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Geotechnical characterization of limestones employed for the reconstruction of a UNESCO world heritage Baroque monument in southeastern Sicily (Italy)

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ABSTRACT

A detailed laboratory characterization of limestones employed for the reconstruction of Saint Nicholas Cathedral, a UNESCO World Heritage monument in southeastern Sicily, is presented herein with the purpose of achieving a complete knowledge on the behavior of such rocks under stress, whose engineering geological aspect had not been investigated before for scientific purposes. Specimens were sampled at three sites, where this rock is quarried from two lithofacies of the same geological formation, and are similar to other limestone varieties quarried worldwide and employed as construction material. Although slight differences between the samples occur at a macroscopic scale, geotechnical tests highlighted relevant differences from the physical and mechanical points of view. In order to look for one or more factors responsible of such dissimilarities, a statistical analysis was carried out and interesting outcomes were achieved with the help of a microscopic analysis of the specimens. Moreover, attention was paid on the modes of failure of tested specimens under compression, whose attitude was described and correlated to selected properties of the rock. Results have both a practical implication, because of the employment of this rock type as engineering material worldwide, and a scientific relevance, due to the peculiar behavior that such rock offered under stress.

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1. Introduction

The seismic history of southeastern Sicily is characterized by several intense events which, over the centuries, caused severe damages and, sometimes, razed entire settlements. An example is represented by Noto city, where the main church experienced more than three collapses after seismic shakings and consequent reconstruction works. It is Saint Nicholas Cathedral, now included in the UNESCO World Heritage List, representing a high level of architectural and artistic achievement among the Sicilian Baroque edifices. The recent reconstruction works, after the 1990 earthquake, were aimed at the restoration of the original architectural style. For this reason, locally quarried carbonate rocks were employed for the reconstruction of the main structural components of the building (Barone et al., 2015). In particular, one of the most employed rock type is represented by two varieties of a limestone widely cropping out in the southeastern sector of Sicily: a yellowish limestone or Noto Stone (NS) and a white-cream limestone or Palazzolo Stone (PS), quarried at three different sites. Both varieties belong to the middle-upper Miocene Palazzolo Formation and show similar features from a macroscopic point of view. This rock was particularly employed for the reconstruction of the pilasters, which were the most damaged structural components by the 1990 earthquake. Nowadays, thanks to their availability, NS and PS are still employed as construction or replacement material, especially for the restoration of Baroque edifices. Due to the historical and artistic importance of the Baroque monuments of this area, these rock types have been studied by several Authors, who mostly investigated on their durability properties in the wide context of Hyblean stone materials (e.g. Punturo et al., 2006; La Russa et al., 2011; Anania et al., 2012; Barbera et al., 2012). Nevertheless, literature data lack of a complete laboratory characterization of this rock from a pure engineering geological point of view. In this light, this paper aims to fill this gap, highlighting similarities and differences between the two varieties of limestones, thus investigating on their mechanical behavior once employed as construction material. The scientific interest on this research is motivated not only by the use of such stone in the rebuilding of a UNESCO World Heritage monument, but also by the choice of similar rocks for the building and restoration of monuments worldwide.

Bell (1993) proposed a comparison between some British limestones, highlighting that the mechanical properties of carbonate sediments are influenced by grain size and post depositional changes. Torok (2003) analyzed a Miocenic limestone, similar to those described herein, widely employed as construction material in Budapest

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(Hungary). He underlined the similarity between the texture of the analyzed rock and some limestones cropping out in France and Great Britain. Geotechnical analyses on Egyptian carbonate rocks, employed for constructions, were carried out by Ali and Yang (2014). Bednarik et al. (2014) studied physical and mechanical properties of Leitha Limestone, broadly used as historical building materials in Eastern Austria, while Al-Omari et al. (2015a) investigated on the petrophysical and mechanical properties of two porous limestones used in the construction and restoration works at the castle of Chambord in France, which is a UNESCO World Heritage site. Al-Omari et al. (2015b) characterized limestones at the site of Al-Nimrud city in northern Iraq as part of the walls of Al-Ziggurat pyramid-shaped mound.

Because of the easy availability of limestones worldwide, this paper represents a contribution to the knowledge of the engineering geological properties of such rock type and could be taken into account as reference for the laboratory characterization of similar rocks, which often needs structural retrofitting if employed in old constructions (e.g. Contrafatto and Cosenza, 2014). In fact, Noto limestones were sampled at three different quarries located in the Hyblean area (southeastern Sicily). Specimens underwent a detailed laboratory characterization aimed at estimating their main physical and mechanical properties, such as bulk density and unit weight, real density and grain specific gravity, total and effective porosity, Uniaxial Compressive Strength (UCS) and Young Modulus (E). Furthermore, ultrasonic velocity and water permeability were measured in laboratory, along with the main mechanical parameters under confining pressure through triaxial compression tests. Assessed parameters were mutually correlated in order to investigate on the relationship between some features and to focus the attention on peculiar characteristics of the rock. Moreover, interesting comments on the observed failure modes are presented.

2. Noto Cathedral

Saint Nicholas Cathedral is one of the most important worship place of Sicily, located in the baroque town of Noto, southeastern sector of the island. Its construction dates back to 1694, one year after a historical earthquake, which razed most of the villages of the area (Bianca et al., 1999; Visini et al., 2009). Its history has been strongly marked by the numerous seismic events occurred over the centuries. In 1727, an earthquake with epicentral area at Noto (Azzaro and Barbano, 2000) caused the failure of some essential structural component of the edifice, leading to the demolition and reconstruction of the whole church. The reconstruction lasted 11 years, but the cathedral did not resist the following 1780 and 1848 seismic shakings, which caused the collapse of the dome and apse in both occasions. In 1862, the re-built structure was opened to the public access, but on 13 December 1990, a 5.3 M earthquake brought severe structural damages and, 6 years later, one of the main pillar of the dome collapsed. This event triggered the failure of the dome itself and, in a domino effect, the collapse of the right aisle and nave (Fig. 1a–b). The damages that after the collapse appeared to be the most significant were a series of vertical cracks on the pilasters, which sustained most of the load of the heavy roof and dome (Tringali et al., 2003). Moreover, such pilasters were found to be the weakest part of the entire building, because of one mistake made during the previous reconstruction: the use of round river stones in their structure.

Fig. 1. a) Noto Cathedral after the 1996 collapse; b) aerial view on the collapsed edifice; c) Noto Cathedral after the latest reconstruction works; d) aerial view on the re-built edifice. The photos were retrieved from the web: a) http://www.raffaeledavinci.it/; c) http://rete.comuni-italiani.it/; b–d) http://www.lct-architettura.it/ accessed 2 March 2016.

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