The stone in a monumental masonry building of the Tyrrhenian coast (Italy): new data on the relationship between stone properties and structural analysis

Forestieri, G., Tedesco, A., Ponte, M.

Abstract: In order to assess physical-mechanical properties of building material ("Fuscaldo sandstone"), non-destructive tests have been performed in the main façade of "Palazzo Carelli - Pignatelli" (14th-15th centuries) in Fiumefreddo Bruzio (Italy), situated in the Tyrrhenian Coast (in the South of Italy). Mechanical properties have been assessed through Schmidt hammer hardness and ultrasound velocity tests. Structural analyses have been carried out to assess collapse mechanisms of the entire façade. Results provide a preliminary comprehensive understanding of the decay level and instability of the building.

Key words: conservation, non-destructive tests, structural analysis, heritage.

El material pétreo en un edificio monumental de la costa tirrenica (Italia): nuevos datos sobre la relación entre propiedades pètreas y análisis estructural

Resumen: Ensayos no-destructivos se han llevado a cabo en la fachada principal del "Palazzo Carelli - Pignatelli" (Siglos XIV-XV) en Fiumefreddo Bruzio (Italia), situado en la Costa Tirrenica de Calabria (en el Sur de Italia), para evaluar las propiedades físico-mecánicas de su material de construcción (Arenisca de Fuscaldo). Las propiedades mecánicas han sido evaluadas a través de las técnicas del martillo de Schmidt y de ultrasonidos. El análisis estructural se ha hecho para identificar los mecanismos de colapso de la fachada. Los resultados han permitido obtener una comprensión preliminar del grado de deterioro y de inestabilidad del edificio.

Palabras clave: conservación, ensayos no-destructivos, análisis estructural, patrimonio.

Introduction and geological setting

The main objective of this research is to assess the influence of deterioration and structural damage on the petrophysical and mechanical properties of the investigated building stone taking as example the case study of "Palazzo Carelli - Pignatelli" in Fiumefreddo Bruzio (Italy). The effects derived from decay have been evaluated combining different non-destructive techniques (NDT) with structural analyses, carrying out *in situ* and laboratory tests performed on selected samples.

For the selection of the case study to investigate, different criteria have been considered. First of all, the architectural importance of the monument. "Palazzo Carelli - Pignatelli" that is an example of the "Renaissance" architecture in the royal style of Naples of the 15th century, kwown as "durazzesco-catalano" (Forestieri et al., in press). In the same architectural style others important buildings have been built in the south of Italy, like "Sersale", "Giannuzzi Savelli", "Spiriti Sersale", "Pitelia", "Alecce" palaces etc. (Canonaco 2012). The portal is characterized by lateral pilasters, architrave and upper trabeation. Sandstone ashlars present smooth and furrowed surface, with ornamental elements, like flowers and vegetal motifs. Another criterion has been the role of the building stone material in the Calabrian context. The entire noble building and its main portal have been realized using the local stone named "Fuscaldo sandstone". Macroscopically, this sandstone is compact, yellow/brownish colored and presents visible fossils from 1 mm to 6.50 mm. It is commercialized under the name of "Pietra dolce o di Fuscaldo" (sweet or Fuscaldo stone) due to its easy workability. It has been principally used by the most important schools of Calabrian stonemasons to build portals of many Calabrian old towns (Forestieri et al. 2015). Geologically, this stone belongs to the Sedimentary Successions of the Upper Oligocene-Middle Pliocene of the Tyrrhenian Coastal Range that includes not only sandstones but also calcarenites, arkoses, conglomerates, clays, marls, gypsums and evaporitic limestones, from 200 m to over 1.500 m in thickness (Critelli and Le Pera 2000). The last criterion has been the high degree of deterioration and the structural instability of the investigated monument. This building is, in fact, affected by different serious problems due to the deterioration processes and structural damages of the masonry.

In order to characterize the building material and its state of conservation, deteriorated samples, representative of the portal of the main façade were selected and compared to unaltered quarry samples of the same lithology. Quarry samples belong to the outcrops situated in "Località Scarcelli" in Fuscaldo, where it is located one of the most ancient Fuscaldo outcrops exploited by stonemasons for the construction of many Calabrian monuments (Forestieri et al. 2016). According to the geological map of figure1 (Casmez 1967), the Upper Miocenic sedimentary succession of this area is composed by dark and light sandstones with a calcareous cement and sandy horizons, locally conglomeratic and dark-light to dark-reddish conglomerates, made of rounded pebbles and fragments of granite, gneiss into an arkosic matrix.

Tests are aimed to show differences in properties of 'fresh' quarry and unaltered stones, and deteriorated sandstones. The overall aim is to clarify the links and the compatibility between these two local sandstones in order to replace the original material.

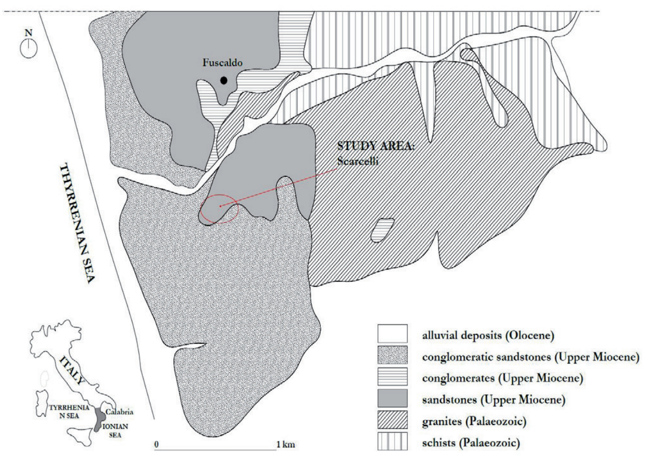

Figure 1.- Geological sketch map of the studied area of "Scarcelli outcrop" in Fuscaldo. Red circle shows the studied area (Casmez 1967, modified).

Methodology and sampling

Laboratory tests included chemical and morphological analyses. The chemical composition of the samples was determined by electron probe micro-analyzer (EPMA) - JEOL JXA 8230, while the morphological composition was obtained by scanning electron microscopy with energy-dispersive X-ray spectroscopy microanalysis (SEM–EDS) on a FEI Quanta 200 instrument, equipped with an EDAX Si (Li detector). The sample "C" was analyzed by the chemical-morphological analysis and taken from the right abutment of the portal at 2.00 m height above ground, that resulted the most deteriorated point thanks to the survey.

The description of the alteration forms which affect the building has been carried out according to the current standard recommendation (UNI EN 1182 2006). The observation of the alteration forms was performed through the naked eye and with the help of a 10X Canon EOS 750D camera.

The petrographic features on thin sections have been analyzed using a Zeiss Axioskop 40 polarized optical microscope.

The *in situ* mechanical tests have been performed in order to characterize physical and mechanical properties of the deteriorated parts. These tests included strength measurement of sandstone surface and deteriorated parts by means of Schmidt Geo-hammer (L-type), according to current standards (ASTM D5873-14 2014), to assess the hardness characteristics of the building stone. Schmidt hammer is a portable and low-cost equipment, nondestructive, which gives the material surface hardness value, being used in laboratory or in field. It is also useful to determine the mechanical properties of stones and can be used when there is only one face available for testing (Yagiz 2009). The rebound test hammer housing was held firmly by hand in a position aligned horizontally downward (~0 degrees) so that the impact plunger stroke at an angle perpendicular to the test surface of the portal. For each examined point twelve impact readings have been recorded. The relationship of Bieniawski (Bienawski 1984; Moomivand 2011) has been employed to determine the correlation between uniaxial compressive strength and Schmidt hammer rebound values. Values of porosity and unit weight employed are referred to fresh unaltered Fuscaldo quarry specimens investigated in other studies: $\gamma = 2{,}25$ g/cm^3 and P = 20,14% (Forestieri et al. 2015).

Through the ultrasonic portable equipment MATEST Ultrasonic Meter Ver, with an accuracy of 0.1 microseconds and equipped with two 55 kHz frequency transducers with a diameter of 1,5 cm, the ultrasonic velocity measurements (P-waves) have been obtained. The ultrasonic equipment is widely used in a variety of materials to verify the existence of fractures or internal discontinuities. This is a nondestructive method that aims to determine elastic wave's propagation speed inside the studied material

(Vasconcelos et al. 2008). During measurements, in order to improve coupling of the trasducers-transmitter and receiver, a couplant was applied. In order to obtain the spatial variability of the ultrasonic velocities, six measurements referred to different orientations were obtained in each ashlar. The obtained velocity values were compared to the ultrasonic measurements of eight quarry specimens (A1-A8). Tests conditions were: dry surfaces and indirect mode with the application of the trasducers parallel to the analyzed surfaces.

The structural analysis of the main façade of the building was performed through the linear and non-linear kinematic structural analysis to define the seismic vulnerability indices. In order to obtain the seismic indices a collapse mechanism of simple overturning of the main façade has been considered. The non-linear kinematic analysis performed aimed to determine the seismic displacement factor (f_d) and the linear acceleration factor (f_a). Structural analysis conditions have been: 1) unconsolidated system (actual condition); 2) consolidated system (applying metal tie-rods). The two considered limit states (LS) are the "damage" limit state (DLS) and the "safeguarding of life" (LLS). The acceleration factor fa,LS for the two possible limit states has been evaluated as:

$$f_{a,DSL} = \frac{a_0^*}{a_g \cdot S}$$

$$f_{a,LLS} = \frac{q \cdot a_0^*}{a_g \cdot S}$$

where the term (ag•S) is the maximum acceleration of the seismic demand compared to the stratigraphic and topographic conditions of the place evaluated through the coefficient S; a_0* is the spectral acceleration of activation of the considered mechanism; q is the structural factor taking into account the plasticity of the masonry system. The displacement factor fd,LLS has been obtained as:

$$f_{d,LLS} = \frac{d_u^*}{\Delta_d} \geq 1$$

where d^*_u is the ultimate capacity of displacement associated with the local collapse mechanism while Δd represents the displacement obtained through the spectral parameters.

To perform the structural analysis, the main facade of the building was schematized according to the representation in figure 2a. In function of the different values of the collapse multipliers (α0) associated to the specific considered mechanism, the lowest value of the multiplier was associated to a mechanism that provides the formation of a cylindrical hinge in a retracted position of 0,1 m in respect of the outer surface of the wall. For the masonry it was supposed a system of rigid blocks (one block for each level), characterized by a thickness ti and a height hi with the following values [figure 2a]: 1st floor 1 (h_i=4m and t_i=0,8m); 2nd floor (h_i=3,8m and t_i=0,65m); 3rd floor (h_i=3,5m and t_i=0,55m); 4th floor (h_i=2,0m and t_i=0,45m). Considered data about the masonry strengths were chosen according to the Italian seismic standards (NTC 2008): compression strength design value f_{md}=1,38 MPa; tensile strength design value f_{ctd}=0,138 MPa; shear strength design value f_{vmd}=0,021 MPa (considering the absence of vertical loads); a level of knowledge of the structure "LC1" corresponding to a confidence factor FC=1,35. Data about the spectral seismic action for the considered site were (NTC 2008): nominal life of the building V_N=50 years; class of use II; category of underground B (S_s=1,2); topographic category T2 (S_t=1,2). Data about the seismic spectral response were (NTC 2008): for the limit state DLS, the following values a_g=0,914 g/10, F_0=2,26, T^*_c=0,31s, C_c=1,4, T_B=0,15s, T_C=0,41s, T_D=1,96s; similarly, for the limit state LLS, the following values a_g=2,64 g/10, F_0=2,41, T^*_c=0,35s, C_c=1,33, T_B=0,17s, T_C=0,50s, T_D=2,65s. Data about the loads (P_i) of the walls of the different levels were: P_1=846,72kN, P_2=703,84kN, P_3=509,34kN, P_4=306,18kN; the vertical and horizontal components of the load trasmitted by the covering structure, respectively equal to $S_{V,C}$=18,81kN/m and $S_{H,C}$=4,2kN/m; the load of floors P_{Si}, equal to P_{S1}=P_{S2}=P_{S3}=350,72kN/m.

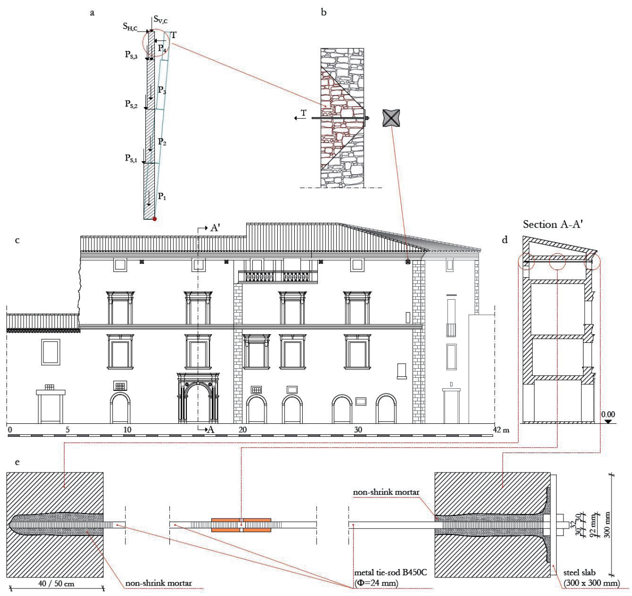

Figure 2.- Static representation of the main façade of "Palazzo Carelli - Pignatelli", divided in rigid blocks and subjected to an overturning mechanism of collapse (a); static effect on the masonry produced by the consolidation design by metal tie-rods (b); final aesthetic appearance of the masonry façade once the proposed metal tie rods consolidation technique is completed (c, d); detailed executive cross sections of the metal tie-rod intervention into the walls (e).

Results and discussion

The observation of the decay forms on the portal surface led to the graphic representation of figure 3. As reported in this picture, deteriorated parts are affected by: back weathering due to the loss of scale; alveolar weathering; missing parts due to the break out; efflorescence; superficial deposits/crusts; delamination and granular disintegration. Structurally, the high parts of the main façade are affected by a mechanism of collapse that shows a strong displacement in the horizontal direction of the façade.

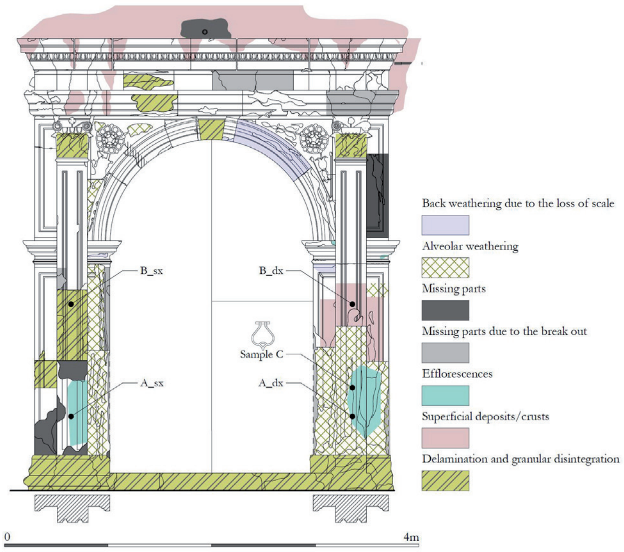

Figure 3.- Portal of "Palazzo Carelli - Pignatelli" with the deteriorated parts. The points A_dx, B_dx, A_sx and B_sx have been analyzed by Schmidt hardness test and by ultrasonic velocity pulse test. The point C (at 1.20 m of height) has been also tested by morphological analysis (SEM analysis).

Petrographycally, quarry samples "Fuscaldo sandstone (AF)" [figure 4a] are composed by 50% of clasts and 50% of carbonate matrix. They show a homogenous composition and texture and are composed by quartz, plagioclase, k-feldspar, biotite. The most significant accessory minerals are zircons and apatite. Subrounded fragments of granitic rocks are also present. The pores with a mean value of 25µm are distinguishable. Fossils attributable to microforaminiferas are also present. According to Pettijohn (1975) they can be classified as a *greywacke*. The building stone of the case study "Pignatelli sandstone (PS)" [figure 4b] shows the same petrographic characteristics of the quarry material. The only difference is due to the higher level of decay and the consequent higher porosity. Thus, it can be said that the two analyzed building stones have similar petrographic features.

Morphological analyses by SEM are reported in figures 4c and 4d. The chemical analysis of the sample "C" of the portal confirms the macroscopic decay analysis [figure 3] and reveals the presence of elements of Cl, Na and K. The analyzed sample shows the presence of crystals of salts of 5-10 x 5-10 µm, a medium level of porosity and an altered substrate. Furthermore fossils are visible and the presence of salts is concentrated along deteriorated areas.

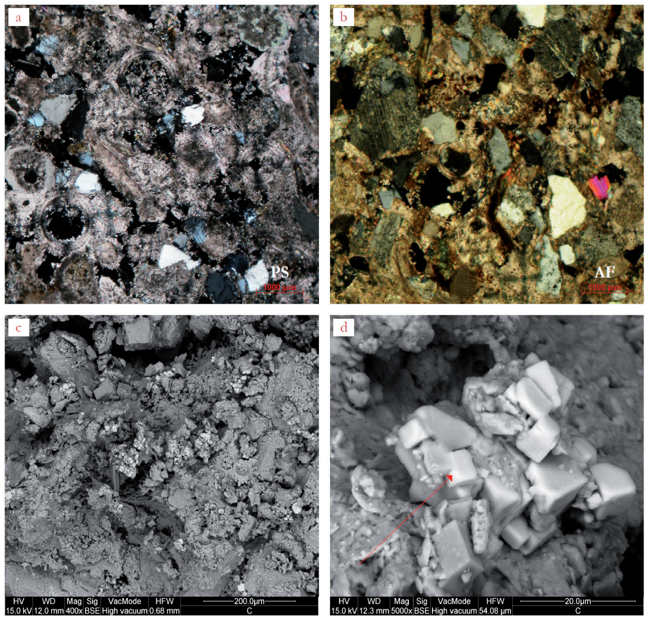

Figure 4.- Micrographs at the crossed polarized light of thin sections from: main portal sample "Pignatelli sandstone" (a); quarry sample "Fuscaldo sandstone" (b). SEM analyses of the sample C, taken from the right abutment of the portal of "Palazzo Carelli - Pignatelli" (c, d)..

Schmidt hammer rebound values (Hs), the uniaxial compressive strength values (UCS) calculated and ultrasonic velocities (Vp) are reported in table 1.

Analyzing values reported in table 1, it can be said that the most deteriorated part of the portal is its right part where have been registered lower resistance values. Moreover the lower parts (points A) are more affected by decay than the higher ones (points B). The higher the ultrasonic pulse velocity, the higher the uniaxial compressive strength as obtained by many authors (Molina et al. 2013) and viceversa. Pignatelli sandstone (PS) shows average resistance values similar to the quarry samples (AF). Thus, the quarry Fuscaldo sandstone can be used to replace the most deteriorated parts of the main façade. Quarry blocks should be placed in the most deteriorated parts, where have been registered the highest concentration of salts and the others forms of decay described above.

Data obtained from the petrographic analysis and mechanical tests are in agree with the structural analysis performed. Through the kinematic analyses, the check of the seismic vulnerability for the limit states DLS and LLS was performed to determine the safety factors listed in table 2.

Table 1.- Schmidt hammer rebound values (Hs), uniaxial compressive strength σc (MPa) and ultrasonic pulse velocity mean values Vp (m/s) for "Pignatelli sandstone" (PS_A; PS_B) and "Fuscaldo sandstone" quarry samples (AF1-AF4).

		ashlar/sample	H_s	σ_c (MPa)	V_p (m/s)
Pignatelli sandstone					
	right	PS_A_dx	22 ± 1,5	23,2 ± 1,4	1.681,94 ± 286,00
		PS_B_dx	31 ± 1,8	33,4 ± 2,3	2.934,21 ± 301,67
			27 ± 4,9	*28,3 ± 5,5*	*2.308,07 ± 711,50*
	left	PS_A_sx	24 ± 1,3	25,2 ± 1,3	1.847,85 ± 239,90
		PS_B_sx	31 ± 1,6	32,6 ± 2,1	3.100,69 ± 349,41
			27 ± 3,6	*28,9 ± 4,1*	*2.474,27 ± 713,95*
Fuscaldo sandstone					
		AF1	32 ± 3,0	35,4 ± 4,5	2.602,12 ± 500,50
		AF2	32 ± 1,8	34,3 ± 2,4	2.561,51 ± 269,17
		AF3	36 ± 2,4	40,8 ± 3,8	3086,08 ± 194,69
		AF4	32 ± 1,8	34,2 ± 2,6	2983,52 ± 287,21
			33 ± 2,9	*36,8 ± 4,3*	*2.808,31 ± 380,80*

Table 2.- Results of safety check for different limit states and values of the vulnerability factor evaluated for the main façade of "Palazzo Carelli - Pignatelli" as: a) unconsolidated system; b) consolidated system using metal tie-rods (DLS = damage limit state; LLS = safeguarding of life limit state; X = not satisfied; √ = satisfied).

	Kinematic analysis	Limit state	Safety check		Vulnerability factor	
a)	LLS	SLV	$a^*_0 > a_g \cdot S/q$	X	$f_{a,LLS}$	0,23
	LLS	SLV	$d^*_u > \Delta_d(T_S)$	X	$f_{d,LLS}$	0,65
	DLS	SLD	$a^*_0 > a_g \cdot S$	X	$f_{a,DLS}$	0,33
b)	Not Linear	LLS	$d^*_u > \Delta_d(T_S)$	√	$f_{d,LLS}$	1,02
	Linear	DLS	$a^*_0 > a_g \cdot S$	√	$f_{a,DLS}$	1,29
		LLS	$a^*_0 > a_g \cdot S/q$	√	$f_{a,LLS}$	1,01

From the low values of the seismic safety indices obtained for the condition of "unconsolidated system", resulted that the examined wall of the case study needs an improvement of the "box effect" with a connection among walls constituting the masonry structure. This intervention is necessary in order to avoid the detected overturning collapse mechanism that compromises the building static stability. The increase of the building safety indices has been obtained, in this study, through the application of 4 metal tie-rods [figure 2b] of B450C steel type, applied next to the eave line, for each cross-section, having a diameter of Φ=24 mm. Each metal tie-rod is blocked on the external wall by a steel slab of small dimensions (300 x 300 mm) while in the opposite wall it is inserted into the masonry thorugh non-shrink mortar [figure 2e] for a lenght at least of 40 or 50 cm. Thus, the final result of the proposed metal tie rods consolidation technique [figures 2c, d] does not modify the final aesthetic appearance of the masonry façade once the intervention is completed. Thanks to these devices the safety factors increased and the check of seismic vulnerability satisfied [table 2]. In fact, as reported in table 2, for the condition of "consolidated system", thorugh this proposed minimal design intervention, the wall seismic stability is satisfied for all the considered limit states and the "box effect" is obtained due to the tie systems blocking the opposite walls of the palace [figure 2e].

Conclusions

The petrophysical, chemical and mechanical characterization of the sandstone samples taken out from the active outcrops and from the case study "Palazzo Carelli - Pignatelli", reveals the compatibility from a petrographic and mechanical point of view, between replacing and replaced materials.

The typical forms of decay detected on "Palazzo Carelli - Pignatelli", symbol of the "Renassaince" architecture in Calabria (Italy), are material loss, deposits, cracks and salts. Tests results show how a high degree of decay of the building material affects the structural stability of the entire building. In particular, the worst action belongs to salts that provoke the formation of micro-cracks, fractures and the total material detachment in the points where salts concentration is higher. The resulting map of decay forms shows that the case study is in a bad state of conservation. For this purpose it is suggested a minimal design intervention that consists in both removing decay factors that could contribute to accelerate structural decay and in strengthening external walls with a "box effect" (through metal tie-rods) in order to prevent the individuated collapse mechanism of the main façade. The suggested minimal restoration design has been chosen as a correct strategy of intervention for the protection, conservation and restoration of the building, because it is restricted only to the eave lines of the façade and it is compatible with its architectonical features without altering its aesthetics characteristics.

Salts detected by morphological-chemical analysis affect the durability of the stone material due to the crystallization mechanisms. The less deteriorated parts exhibit higher resistance values and better physical-mechanical properties. On the contrary, in the most deteriorated parts, sandstone is weakened by salts and shows a reduced durability. Resistance values decreases have been demonstrated by mechanical tests. In relation to the ultrasound pulse velocity measurements, the values obtained are compatible with sandstone changes, which is corroborated by the measures taken with the Schmidt hammer.

Moreover the same diagnostic techniques performed on quarry and deteriorated samples demonstrate the similarity between the two analyzed building materials: Fuscaldo sandstone, the quarry material and Pignatelli sandstone, the building stone of the case study. So, Fuscaldo sandstone can be used to replace the deteriorated building material, because resulted similar and compatible with Pignatelli sandstone.

Conclusively, combining modern restoration techniques (metal tie rods) with the traditional use of local stones, could have many advantages for the conservation of the cultural heritage. First of all, the sustainability of the intervention. Then, the compatibility with the environment, the local culture and the historical traditions. Furthermore, using sustainable local materials could be very useful for the development of the local economy exploiting the active quarries. Thus, an important aspect of this research is that the results can be applied for a correct approach in the restoration of monuments in the investigated area.

Acknowledgements

This research was carried out through laboratory tests at the University of Calabria (DiBEST) of Cosenza, Italy and thanks to the techniques learnt at the IGEO Petrophysic Laboratory (CSIC-UCM) of Madrid, Spain. This study was supported by: "Programa de Geomateriales 2 (S2013/MIT-2914)"; "Fondi 5 per mille D.P.C.M. 23/04/2010".

Bibliography

ASTM D5873 (2014). *Standard Test Method for Determination of Rock Hardness by Rebound Hammer Method*. ASTM International, West Conshohocken, PA.

BIENIAWSKI, Z.T. (1984). *Rock mechanics design in mining and tunneling*. A.A. Balkema, 227pp.

CANONACO, B. (2012). *Note sull'Architettura civile in Calabria: il palazzo del Contestabile Ciaccio a Cosenza. Roma*, Aracne Editrice.

CASMEZ (1967). *Carta Geologica della Calabria - Foglio 229, III S.O. – Paola in scale 1/25.000*. Naples, Poligrafica & CarteValori.

CRITELLI, S., LE PERA, E. (2000). "Geological Map of Calabria, scale 1:330.000". In *Valutazione delle Piene in Calabria. Caratteristiche morfometriche dei bacini della Calabria*, Gabriele, S. (Ed.), Soveria Mannelli (CZ), Rubbettino Editore.

FORESTIERI, G., TEDESCO, A., PONTE, M., et al. (2015). "Relationship between stone characteristics and weathering. Case study: sandstone elements of the old town of Fuscaldo (Italy)". In P*roceedings of the VIth International Conference Diagnosis, Conservation and Valorization of Cultural Heritage*, Campanella, L., Piccioli, C.(eds.), Naples, 173-185.

FORESTIERI, G., CAMPOLONGO, A., PONTE M. (2016). "La pietra e l'architettura. Analisi storica e materica del materiale lapideo nel territorio di Cosenza". In *2nd International Conference on History of Engineerin*g, Naples, 213-222.

FORESTIERI, G., TEDESCO, A., PONTE, M. "Characterization and structural analysis of the main facade of "Palazzo Pignatelli" in Fiumefreddo Bruzio, Italy". In: *Congress Book of the "5th International Conference Youth in Conservation of Cultural Heritage YOCOCU 2016"*, MNCARS, Madrid (Spain), (in press).

MOLINA, E. et al., (2013). "Evaluation of stone durability using a combination of ultrasound, mechanical and accelerated aging tests". *Journal of Geophysics and Engineering,* 10: 1-18. stacks.iop.org/JGE/10/035003.

MOOVIMAND, H. (2011). "Development of a New Method for Estimating the Indirect Uniaxial Compressive Strength of Rock Using Schmidt Hammer". *Berg- und Hüttenmännische Monatshefte*, 156 (4): 142 – 146. DOI 10.1007/s00501-011-0644-5.

NTC 2008. *Norme Tecniche per le costruzioni*. Ministero delle Infrastrutture, G.U. 29, January 14th, Italy.

PETTIJOHN, F. J. (1975). *Sedimentary rocks*. New York, Harper and Brothers Publisher 3rd Edition, 618pp.

UNI-EN 11182 (2006). *Materiali lapidei naturali ed artificiali. Descrizione della forma di alterazione - Termini e definizioni*, Milano.

VASCONCELOS, G., LOURENÇO, P.B., ALVES, C.A.S., et al. (2008). "Ultrasonic evaluation of the physical and mechanical properties of granites". *Ultrasonics*, 48: 453–466.

YAGIZ, S. (2009). "Predicting uniaxial compressive strength, modulus of elasticity and index properties of rocks using the Schmidt hammer". *Bulletin of Engineering Geology and Environment*, 68: 55-63.

Giulia Forestieri
giulia.forestieri@unical.it

Giulia Forestieri (b. 1986). PhD Student ad the Department of Biology, Ecology and Earth Sciences of the University of Calabria, Cubo 15B, Via P. Bucci, Arcavacata di Rende (CS), Italy. PhD Program in "Sciences and Engineering for the Environment, Buildings and Energy", 29th Cycle. European PhD Thesis about "Some Calabrian stones as building materials: characterization, durability and use suggestions". Graduated in Building Engineering and Architecture at the University of Calabria, with Honorific Mention. Specialized in performing labortory, destructive (DT) and non-destructive (NDT) tests for the petrophysical, chemical, mineralogical and mechanical characterization of building materials employed in cultural heritage and new engineering constructions.

Alessandro Tedesco
alessandro_tedesco@hotmail.it

Alessandro Tedesco (b. 1986). PhD Student at the Department of Civil Engineering of the University of Calabria, Cubo 39B, Via P. Bucci, Arcavacata di Rende (CS), Italy. PhD Program in "Sciences and Engineering for the Environment, Buildings and Energy", 29th Cycle. PhD Thesis about "Applications with FRP reinforced composite materials for structural strengthening of monumental ancient architectures". Graduated in Building Engineering and Architecture at the University of Calabria. Specialized in performing structural analysis and recovery of monumental buildings and evaluating consolidation techniques and application of innovative strengthening materials.

Maurizio Ponte
maurizio.ponte@unical.it

Maurizio Ponte (b. 1979). Researcher specialized in Applied Geology, working at the Department of Biology, Ecology and Earth Sciences of the University of Calabria, Cubo 15B, Via P. Bucci, Arcavacata di Rende (CS), Italy. Professor at the Departments of Biology, Ecology and Earth Sciences and Civil Engineering of the University of Calabria. Over 30's years of academic and professional experience as Civil Engineer. Author and co-author of many publications in indexed journals, conference proceedings, books and supervisor of bachelor, master degree and PhD thesis.