General report: Energy and environmental issues

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ABSTRACT: This general report focuses on papers published in the UNSAT2018 Proceedings dealing with the behavior of unsaturated soils relating to energy and environmental issues.

1 INTRODUCTION

In recent years, the study of unsaturated soils subjected to unprecedented and complex thermo, hydro, chemo, and mechanical (THCM) actions has been mainly associated with energy and environmental geotechnics. A total of 25 contributions are included in the Proceedings of the UNSAT2018. A (brief) critical report of these papers are presented below organized by the main themes.

2 SOIL-ATMOSPHERE INTERACTIONS AND EFFECT OF VEGETATION

To predict the potential effects that climate change may have on soil behavior is perhaps one of the major challenges that unsaturated soil mechanics is facing. More intense and driest summers will expose natural soils to unprecedented suction and thermal changes. Soil properties, local weather conditions, ground-air interface phenomena, and vegetation (with its impact on evapotranspiration) are key interconnected components of this problem that need to be properly understood.

A key component of this research is to characterize the local weather conditions using standards that allow recognizing the type of drought, as well as dry and wet periods. Assadollahi and Nowamooz (2018) present a study focused on the characterization of drought in the south of France using two standardized drought indexes, the SPI and the SPEI. Both indexes use climatic parameters (e.g. precipitation rate), but the SPEI considers the evapotranspiration of the unsaturated ground and SPI does not. These two indexes were calculated based on climatic data gathered from the Toulouse-Blagnac meteorological station since 1975. It was concluded that the SPEI index performs better than the SPI because of the inclusion of the soil evapotranspiration in the analysis.

A proper understanding of the soil-atmosphere interactions is critical to estimate the extent and the rate of the moisture changes in the soil mass triggered by weather fluctuations. An et al. (2018) present a numerical study focused on the soil-atmosphere interaction based on the modeling of field data gathered from a monitored embankment constructed in France, in the context of the ANR project. The embankment is 107 m long, 5m height and encompasses two parts made-up of: lime-cement treated clay and lime-cement treated silt. The analysis centers on the lime/cement treated silt portion and was conducted with a TH code coupled with a soil-atmosphere interaction module to account for the ground-air heat and water transfer. Distribution of soil moisture in depth, heat fluxes and other variables were analyzed for the data gathered from June 6th and July 26th 2011.

Dainese et al. (2018) performed an experimental investigation to include the effects of vegetation when analyzing soil-atmosphere interactions. The laboratory tests were based on instrumented infiltration columns. Volumetric water content and suction profiles were tracked during the tests. The evaporation/evapotranspiration rate was tracked by means of a balance. Experiments under natural and forced ventilation were run in parallel on a bare sample and a soil sample vegetated with grass respectively. The proposed set-up was able to properly capture the transition between the energy-limited and the water–limited regimes during drying.

Ni et al. (2018) also studies the effect of vegetation on unsaturated soil behavior with the main focus on the effect of plant-transpiration on soil suction. They combined experimental and numerical investigation to study the influence of both, soil type and plant characteristics (described through the leaf area index, LAI) on transpiration reduction. The investigation was based on 4 tree-plantlets in silty-

sand and 2 in clay, which were subjected to drying to study the effects of the transpiration reduction. It was observed that as LAI increases, plant transpiration decreased more rapidly with soil suction.

The study conducted by Jotisankasa et al. (2018) looked at effect of root-reinforcement on suction and soil strength. Typical models for incorporating the beneficial effects of root reinforcement on soil strength assume a constant (additional) strength contribution. Based on experimental evidences a new strength model for root-reinforced soils is proposed in this work. This paper also investigates the effect of the vegetation on reinforced-soil tensile strength, water retention curve, and elasticity modulus.

Vegetation also affects the flow of water and transport of species. Therefore, soil remediation could also be tackled by designing a proper growth of roots in the ground. Furukawa et al. (2018) proposes a 2-D analytical model for computing water flow, solute transport and root growth in unsaturated soils. Analyses were conducted considering two type of soils, namely, a decomposed granite sand a cultivated natural soil. It was concluded that the larger the soil water retention capacity, the lower the root uptake for a given effective saturation.

Sato and Matsumaru (2018) conducted an experimental and numerical study aimed at investigating the implementation of capillary barriers as a countermeasures against the effects of rainfall infiltration in slopes. The study focuses on capillary barriers in steep slopes in railroads. Scaled laboratory tests were conducted to investigate the performance of different soil combinations and rainfalls intensity. Particular attention was paid to the study of the diversion length and drainage performance. A finite element (FE) code was adopted for the interpretation of the tests. It was concluded that the incorporation of capillary barriers can lead to a reduction of the water inflow up to ~ 65%. It was also observed that the hydraulic-conductivity ratio of the capillary-barrier soil play a critical role in this problem. The larger this ratio the shorter the diversion length.

Another alternative to control moisture variations in the ground is to engineer the soils to become them water repellent. The ability to repel water is a phenomenon developed naturally in some soils (e.g. after bushfires). Beckett et al. (2018) present a preliminary investigation focused on the water retention properties and hydro-mechanical behavior of a natural (hydrophilic) sand from Australia. They found that current testing methods (e.g. axis-translation technique) provided unrealistic results for this type of soil. Developments in this area are underway.

3 DRYING CRACKS IN SOILS

Soil desiccation is generally associated with the formation and propagation of cracks. The process involved in this phenomena are complex and strongly interconnected. This is a topic that is receiving every time more attention as it is also observed in the UNSAT 2018

Cordero et al. (2018) investigate the effect of the soil-atmosphere interaction on the formation of cracks using a large-scale test instrumented with internal sensors to measure the variation of water content, matrix suction and temperature. The evolution of specimen weight during the experiment was also tracked. This setup allowed following the changes of specimen condition when directly exposed to the elements. Atmospheric conditions were also recorded (the test was conducted in Barcelona, Spain). Camera were used to capture the soil response during the four seasons including the formation of cracks.

Demagistri et al. (2018) focus on the problem of crack formation on compacted soils. The compaction curve of a silty clay soil was used to define the initial density and moisture of the compacted specimens subjected to drying in circular and rectangular plates. The crack intensity factor (CIF) was used to characterize the crack morphology and to compare the results from different specimens. Higher CIFs were obtained from samples compacted on the wet-side of the compaction curve.

Stirling et al. (2018) conducted a field study aimed at detecting the formation of desiccation cracks in soils under actual conditions in a trial embankment covered with vegetation. The research was conducted in the BIONICS full-scale embankment in the UK, and combine (amongst others), 2-D electrical resistivity tomography (to visualize moisture accumulation in the embankment), dielectric permittivity sensors (to monitor soil-water content evolution), movement transducers (to monitor crack aperture), meteorological monitoring and runoff catchments. The proposed setup was able to capture changes in the crack aperture, driven by the variation in atmospheric conditions and the unsaturated condition of ground.

4 LANDFILL

Guo et al. (2018) study the behavior of the 3 layers cover system based on recycled crushed concrete in the Xiaping landfill, China. Two sloping areas were analyzed: the vegetated cover with Bermuda grass, and the reference bare soil. The landfill monitoring was done continuously for 13-months tracking the following variables: pore-water pressure, volumetric water content, percolation and atmospheric parameters. It was observed that the Bermuda grass is effective in minimizing the percolation into the 3 layers recycled-concrete cover systems.

Li et al. (2018) present a field and numerical investigation aimed at understanding the effect of thermal gradient and vapor content on water storage in the loess-gravel cover of a landfill-gas. It was observed that the thermal gradient triggers moisture

movement (i.e. from high to low temperature). The accumulation of moisture in the upper part of the cover (i.e. thermally triggered) can accelerate the evaporation at the cover surface inducing a decrease of water storage in the whole cover.

The formation of drying cracks in unsaturated landfill-covers represents a preferential paths for methane migration and its (possible) subsequent release to the atmosphere need to be prevented, as this gas contributes to the greenhouse effect. An important step to tackle this problem is to develop appropriate models/solutions able to capture this complex phenomenon. Wu et al. (2018) propose a 1-D advection-diffusion semi-analytical solution for gas migration in unsaturated fractured landfill-covers. It is anticipated that when the fracture width increases from 1 to 10mm, the surface relative concentration and flux increased about two orders of magnitude.

5 NUCLEAR WASTE DISPOSAL

The safe isolation of high-level nuclear waste (HLW) presents a number of geo-engineering challenges that require a very good understanding of the complex THMC phenomena anticipated in repositories for HLW. Gens et al. (2018) deal with the THM behavior of the unsaturated clay-barrier constructed in the framework of a full-scale heating experiment in Switzerland. The in-situ test ran for more than 18 years. Before the final dismantling of the test, model predictions (in terms of dry density and water content) were requested. The paper presents the comparisons between the post-mortem test results and the predictions. The proposed approach captures very well the observed trends and the model results were also very satisfactory in quantitative terms.

A theoretical study focused on the behavior of compacted bentonite intended for the construction of clay barriers for HLW is presented in Lang et al. (2018). They propose a correlation between applied suction, total suction and swelling pressure for this kind of materials. The research conducted by Ye et al. (2018) deals with the swelling behavior of a clay-barrier made-up by a pellet-powder (80/20) bentonite mixture. The swelling pressure presents a double-peak shaped time-evolution that is characteristic for this type of mixture. Furthermore, they found that the swelling pressure depend linearly on dry density.

Bag et al. (2018) study the behavior of buffer materials based in a bentonite-sand mixture. The aim is to understand the effect of the sand-ratio on both, the swelling pressure and coefficient of permeability. It was observed that, as the sand ratio of the mixture decreases: the maximum dry density decreases; the optimum moisture content increases; the coefficient of permeability increases; and the swelling pressure increases (linearly). It is also suggested that for the case of the indo Bikaner clay the maximum recommendable sand ratio is 60%.

Gas migration though barriers materials has gained increasing attention in the analysis repositories for HLW. Madaschi & Laloui (2018) propose a stochastic framework to model the gas transport through bentonite combining a FE code with the Monte Carlo method. Four already published gas injection tests conducted at different injection pressures were model, first using a deterministic analysis and then a stochastic sensitivity study was carried out. A marked influence of the bentonite intrinsic permeability on the modeling outputs was observed.

Very high temperature (i.e. 100 °C and above) and thermal gradients are anticipated in the design of HLW repositories. Liu et al. (2018) presents an approach to predict the effective thermal conductivity combining clay microstructural characteristics and fractal theory. Pore size distribution (from MIP test) of the GMZ01 clay was modeled using intermingled fractal units to calculate then the effective thermal conductivity based on series-parallel electrical.

6 ENERGY GEOTEHCNICS - OTHERS APPLICATIONS

The analysis of many geo-energy problems requires the use of unsaturated soils principles, as they involve geo-materials in which more than one fluid phase is typically present in the pore space. Contributions in this area alongside others that do not fall in any of the previous Sections are discussed below.

Energy geotechnics problems are generally associated with non-isothermal conditions, being the thermal conductivity a key component in these studies. Shrestha et al (2018) present and experimental and numerical study looking at the effect of fillers, soil gradation and water saturation on thermal conductivity. Thermal conductivity was measured in sand specimens prepared at various water contents. The enhancements of the thermal conductivity of modified geomaterials observed in the experiments was not well reproduced by existent thermal conductivity laws. A new mesoscale model based on lattice model was able to satisfactorily capture the thermal conductivity of the engineered soils. The use of thermo-active geo-structures for air-conditioning of buildings has gained significant attention lately. Sani et al. (2018) adopted a coupled TH FE approach to study the impact of heat storage in an unsaturated swelling clay, a marked drying was anticipated

Hydrate bearing sediments (HBS) present opportunities and challenges, e.g. they are a very attractive source of energy (however methane production from this type of soils is difficult), but also uncontrolled gas release from HBS will contribute to greenhouse effects. As discussed in Gai et al. (2018), particularly complex is the geomechanical behavior of HBS. In this paper an advanced elastoplastic model for HBS is presented and validated against recently published experimental results.

Song et al. (2018) investigate soils treated with enzyme induced carbonate precipitation (EICP) by using microstructural images and shear wave velocity. The experiments confirmed the cemented effects provides by the bio-mediated treatment. In Lai et al. (2018) scanning electron microscopy images were analyzed with an available image processing software to study the wettability of granular materials. The advantages and limitations of the method were clearly discussed.

7 CONCLUSIONS

The UNSAT2018 proceeding compiles high qualities and interesting papers in the area of environmental and energy geotechnics, which were briefly discussed in this contribution.

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