TUFF-BRICK LISTED MASONRY: EXPERIMENTAL BEHAVIOUR

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ABSTRACT :

The last Italian Guideline (2008) contains some indications about the main mechanical properties of masonry structures based on the constituents material (units and mortar) and their assemblage. Amplification factors are also introduced in case of stripes for stone masonry. Nevertheless, no indications are contained for tuff structures, although many examples of listed masonry are present in Southern Italy. In this paper, an experimental campaign carried out on listed tuff and brick masonry panels is presented and the results commented, also in the light of the national Guidelines. Finally, an amplifying coefficient to be used with this kind of masonry is suggested.

KEYWORDS: Tuff Stones, Bricks, Listing, Masonry, Experiments, Guidelines.

1. INTRODUCTION

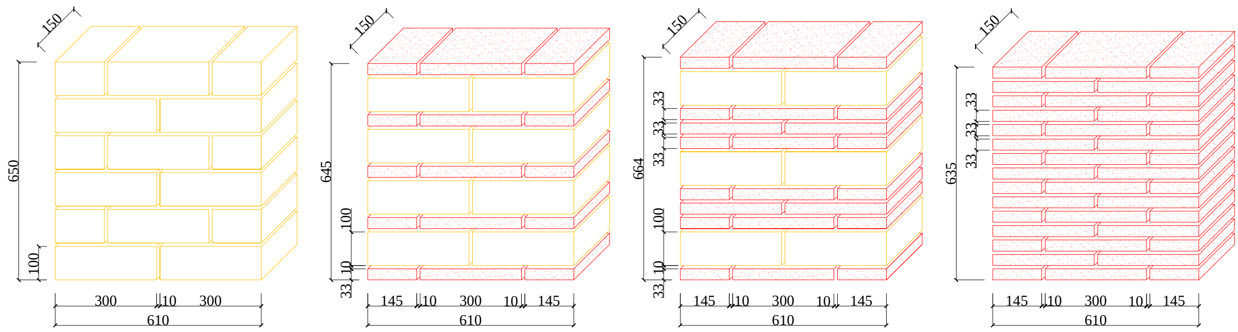
Structural analysis on existing masonry structures requires essentially the knowledge of the mechanical properties of the “masonry material” which values are, generally, rather difficult to deduce. Suggestions of these values are contained in several Italian Guidelines for different kinds of masonry (Romano, 2008). In addition, the documents suggest the use of some amplification coefficients for taking into account improving factors like the presence of stripes with bricks in stone masonry. Notwithstanding this, the tuff class lacks of this indications. Furthermore, although some references are available in literature for rough organized masonry made of lime-stones and sandstones coupled to bricks (Corradi et Al., 2003; Borri et Al., 2004; Shendova et Al., 2008), no experimental data were found for tuff and bricks. Figure 1 shows some examples, varying from roman ruins to a private house, a castle and an aqueduct made of tuff striped with bricks in one to four rows but many others existing constructions like churches, retaining walls, bridges and etc. may be found in Southern Italy. This research originates from this lack and the consequent need to assess the structural behaviour of this kind of masonry. The present paper illustrates the results of an experimental campaign conducted on some listed specimens, variously arranged, and the constituting materials.

Pompei remains | Private house | Castel Nuovo | Serino aqueduct

Figure 1 Some examples of existing listed masonry

2. THE EXPERIMENTAL CAMPAIGN

In the aim of evaluating the influence of brick layers in tuff masonry walls, four kinds of samples were designed starting from whole tuff walls, passing through simple and multiple tuff-brick listed specimens until whole brick samples. Figure 2 depicts the pattern, the geometry and the percentage of tuff stones and bricks in each specimen.



100% Tuff stones
0% Bricks

67% Tuff stones
33% Bricks

49% Tuff stones
51% Bricks

0% Tuff stones
100% Bricks

Figure 2 Samples submitted to experimental tests: geometry and units arrangement

The materials composing the panels were basically tuff stones, handmade bricks and pozzolana mortar. More in detail, the yellow tuff stones were extracted from a pit in the surrounding of Naples and then cut in prisms 300×150×100 mm^3; the red handmade bricks, coming from a Tuscan kiln, were 300×150×33 mm^3; the mortar, premixed, consisted of 4l of water added every 0.25 kN of ready-mixed. The bare materials are shown in Figure 3.

Figure 3 The used materials: Tuff stones, Bricks and premixed Mortar

3. TESTS ON CONSTITUTING ELEMENTS

Before testing the panels, the constituting elements were characterized as shown in the following. An universal load machine (MTS 810) with a stroke of 15 cm (± 7.5 cm) and a 500 kN load cell in tension and compression was used to test the tuff units and the mortar in compressive and tensile tests (Augenti and Romano, 2007). The mechanical properties of the bricks were furnished directly by the supplier who used a MATEST load machine for the compression test and a GABBRIELLI CROMETRO CRAB 24 for the tensile test.
According to the indications contained in the UNI Standards for natural stones (EN 1926), i.e. Tuff Units, two series of six cubic specimens 70 mm long have been tested to determine the compressive strength (Figure 4.a). UNI Standard EN 14580 was used to determine the normal elastic modulus and the tangential elastic modulus on stones 70×70×140 mm^3 (Figure 4.b). Direct tensile tests, although difficult, were finally performed on prismatic trials of 100×100×200 mm^3, provided of two median cuts in order to trigger the crack in that section (Figure 4.c).
For the Bricks, the supplier performed an indirect tensile test on 10 bricks (300×150×33 mm^3) according to the UNI EN 1344 and then a compression test on 10 half-cut samples (150×150×33 mm^3) applying the UNI EN 772-1 (Figure 4.d). No values for elastic moduli were given.
For the pozzolana-based mortar, the procedure indicated by the UNI Standard EN 1015-2 and EN 1015-11 were followed for determining the tensile strength of prisms 40×40×160 mm^3 through a flexural test (Figure 4.e).

Following the same Standards, the half pieces (cubes 40×40×40 mm^3) were tested in compression (Figure 4.f). Finally, the same procedure, instrumentation and UNI Standard (EN 14580) guidelines were considered to determine the elastic normal and shear moduli on prisms 70×70×140 mm^3.

Figure 4 Experimental tests on constituting elements

The numerical results of these tests with the relative coefficient of variation are summarized in Table 1.

Table 1 Mechanical properties of elements

Material	Compressive Strength	Tensile Strength	Normal Modulus	Shear Modulus
Tuff Units	4.13 MPa (18.54%)	0.24 MPa	1540 MPa (6.43%)	444 MPa (25.78%)
Bricks	25.15 MPa (7.47%)	4.52 MPa (9.13%)	--	--
Mortar	7.14 MPa (7.34%)	1.43 MPa (6.23%)	1520 MPa (22.12%)	659 MPa (10.66%)

4. TESTS ON MASONRY SPECIMENS

The panels, realized in a builder yard with the previous materials, were then constrained with two UPN 180. For each kind of panel three specimens were built with the exception of the tuff panel, only in one sample available.
A universal load machine (METROCOM) with a maximum stroke of 100 cm and a 600 kN load cell were used to test the panels. In order to determine the compressive strength and the normal modulus a uni-axial compression, as ruled by the UNI Standard EN 1052-1, was applied. The load procedure was suggested by the same guideline. For the displacement measurements, the cited regulation considers the layout of the transducers only in the vertical direction. In the aim of evaluating the shear modulus, a further horizontal device was also placed. Finally, two mechanical centesimal gauges with 50 mm stroke (BORLETTI) and an horizontal one with a stroke of 30 mm (FEB) were used. The set-up instrumentation and the load path applied to the panels are indicated in Figure 5.

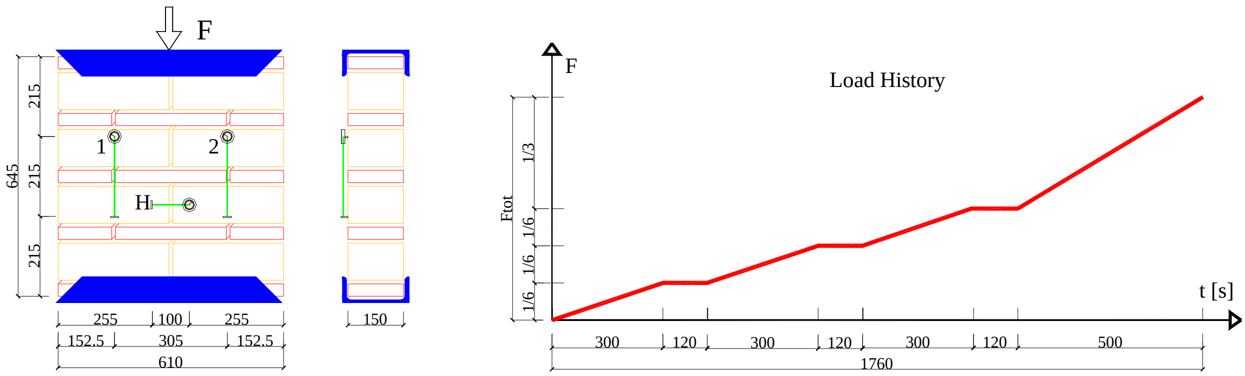


Figure 5 Set-up applied on the panel and load history

In the following, the experimental tests conducted on the four kinds of specimens are illustrated in detail.

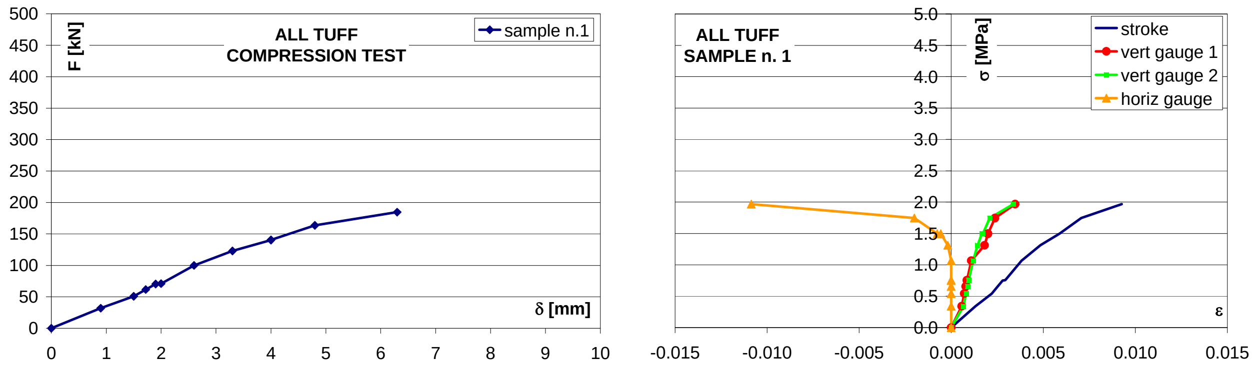
4.1. All Tuff Panels

Figure 6 depicts the specimen made of only tuff stones and mortar. In particular, the sample after the manufacturing (Figure 6.a); the sample under the load machine, instrumented, before the compressive test (Figure 6.b); the crack pattern on the face (Figure 6.c) and in the middle (Figure 6.d) of the specimen after the test are shown. As expected, vertical cracks appeared along the surface, but they were detected also inside the panel, despite the sample was only in one leaf. This phenomenon is accountable to the fact that in uni-axial compression the mortar expands laterally more than the unit due to the larger value of the transversal dilatation coefficient. The continuity between mortar and units, ensured by cohesion and friction, produces a confinement phenomenon in the mortar included between two units. A tri-axial compression state in the mortar and a vertical compression-bilateral tension state in the units form. Due to this phenomenon, the crisis in the units occurs for cracks parallel to the load direction until the splitting phenomenon, characterized by the separation of the element in two vertical parts.

a b c d

Figure 6 Tuff panel: sample, instrumentation, external and internal crack pattern

The force-displacement curve of the whole panel, recorded through the stroke of the load machine is plotted in Figure 7.a. The same curve in the stress-strain diagram together to the trends of the vertical and horizontal gauges are reported in Figure 7.b. It is evident that the deformability of the whole panel (measured by the load machine) is bigger than the strains detected by the two vertical gauges. This fact my be due to local crushing phenomena occurring at the boundary of the panel.



a b

Figure 7 Force-Displacement and Stress-Strain curves for Tuff panel

4.2. Simple Tuff -Brick Listed Panels

The same experimental procedure and set-up used for the tuff panel was applied also to the simple tuff-brick listed panels (Figure 8). In this case, the internal cracks formed both along the bricks and the tuff units.

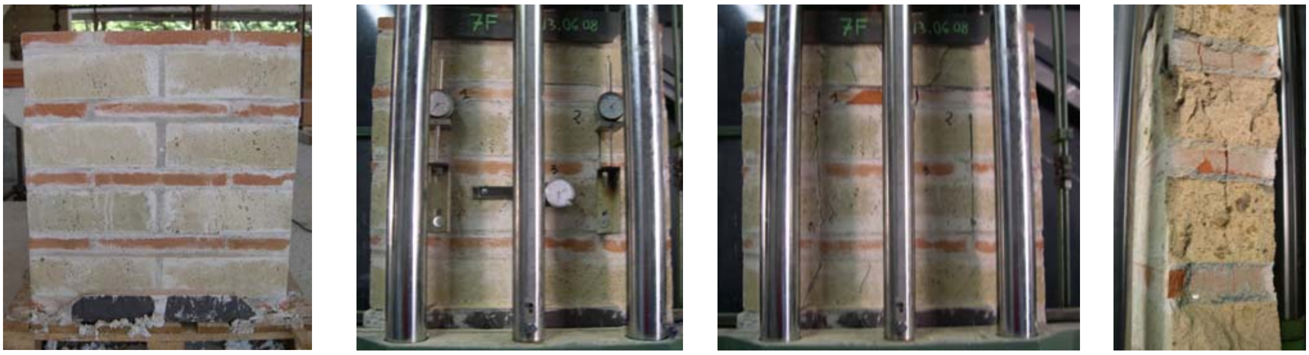


Figure 8 Simple Tuff-Brick listed panel: sample, instrumentation, external and internal crack pattern

The Force-Displacement curves of the three samples were reported in Figure 9.a. The change of slope in the curves is due to the first crack occurred in the middle of the specimen along the height. The variable initial stiffness is probably due to the not uniform thickness of mortar. The Stress-Strain diagram of one sample is plotted in Figure 9.b. In this case, the deformability of the panel in the elastic branch is close to the part instrumented by the gauges.

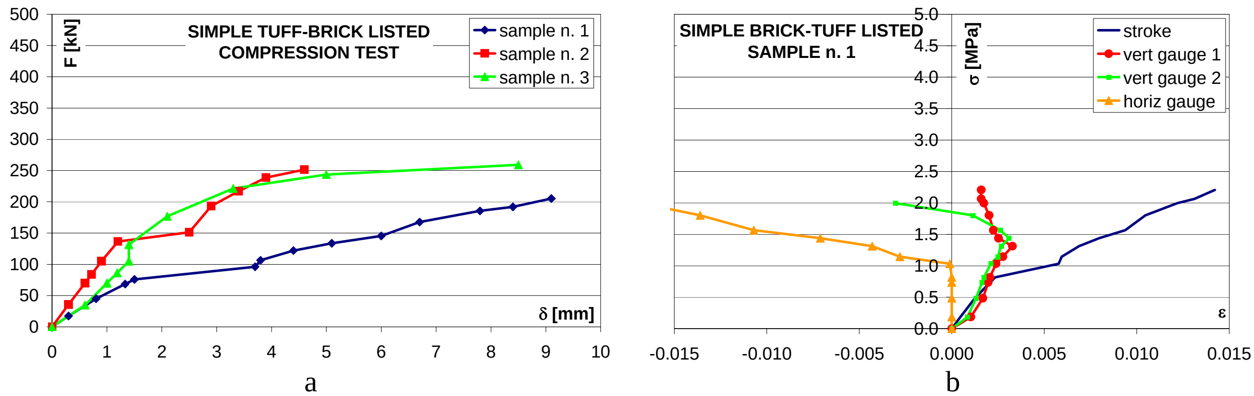
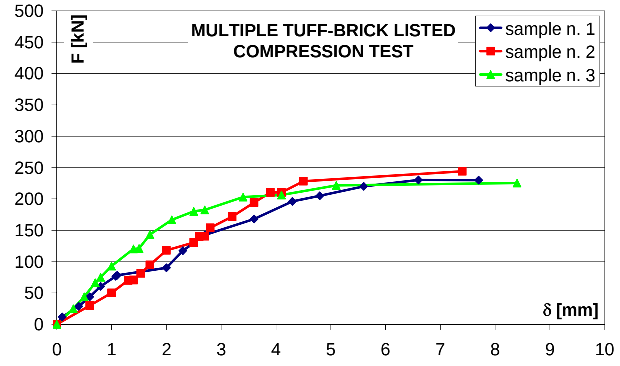


Figure 9 Force-Displacement and Stress-Strain curves for Simple Tuff-Brick listed panels

4.3. Multiple Tuff -Brick Listed Panels

Figures 10 and 11 plot the same steps for the multiple tuff-brick listed panels. It has to be underlined that, although the percentage of bricks is increased from 33% (previous case) to 51%, the peak load for all the three specimens is unchanged and the gauges curves follow better the stroke path and are more stable than the previous ones. About the crack pattern, again, an internal rupture is visible along the bricks and the tuff stones.

Figure 10 Multiple Tuff-Brick listed panel: sample, instrumentation, external and internal crack pattern



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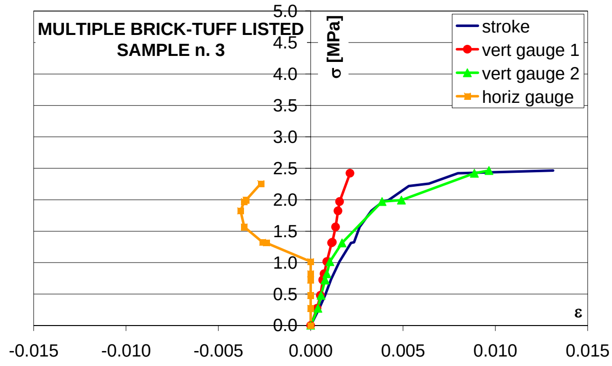

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Figure 11 Force-Displacement and Stress-Strain curves for Multiple Tuff-Brick listed panels

4.4. All Brick Panels

Finally, three samples of whole bricks were tested and a summary of the experiments reported in Figures 12 and 13. As it could be expected a radical change in the peak load and in the elastic properties was recorded. Again, the thickness of the mortar joint and the restrain conditions of the panel played a significant role in the experiments.

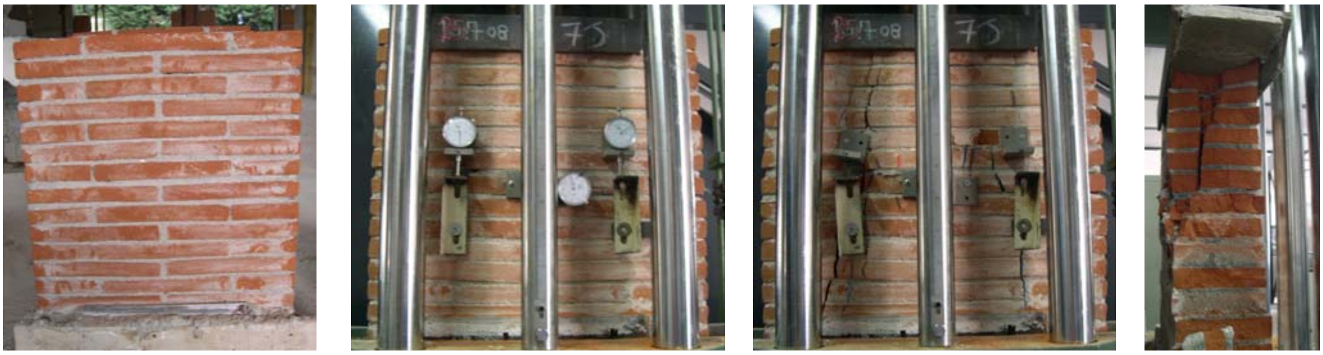
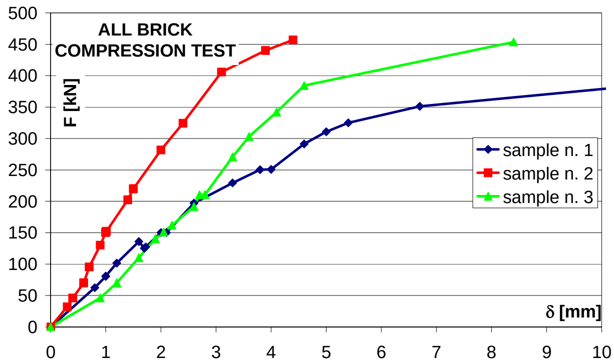


Figure 12 Brick panel: sample, instrumentation, external and internal crack pattern



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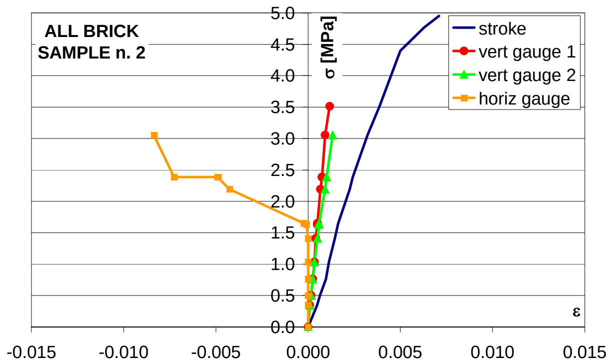

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Figure 13 Force-Displacement and Stress-Strain curves for brick panels

5. COMMENTS ON THE EXPERIMENTAL TESTS

The mechanical properties of the four kind of panels deduced from the tests are summarized in Table 2. The value and the correspondent coefficient of variation is reported for the compressive strength (peak load factorized the gross area), the Young's modulus (at one third of the peak load) and shear modulus (through the Lamè's relation).

Table 2 Mechanical and elastic properties of panels

Specimen	Compressive Strength	Normal Modulus	Shear Modulus
All tuff	1.97 MPa	781 MPa	390 MPa
Simple tuff-brick listed	2.58 MPa (12.81%)	930 MPa (48.92%)	447 MPa (48.54%)
Multiple tuff-brick listed	2.53 MPa (3.36%)	822 MPa (25.11%)	380 MPa (40.00%)
All brick	4.70 MPa (9.43%)	1820 MPa (53.31%)	584 MPa (70.02%)

Since in the last Italian Guideline (D.M. 08) the above values for the whole tuff and whole brick class are indicated, in the following Figure n. 14, the minimum and the maximum thresholds are reported together to the experimental values. Firstly, it can be noticed that the values obtained for the whole tuff and brick panels are likewise to the values suggested. Then, it is fairly evident that the behaviour of the single and the multiple listed panels is closer to the tuff panel than the brick panels. Table 3 illustrates the percentage of scatters of simple, multiple and whole bricks respect to the whole tuff specimens. The compressive strength of the listed panels (independently from the number of brick layers) is around 30% grater than the tuff panels, whilst the scatter of the normal and shear modulus are sensibly lower and close to the reference values.
Recalling the cited guideline, it is mentioned that in stone masonry an amplifying coefficient may be applied in listed masonry only to compressive and shear strength in the following way: 1. Rubble masonry: 10%; 2. Faced masonry: 20%; 3. Rough Organized masonry: 30% that means a value varying in the range 10 to 30%.
Furthermore, in a former national Guideline (Circolare n. 21745, 1981) it was explicitly cited that natural masonry could be amplified of 30% for all the mechanical characteristics in presence of layers of bricks.
For these reasons and as a result of the experimental campaign, it is reasonable to affirm that tuff walls in presence of lists of bricks, in any number, increase their compressive load capacity of around 30% and no sensible difference may be detected for the normal and the shear modulus.

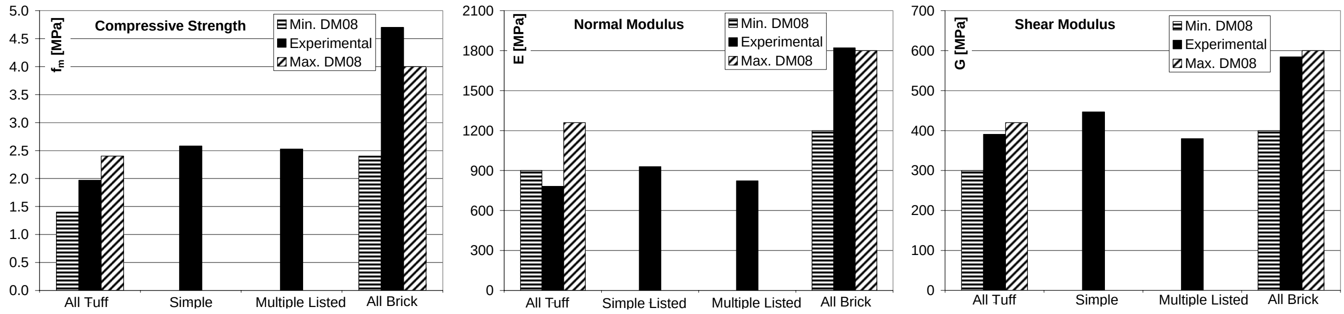

Figure 14 Compressive strength, Normal modulus and Shear Modulus: Comparison

Table 3 Amplifying Factors

Specimen	Compressive Strength	Normal Modulus	Shear Modulus
All tuff	Reference value	Reference value	Reference value
Simple tuff-brick listed	+31.09%	+19.06%	+14.33%
Multiple tuff-brick listed	+28.34%	+5.25%	-2.73%
All brick	+138.73%	+133.12%	+49.69%

6. CONCLUSIONS AND FUTURE DEVELOPMENTS

In this paper the structural behaviour of listed tuff-brick walls was assessed. An experimental campaign on ten

squared panels 60 cm long subjected to compressive load was performed. The main mechanical properties (compressive strength, normal modulus and shear modulus) were experimentally derived. The influence of the presence of bricks in the tuff walls was evaluated through different pattern configurations. The two last enforced Guidelines (D.M. 2008 and Circolare n. 21745) were compared to the experimental values.
In conclusion, for listed tuff-brick walls it can be affirmed that:

- the number of bricks does not considerably influence the compressive strength;
- the normal and shear moduli are not affected by the presence of bricks;
- the experimental mechanical properties agree with the values proposed by enforced Guidelines when possible;
- an increasing percentage of 30% only for compressive strength is proposed to be introduced in the Guidelines.

The uni-axial compression test on this kind of masonry was the initial step of this research. Many other parameters like ductility, fracture energy or shear strength and the related tangential modulus, should be performed in the future in order to have a whole frame of this special type of masonry.

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