Abstract

Artificial Ground Freezing (AGF) is a consolidation technique used when shallow tunnels or shafts are excavated in loose soils or fractured rocks under ground-water level. It guarantees temporal ground stabilization and groundwater control during the excavation process until permanent stability and water-tightness systems are installed. Understanding the behavior of soils and rocks during freezing application is a key aspect of a safe and effective construction design. AGF is often applied in presence of intermediate soils, i.e. soils characterized by intermediate or well-graded granulometry. Therefore, the effects of granulometry upon freezing and thawing must be systematically investigated. In this direction, many research activities are devoted to analyse site materials. This makes the experimental evidences rarely extendable to various cases. The present work contains an experimental investigation aimed at standardizing the behavior of intermediate materials. Particularly, this thesis mainly focuses on the experimental analysis of sandy soils subjected to freezing. It investigates the influence that increasing fine content into the sandy matrix has on these soils. Kaolin content was added at percentages in mass between 0 and 15%. The main experimental campaign was performed with a temperature-controlled triaxial apparatus, developed at the University of Rome Tor Vergata, which reproduces the freezing conditions that occur on-site around a freezing pipe. In this apparatus, freezing proceeds from the center outward of the sample, and thermal loading advances in the radial direction.

In the frame of the PhD thesis, triaxial and oedometric tests were performed to characterize the mechanical behavior of the materials at ambient temperature. Afterwards, the behavior of soils subjected to freezing was investigated through consolidated drained triaxial tests in which an additional freezing stage was carried out between consolidation and shear.

During the experimental campaign on soils subjected to freezing, the sandy samples showed to be particularly influenced by the fine content: at freezing, under a certain

clay percentage the soil was not frost-susceptible. But, when the kaolin content was further increased, the material showed important swelling, which was then gradually inhibited with rising confining pressure. Consequently, water drainage out of / towards the sample was observed. The drainage direction was dictated by two contributing factors: the liquid water turning into ice, thus pushing the remaining liquid water from the freezing front out of the sample, and the cryogenic suction, which provokes a recalling force for water towards the freezing front.
Once the soil was frozen, then it was subjected to shear. Also during this phase, the material behavior was significantly influenced by the fine content: the more the kaolin was increased in the sandy matrix, the more the material was affected by the confining pressure. Additionally, when kaolin was in the mixture, the strength at shear decreased, since the ice matrix power was reduced. In fact, it is well known that the cohesive power of the ice matrix, together with adhesive forces between ice and soil particles, contribute to soil strengthening: however, the cohesive power of the ice contributes more than the adhesive forces.
Coarser-finer grains mixtures showed significant shrinkage when subjected to wetting. Therefore, an experimental analysis through oedometric tests at ambient temperature was further carried out to investigate the influence of fine content at saturation. When the fine was increased into the sandy matrix, the volumetric reduction rose sharply, but its entity depended on the overlying load and the initial water content of the mixture.
Finally, to investigate the influence of the saturation degree on the soil thermo-hydro-mechanical behavior upon freezing, triaxial tests were carried out on mixtures at low saturation. Shrinkage was observed during freezing, while at saturated condition no deformation, or even swelling, was measured. Additionally, the temperature diffusion was slower when air was in the pores.
This work includes a numerical modelling process under development to reproduce the performed experimental tests on the saturated mixtures subjected to freezing. The thermo-hydraulic coupled behavior was firstly analysed in order to faithfully simulate the thermal diffusion process in the samples. Additionally, a thermo-hydro-mechanical model was built to couple the mechanical aspects of the so complex behavior of freezing soils.