General report: Constitutive, numerical and physical modelling

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ABSTRACT: This general report summarises papers presented in the "Modelling" session at the 7th International Conference on Unsaturated Soils. In total, 29 papers accepted by the time the general report has been prepared have been reviewed. Papers have been categorised into five main categories. Most contributions belong to "applications" category (11 papers), followed by the "constitutive modelling" category (9 papers) and "micromechanically motivated modelling approaches" category (5 papers). It is concluded that all the contributions have very high technical quality. The objectives and main findings of all the contributions are summarised in this report. In addition, I am also providing highly subjective list of most interesting contributions, which I, among others, recommend for more detailed study.

1 INTRODUCTION

This general report summarises papers presented in the "Modelling" session at the 7th International Conference on Unsaturated Soils. In total, 29 papers accepted by the time the general report has been prepared have been reviewed. I consider the session as an interesting demonstration of current research trends in the field of modelling partially saturated soils. To better highlight the research trends, the papers have been categorised into five main categories:

1. Constitutive modelling (9 papers)
2. Formulations of coupled governing equations (2 papers)
3. Micromechanically-motivated modelling approaches (5 papers)
4. Applications (11 papers)
5. Physical modelling (2 papers)

I am happy to conclude that all the contributions have very high technical quality. Inevitably, while some contributions represent highly novel approaches, other adopt variations of well-established concepts. It is also interesting to point out discrepancies between advanced modelling techniques presented on one hand, and simplified modelling approaches, which are often used while solving practical engineering problems presented in the "Applications" category.

I would like to encourage the readers to study in detail full texts of individual contributions. In particular, based on my personal highly subjective evaluation, I would like to highlight the following papers:

- Adoption of capillary effective stress in development of a constitutive model by Zhou et al. (2008).
- Evaluation of the anisotropic yield surface shape by Sitarenios and Casini (2018).
- Quantification of permeability of coarse-grained soils at low degrees of saturation by Scarfone et al. (2018).
- Enhancement of existing THM code by chemical coupling effects by Abed et al. (2018).
- Simulation of desiccation cracking by mesh fragmentation methodology by Maedo et al. (2018).
- Micromechanically-based modelling of irregular distribution of saturation in partially saturated sandy soil by Das et al. (2018).
- Simulations of rammed earth structures by François and Gerard (2018).
- Investigation of biologically driven technique to reduce soil liquefaction potential by Hall et al. (2018).
- Evaluation of problematic aspects of vacuum consolidation method by Nagaura et al. (2018).
- A simplified method for considering ground subsidence due to tree root water uptake by Kamchoom and Leung (2018).
- Centrifuge investigation of Shenzen landslide by Zhan et al. (2018).

In the following, I categorise all contributions submitted to the "Modelling" session and highlight their objectives and main findings.

2 CONSTITUTIVE MODELLING

Solving geotechnical problems in the field of mechanics of partially saturated soils requires, in general, fully coupled hydro-mechanical simulations. It is now well accepted that constitutive models predicting general aspects of soil behaviour must be constructed to cover the hydro-mechanical coupling effects, which makes them remarkably complex: retention curve and unsaturated permeability depend on mechanical deformation, which is in turn affected by degree of saturation. Of course, not all the complexity must be considered in all applications, in many cases it is reasonable to consider simplified modelling approaches which require appropriately simplified constitutive models models. Constitutive modelling contributions at the 7th International Conference on Unsaturated Soils involve both the complex and simplified modelling methods and may further be subdivided into the following groups:

1. Complete hydro-mechanical constitutive models, to be used in fully coupled hydro-mechanical simulations;
2. Contributions focusing of specific aspects of mechanical constitutive modelling, which can later be used in complete constitutive models or in simplified modelling approaches; and
3. Contributions focusing on hydraulic modelling.

Contributions from each of the three groups are briefly described in the following paragraphs.

2.1 *Complete hydro-mechanical constitutive models*

Complete hydro-mechanical models are presented in four contributions.

Zhou et al. (2018) present an elasto-plastic critical state hydro-mechanical model. It is based on earlier models developed by the same team of authors, its main new feature is incorporation of "capillary effective stress" and "capillary degree of saturation". In this approach, water in partially saturated soils is first separated into adsorbed fraction and fraction associated with matric suction. It is then assumed that the mechanical behaviour is predominantly controlled by water associated with matric forces: so-called "capillary degree of saturation" is calculated and used in evaluation of "capillary effective stress" using the Bishop equation, which is then used in the model formulation. The authors compare predictions of the model with predictions of model defined in terms of global degree of saturation and demonstrate prediction improvement (Figure 1).

Ghiadistri et al. (2018) present a double-structure extension of an existing model for partially saturated soils developed earlier in the same research group. The model has been developed with the aim to predict behaviour of expansive soils, where deformability of microstructural units (aggregates) contributes significantly to global swelling properties and retention properties of soil. The approach selected by the authors is motivated by the double structure concepts developed by Gens & Alonso (1992). The authors observe that, for the given swelling test they are interested in, calibration of the model is not unique: different combinations of swelling properties of macrostructure and microstructure with appropriately modified coupling component lead to the same swelling pressures. To appropriately distinguish the micro- and macro-structural components, experiments at various dry densities would be needed.

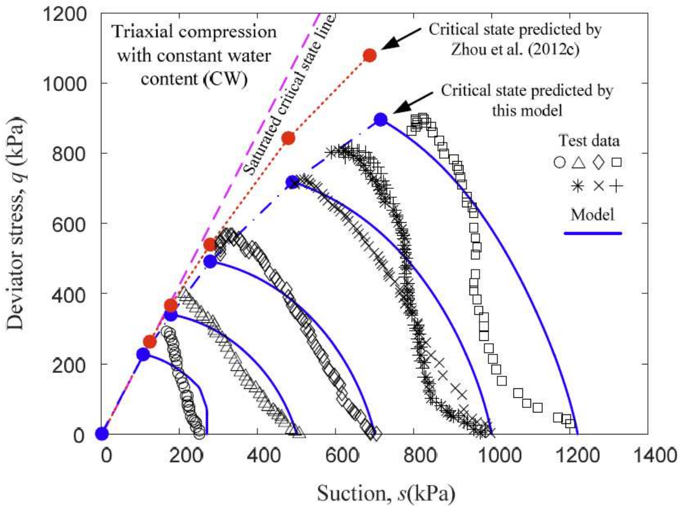

Figure 1. Improvement of predictions of shear strength when adopting model definition using capillary suction, Zhou et al. (2018).

Patil et al. (2018) present a constitutive model for partially saturated silty sand based on bounding surface concept. Model is based on the Bishop effective stress, while the size of the bounding surface additionally depends on degree of saturation. The authors focus on correct predicting the peak and post-peak behaviour and present also suction-controlled drained triaxial test data to evaluate the model predictions. Reasonably good predictions of post-peak softening and dilatant behaviour have been presented. In the simulations, experimental results are assumed to represent element test results with homogeneous distributions of stresses and strains and any possible shear bending is neglected.

Al-Sharrad & Gallipoli (2018) present an elasto-plastic model which incorporates the effects of evolving fabric anisotropy on the stress-strain response. An existing coupled hydro-mechanical elasto-plastic critical state model, defined in terms of Bishop stress and modified suction, is enhanced by the rotated shape of the yield surface (Figure 2), where the rotation is achieved by the method of "skewing" the stress space (see also Sitarenios & Casini, 2018, for evaluation of the rotated yield surface shape). Better predictions of the ultimate state are reached when compared with the original model with isotropic yield surface shape.

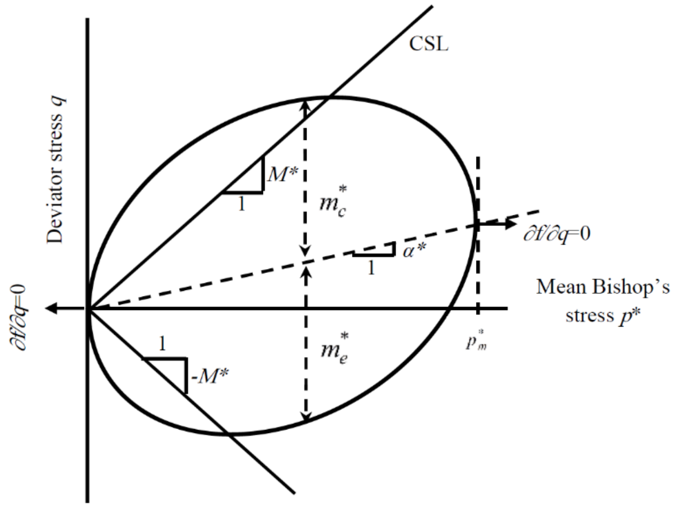

Figure 2. Anisotropic yield surface shape from the contribution of Al-Sharrad & Gallipoli (2018).

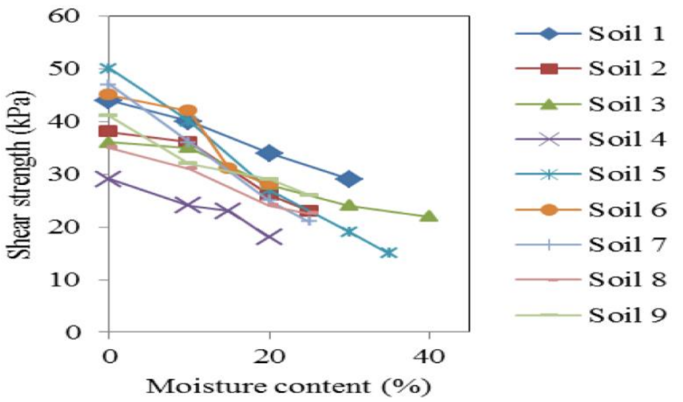

Figure 3. Dependency of shear strength measured in shear box test at vertical stress of 28.5 kPa on moisture content (from Ravindran et al., 2018)

2.2 *Contributions focusing of specific aspects of mechanical constitutive modelling*

One of the typical applications, where simplified modelling approaches (compared with fully coupled hydro-mechanical modelling) are often used (see contributions described in section "Applications"), is predicting the stability of slopes in partially saturated materials. Here, the central part is played by the models predicting shear strength and its dependency on partial saturation. Three contributions have been submitted to "Modelling" session evaluating shear strength of partially saturated soils.

Yin & Vanapalli (2018) present a review of different shear strength equations. They subdivided the existing models into three groups: "empirical models" with phenomenological formulations of various forms, models based on the effective stress approach and models based on apparent cohesion. Yin & Vanapalli (2018) evaluated six existing equations (two from each group) using two experimental datasets from the literature (Nanjing clay and Plessa clay). Different equations led to predictions of variable accuracy, which depended on the particular form of the equation, rather than on the group to which the model belongs.

Ravindran et al. (2018) present experimental data from direct shear tests on nine different sandy soils from landslide areas in New South Wales, Australia, with various initial water contents. They focused on low stresses (below 100 kPa) relevant for the particular slope stability calculations. Experiments show consistently a decrease of shear strength with increasing moisture content, it is however surprising that tests on 0% moisture content samples (thus effectively dry samples) have shown the highest shear strength, probably due to the sample preparation method and non-negligible amount of fines under hygroscopic humidity (Figure 3). The authors tested representativeness of three different shear strength equations (two existing and one new). A new equation, based on matric suction and non-uniformity coefficient, is shown to give best predictions. Arguably, the equation is equivalent to Fredlund et al. (1978) formulation, which may be recast by appropriate selection of material parameters.

Ahangar Asr & Javadi (1978) presented an approach to evaluate the Bishop stress factor χ in shear strength equation using evolutionary polynomial regression. This method is a data mining-based technique which, unlike various neural network algorithms acting as a "black box", searches for results in terms of polynomial equation, which can subsequently be explicitly used in constitutive models. Predictions of the obtained equation for χ, found using the "training" data from the literature, was evaluated with respect to "testing" data which were not known a priori to the evolutionary algorithm. Reasonably good predictions of χ have been obtained. No comparison has been done with other, more physically-based approaches to χ determination.

Sitarenios & Casini (2018) evaluated the shape of the yield surface of anisotropically consolidated partially saturated soils at three different initial water contents and three different initial stress obliquities. An interesting method is used, where failure is reached by reducing mean stress under constant deviator stress: two points are thus identified in a single experiment which both belong to the same yield surface (assuming that plastic strains inside the yield surface are neglected). It is demonstrated that the rotated yield surface shape is representing the data better than elliptic or distorted elliptic isotropic surfaces (Figure 4).

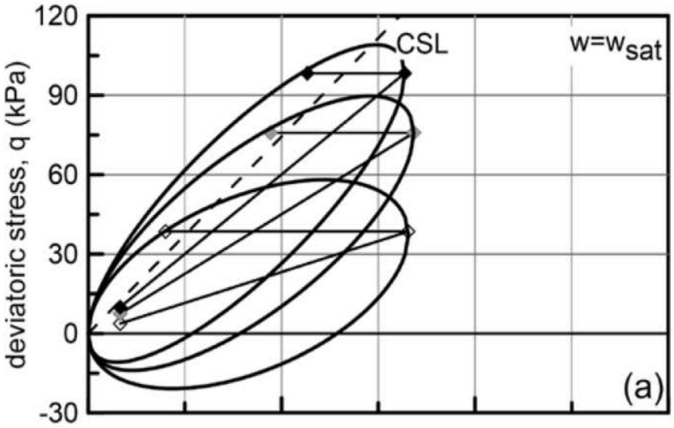

Figure 4. Example representations of yield stresses obtained in constant total axial load unloading tests using rotated elliptical yield sur-faces (Sitarenios & Casini, 2018).

2.3 *Contributions focusing on hydraulic modelling*

Hydraulic constitutive modelling is a subject of one contribution at the 7th International Conference on Unsaturated Soils by Scarfone et al. (2018). The authors focus on the following problem of "conventional" modelling of soil permeability: when van Genuchten – Mualem model is used for evaluating soil permeability based on the degree of saturation, hydraulic conductivity only tends to zero when suction tends to infinity. This is, however, physically unreasonable, as continuity of liquid water will be lost at finite value of suction. This, for example, leads to incorrect predictions of the breakthrough of water from finer to coarser layer in capillary barrier systems, which was a motivation for this work. A modification of the Mualem model is presented overcoming this shortcoming. Finite element simulations of unsaturated flow in capillary barrier system are then presented demonstrating significant effect of the adopted modification on breakthrough times in constant infiltration rate experiments (Figure 5).

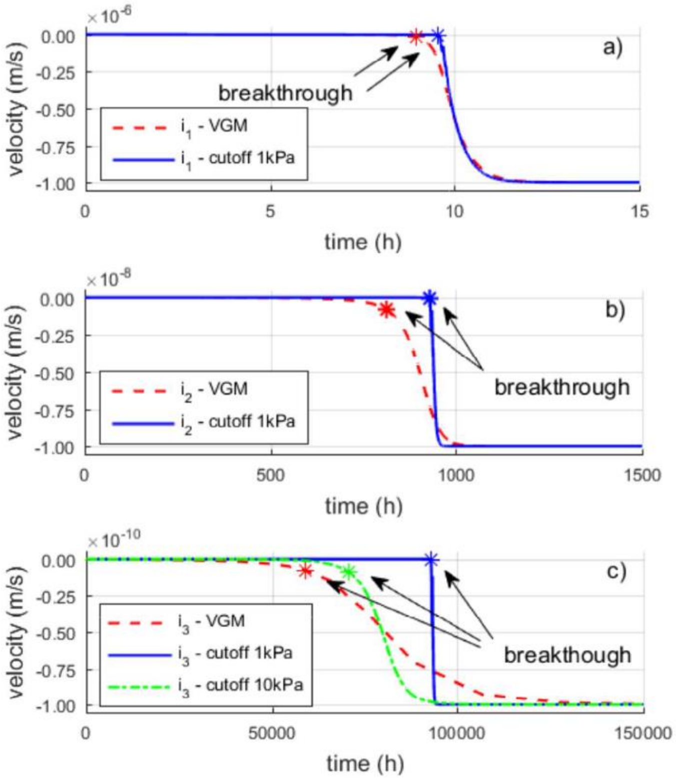

Figure 5. The effect of modelling of the dependency of unsaturated permeability on soil suction on breakthrough time through the capillary barrier (Scarfone et al., 2018).

3 FORMULATION OF COUPLED GOVERNING EQUATIONS

Two contributions in the "Modelling" session focus on formulation of coupled governing equations for predicting thermo-hydro-(chemo)-mechanical response of partially saturated soil and their use in fully coupled finite element codes.

Abed et al. (2018) formulate an extension of an existing coupled thermo-hydro-mechanical finite element code to include chemical effects. Governing balance equations are enhanced by the salt component balance, with simplifying assumption of neglecting the effect of mechanical deformation on salt balance. The balance equations are implemented into the existing coupled finite element code and they are verified by simulating salt transport problem for which analytical solution is available. The solution is subsequently validated by simulating coupled liquid-salt movement experiment, with very good agreement between new and few reference solutions and reasonable agreement with the experimental data (Figure 6). The final goal of the authors is to develop a code capable of simulating complex coupled THMC behaviour of clay under extreme environmental loading conditions, such as those in the future repositories of nuclear waste.

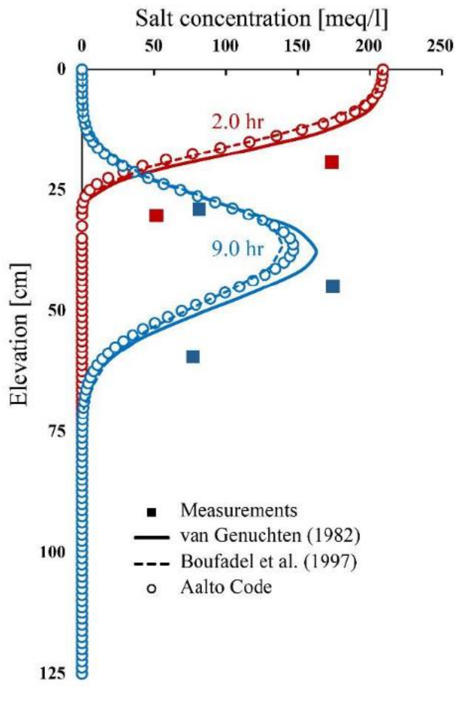

Figure 6. Predicted salt concentrations in coupled liquid-salt movement experiment by Abed et al. (2018).

Zhang et al. (2018) present numerical implementation algorithm for the coupled hydro-mechanical constitutive model. As standard in coupled partially saturated mechanical – ground water flow formulations, suction and strain increments are treated as controlling (strain-like) variables, while increments of stresses and degree of saturation as controlled (stress-like) variables. It is pointed out that proper implementation of a coupled hydro-mechanical constitutive model requires to not only properly formulate the constitutive model, but also to update water balance questions which need to consider the effect of mechanical strain on degree of saturation. The implementation is validated by simulating suction controlled isotropic consolidation and wetting tests and subsequently an illustrative example of flexible strip footing on partially saturated soil subject to wetting is presented.

4 MICROMECHANICALLY-MOTIVATED MODELLING APPROACHES

Five contributions in the "Modelling" session at the the 7th International Conference on Unsaturated Soils may be categorised into "Micromechanically-motivated modelling approaches" category.

Maedo et al. (2018) present a method for numerical simulation of desiccation cracking. The approach adopts finite element method with so-called "mesh fragmentation methodology", where finite elements with high aspect ratio are placed among standard shape finite elements to reproduce development of desiccation cracks (Figure 7). Mechanical behaviour of the high aspect ratio elements is governed by appropriately selected tensile damage model. Two damage models are tested: isotropic and orthotropic. The models are evaluated by simulating a desiccation test from the literature. It is shown that the orthotropic damage model leads to distribution and shape of desiccation cracks which better resembles experimental results.

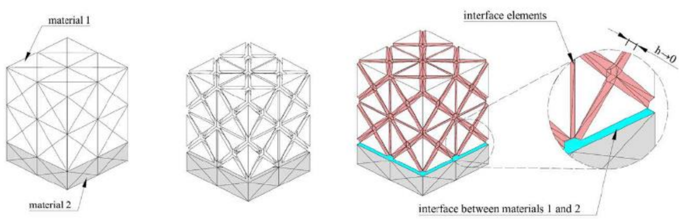

Figure 7. Demonstration of mesh fragmentation technique to simulate dessication cracking (Meado et al., 2018).

Desiccation cracking is also a topic of contribution by Gerard et al. (2018). They studied onset of development of desiccation cracks in "double T" desiccation experiment (Figure). The experiment has been modelled using coupled finite element model with constitutive equation adopting failure condition defined within modified Bishop effective stress space. It is shown that at the onset of cracking within inner corner of double T-bar experiment is reached not in tension, as typically assumed in desiccation cracking modelling, but rather in shear at compressive mean effective stress and relatively high effective mobilised friction angles. It is not clear whether the results are applicable to desiccation cracking initiation in general, or whether the results are only bound to specific geometry of the experiment investigated in this work.

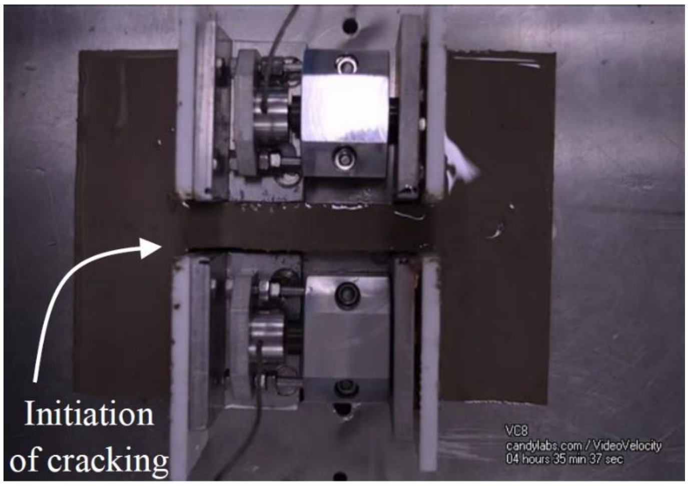

Figure 8. "Double-T" bar specimen geometry investigated in Gerard et al. (2018).

Suh et al. (2018) present a method to consider the shape of pore throat in micromechanical simulations of water retention behaviour. In their approach, pore network model assuming pore chambers and interconnected pore throats is adopted for simulation of retention behaviour. Instead of using standard approach of adopting Young-Laplace equation with inscribed-circle cylindrical geometry to quantify capillary pressure, more advanced approach is adopted. True pore geometry is studied using 3D X-ray CT scanning. Representative 2D cross-sections are then selected and capillary pressure is quantified using Lattice Bolzmann simulations on these cross-sections extended linearly to 3D (Figure), which is used as an input into pore network models. The method is adopted for predicting water retention curve of two sands. More accurate fit of experimental data is demonstrated for the enhanced modelling approach.

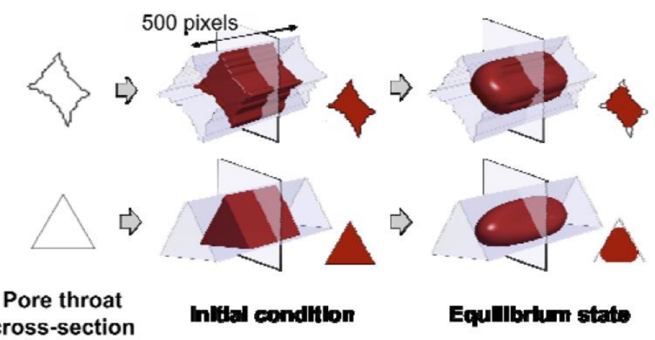

Figure 9. Demonstration of Lattice Bolzmann simulations of capillary pressure in irregularly shaped pore throats.

Das et al. (2018) present modelling technique for predicting water retention behaviour based on so-called pore finite volume discrete element method (PFV-DEM). This method is typically bound to water in pendular regime only. In the proposed method, two scales of pores are introduced, in which pore spaces are discretised as set of pore bodies and throats and the movement of water is simulated locally within these bodies. As a consequence, it is possible to simulate local patches of saturated soil and preferencial air pathways between them. Predictions of this method are demonstrated by simulating isotropic compression test, showing development of localised patches of partially saturated areas within saturated specimen (Figure 8).

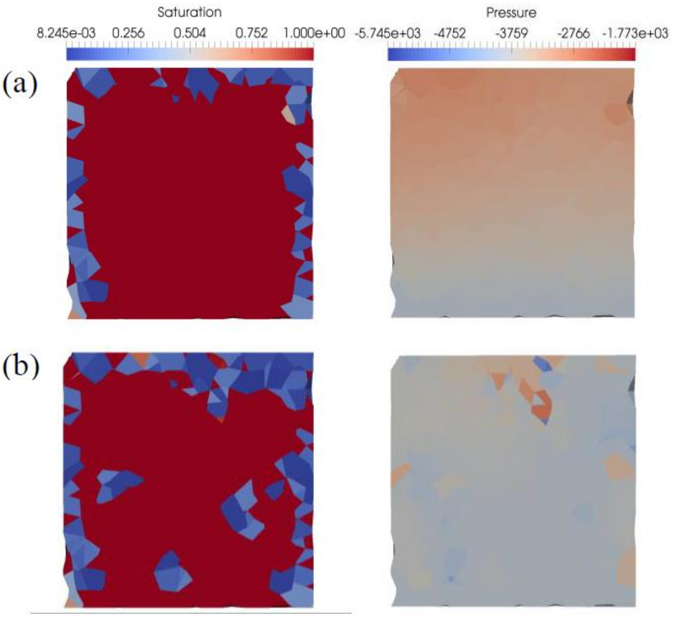

Figure 8. Development of localised patches of partially saturated areas during isotropic compression test, from Das et al. (2018).

Song et al. (2018) presented a model for tempera-

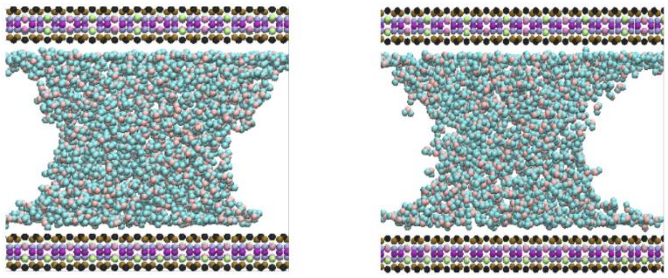

Figure 9. Water meniscus between two clay particles simulated using molecular dynamics method for lower (left) and higher (right) temperature. From Song et al. (2018).

ture effects on capillary force and air-water interface contact angles in unsaturated systems of clay particles. The simulations adopt molecular dynamics computational method, where positions, velocities and accelerations of atoms in molecular systems are computed by numerically solving the equations of Newton's second law of motion where energy of the molecular system is expressed using suitable empirical potential energy functions of force fields. The results, considered by the authors as preliminary, show potential of the method. They indicate that increase of temperature reduces capillary forces on clay particles and that it leads to a decrease of the contact angle between water meniscus and clay surface.

5 APPLICATIONS

Eleven contributions in the "Modelling" session at the 7th International Conference on Unsaturated Soils belong to this category.

These contributions demonstrate a gap between theoretical developments of numerical methods and a need of engineering practice. While contributions from the "Constitutive modelling" category often represent advanced coupled hydro-mechanical non-linear constitutive models based on critical state soil mechanics, such models are (with one exception by Kamchoom and Leung 2018) not used in contributions focusing on solving practical engineering problems. Instead, elastic perfectly plastic models (with appropriately selected suction-dependent apparent cohesion and stiffness) are adopted in most cases.

One may argue whether this is because advanced modelling techniques bring level of accuracy which is for the given purpose unnecessary (or even counter-productive), whether the advanced techniques are unknown to engineers solving these problems or whether it is because advanced techniques are not available in the commercial software codes adopted in the calculations. A combination of these reasons will probably be a cause and I consider this fact as an interesting topics for discussion.

Contributions at the 7th International Conference on Unsaturated Soils from this category may be sub-divided into the following groups:

1. Applications focusing on stability of geotechnical structures calculated using failure conditions considering partial saturation.
2. Applications focusing on deformation of geotechnical structures calculated using elastic perfectly plastic models considering partial saturation.
3. Applications adopting advanced coupled hydro-mechanical formulations.
4. Applications of partially saturated ground water flow simulations.

Contributions from each of the groups are briefly described in the following paragraphs. It is pointed out that the grouping is indeed simplified and some contributions may actually be considered to belong to more groups.

5.1 *Applications focusing on stability of geotechnical structures calculated using failure conditions considering partial saturation*

Four contributions may be classified as belonging to this group.

Richard et al. (2018) and Ileme et al. (2018) presented simulations of unsupported trenches in sands. These contributions are motivated by the fact that trench failures represent common type of geotechnical failures with potentially serious consequences including losses of lives, on the other hand the existing design methods are often based on simple empirical methods. In these works, trench stability in sand is calculated using commercial software with the following procedure: assumed hydrostatic suction profile is used to estimate the distribution of degree of saturation with depth, which is then used to estimate distribution of unsaturated permeability, which is used in unsaturated ground water flow analyses. Stability of a trench is evaluated using limit equilibrium analyses with suction-dependent failure condition. Richard et al. (2018) focuses on estimation of critical unsupported vertical height and the positive effect of sloping on stability. Ileme et al. (2018) evaluates the effect of rainfall infiltration with prescribed infiltration rates on stand-up time of trenches. The effect of surface cover is also investigated and found to not be remarkably efficient.

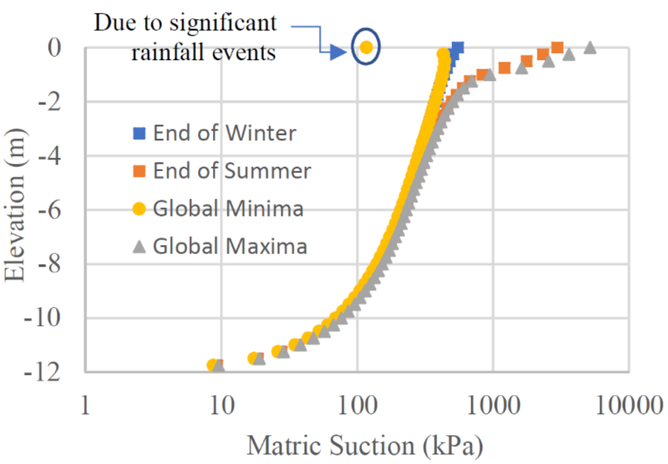

Figure 10. Variation of suction with depth for Adelaide climatic data evaluated for piled retaining wall simulations. From Kuo et al. (2018).

Kuo et al. (2018) present a model of piled retaining wall in unsaturated clay of Adelaide, Australia. Unsaturated ground water flow analyses have been performed for climate data from the site of interest and also for the possible case of pipe leakage. The unsaturated flow analyses were used to find matric suction distribution with depth, which has been input into stability analyses using limit equilibrium method by adopting effective stress principle by Khalili & Khabbaz (1998) to quantify the effect of partial saturation on shear strength. It is shown that the vertical cuts in clays can even stand unsupported in Adelaide semi-arid climate.

Li et al. (2018) adopted fully coupled hydro-mechanical model to study the effect of river fluctuations on the stability of slope of the river bank. Water levels were varied in the analyses and suction profiles were evaluated using unsaturated groundwater flow analyses. Mechanical behaviour was described using elastic perfectly plastic model considering the effect of partial saturation on soil behaviour through adoption of Bishop effective stress considering residual degree of saturation. The authors have found that, in this case, considering partially saturated zone above the water level has little effect on the overall river bank stability.

5.2 *Applications focusing on deformation of geotechnical structures calculated using elastic perfectly plastic models considering partial saturation*

Three contributions may be classified as belonging to this group.

Al-Khazaali and Vanapalli (2018) studied displacements of axially loaded pipeline in an unsaturated silica sand at three different suction values. The paper describes physical experiment studying the pipeline response to axial loading (Figure 11). Simplified model is presented subsequently adopting perfectly plastic model considering the effect of partial saturation on shear strength and Young modulus. Alt-

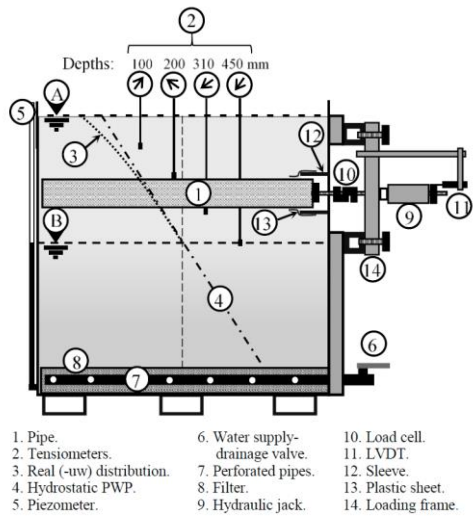

Figure 11. Setup of the physical model of axially loaded pipeline by Al-Khazaali and Vanapalli (2018).

hough the numerical analyses are remarkably simple, results compare relatively well with experimental data, which showed quite a remarkable effect (by more than 100%) of partial saturation on axial displacements.

François & Gerard (2018) adopted partially saturated soil mechanics principles in simulating construction from rammed earth subject to moisture variations. A coupled thermo-hydro-mechanical formulation adopting elastic perfectly plastic model considering the effect of partial saturation on soil behaviour has been used for simulating two-storey building supported by 45 cm thick rammed earth external walls. In the model, the building has been subject to climatic data (external relative air humidity) from Belgium. Building response has been quantified, demonstrating that deformations imposed by the material drying and wetting remain in very reasonable range (Figure 12).

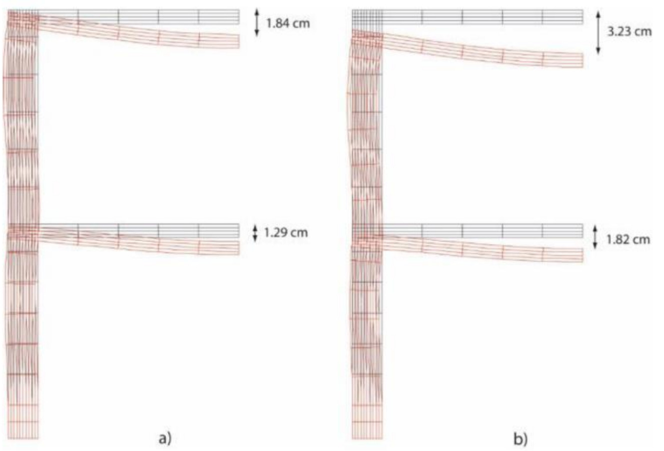

Figure 12. Rammed earth structure displacements after contruction and floor loading (left) and after 6 years (right). From François & Gerard (2018)

Brennan & Oh (2018) presented a simplified analysis of settlement of shallow foundations on partially saturated sand. Suction has been assumed as hydrostatic above water table, and these analyses have been compared with "average matric suction" profiles constant with depth. Elastic perfectly plastic model considering the effect of partial saturation on soil behaviour has been adopted (due to limitations of adopted commercial software, suction-dependence of Young modulus had to be implied indirectly by relating it to vertical coordinate). The authors concluded that the simplified "average matric suction" method is in studied cases inappropriate for deeper water level, where suction leading to residual degree of saturation is reached.

5.3 *Applications adopting advanced coupled hydro-mechanical formulations*

Two interesting contributions within this group have been submitted to the "Modelling" session.

Hall et al. (2018) investigated biological driven ground improvement technique to reduce soil liquefaction potential through precipitation of bonding agent ($CaCO_3$) and generation of di-nitrogen gas to desaturate soil and dampen pore pressure buildup in undrained loading due to earthquake (Figure 13). A model has been developed quantifying amount of biologically generated N_2. The aim of the model was to evaluate differences between centrifuge and 1g experiments: diffusive transport of N_2 scales at higher g conditions differently from stress (diffusive time in the centrifuge scales with the squared gravitational constant), relevance of centrifuge experiments to model these process can thus be compromised. The mathematical model has shown that diffusion of soluble N_2 is neglibible and thus changes in saturation between centrifuge model and field scales are similar. Unfortunately, it is not stated in the paper which bacteria have been adopted in the experiments.

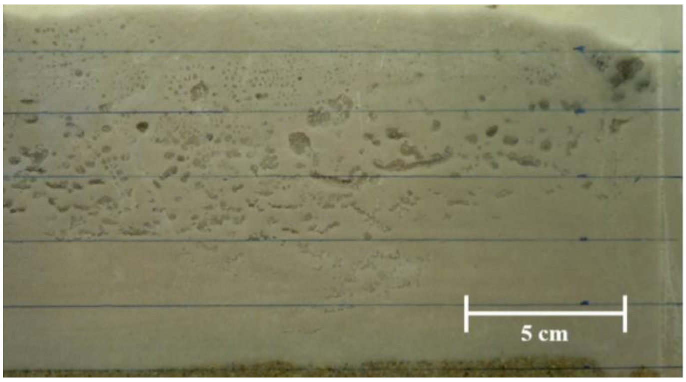

Figure 13. Generation of biogenic gas pockets in 1 g experiment by Hall et al. (2018).

Nagaura et al. (2018) presented numerical analysis of vacuum consolidation method. The aim of the study was to investigate why vacuum consolidation is less efficient than it would have been expected from the assumption that the negative pore water pressure applied from the vacuum pump is fully transferred into the soil. Based on fully coupled hydro-mechanical finite element modelling it was found that due to dissolution of gas from pore water, soil becomes partially saturated under vacuum application, which reduces water pore decrease and thus reduces efficiency of vacuum consolidation. It is also noted that by simultaneous loading of the surface by an embankment reduces gas dissolution and thus increases vacuum consolidation efficiency.

5.4 *Applications of partially saturated ground water flow simulations*

Two contributions may be classified as belonging to this group.

Tang et al. (2018) studied the effect of hydraulic hysteresis on the consolidation of partially saturated soil. Fully coupled simulations of ground water flow considering advanced water retention/permeability model, combined with assumed elastic mechanical behaviour of soil, have been performed. The water retention model adopted was hysteretic and void ratio dependent. As soil permeability was calculated from degree of saturation and void ratio, the consolidation rate was found to depend on hydraulic history (wetting/drying/scanning curve) and on mechanical loading history (considered via its effect on void ratio).

Kamchoom & Leung (2018) investigated the effects of seasonal tree root water uptake effects on pore water pressure and on ground subsidence. Non-linear hypoplastic model by Mašín and Khalili (2008) has been considered to simulate soil mechanical behaviour, while water uptake by tree root system has been simulated using a simplified method by introducing variable hydraulic head boundaries into the soil (Figure 14). By varying the head boundaries according to the known season-dependent potential transpiration of two tree species, Silver Birch and Leyland Cypress, the effect of tree root system water uptake is approximately introduced into the model. The effect of water uptake on ground subsidence has been quantified and shown to depend on season as well as on tree species.

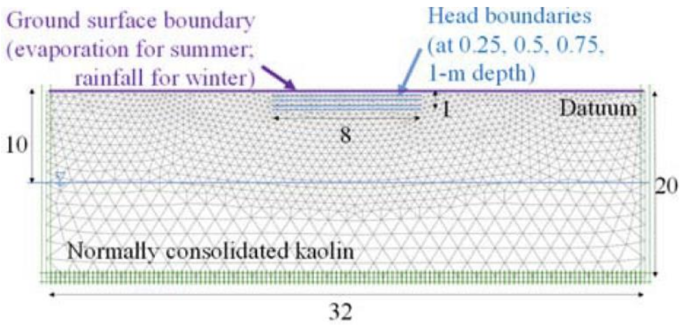

Figure 14. Simplified modelling of water uptake by tree root system through seasonal variation of hydraulic head boundaries (Kamchoom & Leung 2018).

6 PHYSICAL MODELLING

Two contributions in the “Modelling” session at the 7th International Conference on Unsaturated Soils belong are specifically focusing on physical modelling.

Zhan et al. (2018) present centrifuge experiment aiming to clarify triggering mechanism of a catastrophic landslide occurring in 110 m high waste dump in Shanzen, China, on December 20 2015. The landslide caused 77 fatalities and it may thus be considered as one of the major recent geotechnical-related disasters at the international scale. Figure 15 shows landslide cross-section.

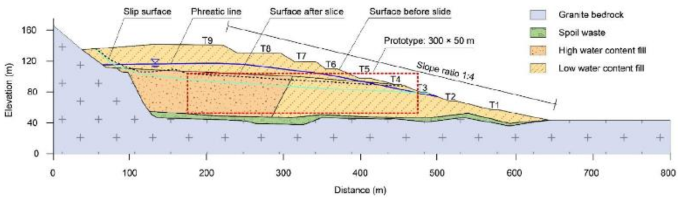

Figure 15. Cross-section through the Shenzen landslide (Zhan et al., 2018).

It is expected that the landslide has been caused by the excess pore water pressure build-up in the rear part of the slope due to rapid surcharge and high water level. A centrifuge model has been setup considering specifically low moisture content front part of the slope and high moisture content rear part of the slope. Development of excess pore water pressures in the rear part of the slope has been documented in centrifuge experiment. Failure has, however, been localised in the front part of the slope only, due to simplification in the geometry and loading conditions of the centrifuge model (the presented experiments have been considered as preparatory tests for larger project). The centrifuge results need careful evaluation due to different scaling laws for stress generation and for consolidation process and due to the fact that the centrifuge model has been prepared at a reduced scale with respect to prototype.

Ghayoomi et al. (2018) presented centrifuge experiments focusing on evaluation of cone penetrometer resistance in partially saturated soils. A miniature piezocone is penetrated in-flight in a centrifuge into a dry, partially saturated and saturated Ottawa sand. The results are evaluated in terms of normalised cone resistance. It is shown to be comparable in all three cases if Bishop effective stress rather than net stress or “saturated” effective stress is used for cone tip resistance normalization.

7 CONCLUSIONS

Papers presented in the “Modelling” session at the 7th International Conference on Unsaturated Soils have been categorised in this general report to five categories and findings, which were considered as the most important by the general reporter, have been highlighted.

The contributions reflect current research trends in the field of modelling of partially saturated soils. I have observed, on one end, a trend of moving from advanced phenomenologically-based continuum constitutive modelling into micromechanically-based approaches. On the other hand, it is interesting to observe that application examples adopt in vast majority of cases simplified modelling methods, often based on simple failure criteria or elastic perfectly plastic models considering partial saturation. This is not consistent with advancement in the development of modelling techniques, which I consider as an interesting topic for discussion.

I am happy to conclude that contributions to “Modelling” session have very high technical quality and encourage the readers to refer to full text of individual papers for more detailed study.

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