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Editorial

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Editorial: Soil–atmosphere interaction

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This themed issue has its origin in the 14th IACMAG conference in Kyoto, Japan where a conference session on this topic was convened. The success of the session and debate caused by the session led to the idea of a special issue published in *Environmental Geotechnics*. After which, a call was made to the research community for papers. The wide range of topics and enthusiastic response illustrates that this topic is an important one for geotechnical engineering and the wider society.

Soil is a key building material, used to form land, defend against water ingress and more recently has been used, amongst other uses, as an energy source/store. Soil is generally available at most sites, is of low cost and can form structures which remain intact for many decades or even centuries. Over the last few decades substantial advances have been made in understanding the behaviour of soil, its mechanics, flow of water or heat through soil and its chemical behaviour. In particular, much attention has been given to the behaviour of unsaturated soils (Fredlund and Raharjdo, 1993).

As engineers, typically we like to divide problem domains and simplify complex systems and this has led, in general, to the consideration of soil apart from the atmosphere. In numerical models, this has meant the elimination of the atmosphere from model domains and the imposition of boundary conditions and, experimentally, this has meant generally sealing samples so that evaporation or water ingress does not occur without control. However, changes in soil behaviour, for example the collapsing of a previously stable slope (Elia *et al*., 2017) or the erosion of soil cover (Morgan, 2009), are due to the interaction of soil with the atmosphere. In other words the atmospheric conditions provide the driving force for the soil behaviour. As reviewed by Vardon (2015) the changing climate may change otherwise meta-stable systems, with an example given by Robinson and Vahedifard (2016) on weakening mechanisms on flood defences in California. What is also clear is that it is not a simple boundary condition, the effect of the atmosphere on the soil is partly due to the condition of the soil, itself driven by the history of the atmospheric interaction.

The atmosphere provides a complex interaction/boundary to soil. Precipitation, humidity, evaporation, temperature, radiation, wind and so on lead to changes in soils, but also the current state of the soil plays a critical role. Figure 1 gives a conceptualisation of this system, however it is noted that due to the complexity of the system a number of processes or forcing phenomena may be missing.

Given the very strong hydro–mechanical interaction in soils, in the stress state (and therefore strength of soils), the exchange of water between the soil and the atmosphere is important. The maximum evapotranspiration ration of water is typically quantified using the Penman–Monteith equation (Monteith, 1965), which takes into account both atmospheric and soil properties but has a series of parameters which are not typically easy to quantify. Wilson *et al*. (1997) recognised that the Penman–Monteith equation represented a maximum and did not well represent the reduction in evaporation due to suction in the soil and the availability of water, and they presented a modification to take this into account. Gerard *et al*. (2019) presents an experimental investigation of evaporation from soil and concentrated on the quantification of evaporation from bare soil (i.e. without vegetation), and specifically examined and quantified when the atmospheric conditions or the soil conditions limited the evaporation rate. Simms *et al*. (2019) investigates a beneficial aspect of evaporation from soils, the dewatering and stabilisation of mine waste. The work presents the behaviour of three different materials and investigated the evaporation rate, the cracking and the salinity in meso-scale tests. Different evaporation driven phenomena were observed in the different materials.

Soltani *et al*. (2019) utilise a dataset collected by way of a large-scale soil moisture monitoring project and a commercially available thermo–hydraulic finite element code. Specific attention is paid to the impact of vegetation, in particular the distribution of the transpiration flux over the surface layer of soil, as opposed to other methods which assume this occurs at the interface. It is noted that in both papers the temperature at the soil-atmosphere interface play and important role in the quantification.

One of the phenomena associated with vegetation is its ability to provide additional shear strength, from both the mechanical strength and suctions generated. Pathirage *et al*. (2019) analyse and present a model for the suction provided by vegetation. Their new model takes into account osmotic suctions, due to the nutrients in the root zone, rather than only considering matric suction as in previous work.

Both Toll *et al*. (2019), and recently Bosco *et al*. (2018), examined the impact of climate on the stability of vegetated slopes, that is at a geotechnical structure scale. Toll *et al*. (2019) compared a numerical model and experimentally instrumented full scale slope. It was found that the hydraulic properties of a layer of material at the surface of a slope is important to consider to properly include the effects of soil-atmosphere interaction on the hydraulic state of the slope. The properties of this layer were suggested to be dominated by the effects of cracking and vegetation, which has impacts on anisotropy as well as the magnitude, and a pragmatic method of quantification was taken. This paper continues by examining two existing approaches (two independent stress states and Bishop's stress) to characterise the changes in strength of the slope due to the de-saturation and rewetting. The conclusions follow that of Jommi (2000) where these methods were seen to give comparative results given appropriate parameterisation. Bosco *et al*. (2018) utilise the Penman–Moneith and Wilson equations, coupled with the Bishop's stress approach, to analyse the impact of changing vegetation on slope stability. It was seen that by switching grassland to highly irrigated crop production may result in a significant reduction in safety.

Another important set of geotechnical structures are used for waste isolation for example in waste dump covers in municipal landfill sites. These structures play a role in the isolation of waste from the rest of the environment and must resist flow of moisture through them. To do so, they must stay in place and therefore resist erosion from the water which must runoff (due to the low hydraulic conductivity). Kumar *et al*. (2019) investigate the effect of soil compaction and rainfall rate on the ability of soils to resist erosion. A simple test was demonstrated to be able to provide a quantification of the critical shear stress and rate of erosion which both depend on the soil state. In mining waste sites, waste rock is required to be safely stored and in some cases the waste isolated. Lefebvre *et al*. (2019) studied a site where Uranium mining waste was stored and Radon emissions were possible. A conceptual and numerical model, based on field observations, was made based on convective airflow and gas buoyancy, effected by the atmospheric temperature.

While evaporative fluxes include the impact of temperatures, the focus is mainly in the quantification of hydraulic behaviour, and the subsequent impact on the mechanics. More recently, partly due to the increased interest in thermal energy extraction and storage in the subsurface, the thermal fluxes have gained more interest. Both Muñoz-Criollo *et al*. (2019) and Sedighi *et al*. (2018) present theoretical/numerical methods to simulate the thermal fluxes and both compare with existing experimental data. In contrast, Reder *et al*. (2019) present the results of a detailed 4 year experimental programme to measure the thermal flux and evaporative fluxes. All of these papers recognise the intrinsic thermo–hydraulic coupling between evaporation and energy balance in the formulation. Muñoz-Criollo *et al*. (2019) focused on investigating differing approaches to input the meteological data to simulate the boundary conditions required, whereas Sedighi *et al*. (2018) focus on the evaporation–thermal coupling.

Steeves *et al*. (2019) investigated the heat transfer in frozen slopes, focusing on the interplay between conduction, the typically presumed dominant process and convection, where a flow in a hydraulically conductive layer exists. This was placed in the context of the utilisation of frozen soils to divert melt water away from mine waste sites. It was found that convection would typically remain a secondary process but could contribute.

It is clear from the papers submitted for this special issue and other recent work that soil-atmosphere interaction is a wide topic, which until recently had little comprehensive attention. Many issues are currently being investigated and this special issue is a good overview of the current research topics and state of the art. There remain a number of outstanding issues, including the accurate prediction of long-term properties in the very upper soil layer and

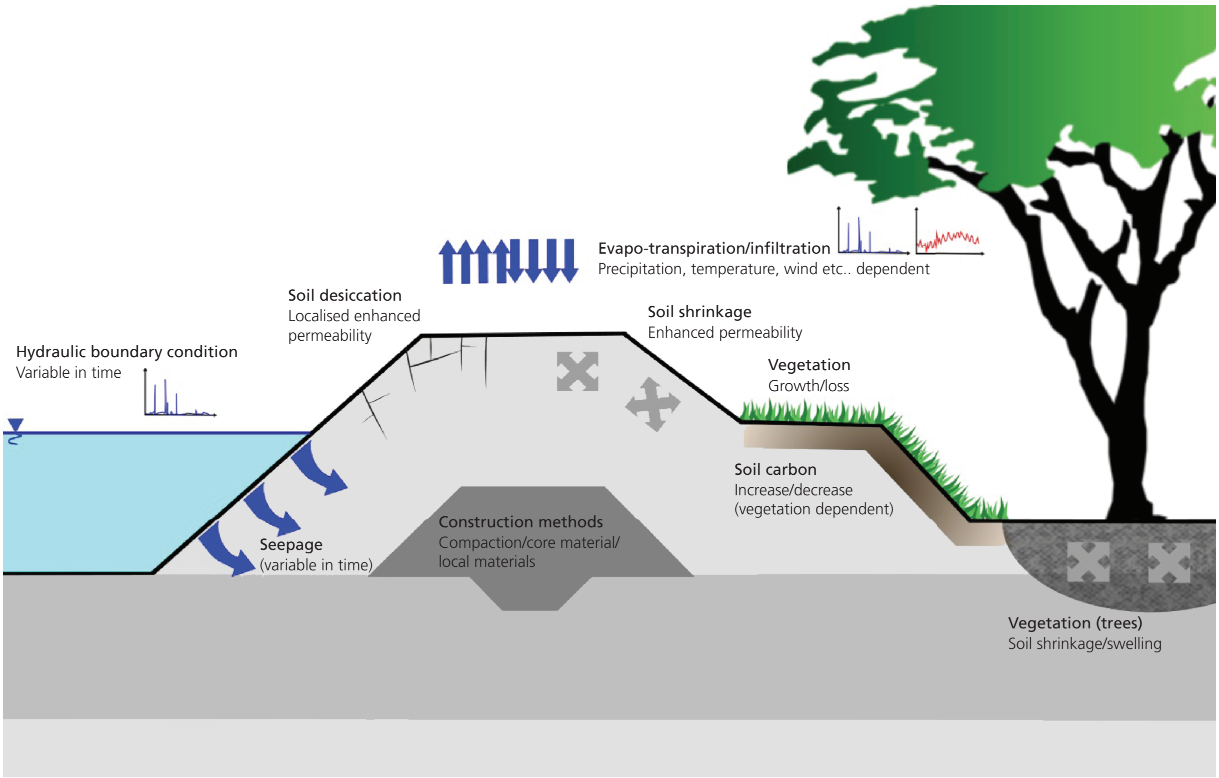

Figure 1. A conceptualisation of soil–atmosphere interaction (Vardon, 2015)

the chemical processes occurring, of which further investigation can only lead to better understanding of these processes, the better use of geomaterials and improved safety. I hope you find the papers in this themed issue interesting.

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