen by mercury intrusion porosimetry

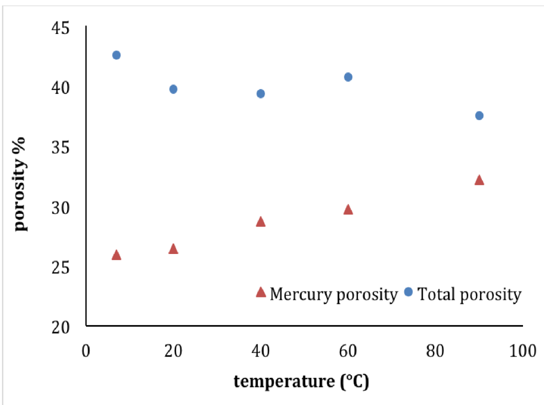

Figure 3: Porosity given by mercury intrusion porosimetry and total porosity measured by oven drying at 105°C of hardened cement pastes cured at different temperatures

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