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Experimental study on the volume and strength change of an unsaturated silty clay upon freezing

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Abstract: In order to investigate the frost deformation and shear strength increment characteristics of unsaturated soil, a comprehensive experimental study was conducted to unsaturated slity clay samples with considering the influence of soil initial dry density and water content. Micro-structure observation tests, three-dimensional frost deformation tests, direct shear tests and soil compression tests are carried out. The frost deformation test results demonstrate that frost shrinkage happens when soil initial degree of saturation (S_r) is low, whereas frost heave and frost cracking happen when soil initial S_r is high. There is a critical degree of saturation at which frost shrinkage will turn into frost expansion. For the silty clay tested, this critical value is about 0.75. The frost shrinkage of soil is considered to be owing to the increase of cohesion upon freezing. The frost expansion of soil is induced by the fabric rearrangement which happens when pore-water changes into ice upon freezing. The shear strength test results demonstrate that soil friction angle does not vary much upon freezing, whereas soil cohesion increases a lot because of the generation of ice cementation and the increase of capillary cohesion. With assuming the increment of capillary cohesion upon freezing is equal to that upon drying for soil samples with same reduction of pore-water content, the ice cementation of frozen soil is found to be linear to its volumetric ice content. If the volume shrinkage induced by the increase of cohesion is assumed to be equal to that induced by the increase of mean principle stress with same values, the frost expansion induced by the water-ice phase transition is also linear to the volumetric ice content of unsaturated soil. Such linear relations seem to be unique and are applicable to unsaturated soil samples with any initial void ratio and water content.

Keywords: unsaturated soil; frost heave; frost shrinkage; ice cementation; capillary cohesion