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A Tribute to Prof. Renato Olivito's Career

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Abstract **–The special session, in which this paper is submitted, is dedicated to stimulate scientific discussion in the research fields in which Professor Renato Sante Olivito worked for many years giving his innovative and indisputable contribution. Professor Olivito's research involved civil engineering and structural mechanics. His research fields over the years are: Eco-sustainable composite materials for reinforcing modern and historic masonry constructions; experimentation on Fiber Reinforced Cementitious Matrix (FRCM); monitoring of structures; fracture analysis in brittle materials; structural health monitoring systems based on the IoT paradigm; Artificial Intelligence for structural health monitoring; mechanical and physical characterization of traditional masonry techniques; numerical analysis; micro-tomography; 3-D printing; Genetic Algorithm, Mathematical Modeling and Mathematical Physics applied to modeling and analysis of structures.**

I. INTRODUCTION

Prof. Renato Sante Olivito received his engineering degree from the Polytechnic University of Turin at a young age. He immediately embarked on his academic career at the University of Calabria, where he became a full professor of structural mechanics and held various institutional positions such as president of the degree program in Construction Engineering Architecture.

His career is crowned with national and international successes and to date, he has 80 scientific papers, 1237 citations and h-index 18 from the SCOPUS platform.

In the early 1990s began its experimentation in the area of frequency domain analysis of ultrasonic signals used to detect and monitor crack propagation in structural materials. A very sensitive and accurate testing technique was obtained compared to the usual methods of measuring pulse velocity or attenuation. With Prof. Pasquale Daponte, he highlighted in the early scientific works the importance of experimental research, and the results obtained were discussed in relation to uniaxial compression tests performed on cubic concrete specimens or bricks [1],[2].

Prof. Olivito was one of the first scientists to obtain important results on nondestructive evaluation conducted on wood samples using pulse velocity and attenuation measurements with piezoelectric transducers at 54 kHz. The obtained results showed that ultrasonic velocity measurements are effective in determining the moisture content in wood, while attenuation measurements are useful for detecting and monitoring internal defects [3].

This conference paper is a tribute to his career and seeks to summarize Prof. Olivito's most important achievements during his years devoted to academic research.

II. MASONRY ARCH REINFORCED WITH CFRP

One of the first research topics was inherent in the effects on improving the strength and stiffness of damaged solid clay brick masonry arches by reinforcing with carbon fiber reinforced plastic (CFRP) materials. The masonry arch is modeled assuming a stress-free law. In addition, the interface between mortar and brick is modeled assuming one-sided contact behavior. A 3D finite element model of the structure was developed that takes into account the actual geometry of the brick and mortar components of the masonry arch and the reinforcement layer [4],[5]. An experimental campaign was developed to study the behavior of damaged full clay brick masonry arches reinforced with carbon fiber reinforced plastic.

To obtain realistic damage conditions of the unreinforced arch, a preload was applied to reach a state of crack deformation corresponding to that just prior to the incipient collapse of the structure. Subsequently, layers of CFRP reinforcement were applied to the intrados and extrados immediately after damage, and the arch was tested again to analyze the behavior of the reinforced structure compared with the unreinforced one. It should be noted that to avoid a hinge collapse mechanism of the arch, the composite reinforcement strips were placed only in the areas where the hinges at the intrados and extrados could be activated.

A numerical model was developed using the contact elements of the commercial ANSYS software; it requires fewer parameters with respect the other models available in literature at those times, that can be easily obtained from laboratory tests. The Prof. Olivito's model is appropriate for predicting the load capacity with reasonable accuracy and for simulating the overall behavior of the structure and predicting the load-deformation relationship. Therefore, it can be used as a satisfactory tool for the analysis of masonry arches and can be a good reference point for further developments related to the parametric study of damaged arches, analyzing the influence of the damage state with respect to the reinforcement requirements and structural performance of the restored structure. Specifically, with reference to the point load F acting at the key of the arch, Fig. 1 shows the force-displacement diagram, from which both the stiffness and strength-increasing capacity following the application of CFRP reinforcement can be observed. As experimentally found, the maximum load capacity of the unreinforced arch is represented by the applied to the deformed arch at the state of crack maximum load value F = 5.2 kN. The reinforcement was deformation corresponding to that immediately preceding the incipient collapse of the arch. At the load level F = 16 kN, the corresponding displacement of the key section is v = 2.0 mm, comparable to the experimental displacement of v = 1.9 mm.

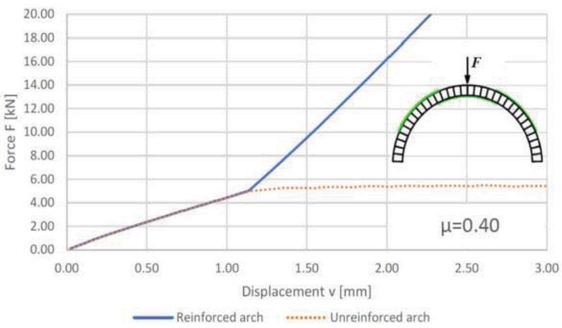

Fig.1. Force-displacement diagram of the key section.

III. FIBER REINFORCED CEMENTITIOUS MATRIX EXPERIMENTATION

Another important research topic explored over the years has been that inherent in fiber reinforced cementitious matrix (FRCM) [6]-[9] and research on natural fibers for structural reinforcement that has led him to important international collaborations with Prof. Paulo Lourenço and Daniel Oliveira of the Universidade do Minho [10].

FRCM systems are specifically suited for applications where modest deformations are required, as it is typically the case for reinforcing masonry structures. In fact, the use of FRCM materials for structural rehabilitation has been growing in the recent past. This is due to the compatibility between substrate and matrix, which is not guaranteed in CFRPs since epoxy resins could hardly meet the conditions of continuity with masonry structures, for example, those made of rubble and clay bricks.

In order to define the mechanical behavior of FRCM composites, the research group leaded by Prof. Olivito performed tensile tests using a clevis grip system. They used a Zwick Roell Z250 universal machine working in displacement control with a constant speed of 0.3 mm/min; no preloads were applied. To ensure a homogeneous distribution of the stresses as well as to prevent the sample from slipping out of the machine grips, 50 mm long metal plates were applied to the ends of the specimens. The gripper system was hydraulic and it was calibrated by the manufacturer. The prismatic samples had a thickness of 10 mm and a width equal to a multiple of the distance between the fiber bundles.

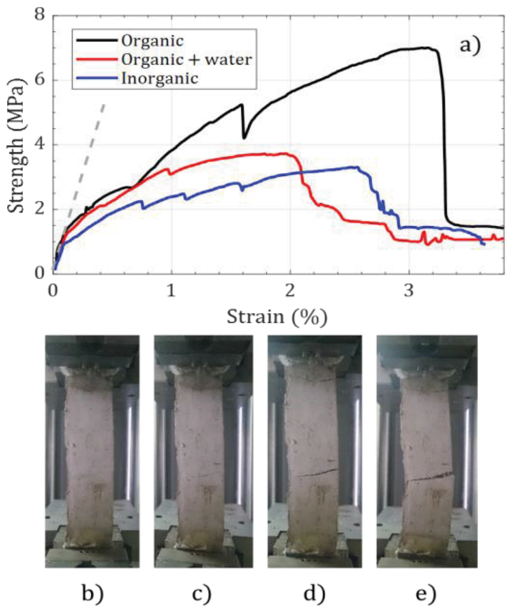

Fig. 2. Tensile tests of FRCM composites. (a) Strength-strain diagram. (b-e) Pictures of the specimens corresponding to each phase in diagram (a).

During the test, the displacements relating to the machine cross-member were recorded by detecting the load levels reached by the specimen. Processing the tensile test data allowed for defining the mechanical behavior of the composites. They could then draw the stress-strain diagrams (Fig.2a) and gather information about each specimen's failure modes (Fig.2b-e).

IV. ACOUSTIC EMISSIONS AND STRUCTURAL HEALTH MONITORING SYSTEMS.

This field of research has been deepened over the years by Prof. Olivito ensuring a fruitful scientific production and a solid collaboration with Prof. Domenico Grimaldi, Professor of Electronic Measurements at the University of Calabria and prematurely passed away some years ago [11][12].

In particular, historical heritage buildings, due to their size and different components, materials and realizations, require innovative systems for their conservation. In this field, it is evident how critical damages in these structures can be caused by the sum of minor damages. These non-critical events are due to different sources [13],[14]. In order to obtain the necessary data to assess the state of the building and monitor the health of the structure over time, the use of structural health monitoring (SHM) systems has become essential [15],[16]. SHM systems using acoustic emission (AE) signal analysis play a privileged role among building condition monitoring systems.

In light of this, one of the main scientific results and discoveries achieved by Prof. Olivito, in collaboration with roof. Domenico Grimaldi, Domenico Luca Carnì, Francesco Lamonaca and Carmelo Scuro, was the identification of the damage state of concrete subjected to uniaxial compression through the acquisition of acoustic emissions during experimental tests. Such results, published in [17],[18] highlight that event frequency of the critical AE signals of 0.05 (events/s) is correlated to a normalized stress in the range [64.7, 67.4] % and therefore can be considered as a safety threshold for the structure under examination.

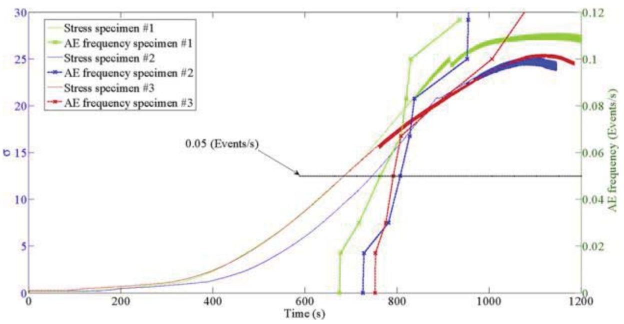

Fig. 3. Overlapping of the stress trend versus time and the corresponding increasing frequency of the AE event for the three specimens under consideration.

Fig. 3 shows the superposition of the stress trend curves versus time and the corresponding increasing frequency of AE event for the three specimens under consideration. The frequency of 0.05 event/s identifies a similar stress condition for the compression specimens.

In this research field, different SHM systems have been studied over the years. With his research group, in fact, Prof. Olivito has conducted experiments that have ensured the use of numerical finite element models with systems that allow the acquisition of information to be used as input in the latter numerical model. These results were also attained through collaboration with Prof. Gabriele Milani, a full professor of structural mechanics at Milan Polytechnic University [19][20].

The proposed SHM system is composed of piezoelectric accelerometric sensors:

• KB12VD-MMF with full scale range of ±0.6 g and sensitivity if 10 V/g

• KS48C-MMF with full scale range of ±6 g and sensitivity 1 V/g.

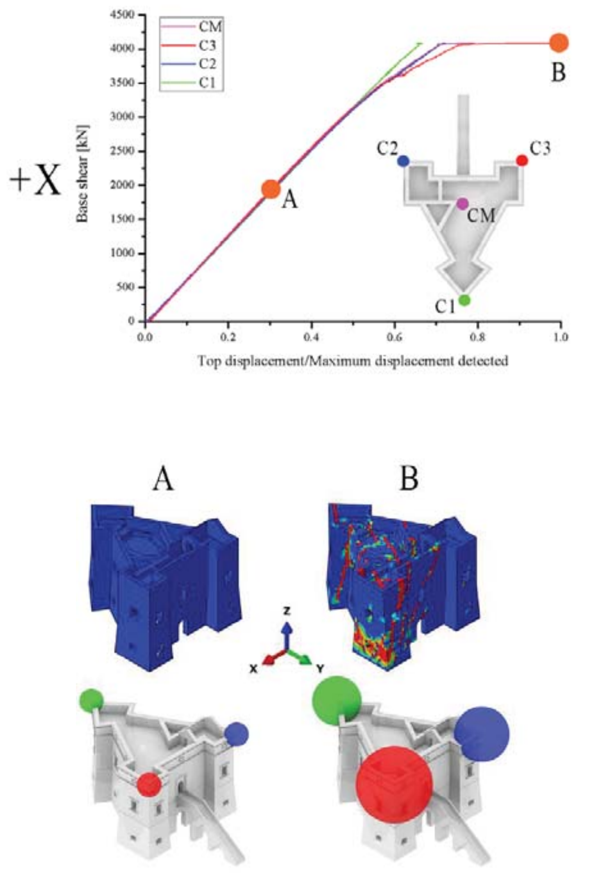

Fig. 4. Comparisons in terms of damage prediction and pushover curves of the three Control points (CP) and the fictitious CP located in the center of mass for load +X.

In a seismic event, the gateway collects the data acquired by the accelerometric sensors and transmits them to a remote-control room, where they are analyzed online to extract high level measurement information to be sent as input for the Finite Elements analysis programs. The data exchange deploys internet connectivity.
In Fig. 4 the FEM analysis conducted on a masonry building is shown.

V. FICTILE TUBULES

Last, but certainly not least, is the numerical and laboratory experimentation conducted by the research group led by Prof. Olivito on masonry constructions made of fictile tubules. In fact, he was the forerunner of studies on this very ancient building technique by beginning a line of research never before addressed in the academic field [21][22].
Typically, bricks are usually characterized by a parallelepiped shape, but there are some notable exceptions. Among them, the so-called fictile tubules stand out for being a relevant example, due to their cylindrical shape, their widespread presence in historical buildings of many Mediterranean countries, and because they are arguably among the first hollow bricks in history.
Over the years, an experimental campaign was started that led to the mechanical and chemical-physical characterization of the fictile tubules by initiating SEM (electron microscope) analyses and mechanical characterization tests to identify the characteristic compressive strength, elastic modulus and other engineering constants of this hollow brick [23].

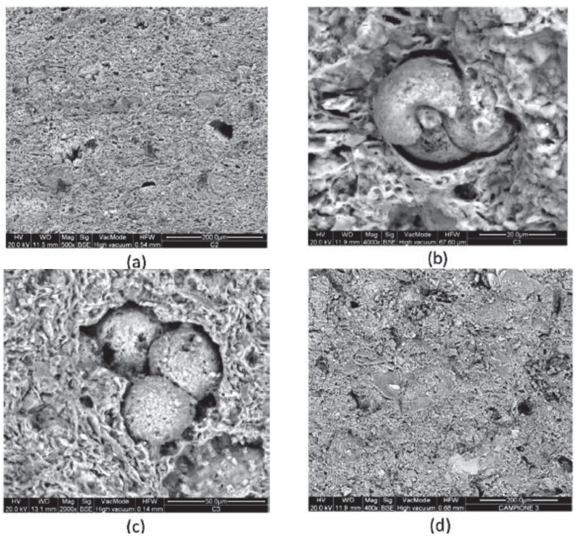

Fig. 5. (a) Vitrified vesicular texture in industrial caroselli – zoom 500x; (b) imprints of microorganisms. (c) imprints of microorganisms; (d) vitrified vesicular texture in old caroselli – zoom 400x.

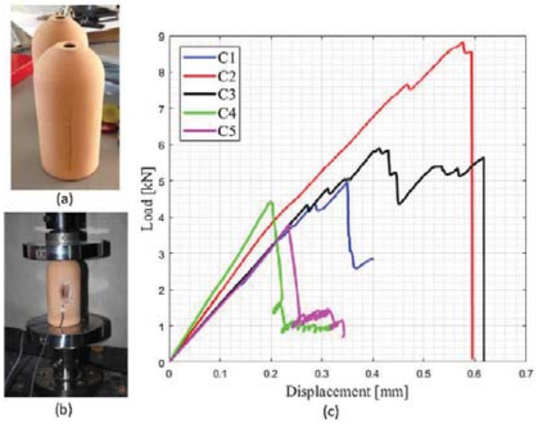

Fig. 6. (a) Samples from the investigated fictile tubules bricks (b) testing machine; (c) load-displacement diagrams of the compressive tests on fictile tubules bricks.

Fig. 7. Experimental test on a masonry arch realized with fictile tubules arranged in staggered manner [24].

In Figs. 5, 6 and 7 are represented the most important experimental campaign conducted on the fictile tubule bricks.

VI. FUTURES WORKS

Historical and cultural heritage has always been exposed to numerous risk factors that compromise its health and structural integrity. In the Italian territory, one of the biggest problems is caused by seismic events, as evidenced by the territory's past and recent history.
However, in recent years, researchers have paid more attention to pollution-related factors that cause deterioration and subsequent collapse of portions of masonry buildings. The main purpose of the latest research topic addressed by Prof. Olivito, in the field of mathematical modelling [25]-[29], is to propose a simplified differential model to describe the aggression of calcium carbonate ($CaCO_3$) rocks in the presence of an

acidic atmosphere by performing qualitative behavior of solutions in the fast reaction limit. The major aggression is caused by SO_2 and NO_3. In this work, today in press, the authors considered corrosion caused by sulfur dioxide, which reacts with calcium carbonate to produce gypsum. The model is obtained by considering both convective and diffusive effects of propagation and assuming that the porous medium is saturated with a compressible fluid with an assigned polytropic constitutive equation for pressure. The first result since now obtained is the description of the qualitative behavior of one-dimensional solutions in the fast reaction limit exposed in the equation (1).

$$\begin{aligned} F_\alpha(\xi_\alpha) &:= \frac{1}{2\beta}\frac{\xi_\alpha e^{\beta^2\xi_\alpha^2}}{V_2(\lambda;\beta\xi_\alpha)}\frac{v_\alpha(\beta\xi_\alpha)}{v'_\alpha(\beta\xi_\alpha)} = \varphi(0)\frac{\hat{s}}{c_0}, \quad \text{on } x = \xi_\alpha t^{\frac{1}{2}},\, t < t^*_\alpha, \\ F_0(\xi_0) &:= \xi_0 e^{\frac{1}{4}\xi_0^2}\frac{\sqrt{\pi}}{2}\mathrm{erf}(\frac{1}{2}\xi_0) = \varphi(0)\frac{\hat{s}}{c_0}, \qquad \text{on } x = \xi_0 t^{\frac{1}{2}},\, t > t^*_0. \end{aligned} \tag{1}$$

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