A discontinuous approach for modelling distinct ice lenses in frost heave phenomenon

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Abstract:

Particle surface forces and capillarity cause the freezing point of the remaining water phase in a soil system to decrease as ice forms. The remaining unfrozen water has a thermodynamic potential that causes the pore water to migrate along the temperature gradient (Fig. 1). This will result in formation of ice lenses and frost heave as a consequence.

Frost heave is an upward movement of soil during freezing conditions caused by transportation of sub-cooled water into a growing ice lens. It happens when three conditions coincide: the temperature is below the normal freezing point of bulk water, the sub-cooled water is connected to a water reservoir, and the mechanical conditions of the soil allows the ice to grow. We used non-equilibrium thermodynamics to capture the coupled transport of heat and mass, and fracture mechanics to capture the mechanical requirements for the position and growth of ice lenses.

When ice lens forms, the solution domain will not be continuous anymore. As shown in Fig. 2, a volume that contains an ice lens (REV2) is totally different from other volumes (REV1) in the domain. Thus, a discontinuous solution method is required to handle the problem. We developed a version of the extended finite element method for this problem.

Model predictions are compared with the available test results and reasonable agreement is achieved.

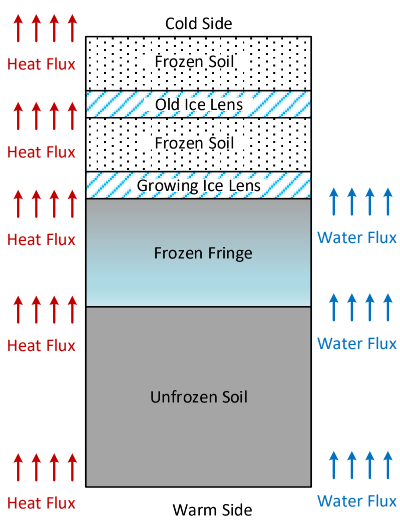

Fig. 1. Water migration along the temperature gradient toward an ice lens

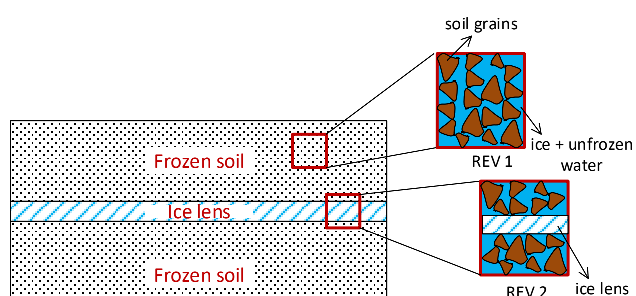

Fig. 2. Different representative elementary volume in the presence of ice lens