Wednesday, 3/15/2017

1:30–3 p.m.

Thermal & Hydraulic Conduction 3

Chairs: Ingrid Tomac, University of California, San Diego; John McCartney, University of California, San Diego

Microstructure-based Random Finite Element Simulation of Thermal and Hydraulic Conduction Processes in Unsaturated Frozen Soils

Shaoyang Dong and Xiong Yu, Case Western Reserve University

The freeze-thaw cycles in unsaturated frozen soils can cause serious damage to civil infrastructure. In this paper, a microstructure-based four-phase clay model is generated in Matlab. The model is then converted into a finite element software Comsol. The thermal, hydraulic and mechanical properties of each phase (soil particle, ice, water and air) of the clay are applied randomly to each pixel of the image model based on the volumetric content of each phase. The simulation results show that: (1) The thermal and hydraulic flow are observed during the freeze-thaw cycle. (2) The temperature, matric suction and potential head are obtained during the thawing process of the clay model. (3) The internal stress distribution versus time are calculated during the freezing process. The simulation results agree well with the engineering experience, which provides a simulation model to microstructurally analyze the thermal, hydraulic and mechanical properties of unsaturated frozen soils.

Measurement of Thermal Conductivity Dry-out Curves for Sands and Model Prediction

Nan Zhang, Xuelin Wang, and Xinbao Yu, University of Texas at Arlington

Study on soil thermal conductivity draws much attention recently since it is a governing soil thermal property in heat transfer process for geothermal applications. The variation of soil thermal conductivity at shallow depth is less understood because it is affected by various environmental factors (e.g. temperature, humidity, precipitation, etc.). This paper presents the measurement of thermal conductivity dry-out curves (TCDCs) for sands using a modified hanging column device (MHCD). Thermal conductivity of three sands was measured continuously from fully saturated condition to dry condition using a KD2 Pro (i.e. TR-1 single probe). A thermo-TDR probe was also used to measure sand moisture content. TCDCs of test sands were established with respect to degree of saturation, and then compared with the measured thermal conductivities obtained by multiple-specimen method (MSM). A good agreement of measured thermal conductivity was found between the MHCD and the MSM. The predicted TCDCs by three alternative thermal conductivity models were also compared with the measured curves. Recommendations have been provided to improve the models for wider applications.

A Review of Two Methods to Model the Thermal Conductivity of Sands

Aaron J. Rubin and Carlton L. Ho, University of Massachusetts, Amherst

The effectiveness of two models to estimate the thermal conductivity of sands is reviewed. Haigh (2012) proposed an analytical model based on unidirectional heat flow through a three-phase soil element. Using a database of 155 test measurements, his model performed with similar effectiveness to the empirical model proposed by Chen (2008). The database used by Haigh (2012) depended largely on the measurements conducted by Chen (2008). Eighty of the 155 measurements were conducted on 4 high quartz content sands presented by Chen (2008). In this study thermal conductivity tests were conducted on 3 sands at dry and wet conditions. The effectiveness of the Haigh (2012) and Chen (2008) models are reviewed using the new dataset. Overall, both methods performed reasonably well and the conclusion of Haigh (2012) that his model out performed the empirical models was confirmed.

Comparison of Two Laboratory Methods for Measuring Critical Temperature of Sandy Soils

Hyunjun Oh and James M. Tinjum, University of Wisconsin–Madison

In this study, soil critical temperature was measured using two distinct approaches: (1) a temperature profile established from a heating element located at the top of a vertical column and (2) temperature and moisture profiles induced from a centrally placed heating source in a 'horizontal' apparatus. Steady-state thermal and moisture equilibrium took longer to establish in the horizontal apparatus (on average, nine hours longer); however, the resulting temperature and moisture profiles were more consistent in the horizontal apparatus and with easily discerned slope discontinuities between the dry and moist zones. More ambiguous temperature profiles were observed in the vertical apparatus, even with insulation and heat tape applied to minimize horizontal boundary losses. This is indicative of the difficulty in maintaining one-dimensional heat flow in a vertical column. As soil critical temperature is an important parameter used in designing underground infrastructure impacted by significant heat transfer, such as buried power cables, refinement and standardization of equipment and protocol for determining this parameter in a precise and mechanistically sound manner is of prime concern.

Coupled Flow of Heat and Moisture through Compacted Geomaterials

Surya S. S., Arsha Lekshmi K. R., Nkhil John, and Dali Naidu Arnepalli, IIT Madras

A deep geological repository, DGR is an underground disposal facility for the safe disposal of high-level radioactive wastes. In DGR, the radioactive waste is vitrified and placed in metallic canister, which is encrusted with a thick layer of engineered geomaterial called buffer material. As the radioactive waste generates moderate amount of heat due to its decay, a thorough performance evaluation of the buffer material demands the knowledge of their thermal properties and rate of moisture loss. With this in view, it is proposed to investigate the coupled flow of heat and moisture. Experimental study involves imposing heat flux to the buffer material using a constant heat source representing radioactive waste contained canister. Thereby, the soil near the vicinity of the heat source is subjected to a higher temperature when compared to the rest, causing heat and moisture migration from the surface of the heat source towards the periphery. From the spatial and temporal variation of temperature and relative humidity (RH) obtained experimentally by means of deploying sensors over varying depth and radial distance, the vapor flow within the system is demonstrated in terms of its isothermal vapor diffusion coefficient.