Thermo-Hydro-Mechanical simulations of Artificial Ground Freezing

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Motivation

Hundreds of thousands of people in Alaska, Canada, Russia and Greenland live on permafrost, which covers nearly 24% of the northern hemisphere (National Snow and Ice Data Center, 2018). Living conditions can be challenged by the fragile nature of the frozen ground, especially if framed in the context of global warming. Indeed, permafrost effects like frost heave and thaw settlement may heavily affect existing buildings and transportation infrastructure such as roads, railways, embankments and runways. These being vital for isolated Arctic communities, should be preserved and maintained to avoid any unfavourable happening. Artificial Ground Freezing (AGF) can be employed to keep soil frozen and hence ensure structure stability by means of one-way heat pipe systems, also called thermosyphons. Such devices have been widely used in China where permafrost degradation of the Tibet plateau posed severe threats to the normal functioning of the Qinghai-Tibet railway and in Greenland, where buildings in the settlement of Kangerlussuaq were threatened by the shifting thermal regime of the underneath soil. Furthermore, AGF is also used nowadays as a valuable and efficient construction method for underground engineering projects in densely built up areas, due to the enhanced soil strength and decreased permeability. This technique allows to form earth support systems covering a variety of problems such as structural underpinning for foundation improvement, tunnel constructions and temporary control of groundwater flow in construction processes. A good example is the construction of Naples underground in Italy, where artificial ground freezing has been successfully applied. It seems clear that the interest in frozen ground engineering, whether soil freezing is induced by natural conditions or by human activities, has rapidly developed over the last decades. To predict the coupled thermo-mechanical behaviour of frozen soil and to provide a reliable design tool for geotechnical engineers, the development of a numerical modelling approach is necessary.

Methodology

This MSc thesis aims to back-calculate available measurements of the tunnelling project in the new underground of Naples, using a new constitutive model called Elastic-Plastic Frozen/Unfrozen Soil model, recently developed at NTNU by Ghoreishian Amiri et al. (2016a). Results will be used to validate the numerical model, as little data for artificial ground freezing in cold climate exists as of today but might be used in future. The model is based on the Modified Cam Clay model and it is formulated on the concept of two-stress state, namely solid phase stress and cryogenic suction, allowing to build a complete Thermo-Hydro-Mechanical (THM) framework where temperature, mechanical strength and hydraulic pressure are considered at the same time (Ghoreishian Amiri et al., 2016b). In this MSc thesis, the Finite Element program PLAXIS 2D is used as numerical tool to perform THM modelling of frozen soil for the railway tunnel construction at Municipio and/or Garibaldi stations in Naples. Literature data, obtained by Pelaez et al. (2014) on Yellow Tuff retrieved from the subsoil of Naples will be used to calibrate the constitutive model.

Expected results

The primary aim is to evaluate the accuracy of the proposed model in terms of predicting the temperature and displacement profiles of the ground subjected to artificial ground freezing. It should be noticed, that the model has been previously validated against available element tests data and large-scale test data by Rostami H. (2017) and that the necessary improvement has already been applied. The next step will consist of evaluating the accuracy and robustness of the model in a practical engineering project. Commonly, some improvements will be required to increase the accuracy and to make it even more stable and robust.

References

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