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Comparison between experimental methods for evaluating the compressive strength of existing masonry buildings

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HIGHLIGHTS

- Assessing the load bearing capacity of existing masonries is a fundamental issue.
- The suitability of two moderately destructive techniques was here evaluated.
- Masonry specimens purposely constructed in laboratory conditions were used.
- Masonry compressive strength was calculated from brick and mortar characteristics.
- Testing masonry cores completed with cement mortar castings is a promising method.

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ABSTRACT

In this study, the suitability of determining masonry compressive strength by using the following two moderately destructive techniques was evaluated: (i) testing bricks and mortar, separately, and then using formulas available in literature for calculating masonry compressive strength; (ii) testing cylindrical cores, completed with cement mortar castings above and beneath the core, according to a procedure recently proposed by the authors. Two sets of masonry specimens were purposely constructed in laboratory conditions, using bricks and mortar with different mechanical characteristics. From the results of the study, an evaluation of the reliability of the two testing techniques was possible.

1. Introduction

At present, a large part of the built heritage is composed of masonry buildings, as brick–mortar masonry has been a traditional construction technique since ancient times and it is still widely used nowadays for new buildings. Modern awareness of seismic risk characterizing many areas around the Mediterranean basin and recognition of natural weathering of materials, rise a serious challenge to keep using masonry as a reference construction system. In this framework, for both human health safeguard and cultural heritage preservation, the assessment of the structural safety of existing masonries and the evaluation of the effects of possible retrofitting interventions are fundamental issues to be addressed [1]. To this purpose, a better knowledge of the geometrical and mechanical characteristics of existing masonries leads to a more reliable intervention. Among the latter parameters, the most important mechanical property to be determined is masonry compressive strength. Even though for new masonries a single, very effective laboratory experimental test can be used [2,3], when dealing with existing masonries, several experimental techniques

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Nomenclature

E_b	Young's modulus of elasticity of bricks (GPa)
E_m	Young's modulus of elasticity of mortar (GPa)
$E_{m,cast}$	Young's modulus of elasticity of mortar used for castings (GPa)
f_{bc}	brick mean compressive strength (MPa)
f_{bcn}	brick normalized compressive strength (MPa)
$f_{bc,//}$	brick compressive strength in the direction parallel to brick's longest edge (MPa)
f_{mc}	mortar mean compressive strength (MPa)
f_{mc^*}	mortar mean compressive strength, calculated according to Eq. (1) (MPa)
$f_{mc^{**}}$	mortar mean compressive strength, calculated according to Eq. (2) (MPa)
$f_{mc,dpt}$	mortar mean compressive strength, determined by double punch test on samples obtained from the masonry joints (MPa)
$f_{mc,dpt,prism}$	mortar mean compressive strength, determined by double punch test on samples sliced from standard prisms (MPa)
f_{mf}	mortar mean flexural strength (MPa)
$f_{m,cast}$	compressive strength of mortar used for castings (MPa)
f_{wc}	wall mean compressive strength (MPa)
f_{wc^*}	masonry mean compressive strength, calculated using f_{mc^*}
$f_{wc^{**}}$	masonry mean compressive strength, calculated using $f_{mc^{**}}$
h_b	average brick thickness (mm)
h_m	average mortar joint thickness (mm)
N	number of tested specimens
s_w	wall compressive strength standard deviation (MPa)
WA	brick water absorption after immersion in water (%)
WA_{sat}	brick water absorption after saturation in water for 3 days (%)
α	h_m/h_b (–)
ν_b	brick Poisson's ratio (–)
ν_m	mortar Poisson's ratio (–)
$\nu_{m,cast}$	Poisson's ratio of mortar used for castings (–)

can be adopted, differing with respect to their invasiveness, technical challenge and economic costs.

The most direct, as well as largely destructive, method is subjecting a masonry portion (about 90×180 cm^2) to *in situ* compression test; this can be accomplished by separating the masonry panel from the wall along three sides (demolition or cutting are often used) and then loading it from the top by means of a steel beam and hydraulic jacks [4]. The method has the advantage of directly providing masonry compressive strength and modulus of elasticity, if displacement transducers are applied, in its real configuration. However, because of its invasiveness (a wall is largely destroyed), technical challenge and cost, this method is currently performed only in a few cases, while less destructive and less expensive methods are usually preferred.

A moderately destructive technique that can be performed *in situ* is subjecting a masonry portion to compression test by means of two flat-jacks [5]. Two horizontal mortar joints, at a distance of about 50 cm, are removed by saw cutting and, in their place, two flat-jacks are inserted; finally, compression load is increased until failure of the masonry portion comprised between the jacks. This technique has the advantage that the tested masonry portion is relatively small. However, its accuracy is somehow limited by the influence of the masonry surrounding the jacks, involved in a complex diffusion problem. Finally, in case of masonry with poor shear capacity, the test could be arrested due to the inability of the overlying masonry to provide a sufficient contrast to the action exerted by the flat-jacks.

Following a more indirect approach, the masonry compression strength can also be obtained as a function of its components strength (bricks and mortar). To this purpose, the two components have to be separately sampled from the wall. In order to properly combine the two strengths, several formulas were proposed in the scientific literature (see for instance review in [6]). In addition, National Codes (such as Italian Code for constructions [2]) and International Codes (such as Eurocode 6 [3]) provide tables and formulas that allow determination of masonry characteristic compressive strength from brick and mortar compressive strength. This method has the advantage of requiring only moderately destructive sampling, as both brick and mortar samples can be easily obtained from small diameter core-drills [7]. As an example, from 50 mm diameter cores, made exclusively of brick, cylindrical samples can be obtained for determining brick compressive strength. In addition, from 50 mm diameter cores, made of two bricks portions and a central mortar layer, flat prismatic samples of mortar (about $40\ \text{mm} \times 40\ \text{mm} \times 10\ \text{mm}$) can be extracted and used for determining mortar compressive strength by double punch test [7,8]. However, this indirect method for assessing masonry compressive strength has some drawbacks as well: (i) in the case of bricks, the testing direction is generally different from the loading direction in the wall, as the cores are obtained perpendicular to the loading direction in the wall; consequently, not negligible differences in brick compressive strength may be found [9]; (ii) in the case of mortar, the size of the testing specimens and the size of the two punches significantly affect the estimation of mortar compressive strength, hence careful interpretation of test results should be performed [8,10–12]. For more straightforward and reliable results to be obtained, brick and mortar samples should be obtained by removing entire bricks and mortar joints from the wall by chisel; however, this makes the testing procedure more invasive.

Another technique is based on the use of large diameter cores (150 mm), subjected to uniaxial compressive test by loading in the same direction as the masonry is usually loaded in the wall (i.e. by applying load perpendicular to the horizontal mortar joints), by making use of two steel cradles [13,14]. The cores should be core-drilled so as to have two horizontal mortar joints and a vertical one near the center of the core, to ensure that the brickwork is properly represented; in this way, the core failure mechanism is expected to suitably resemble that of the masonry from which the core was extracted [13,14]. Even if this technique has the advantage of testing masonry cores in the same direction as they are loaded in the original wall, it has the limitation that cores with 150 mm diameter are not very often available. Moreover, the use of steel-made cradles for loading the cores might lead to stress concentration if some irregularities are present on core lateral surface.

To overcome the above-mentioned limitations, an alternative version of the compressive test on masonry cores has recently been proposed by the authors [8]. The method is based on the idea of subjecting cores with 100 mm diameter to uniaxial compression, by completing the cores with two high-strength mortar horizontal castings, one below and one above the core. The mortar castings are the transition from the core curved surface to the test machine's flat horizontal surfaces, where vertical distributed load