Evaluation of Soil Thermal and Hydraulic Properties at Unsaturated Conditions for Frost Depth Prediction

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Spring thawing of frozen subgrade soils causes considerable damage to granular-surfaced roads when saturated thawed soils overlie impermeable still-frozen layers. However, the evolution of the frozen zone during freeze-thaw cycles depends largely on the moisture transport and thermal properties of unsaturated soils. The physical, thermal, and hydraulic properties of unsaturated soils are often considerably different from those at saturated conditions. In unsaturated soils, the existence of the air phase and contractile skin in addition to solid and liquid phases significantly alter the soil thermal and hydraulic properties, which are deemed the most influential factors controlling the heat transport, water movement, and freeze-thaw events in subgrade soils. In this study, the variation of soil thermal properties (i.e., volumetric heat capacity, thermal conductivity and thermal diffusivity) and hydraulic properties (i.e., hydraulic conductivity, water retention characteristics and water diffusivity) were evaluated at different degrees of soil saturation. Intact soil samples were collected by thin-walled tube sampling at depths up to 2.2 m beneath four granular-surfaced roads around Iowa. The effects of soil moisture content and matric potential on the thermal and hydraulic properties were assessed. The results demonstrate that the soil thermal properties are most reliant on moisture content and dry unit weight, and tend to increase with these two properties. Soil water diffusivity also increased with volumetric moisture content. Distinct soil water retention characteristic curves (SWCC) were measured for the various soil types. The hydraulic conductivity of the soils can then be estimated at different moisture contents by employing the saturated hydraulic conductivity and SWCC of the soils. In addition, the in situ spatial distribution of soil thermal and hydraulic properties were estimated from the observed moisture contents. These results are being used in a project aimed at frost depth monitoring and prediction under granular roadways in Iowa.

Keywords: granular roads; soil thermo-hydraulic properties, frost boils.