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Coupled THM modelling of freezing soil based upon strength upscaling

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Within the framework of thermo-poro-plasticity [1], a three-phase Finite Element model of freezing soils is presented that considers solid particles, liquid water and crystal ice as separate phases, and mixture temperature, liquid pressure, and solid displacement as primary field variables. Through three fundamental physical laws and corresponding state relations, the model captures the most relevant couplings between the phase transition, the liquid transport within the pores, and the accompanying mechanical deformation. To describe the elastoplastic stress-strain response of freezing soil, a new critical state constitutive model is developed by employing the Clay and Sand Model for the reference unfrozen state, and extending to the freezing state by adopting concepts of the enhanced Barcelona Basic Model [2]. In particular, for the prediction of the temperature- and porosity-dependent strength criterion of freezing soils, a novel multi-scale strength homogenization procedure is proposed, which allows to determine the macroscopic cohesion and frictional coefficient based on the current state of the micro-structure of freezing soils. The performance and applicability of the presented model are demonstrated by means of a one-dimensional soil freezing test and a case study on artificial ground freezing processes during tunnel excavation.

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