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Compression test of masonry core samples extracted from existing brickwork

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HIGHLIGHTS

- MDT to evaluate the compressive behaviour of masonry in existing structures.
- Core-drilling of brick and lime mortar masonry walls using dry (no water) procedure.
- Regularization of cylindrical specimens and laboratory testing under compression.
- Evaluation of compressive strength and elastic parameters of existing masonry.
- Comparisons with experimental results on standard samples and analytical expressions.

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ABSTRACT

This research is focused on the experimental characterisation of the compressive behaviour of masonry in existing buildings. The proposed technique is based on in situ core drilling of masonry members. Two walls were built making use of terracotta handmade bricks and lime mortar, without cement, to reproduce a low-strength historical masonry. Core samples were extracted from the walls and then regularized to perform a non-standard compression test in the laboratory. Stack-bonded prisms were also tested under compression. A direct comparison is made between the results from the proposed non-standard tests on core samples and the tests suggested by the available standards on prismatic samples. The proposed minor destructive technique shows to be effective for the mechanical characterisation of existing masonry structures, including historical ones.

1. Introduction

Masonry is one of the oldest construction materials that still finds wide use in the current building practice. Ancient masonry buildings represent most of the built cultural heritage and they can be found in many Mediterranean countries. The analysis of the behaviour of masonry constructions still remains a true challenge [1] since the mechanical response of this composite material is determined by the properties of the components and their complex interaction.

Compressive strength of masonry is considered by available standards as a fundamental design parameter. Several studies were performed to understand the behaviour of masonry under uniaxial compression [2–9]. These studies investigated newly built masonry and dealt with compression tests executed on EN standard wallets [10] and RILEM standard stack-bonded prisms [11].

The experimental evaluation of the compressive behaviour of masonry is even more complex in existing buildings. In this case, the large prismatic samples considered by the technical standards cannot be normally extracted due to the need to preserve the integrity of structural members. Moreover, the extraction of sufficiently intact samples is made difficult by the low strength

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of the materials and the poor bonding frequently shown by the mortar-unit interfaces.

Difficulties arise even from the sampling and subsequent characterisation of the components in the laboratory, both in the case of old bricks [12,13] and historical mortars [14–17]. Due to the limited thickness of mortar beds and brick courses, it is normally impossible to extract samples sufficiently large to be tested according to standard procedures.

Recent researches have shown the great potential of Minor Destructive Tests (MDT) for existing and historical masonry buildings, consisting in the extraction of small cylindrical samples to be subjected to destructive testing in the laboratory [18–26]. The in situ core drilling is carried out horizontally and perpendicularly to the face of a structural member, as for instance a masonry wall. The sampling procedure induces limited damage to the structure, which can be easily repaired after the inspection. The cores can be extracted from hidden parts of the historical structure. A direct evaluation of the mechanical properties of masonry can be derived from experimental laboratory tests.

Compression tests can be carried out on in situ drilled masonry cores, as proposed by the UIC 778-3 recommendations of the International Union of Railways [22]. In the case of metric bricks, 150 mm diameter cylindrical samples of masonry can be extracted including two horizontal mortar joints and one vertical joint. The sample is centred in the middle of the vertical joint and the compression test is carried out in the same direction in which the load is applied in the original structural member. The upper and bottom parts of the lateral surface of the cylinder are regularized making use of a lead sheet between the core and concave steel plates fixed to the loading machine (Fig. 1). The UIC 778-3 suggests at least three compression tests for each kind of brickwork and preferably six tests when possible. The standard also advises not to test cores with diameter smaller than 150 mm to characterise the compressive strength of masonry, since smaller samples are suitable only for the evaluation of the brick's properties. The procedure proposed by the UIC 778-3 combines the advantage of minor destructive sampling, since a limited portion of the structure is damaged by the extraction, with the possibility of testing a sufficiently complex masonry specimen, able to represent the interaction among units, horizontal and vertical mortar joints upon compression loading. For all these reasons, this method was used in previous researches to evaluate the compressive strength of clay brick masonry [20,23–24].

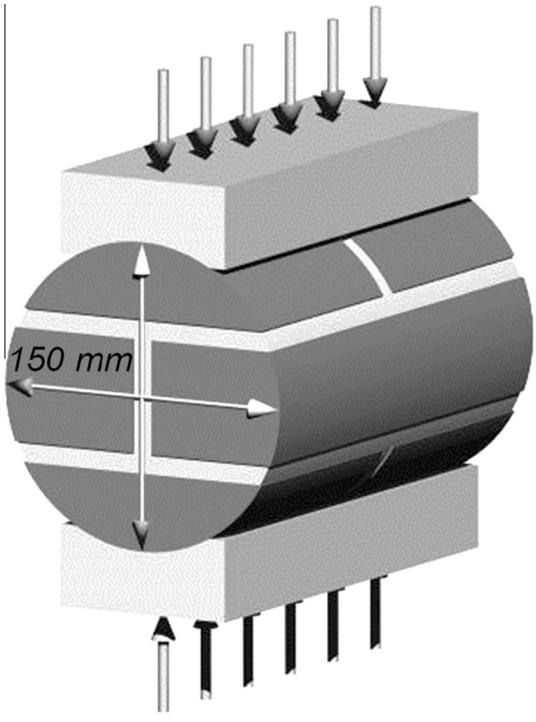

Fig. 1. Compression test on brickwork core sample [22].

The present work is aimed at investigating the applicability of the aforementioned MDT to historical buildings, while also providing possible practical improvements. The study was carried out in the laboratory in order to provide a reliable calibration of the experimental method. Two masonry walls were built using solid clay bricks and lime mortar, material combination which corresponds to the vast majority of historical and existing masonry structures. After a sufficient curing time, the walls were core drilled using a novel dry extraction procedure, based on air cooling system. This is an improvement to common wet core drilling, in which water could spoil the lime mortar joints in the samples. Two different types of 150 mm diameter cylindrical samples were extracted: masonry cores with two horizontal mortar joints and one vertical (three-joint cylinders, called 3JCs) and cores including two horizontal joints without the vertical one (two-joint cylinders, called 2JCs). The curved surfaces of the extracted cores were regularized in a different way than that proposed by UIC 778-3, i.e. using cement mortar caps to produce loading planes parallel to the horizontal mortar joints [20–25]. Compression tests were carried out on both 3JCs and 2JCs. The two different types of samples were analysed in order to investigate the influence of the presence of the head joint in the core. The experimental results were compared with those obtained from stack-bonded prisms [10–11] that were built with the same materials used during the construction of the walls.

The direct comparison between the novel non-standard testing method and well-known standard tests provides useful suggestions for experimental activities aimed at evaluating the compressive behaviour of existing masonry. The discussion of the experimental results and the comparison with analytical models are finally presented for a better comprehension of the proposed MDT.

2. Materials and test methods

The experimental program was carried out at the Laboratory of Technology of Structures and Materials of the Technical University of Catalonia (UPC-BarcelonaTech). Different masonry specimens were manufactured in the laboratory using handmade terracotta bricks and Natural Hydraulic Lime (NHL) mortar, classified as NHL 3.5 by EN 459-1 [27]. Two single-leaf walls with dimensions of $1605 \times 870 \times 145$ mm^3 were built in order to extract fifteen 3JCs and fifteen 2JCs (see Fig. 2a). Six stack-bonded prisms (SP1-SP6), with dimensions of $305 \times 297 \times 145$ mm^3, were built following the RILEM [1] (Fig. 2b). At the same time of the construction of masonry specimens, mortar prisms ($40 \times 40 \times 160$ mm^3) were prepared according to EN 1015-11 [28] using metallic moulds. The NHL mortar prisms were tested at different ages in order to control the curing and hardening of the material until the moment of core-drilling.

2.1. Characterisation of material components

Handmade terracotta bricks, fired following traditional procedures, were adopted to replicate historical masonry. The nominal dimensions of the units were $305 \times 145 \times 45$ mm^3, even though there was a small variability among bricks' dimensions due to their construction procedure. The compression test of the whole unit was carried out to evaluate the uniaxial compressive strength $f_{cb,u}$ perpendicular to the larger face of the brick. Six tests were performed according to EN 772-1 [29], using a testing machine with a load cell of 3000 kN. The average value of $f_{cb,u}$ was 30.7 MPa. The normalized compressive strength of the units was obtained using the shape factor of 0.7 recommended by the standard, yielding 21.5 MPa. In order to obtain a complete characterisation of the brick from different types of samples, some units were cut into cubes and prisms (Fig. 3a). Cubes were used to investigate the uniaxial compressive strength $f_{cb,c}$ in the vertical direction. Prisms were used to investigate the flexural strengths along the stretcher ($f_{fb,x}$) and header