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Mechanical behaviour of Palermo and Marsala calcarenites (Sicily), Italy

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ABSTRACT

This paper aims at finding a framework for the Sicilian Calcarenites relating the strength and the deformability of these materials to their geological and structural features: fabric, bonding, initial and actual specific volume. In particular, this study sets out to separate the effects of fabric and of bonding on the mechanical response.

The investigated lithotypes, Calcarenites from Palermo and Marsala, outcropping in many areas of southwestern Sicily, are characterized by sudden changes in their deformability, strength and permeability characteristics.

The geotechnical identification, by means of computerized axial tomography and thin section petrographic analysis suggested a subdivision of these two calcarenites into five lithotypes as a function of their structural configuration. These calcarenites are metastable rocks whose mechanical behaviour depends on the fabric and bonding. Oedometer, triaxial and isotropic tests were conducted to analyzed interparticle bonding and/or fabric effects on the mechanical behaviours. For each lithotype the yield limit was defined and three distinct behavioural patterns were identified as a function of the confining stress level: 1) an initial linear elastic behaviour up to the yielding strength, 2) a yielding phase characterized by a strain-softening response, 3) a final phase of the destructured material.

At yield state, bonding is the major factor contributing to the soil strength, while the effect of fabric comes into play at post-yield stress state. For the assessment of the yielding conditions the yield stress values obtained from various stress-paths were taken into account.

1. Introduction

The Quaternary complex of Western Sicily, which represents a large part of its outcropping soils, consists of a multiplicity of rocks that fall into the field of the Hard Soils - Soft Rocks. The transition from one type to another occurs in both vertical and horizontal directions indicating complex sedimentary processes (Arces et al., 2000). The consequent variation of the mechanical properties is reported in this article to evaluate the relationship between the stress-strain response and the microstructural features.

These structured Quaternary rocks, outcropping in South-West Sicily in the area between Marsala and Mazara (Marsala Calcarenites), and in Western Sicily, in Piana of Palermo (Palermo Calcarenites) belonging to the calcarenitic-sandy-silty complex, were extensively used as building material, extracted almost always from underground quarries in areas adjacent to the ancient settlements. The quarry extraction was sometimes so intense as to determine large underground spaces, supported by pillars of non-resistant material, resulting in a fragile “osteoporotic skeleton.”

These areas are characterized by high risk. In fact, due to the uncontrolled expansion of urban centers, these zones have witnessed frequent collapse episodes.

The rocks present in these areas are transitional rock types between non-cohesive soils and hard rocks, and it is known that their mechanical behaviour is conditioned by the texture (Lambe and Whitman, 1979) and in particular by fabric (orientation, distribution, density of the particles) and bonding (electro-chemical interparticle forces and synsedimentary and/or diagenetic cementation). Typically, the combined effects of the fabric and the bonding are identified by the generic term “structure” and the soils are called “structured”. On the other hand, the soils with the original structure partially or totally destroyed by deformation are referred to as “unstructured” (Mitchell, 1976).

Dobereiner and DeFreitas (1985) recommend adopting Packing Density (PD) and Grain Contact (GC) as suggested by Kahn (1956) as a quantitative method to evaluate the structure.

Non-destructive methods like X-ray tomography provide valuable information about the microstructure of the calcarenite (Lanzón et al., 2014) and allow a quantitative assessment of the density, texture and degree of cementation of a soil (Fonseca et al., 2012; Jacobs and Cnudde, 2009; Landis and Keane, 2010; Ren and Ge, 2004).

It has been recognized that the void index, stress history, interparticle bonding (electrical forces or cementation) have a predominant influence on the mechanical behaviour of structured soils (Leroueil and Vaughan, 1990).

Also fabric changes, depending on the age of the deposit (locked sands, for example), could determine the transition from non-

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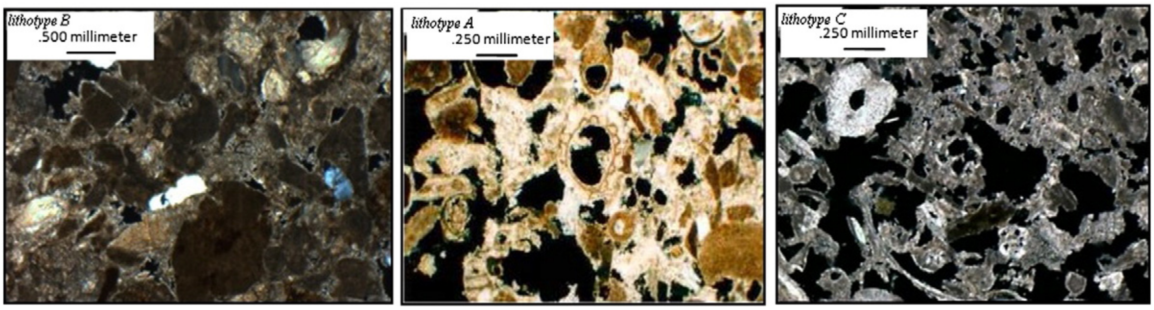

Fig. 1. Thin section of Marsala Calcarenite: I) lithotype B II) lithotype A III) lithotype C (note: photos with different scales).

cohesive sands to soft rocks (Barton, 1993; Dussealt and Morgenstern, 1979).

Early or late diagenetic sin-sedimentary processes are responsible for bonding development, due to the presence of cement between grains (Moore, 1989). As the diagenetic grade advances, the bonding becomes tenacious and the intergranular voids decrease.

The yield stress of the material and the consequent structural reorganization depend on the specific volume (Leroueil and Vaughan, 1990). The yielding process can be gradual or sudden (Lagioia and Nova, 1995; Zimbardo et al., 2011). In any case, two stress regimes are clearly distinguishable: the first one is characterized, at low stress levels, by an elastic behaviour and reduced volumetric strains (rock-like), the second one, at high stress levels, exhibits a plastic behaviour characterized by large volumetric strains (soil-like) (Pellegrino, 1970; Pellegrino and Evangelista, 1990; Aversa and Evangelista, 1998).

In the rock-like behaviour, the reduced deformation of the material is influenced both by the bonds cementing and the shear strength at grain contacts. When the stress state reaches the bond strength, the destructuration process is triggered and the stress is gradually transferred from interparticle bonding (rock-like) to the contact between the particles (soil-like) (Vaughan, 1988).

Usually it is thought that deformation induces destructuration only after reaching the yield stress and any stress paths that do not reach the yield locus do not cause weakening of the structure. But even low deformation levels can cause an appreciable degradation of structure and a decay of the material (Zimbardo et al., 2011). However, the complete destructuration is obtained at very high levels of deformation (Leroueil and Vaughan, 1990). Baudet and Stallebrass (2004) divided the soil structure into stable structures that do not degrade and metastable structures which undergo destructuring. The yield limit in isotropic compression condition is represented by the Normal Compression Line (NCL). The interparticle bonding was found to have a major effect not only on the yield limit, but also on the post-yield and on the material response during the occurrence of yielding.

The Critical State Line (CSL) of calcareous sands, is controlled by particle breakage and in the plane deviatoric stress q - mean effective stress p' is described by a line characterized by a constant gradient M (Coop and Lee, 1993). The localization of the NCL and CSL in the plane p'-q would depend on the mineralogical composition of the sands and on the strength of the grains. One of the most interesting features observed in isotropic compression is the effect of the strength of the bonds on the onset of plastic deformations.

Coop and Cuccovillo (1999) defined two different types of behaviour: strong-bonding when the strength of the bonds is higher than the strength of the particles and weak-bonding when the strength of the bonds is lower than the strength of the particles. In this last case, therefore, during compression the bonds might start breaking before the onset of particle breakage and a second yield strength (gross yield), due to the onset of grain breakage, could occur (Kavvadas, 2000; Zimbardo et al., 2011). The existence of weak-bond and strong-bond behaviours implies that for strongly bonded material, yielding in compression would be controlled mainly by the strength of the bonds and would be better defined than for weakly bonded materials whose yield would occur gradually and would be controlled mainly by particle crushing.

Recent studies (Alvarado et al., 2012) introduced the existence of strong fabric; despite their light cementing, sandstones can show a mechanical behaviour similar to that seen in rocks with much stronger cementation.

The aim of this paper is to provide data for a better understanding of the destructuration mechanism. Here are reported the results of wide experimentation conducted by means of textural identification tests, oedometer, isotropic and triaxial tests. For each lithotype the conditions of critical state and yield are defined. Analysis of these test results shows that the relation between structural features and mechanical response changes, and at any moment the relative importance of bonding and fabric varies during loading as the bonds progressively degrade.

2. Geotechnical characterization

2.1. Textural and petrographic characterization

Marsala calcarenite can be divided into three lithotypes (A, B, C) depending on grain contact types, porosity and on degree and type of

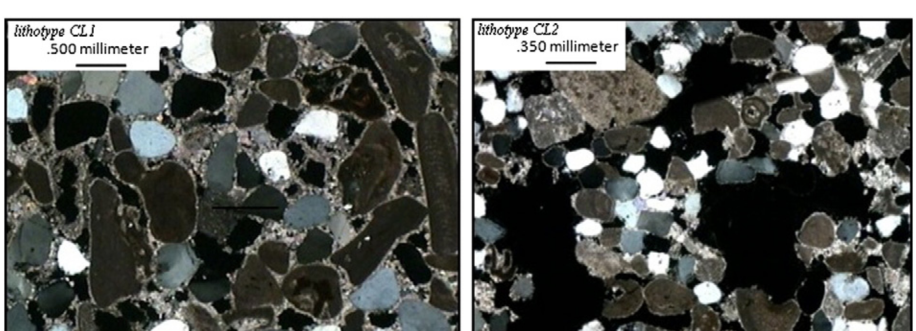

Fig. 2. Thin section of Palermo Calcarenite: I) lithotype CL1 II) lithotype CL2 (note: photos with different scales).