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Testing Methods for Masonry Cores: A way forward to increase reliability of mechanical properties evaluation

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Abstract

The assessment of unreinforced brick masonry structures and infrastructure is a worldwide challenge for the development of resilient urban areas and preservation of historical assets. Among other factors, the estimation of mechanical performance of masonry in existing construction is of importance. However, the characterisation effort does not always satisfy the requirements from structural analyses point of view, i.e. need of elastic, strength and toughness properties, and/or from technical point of view, i.e. use of conventional technical expertise and limited invasiveness. In this respect, the new RILEM Technical Committee CTM aims at promoting the use of tests on masonry cores for the evaluation of compression and shear properties of unreinforced masonry with regular units. Upon a state-of-the-art review, a database of previous experimental test series will be created to identify influencing factors (e.g., core's geometry, boundary conditions). Selected testing procedures will be compared at various international institutes for a variety of masonry types typically used in existing structures and infrastructure. By comparing results with standardise tests, correction factors will be identified. Eventually, testing guidelines to characterise masonry with core specimens will be defined and shared within the research and engineering community.

Keywords: Unreinforced masonry; Cylindrical core; Compression properties; Shear properties; International committee.

1 Introduction

To perform the vulnerability assessment of existing masonry structures and infrastructure, Building Codes and Standards indicate the need of determining the mechanical properties of the materials to be used, e.g., in numerical models, for structural analyses and verification. With this purpose, experimental tests can be either performed on-site or samples can be extracted in-situ and then tested in the laboratory. In general, testing methods can be classified as non-destructive, minor destructive or destructive depending on their invasiveness, i.e., the damage level they can cause to the construction [1]. The choice about the most appropriate testing methodologies should consider that existing structures and infrastructure, especially with an historical, architectural or artistic value cannot be severely damaged by testing; therefore, minor destructive tests (MDT) are usually preferred to destructive tests when dealing with existing constructions.

To balance the invasiveness of the testing method with the knowledge acquired on mechanical properties, tests on horizontally-loaded cores have been used in the last 80 years as MDT for unreinforced masonry with regular units. As part of a research project for the assessment of masonry arch bridges, the International Union of Railways (UIC) provided the first recommendation to evaluate the compressive strength of masonry with core testing [2], based on the work in [3]. After a first application mainly to infrastructure, the method was employed by some research groups to evaluate properties of existing masonry buildings, e.g. [4],[5],[6]. Additionally, a testing procedure to obtain shear properties of masonry was also developed in the framework of seismic assessment of buildings, e.g. [7],[8],[9].

With respect to other MDT, tests on cores can be executed with limited technical skills, combining a minor destructive technique for in-situ sampling with a destructive laboratory test. The fact that samples can be tested in laboratory with a conventional compression testing rig reduce the need of employing high-skilled technicians, which are for example required for double flat-jack tests [10] and shove tests [11]. Additionally, it can open up the possibility to evaluate toughness properties besides elastic and strength ones, in case displacement or deformation control procedure can be employed. Regarding sampling and transportation, it can rely

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on procedure well-established for other materials, such as concrete, asphalt and rocks.

Despite their use and advantages, testing methods on cores are not yet mature to yield reliable and consistent results for the assessment of mechanical properties of regular masonry in existing constructions. Indeed, variations exist in terms of testing set-ups and procedures among the laboratories. Additionally, and more important, differences are observed when comparing the mechanical properties obtained from tests on cores with the ones evaluated through standard procedures, such as compressive tests on wallets [12] or prisms [13], and shear-compression tests on triplets [14].

This highlights the need of harmonised testing guidelines, that is the scope of the RILEM Technical Committee on “Testing Methods for Masonry Cores” (CTM). The committee aims at providing testing procedures to evaluate the compression and shear properties of masonry with regular units by using core testing methods. By gathering international researchers, the committee aims at revealing what are the factors providing inconsistent findings in the current use of the methods. The development of testing guidelines will further boost its use in engineering practice improving the reliability of (infra)structural assessment and thus the sustainable maintenance of the existing assets.

2 Overview of testing procedures

Two types of tests on masonry cores are currently employed: one to evaluate compressive properties of masonry and another to evaluate shear properties of brick-mortar interface. In this section, an overview of the procedures is briefly presented.

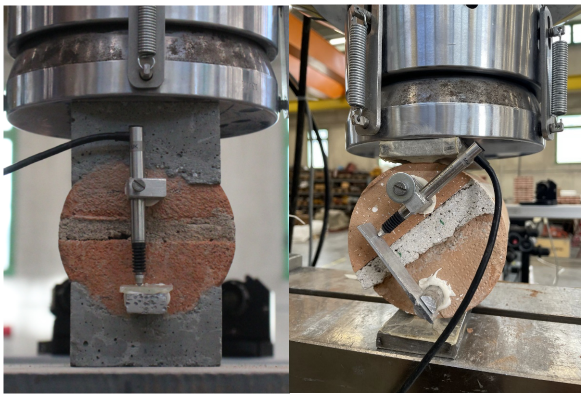
Unlike other materials, such as concrete, rock and asphalt, the direction of sampling and loading is particularly important in masonry due to its orthotropic behaviour. The cores are generally sampled from the front side of walls or pillars (Figure 1) and should then be tested horizontally to preserve the original bond layout.

To evaluate compressive properties, cores are capped with a strong material at top and bottom (Figure 2a). This aims at providing a flat loading surface and recreating the confinement effect given by the surrounding masonry on the core before the extraction. Initially, steel cradles were used [3], later substituted by high-strength mortar capping to ensure a more uniform load application and reduce the effect of stress concentrations [5],[6],[15]. Elastic modulus and compressive strength of masonry are generally evaluated; in some cases, an effort is made to determine also post-peak properties such as strain at peak and compressive fracture energy.

To evaluate shear properties (Figure 2b), splitting tests are performed on core having only one bed joint. The test was first introduced to evaluate the properties of mortar [7]. Afterwards, it was used to evaluate cohesion and friction coefficient of masonry relying on the fact that a shear-sliding failure will occur along the joint, i.e., within the mortar or at the brick-to-mortar interface [8],[9]. By rotating the bed joint with respect to the vertically applied load and by considering multiple inclination angles, different shear-compression stress state can be imposed to the joint. The shear properties are usually determined considering Coulomb friction law. In few cases, an attempt is made to evaluate the dissipated energy [16], but a correlation with the mode-II fracture energy evaluated with shear-compression tests on triplets still has to be established.

(a) (b)

Figure 1. Extraction of cores from a) a building’s wall in Italy; b) an earth-retaining wall in the Netherlands.



(a) (b)

Figure 2. Tests on masonry cores to evaluate a) compression properties; b) shear properties.

3 Current points of attention

In literature, a variety of testing methods considering different core geometries and bond patterns is available to determine compressive properties. The method is mostly used for clay and calcium silicate brick masonry, but in principle it can be applicable to any masonry type with regular solid units. Generally, sample geometry depends on the core diameter, typically ranging between 90 and 150 mm, and on the core length, related to the number of wall wythes considered during sampling, i.e., typically single- or double-wythe cores are tested. The variation in terms of diameter leads to differences in terms of bond pattern as well: small cores have typically one bed joint only (I-shape core), or one bed and one head joint (T-shape core), while larger cores may be characterised by the presence of two bed joints and one central head joint (H-shape core). The differences in testing procedures may often lead to contradictory results. In some works [17], no influence of core diameter on elastic modulus and compressive strength of masonry is observed, while in some others [15],[18] it is shown that the bond pattern can have a substantial influence on compressive strength with lower values reported for T-shape and H-shape core compared to I-shape core.

It should also be mentioned that the large majority of previous studies focus on the characterisation of single-wythe masonry with running bond pattern, while the case of multi-wythe masonry is seldom addressed, mainly due to difficulties in sampling and testing, given the presence of collar joints. Even in the case of infrastructure, tests are often performed on cut out parts of longer core samples having any collar joint [19],[20]. Additionally, in poor-quality masonry, the collar joints are usually not properly filled with mortar, thus influencing the integrity of multi-wythe cores after the extractions.

For splitting tests, significant variations in terms of geometry and bond pattern are not usually considered, since the test is aimed at the activation of a local shear-sliding failure on a single bed joint. This is often the case for masonry with a weak bond, but in case of masonry with good bond properties it has been found that a mixed failure can be triggered, involving both sliding at the brick-mortar interface and splitting of the brick under the loading points [19]. Additionally, the inclination angle adopted can influence the failure mode, i.e. sliding or splitting [8]. This questions the (range of) applicability of the core testing method to evaluate cohesion and coefficient of friction for masonry and demands for further investigations.

Generally, a large variety of sampling and testing procedures are adopted. Regarding extraction of samples, both wet and dry extraction procedures are used. On one side, wet extraction procedures are easy to implement in practice and minimise risks during the activity. On the other side, dry extraction procedures with an air cooling system are found more effective when dealing with masonry with weak mortars [6].

Moreover, tests may be executed under force, displacement or deformation control leading to a different acquisition of the post-peak response of masonry. In case of compression behaviour, controlling the displacements of the actuator is generally sufficient to acquire both pre- and post-peak properties. In case of shear behaviour, the only possibility to acquire information on post-peak response is to control the sliding along the mortar joint. This is however limited to use of the method in research settings.

Cross-comparison between the experimental results of core testing and standard tests on rectangular specimens, as wallets [12], stack-bonded prisms [13], and triplets [14], provides different outcomes for masonry types in different countries. For example, factors ranging between 0.5 and 1.9 were found to correlate the compressive strength obtained from standard tests on wallets to the one obtained from tests on cores. In terms of elastic modulus, a broader range of correlation factors was observed, between 1.05 and 3.1. For what concerns shear properties, a quite good correlation was observed in terms of both cohesion and friction coefficient by comparing results from test on cores and standard shear-compression tests. A synthesis of the correction factors obtained from a literature overview is reported in Table 1.

Table 1. Correction factors proposed in literature (adapted from [21]).

	Ratio between property obtained with standard tests and with core testing			
Reference	**Elastic modulus**	**Compressive strength**	**Cohesion**	**Friction coefficient**
Brencich and Sterpi, 2006 [3]	3.1	1.6	-	-
Ispir et al., 2010 [4]	0.8	0.5	-	-
Sassoni and Mazzotti, 2013 [5]	-	0.6-1.0	-	-
Pela' et al., 2016 [6]	1.1	1.0	-	-
Matysek, 2016 [22]		1.6-1.9		
Mazzotti et al., 2014 [8]	-	-	0.9	1.03
Jafari et al. 2019 [17]	1.05	0.99		
Jafari et al. 2020 [16]	-	-	0.88	0.97

4 Activities of RILEM Technical Committee CTM

To develop harmonised testing procedures, the committee will first provide a comprehensive state-of-the-art of adopted procedures and available experimental results for both compression and shear tests on cores, upon which influencing factors will be determined. This will set the basis for experimental test series on various unreinforced masonry types in different countries to obtain a general validity of the methods. The work will mostly consider masonry with regular solid units, such as brick and blocks, thus excluding applications to stone masonry. Eventually, guidelines to evaluate compressive and shear properties of masonry with testing methods on core will be drafted and published as RILEM recommendations.

As first step, previous experimental data will be collected from various sources, such as conference papers, journal articles, and technical reports available in testing institutes or engineering companies. Data will regard tests on field-extracted and lab-replicated samples. If possible, information on companion tests, i.e., according to standard tests on rectangular specimens or non-destructive tests, will also be collected. Information on testing set-ups, testing procedures, sampling protocols will be gathered.

The analyses of the database will allow identify potential influencing factors that are crucial for the estimation of mechanical properties via tests on core. It is expected that these factors could be properties of brick and mortar, boundary conditions, diameter and length of the core, bond pattern of the core, loading conditions, etc.

Experiments will be performed by the TC members at the different international institutes for a variety of masonry types typically used in existing buildings and infrastructure. Considering the analyses of the database and the determination of the influencing factors, few variations of testing procedures will be selected and used for the experimental test series. Companion tests will be also performed next to core testing to define correlations factors between properties. For both core testing and companion tests, the complete nonlinear behaviour of masonry and corresponding crack pattern will be evaluated and analyzed to estimate elastic, strength and toughness properties. The use of detailed numerical models will be considered to further optimize the experimental test series, to perform parametric analyses, and, possibly, extend the experimental outcomes to other masonry typologies.

Based on the analyses of the database and the outcome of the experimental test series, guidelines for core testing to evaluate compression and shear properties of masonry will be drafted. The guidelines will at least address the estimation of elastic modulus, compressive strength, cohesion and friction coefficient.

With the aim of bringing forward the application of testing methods on core in engineering practice, various dissemination activities will be considered, such as dissemination at international conference, organisation of webinar and/or international workshop with industrial parties, and open access publications.

5 Challenges

The variability of masonry typologies throughout the world represents an intrinsic challenge to determine common testing procedures since the main outcomes of tests on core may be extremely susceptible to the characteristics of the constituents and to the quality of the bond between units and mortar. Given the differences in terms of test set-ups and protocols, previously described, it might be challenging to determine whether correlation factors found from the comparisons between core tests and standard tests depend on the test procedure itself or on the specific characteristic of the investigated masonry typology. For this reason, besides the collection of literature studies, further experimental investigations are needed to properly assess the influence of the mentioned aspects on the test outcomes with the objective of providing testing guidelines. In more detail, for compressive tests, it is not trivial to evaluate the influence of the core geometry and bond pattern, which might be related to the size effect, together with the stiffness ratio between constituents and mortar capping. Especially when dealing with shear tests on cores, the poor or good adhesion between units and mortar should also be assessed through different experimental tests to understand its influence on the values of shear properties and on the obtainable failure mode. To properly understand the evolution of the cracking process and accurately map crack propagation, the use of Digital Image Correlation (DIC) and acoustic emission can be considered, depending on the availability of these equipment at the different institutions.

The execution of a Round Robin laboratory experimental campaign, involving several institutions, represents a very challenging task in the work of the RILEM Committee. Testing the same masonry typologies in various countries poses significant logistic difficulties for the preparation and transportation of the samples. Indeed, to ensure that all samples have the same characteristics, they should be prepared by the same masons and cured within the same controlled environment, and they should be then shipped to the other laboratories without damaging them, which is not easy, especially for poor-quality masonries. The back-up plan will consists in performing tests in various laboratories using the same procedures on different materials or to limit the Round Robin testing to a few countries.

The activities of the committee will mainly focus on experimental tests, however the creation of detailed models to support the identification and assessment of the main influencing factors will be also considered. Besides the determination of all the elastic and nonlinear properties needed for a complete description of the core behavior, it would be interesting and, at the same time, very challenging, to compare results of numerical simulations performed with different software and constitutive models' hypothesis.

6 Concluding remarks

Considering the widespread use of simplified as well as advanced structural analysis methods for the vulnerability assessment of existing structure and infrastructure, there is the need of obtaining reliable information on material properties using minor destructive testing methods (MDT). Among the current testing methods available for existing unreinforced masonry with regular units, core testing method has the potentiality to balance the invasiveness of sampling and required technical skills with the level of knowledge achieved in terms of mechanical characterisation. By providing testing guidelines, which is the main objective of the RILEM Technical Committee CTM, the core testing methods will be consistently and more often used by practitioners. In turn, this will increase the reliability of structural assessment procedures, thus leading to optimising the maintenance of the existing masonry assets and contributing to the sustainability goals of the construction sector.

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