Evaluating Artificial Ground Freezing sustainability through numerical analysis of monitoring data in a trial site

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ABSTRACT

Artificial Ground Freezing (AGF) is a controllable temporary process used by civil and mining engineers to increase the strength of the ground and to control groundwater during excavation until construction of the permanent structures provides permanent stability and water tightness. AGF has been extensively adopted as temporary support during the construction of Line 1 of Napoli underground (Viggiani & De Sanctis, 2009). In order to optimize the method in terms of freezing pipe geometry, coolant consumption and thickness of the resulting frozen wall, a field test has been performed in Piazza Municipio. The main purposes of the experimental field tests were to optimize the in-situ ground freezing technique to form the ice barrier around the station tunnels in the most efficient and safe way, and to determine the consumption of coolant required for the formation of a frozen ground barrier fulfilling the minimum design requirements (temperature of the frozen front, T=-10°C, thickness of the frozen barrier s=1 m). The freezing tests were conducted using either nitrogen, liquid at T=-196 °C and then exhaust as gas in the atmosphere, or brine (calcium chloride) at about -35°C; in this case the refrigerating fluid was re-circulated through a refrigeration plant.

The experimental program included: nitrogen-freezing tests, brine (calcium chloride) freezing tests, and mixed freezing tests trough activation with nitrogen and maintenance with brine. The nitrogen freezing test was conducted for both single-pipe and double-pipe systems. The brine freezing test was performed circulating the refrigerant fluid simultaneously in two probes, which were at a distance of 1 m from one another. The freezing test with nitrogen activation and brine maintenance was performed using the same two probes and the same lining. Ground temperatures during the freezing stages were measured using thermocouples installed in observation holes.

The main advantage of AGF as a temporary support system in comparison to other support methods, such as those based on injections of chemical or cement grout into the soil, is the low impact on the surrounding environment as the refrigerating medium required to obtain AGF is circulated in pipes and exhausted in the atmosphere or re-circulated without contamination of the ground water. Anyway, the available methods may vary significantly in their sustainability and complexity, in terms of times and costs required for their installation and maintenance. Engineering considerations require an understanding of the freezing process, the effects of swelling-thawing frozen-unfrozen ground which is crucial to assessing construction time and cost, and to optimize the method.

The field monitored data has been back analyzed with a fully coupled THM formulation in order to evaluate the effectiveness of the installation pipe and their maintenance. Another purpose of the back analysis has been the definition of thermal properties that govern the phenomenon of heat diffusion in the volcanic ash where the pipe was installed.

The THM formulation implemented in a finite element program (CODE BRIGHT) is based upon fundamental physics and provides a unified model that can reproduce both failure/deformation and coupled heat/mass transfer in frozen ground, which conventionally are treated separately. The same mechanical constitutive model (see e.g., Nishimura et al., 2009; Gens, 2010; Casini et al., 2014) is adopted for the soil in both frozen and unfrozen conditions.

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