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Experimental characterization of "non-engineered" masonry systems in a highly seismic prone area

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HIGHLIGHTS

- A study is presented on "non-engineered" masonry in a area with a high seismic risk.
- The analysis consisted of laboratory experimental tests on blocks, mortars and panels.
- The results are commented referring to in law prescriptions.

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ABSTRACT

The mechanical characterization of in situ materials is one of the most important issues in the safety assessment of existing buildings, and – especially for masonry structures – represents a major source of uncertainty. In fact, the possibility of achieving a good "Level of Knowledge" is strictly related to the availability of comprehensive experimental tests on the structures, including destructive testing. In the case of masonry buildings, it is very difficult to extract a representative number of "*undisturbed*" samples or apply alternative techniques (such as in situ diagonal test) without causing unacceptable damages to the structure.

The research work presented in the paper concerns the analysis and experimental characterization of a number of "*non-engineered*" masonry types commonly present in Calabria (a high seismic prone region located in Southern Italy). The definition of non-engineered is actually referred to self-constructed masonry buildings dated back to the first half of the 20th Century, in the absence of any kind of design and technical control about materials and procedures.

The attention has been focused on a number of towns in the Province of Cosenza. Here, a survey has been carried out in order to detect and classify the structural features of the buildings: elements, textures, structural configurations. Afterwards, masonry elements and materials have been experimentally investigated (by testing samples taken on site and manufactured in laboratory). All data have been processed and compared with the Italian and European Standards, in order to derive a reference database for the local masonry building types.

In a context where it would be very difficult to directly obtain the required experimental information, the objective is to improve the knowledge about local materials and their mechanical features, providing at the same time a reference methodological approach. In the absence of appropriate information (i.e., of a low level of knowledge) the safety verification and vulnerability assessment turn out to be very conservative. It is thence nearly impossible to provide an effective strategy for the rehabilitation/retrofitting against seismic risk, whereas the systematic, complete substitution of the existing residential housing would became the only solution, which is nowadays a non sustainable option.

1. Introduction

The research work presented in the paper is aimed at the characterization of "*non-engineered*" masonry types extensively used, in the past, in the Province of Cosenza (Calabria Region, Italy). This is a highly seismic prone hazard area where, also in relatively recent times (1970s–1980s), the "self-construction" of residential masonry buildings has been a common practice, with the use of the most heterogeneous and diverse materials in place of the traditional masonry types (solid brickwork, rubble stone, etc.). Indeed, a common practice was the use of cheap hollow brick/concrete blocks designed for secondary elements (curtain or partition walls)

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in the construction of load-bearing walls. As a matter of fact, thence, there is a great number of buildings for which almost no technical control has been ever acted, and that are presently severely out of the law requirements.

In current European and Italian codes [1,2], it is clearly stated that the seismic assessment of existing buildings should be based on an adequate preliminary knowledge of the structure, of the mechanical properties and condition of materials. Three Levels of Knowledge are identified: KL1 – Limited Knowledge; KL2 – Normal Knowledge; KL3 – Full Knowledge. The value of the mechanical parameters to be used for the materials (as provided by on site investigations, for example) shall be reduced by a proper Partial Safety Factor: in the case of a too low knowledge level, the penalization might be relevant, and a positive outcome of the verification is not obvious.

It is evident, within this framework, that the question of the appraisal of the materials' mechanical properties assumes a crucial importance, and should be considered with particular attention, especially in the case of masonry structures, characterized by a great variety of typologies and constructive techniques, depending on the local traditions and the available materials.

Moreover, while the methodologies for determining the mechanical strength of in-place concrete have been widely developed in the last decades [3,4], in the field of masonry construction the technical possibilities for measuring in situ mechanical parameters according to strict, quantitative approaches are much more limited. Moreover, the dispersion of the experimental mechanical parameters – which is a delicate issue already for RC structures [4] – becomes an overwhelming question for masonry, which is intrinsically a craftsmanlike work.

The difficulties related to the knowledge about materials and the identification of the mechanical parameters of masonry is strictly interlaced with the development of the theoretical and numerical models, of which it represents the necessary basis.

The mechanical behavior of masonry structures is a very complex issue, and still presents many unsolved aspects. Indeed, masonry is a composite material, highly inhomogeneous and anisotropic, because of the presence of mortar joints acting as weak points within the structure, and the seismic response exhibits significant non-linear, irreversible and dissipative phenomena.

The experimental uncertainty has strongly influenced the evolution of theoretical studies in this field. The scientific context, in this sense, has been very lively and prolific [5,6] and, in front of the aforementioned questions, has moved in different directions. One of the most acknowledged approach, which has indeed a very ancient tradition, is the resort to limit analysis-based methods, which are very manageable and effective in view of the operational verification and, although simplified, have the undoubted advantage of providing a simple but reliable estimate of the collapse condition. This thread, inspired by the fundamental research work of Giuffré [7], which has brought back to light the traditional knowledge of ancient architects and masons, is fully recognized by the current Italian Building codes [1].

On the opposite side, many efforts have been devoted in order to fill the gap between the operational needs and the possibility of implementing realistic and complex mechanical models. These models are generally characterized by a deep micromechanical insight, that can be eventually managed at different scales. In continuum models, the constitutive complexity and the heterogeneity of the constituent materials is brought up to an equivalent continuous medium by means of proper homogenization techniques [8–10], solving then the structural problem by FEM approaches. Discrete models instead, are aimed at the detailed solution of the mechanical problem, which is faced at the level of single blocks and joints [11–13] or by describing the masonry panel as a "mechanism" composed by periodic rigid cells connected by nonlinear springs [14–16]. In this case, the ambitious objective is to manage the mechanical modeling of masonry in a complex operational context (i.e. nonlinear analysis, dynamics, multi-whythe walls). This approach has been fruitfully applied, in the last few years, for modeling the behavior of masonry structures both in-plane and out-of-plane [17,18], allowing to perform the vulnerability assessment for whole masonry buildings [19–22].

Whenever is the modeling strategy that is chosen, the fundamental premise for the development, testing and validation of the theoretical and numerical models is the possibility of relying on a valid experimental basis which provides the basic mechanical characterization of materials and reference benchmarks. Within the scientific literature, there are several studies devoted to the experimental mechanical characterization of masonry (a few references, that of course are not exhaustive, are provided in the bibliography [23–32]).

An important thread is directly oriented to the knowledge of in-place materials (in view of the safety verification procedures for existing buildings), both in terms of development of diagnostic techniques and in terms of the inventory of masonry types and their characteristics at a regional scale. Many efforts in this sense have been made in different Italian Regions, by performing field investigations in which information are collected by compiling a standard survey-form, including all the relevant features that can identify that specific masonry type (dimensions, geometry, internal units' arrangement, materials) [23,25,29].

Another line of work of the experimental research is specifically aimed at the implementation of tests and benchmarks for supporting the theoretical and numerical modeling. It should be observed that these activities are mostly concerned with periodic masonry brickwork, for which both the mechanical characterization and the theoretical/numerical modeling is much easier. The execution of experimental tests in laboratory can in fact resort on an easier (and more realistic) design of the experiment, reproduction of the wall set up, interpretation of results.

Many experimental applications and tests, then, have been boosted by the issue of infilled Rc frames, that in recent years has increasingly gained the attention of scholars. The need of appraising the effect of masonry infill over the seismic response of existing building has promoted the development of specific studies that, again, require the support of the experimental investigation and of the knowledge of the actual materials used [33–35].

Anyway, there are presently very few studies concerning the systematic investigation, inventory and evaluation of mechanical properties of local brick masonry types, especially those made with atypical materials and nontraditional or engineered constructive techniques. This due to the high number of units' types and the difficulty in classification and characterization of the panels [36–38].

2. The case study

2.1. Motivations and objective of the research study

The research work is focused on the characterization of masonry systems which are peculiar of a specific geographic area, both from a morpho-typological and mechanical point of view. The aim is to effectively support the procedure of safety assessment in those situation in which there are no reference literature studies and data, and few possibilities of directly collecting experimental information (from original design and documentation or on site experimental tests). This problems, which are indeed typical of all historical masonry buildings, are here faced for relatively recent "*non engineered*" unreinforced masonry buildings,