Investigation and calculation of frost heave considering specific boundary conditions of ground freezing

Conventional frost heave laboratory tests are performed by freezing a cylindrical soil sample from the top towards the bottom of the sample (cf. road construction). In contrast to these tests, the ground freezing applied in inner-city construction projects usually starts from inside the soil mass and grows in the opposite direction towards the soil surface. This causes at first a 9 % volume expansion of the pore water, and in addition for frost susceptible soils, the formation of ice lenses which results in additional soil heave at the surface. Until now there are no investigations which consider the upward freezing direction. Thus, the formation of ice lenses under these conditions is unknown. For the calculation of frost heave, the complex physical processes during freezing must be taken into account. This requires a simulation model, which focuses on the poro-thermo-hydro-mechanical coupling phenomena.

The aim of this project is to determine and describe the frost heave behavior of frost susceptible soils caused by ground freezing with horizontal freezing pipes. Part of this research project are frost heave tests which simulate, different to conventional tests, a freezing direction towards the top ground surface. The formation of ice lenses occur above the frozen zone where the water flow towards the frost line is affected not only by the arising vacuum but also by gravitation. In contrast to tests with a downwards freezing direction, the heave direction of the frozen soil occurs in the opposite direction of the water flow. The experimental tests verify how far this influences the formation of the ice lenses. With these tests, the temporal and spatial distribution of water in the soil sample is investigated. Within the scope of a parameter study the influence of relevant parameters will be determined. In addition, standard frost heave test will be carried out to compare the resulting heaves as well as the formed ice lenses in order to carve out differences due to the freezing direction. Furthermore, a numerical multiphase model will be developed to simulate the frost heave with the various physical effects and under defined initial and boundary conditions. A theory of porous media (TPM) based multiphase model is formulated and extended with the phase field method (PFM) to model ice formation and phase change from pore water to ice in porous media. The TPM-PFM model considers the flow of the pore fluid reduced or prevented as a result of ice formation as well as the finite deformations of the solid skeleton due to an volume increase during the phase transition from water to ice. The frost heave tests are used to calibrate and validate the numerical model to calculate freezing processes with upwards and downwards freezing.

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