Experimental behaviour of frozen coarse-matrix soils with variable fine content

EXPERIMENTAL BEHAVIOUR OF FROZEN COARSE-MATRIX SOILS WITH VARIABLE FINE CONTENT

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1. Introduction

Artificial Ground Freezing (AGF) is an eco-friendly consolidation technique, commonly adopted for the construction of shallow tunnels and wells below groundwater level [1]. The application consists of the insertion of freezing pipes around the excavation area. A coolant is circulated inside the pipes, thus provoking the surrounding soil to freeze. When a continuous frozen wall is formed, the area with lower permeability and higher strength allows for a safer and easier building phase.

AGF is often applied in soils characterized by intermediate or well-graded granulometry (e.g., along the new Line C of Rome Underground [2]). Consequently, the influence of heterogeneous and variegate grain size distribution on the thermo-hydro-mechanical (THM) behavior of soils must be systematically investigated. In literature different experimental studies focus on site materials. Although they are important for the effectiveness of individual projects, they are rarely generalizable. The presented research consists of an experimental campaign on gap-graded materials aimed at standardizing the behavior of intermediate soils. A sandy matrix is mixed with kaolin at percentages in mass from 0 to 15%, then the mixtures are subjected to a freezing process to investigate the influence of fine content on the THM behaviour observed. To these aims, a temperature-controlled triaxial apparatus, *FROZEN*, is used [3]. Its setup allows for the reproduction of on-site freezing conditions around a freezing pipe.

After a brief description of the materials and experimental device, the paper contains the main results of the experimental campaign aimed at understanding the THM behavior of the mixtures upon freezing. In particular, the performance of pure sand is compared with that observed when kaolin is added to the matrix. Additionally, the influence of increasing confining pressure (from 50 to 800 kPa) on freezing behavior is investigated.

2. Materials

The Fontainebleau sand, adopted for the experimental campaign, is characterized by an almost uniform grain size distribution [4]. Speswhite kaolin, a common clay of the literature, is mixed with the coarser matrix [5].

Kaolin is added to sandy soil at percentages of 0 and 15%. All mixtures are prepared with a constant theoretical initial water content and a fixed initial porosity, to be able to quantitatively compare the water movement (inlet/outlet) during freezing between mixtures.

3. Experimental setup

FROZEN [3] is a temperature-controlled triaxial device developed at the Tor Vergata University of Rome (Rome, Italy) and it is constituted by three main parts (Figure 1): 1. a triaxial cell, 2. a mechanical press, 3. a refrigeration system. A copper tube axially crosses the centre of the specimen, and the refrigeration system circulates a coolant inside it with a mechanical pump, thus the frozen front advances radially from the center outwards.

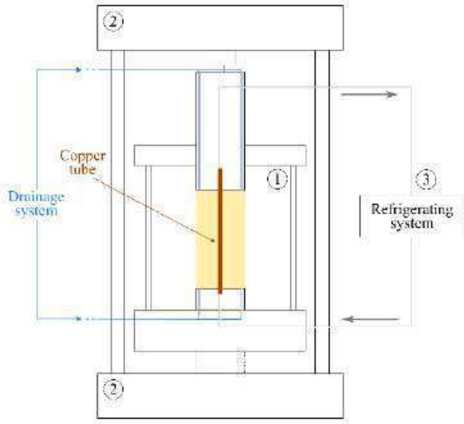

Figure 1: Scheme of the temperature-controlled triaxial device *FROZEN*.

The drainage system is designed as far away as possible from the copper tube: in this way, the sample is free to drain water until it is almost completely frozen, when the freezing front reaches the drainage tubes.

Tests follow the standard triaxial procedure, except for an additional freezing step: the sample is first saturated and then consolidated. Then freezing starts while the isotropic consolidation pressure is maintained. This stage lasts around ten hours.

4. Main results

During the experimental campaign, the pure sand showed to be not frost-susceptible, i.e., no strain was measured at freezing, as expected. Water outflow was registered, because of the water on the freezing front turning into ice, causing the drainage of the remaining liquid water out of the sample. This behaviour was confirmed in all confinements. On the contrary, the sand with 15% kaolin importantly swelled during freezing, with associated water inflow towards the freezing front, due to cryogenic suction. However, increasing confinement gradually inhibited strain and water inflow, so that at the highest confining pressure the water outflow turned to govern the behavior and the sample did not deform.

5. References

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