Mechanical characterization of particular masonry panels in Tuscany

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ABSTRACT: The knowledge of masonries' mechanical parameters is an essential requirement for a reliable structural assessment on existing masonry buildings. Table C8A.2.1 (Circ. 617/2009, Italian Code) provides average values of mechanical characteristics for 11 masonry categories typical of existing structures. In certain cases, they are not sufficient to cover specific masonry types individuated in regional context. In this paper, the results of experimental tests performed on particular masonry panels "out-of-Code" taken from bearing walls realized with hollow brick blocks or hand-made concrete blocks, are shown. The main qualitative characteristics of these two masonry types are identified through the filling out of a Masonry Quality Form, in which the features of the walls' weaving and cross section are illustrated. The analysis of the experimental tests' results, accompanied by a careful qualitative description of the masonry panels, is a preliminary step for the integration of the masonry categories of the Italian structural Code.

1 INTRODUCTION

The Italian territory is characterized by a significant cultural heritage, mainly composed of historic stone load-masonry buildings, and by a high site construction hazard.

The evaluation of the seismic safety assessment for existing buildings is an essential scientific activity, necessary for the protection of the cultural building stock. The procedure to be followed for the analysis of existing buildings is currently described in Circ. 617/2009 of the Italian Code for Constructions (D.M. 2008). That procedure, at first introduced in the OPCM 3274/03, is based on three knowledge levels (LC1 limited, LC2 adequate and LC3 accurate), depending on the accuracy of the level of information gained for the structure about geometry, structural details and materials' properties.

The characterization of the materials' mechanical parameters is one of the most problematic aspects, because the realization of the necessary in situ experimental tests on masonries would be executively and economically difficult. In absence of experimental tests, the mechanical parameters can be taken from Table C8A.2.1 (Circ. 617/2009), that provides average values (minimum and maximum) of mechanical characteristics for 11 masonry categories, which are typical of the Italian constructions. The first 6 can be considered as "historic" masonries, while the last 5 can be considered as "modern" ones. The mechanical characteristics refer to historic masonry types in poor conditions (i.e. not good quality mortar, thick joints…) but their properties can be modified through corrective coefficients proposed in Table C8A.2.2 (Circ. 617/2009), if the presence of some qualifying characteristics (such as the stringcourses or the good quality mortar) is recognized.

It is not always immediate to frame existing masonry panels into the stone-categories defined in the Code, due to the heterogeneity and variety of the elements and to the distinct construction techniques. Moreover, in homogeneous territorial zones (i.e. regional framework), it is possible to find specific masonry types which do not properly fit into any of the categories defined in the Code since are linked to the local materials and specific construction techniques. For example in Tuscany Region, in the areas of Pistoia and Firenze, it was observed the quite widespread presence of two particular masonry types that are different from those defined in the Code. They are the hollow brick blocks masonry, with the holes percentage of the elements major than the upper limit expressed in Tab. C8A.2.1 (Circ.617/09, φ>45%) and hand-made (and built-in-work-site) concrete blocks masonry, denominated "masselli" masonry.

In literature, results of in situ experimental campaign on few types of holes brick masonries are available (Borri et *al.*, 2009b), while no information have been found for the mechanical characterization of "masselli" ones. To upgrade the knowledge of the mechanical parameters of these particular masonry types, for years, experimental campaigns have been performed in Tuscany Region. In this paper, the results of three experimental campaigns carried out over hollow brick blocks (φ>45%) and "masselli" panels are presented. The results of the experimentations, critically evaluated in relation also to the qualitative characteristics of the masonries, could be considered as the starting point to integrate the masonry categories defined in the Structural Code.

2 THE ANALYZED MASONRIES

The detailed characterization of the masonry panels has been carried out by filling out specific Forms implemented by the Department of Civil and Environmental Engineering (DICEA, University of Firenze) as part of the research project DPC-ReLUIS 2014-16. These Forms, based on the Masonry Quality Form (Binda et *al.*, 2008) in which some integration were added in order to cover all the masonry categories defined in the Circ.617/09, allow a complete characterization of the masonry type through the description of blocks and mortar, panel weaving and section and with the individuation of the characteristics that could modify the masonry response toward in-plane and out-plane loads (diaton, mortar joints..). The filling out of the Quality of Masonry Form allows the individuation of the Masonry Quality Index (Borri et *al.*, 2009a), "MQI", a numerical coefficient that allows to classify the masonry type depending on its response towards out-of-plane and in-plane behaviors.

2.1 Hollow brick blocks masonry

The tests on the hollow brick blocks masonry have been performed both in situ on panels belonging to a strategic military building in Pistoia (Figure 1) and in laboratory on specimens of elements taken from the building (Figure 2).

The construction is a three-level load-bearing masonry building, with a "U" shape, entering in a rectangle of about 60x66 m. The building represents a typical structural and architectural military model developed between the two world wars: examples of these districts can be found in many other Italian Regions, in a period of expansion of the hollow brick as a construction technique in Italy. The horizontal elements of the structure are made of brick-concrete elements typical of that period ("S.A.P." type), the roof is composed of a wooden structure and the vertical bearing walls are constituted of brick and hollow bricks masonry panels. In particular, all the external walls and the web-"U" area internal ones are composed of brick masonry 40 cm thin, with brick blocks of not current standardized dimensions, commonly encountered in historic constructions (13x26x5.5 cm). The interior walls are composed of different types of hollow brick elements, characterized by an average holes percentage among the 40 and 50%. On the first and second floor, the internal walls have a double leaf texture, composed of circular ("occhialoni", Figure 2a) and rectangular ("foratoni", Figure 2b) hollow brick blocks, while on the last level the bearing walls have a single leaf texture (about 30 cm thin with plaster), composed of "occhialoni" elements.

Figure 1. External front of the strategic building of Pistoia.

The "occhialoni" blocks have a square shape (26x26x13 cm) and thery are characterized by two main contiguous circular holes in the corss section, two secondary triangular ones and four small triangular arranged at the edges (Figure 2a). The "foratoni" elements, characterized by three symmetric squared holes on the cross section, have comparable sizes to the "occhialoni type", but with a greater weight. (Figure 2b).

The feature that distinguishes these types of hollow brick blocks is the percentage of holes (φ). In the case of the circular elements, φ measured on 24 elements oscillate between 42% and 52%, exceeding the limit value of 40-45% of the D.M. 2008 for entire and semi-entire brick blocks allowed for masonry constructions in seismic zones. The "foratoni" have a lower percentage of holes, included between 39% and 43%. Unlike the modern hollow bricks that are set in the masonry with the holes orthogonal to the laying surface, these particular types are organized with the holes' axis parallel to the masonry development (horizontal). Thus, in the cross section, these masonry types are characterized by a holes percentage much higher than that of the standard hollow brick blocks ones.

As previous expressed, there are different types of masonry panels in the building in Pistoia. The single leaf walls have a thickness of 30 cm, constituted by a single diaton element of 26 cm (and plaster in both faces), while the double leaf walls are 44 cm thin: 26 cm plus 13 cm refers to the hollow bricks (horizontal and vertical arrangement), 1.5-2.0 cm for the mortar vertical joints and what remains is the contribution of the external plaster. The in situ experimental tests have been carried out in double leaf walls. Their graphic schemas (MQ Form) are shown in Figure 3. In the panels, the section arrangement of the two types of hollow brick blocks is random (in green the "foratoni" and in red the "occhialoni"). The only respected rule is the horizontal disposition of two elements in diaton supported by a vertical orthostat element and repeating this offset order in the upper rows (Figure 3).

The calculated values of MQI provide that these masonries, thanks to regular shape of elements and horizontal joints, could be considered as good masonries ("A" class) in respect to vertical loads, and middle class ("B" class) for the out-of and in-plane loads. This can be explained both with the absence of entire diatons (as visible in the Figure 3) and the not good quality of the mortar that, characterized by weak cement-base mixture, explicates minor resistance in respect of that of the blocks. This is confirmed also by the cracks visible in Figure 8 after the executions of the shear compression tests.

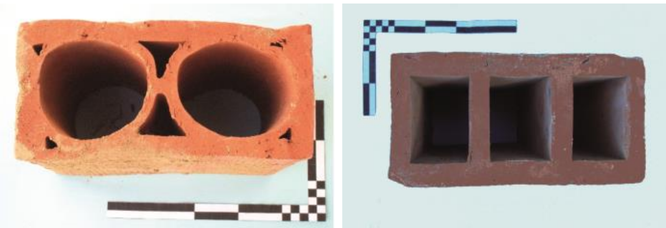

Figure 2. Circular hollow brick block (occhialoni) (a) and rectangular hollow brick block (foratoni) (b).

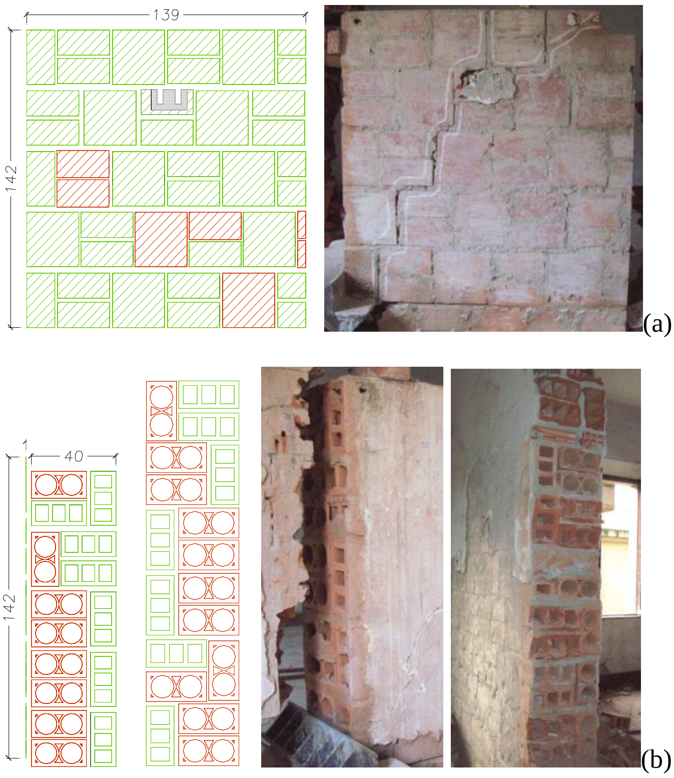

Figure 3. Graphic schemas relative to hollow brick blocks panels: examples of fronts (a) and sections (b).

2.2 *Hand-made concrete blocks masonry*

Vulnerability analysis conducted in building stock of the province of Firenze highlighted the presence of the masonry composed by "masselli" blocks. These elements consist of built-in-work-site or precast concrete elements, made up of sand and river pebbles with a great granulometric irregularity (Figure 4). The constructions composed of the "masselli" masonry were generally built between the XIX and XX century or the two world wars and developed in zones near the rivers or, in certain cases, in the historical inner city. The presence of this "artificial stone" is signaled also in the Piedmont area (Menicali, 1992). The masonry is often characterized by only "masselli" elements but it can be accompanied by brick elements, in the form of random blocks or stringcourses (Figure 4b). This masonry, characterized by a concrete not precast mixture and without holes, is difficulty recognizable in one of those provided by the Code. The tests on this masonry type have been performed both in situ (in one panel belonging of a private building in Brozzi street, in Firenze West zone) and in laboratory, both in reconstructed masonry panels and on some specimens of "masselli" taken from both Brozzi building and from another one in Firenze province.

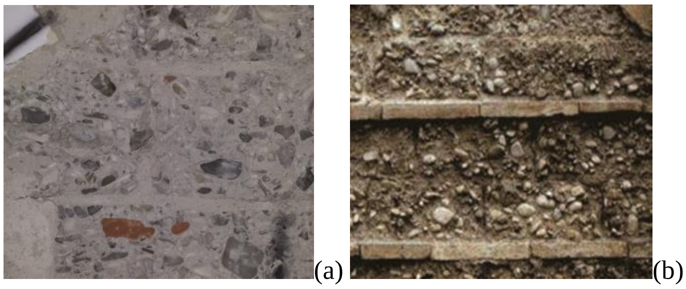

Figure 4. Examples of "masselli" in Firenze province buildings.

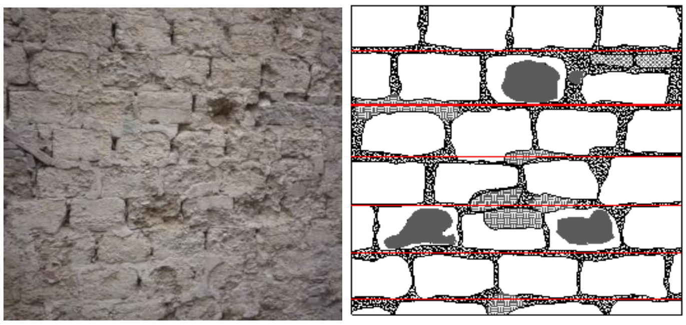

Figure 5. Photo and graphic schema of Brozzi masonry panel.

The structure in Brozzi has one level and it's characterized by load-bearing walls composed of "masselli" of dimensions of 30x29x18 cm (one-leaf masonry) walled with hydraulic mortar and plastered on both sides with cement-based mortar. The photo and the weaving scheme related to the Brozzi panel are shown in Figure 5. About MQI, for "masselli" panels, the arrangement of the blocks is good set, the definition of the horizontal mortar joints and their vertical offsettings are respected, but the quality of the "masselli" blocks is generally not respected since it is strongly correlated to the binder quality and manufacturing and the various dimensions of aggregates that constitute the blocks. The mixture has generally poor lime-base quality, making the blocks in certain cases even friable to the touch. Indeed the values of MQI could vary entre the values of 2.25 ("C" class) and 5.25 ("A" class) if the block quality is considered respectively partially or not "fulfilled".

3 EXPERIMENTAL CAMPAIGN

The experimental investigations have been carried out by the Structures and Materials Laboratory of the DICEA, through in situ and laboratory tests' type.

3.1 Description of the experimental campaign

The experimental campaign refers to:

- in laboratory compression tests on blocks to determine the compressive resistance (f_b). N°31 tests in hollow blocks (with loads acting orthogonal to the holes's axis) and n°9 for "masselli";
- n°1 in situ compression test on hollow brick masonry panel to determine the masonry compressive resistance (f_m) and its elastic modulus (E);
- in situ and in laboratory diagonal compression tests on panels to determine the masonry shear resistance, associated to the diagonal collapse (τ_0) and the shear modulus of elasticity (G). N°2 tests for hollow brick masonry and n°4 tests for "masselli" type.

A brief description of each test and the procedure of interpretation of the results it provided are explained in the following.

3.1.1 *Compression test on masonry blocks*

The compression test on the elements, that allows to determine the compressive strength of the block f_b, has been performed with reference to UNI EN 772-1 2002 and it consists of compressing the parallel surfaces of the specimens with a uniform distributed vertical load, increasing until collapse. The characteristic value of compression resistance for a certain number of specimens is determined with the Eq.(1), provided by Italian Code:

$$f_{bk} = f_{bm} - ks \tag{1}$$

where f_{bk} = characteristic compression strength; f_{bm} = average compression strength of the sample of records; s = standard deviation and k = coefficient depending on the recorded tests number.

3.1.2 *Compression test*

The compression test on masonry panels has the purpose to determine the compression strength (f_m) and the elastic modulus E of the masonry. The test procedure and the elaboration of the data refers to the provisions of "Test Specification – Compression Test" of ReLUIS Project (ReLUIS 2009).

The tested panel, of average size of 180x90 cm, is isolated from the surrounding masonry wall through two vertical slots and one horizontal in its upper part. During the test the panel is subjected to cycles load with increasing maximum value of the vertical compression stress. The placement of vertical and horizontal inductive transducers on the two panel's sides allows the measurement of the vertical and transverse strains of the two leaves continuously with the variation of the vertical load.

The value of the elastic modulus (E) is determined as the secant value enter the minimum inferior load (F_{inf}) and the load equal to 1/3 of the ultimate load of the panel (F_u) as reported in Eq.(2):

$$E_{s,1/3} = \frac{f_{c,1/3} - f_{c,\inf}}{\varepsilon_{v,1/3} - \varepsilon_{v,\inf}} \tag{2}$$

where: $f_{c,1/3}$ = vertical stress acting on the panel in correspondence of 1/3 of the ultimate load (F_u) applied during the test; $f_{c,inf}$ = vertical stress acting on the panel in correspondence of the minimum inferior load (F_{inf}); $\varepsilon_{v,1/3}$ = vertical strain measured at 1/3 of the ultimate load (F_u); $\varepsilon_{v,inf}$ = vertical strain measured in correspondence of the minimum inferior load. The compressive strength f_m is obtained from tests considering the collapse force F_u with the following equation:

$$f_m = \frac{F_u}{A} \tag{3}$$

where A = area of the cross section of the panel.

3.1.3 *Diagonal compression test*

The diagonal compression test on masonry panels, codified in its laboratory version in ASTM E 519-07 (2007), consists in applying a compression increasing load along a diagonal of a masonry panel, causing its shear failure for cracking diagonal collapse. The description of the in situ test apparatus, the measurement of the physical quantities and the elaboration of the data are described in ReLUIS (2009). The value of the shear strength (τ_0) is calculated as in Eq.(4), considering the compresence of shear and compression stress in the center of the panel (Brignola et *al.*, 2010):

$$\tau_0 = \frac{f_{tu}}{1.5} = \frac{F_u}{2A} \cdot \frac{1}{1.5} \tag{4}$$

where F_u = maximum recorded load, f_{tu} = maximum tensile strength of masonry (calculated for $F=F_u$) and A = panel's area (calculated as in ASTM, 2007). Starting from the shear stress (τ) – angular strain (γ)

diagram, the shear modulus (G) at every record is determined through the Eq.(5):

$$G = \frac{\tau}{\gamma} = 1.05 \frac{F}{A} \cdot \frac{1}{\gamma} \qquad (5)$$

where τ = is the value of the shear stress at the generic load step and γ = the correspondent angular strain.

The G value, representative of the elastic behavior of the test, is calculated as the slope of the bilinear behavior of the masonry equivalent to the test curve (τ-γ) in terms of dissipated energy, while the ultimate value, G_u, is determined with the Eq.(5), in correspondence of the shear stress and strain (τ_u-γ_u) for the maximum load achieved during the test, F_u.

3.2 *Results of the hollow brick blocks masonry tests*

The experimental campaign for the hollow brick masonry consisted of:

- n°31 compression tests on the hollow brick blocks extracted from the Pistoia building;
- n°1 in situ compression test;
- n°2 in situ diagonal compression tests.

The in situ tests have been carried out on panels of internal double leaf walls (43 cm thin), belonging at the first floor of the Pistoia building.

3.2.1 *Compression tests on the blocks*

The compression tests have been performed on 22 elements belonging to internal walls even if exposed to external weather conditions due to the presence of a damaged roof. Four test configurations have been considered, applying the loads in the direction orthogonal to the holes' axis for each specimen:

- 1° specimen (1°C): n°11 *circular* hollow elements, characterized by an average φ of 50.7%, have been tested with compression on their larger surface (Figure 6a);
- 2° specimen (2°C): n°6 *circular* hollow elements, characterized by an average value of φ of 47.4%, have been tested with compression on their smaller surface (Figure 6b);
- 3° specimen (3°R): n°7 *rectangular* hollow elements, characterized by an average value of φ of 40.9%, have been tested with compression on their larger surface (Figure 6c);
- 4° specimen (4°R): n°7 *rectangular* hollow elements, characterized by an average value of φ of 41.9%, have been tested with compression on their smaller surface (Figure 6d).

The results for the 4 specimens compression tests are summarized in Table 1, in which are reported: the average compression of the tests, the variation coefficient (ratio among the standard deviation and the average value), the percentile depending on the number of specimen (as reported in 3.1.1) and the 5% percentile calculated as the specimens for each test configuration would have been 30 (k=1.64).

Table 1. Hollow brick blocks tests' results.

Specimen	Average f_{bm}	Variation coeff. δ	Percentile	Percentile 5%
	N/mm^2	-	N/mm^2	N/mm^2
All values				
1° C	3.20	0.29	1.29	1.69
2° C	3.09	0.57	-	-
3° R	13.76	0.24	6.18	8.26
4° R	10.44	0.33	2.68	4.81
All values deleting the biggest one				
1° C	3.05	0.26	1.35	1.72
2° C	2.56	0.52	-	-
3° R	12.99	0.22	6.19	8.20
4° R	9.38	0.23	4.32	5.82
All values deleting the smallest one				
1° C	3.36	0.23	1.70	2.07
2° C	3.48	0.47	-	-
3° R	14.60	0.19	8.18	10.08
4° R	10.97	0.31	2.95	5.32
Average of all values deleting the biggest and the smallest ones				
1° C	3.21	0.21	1.79	2.13
2° C	2.92	0.42	-	-
3° R	13.84	0.16	8.52	10.10
4° R	9.80	0.22	4.80	6.28

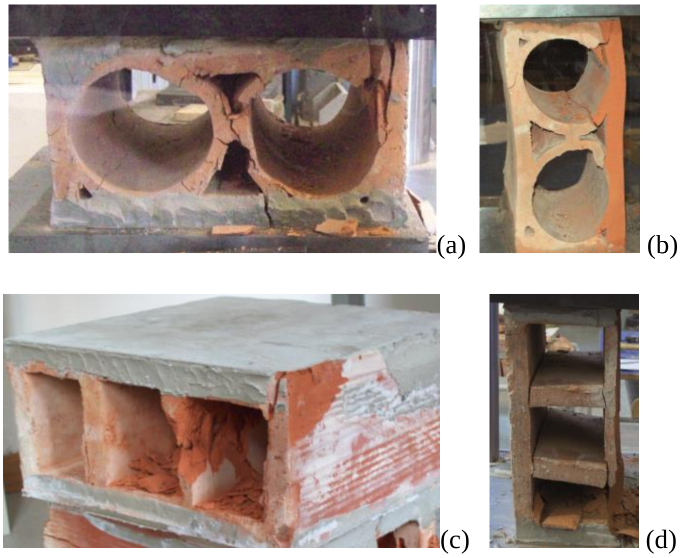

Figure 6. Test load direction of the 1° (a) and 2° specimens (b), 3° (c) and 4° ones (d).

The test results on the sample of specimens provide a higher values of compressive strength for the "foratoni" (on average, more than three times higher). Considering all the tests' results, the average f_{bm} for "occhialoni" loaded in the larger surface is 3.2 N/mm^2, and 13.8 for "foratoni". For both the elements types, the resistance on the larger surface overcomes 1-1.5 times the resistance on the orthogonal direction, since the solid brick resistance area for surface unit is larger. The six tests over the "occhialoni" on the smaller surface (tests named 2°C) provide not homogeneous values, characterized by high dispersion, which do not allow the calculation of the characteristics value.

3.2.2 *In situ compression test*

The compression test has been performed on a panel belonging to a double leaf masonry wall, of dimensions 81x172x40 cm (CS1, Figure 7a). The test results are indicated in Table 2, with a f_m equal to 90.6 N/cm^2 and E=1763 N/mm^2. The test provided values of mechanical parameters significantly lower than those defined in Code for hollow brick masonry with standard percentage of holes. The first cracks opened in the "occhialoni" blocks in the front panel (Figure 7b), since they represent the weakest point of the panel cross section; after that, it is observed a final collapse for out-of-plane rotation of the panel among the hinge developed exactly in the "occhialoni" central section of the front side. This behavior was probably due to the particular disposition of the elements in the external leaf of the masonry, the nature of hollow circular blocks that are susceptible to compression load orthogonal the development of their holes and the wide weighted metallic test apparatus. For all these reasons, the calculated compression strength of the masonry is influenced by the out-of-plane mechanism collapse and it has to be considered as a non-significant value.

Table 2. Results of the compression test, CS1.

F_U	f_m*	$\varepsilon_{v,u}$	$\varepsilon_{v,inf}$	$\varepsilon_{v,1/3}$	E
kN	N/cm^2	μm/m	μm/m	μm/m	N/mm^2
293.5	90.6	648.8	0.00	153.9	1763

* result influenced by the out-of-plane collapse of the panel

Figure 7. CS1 panel rear (a) and front (b) at the end of the test.

3.2.3 *In situ diagonal compression tests*

The diagonal compression tests have been performed on 2 panels of the first floor, constituted of a double leaf masonry wall (CD1 and CD2). Their dimensions are: 139x142x43 and 136x146x43 cm. The tests results are shown in Table 3 and the curves shear stress-strain are reported in Figure 9, with the individuation of the G moduli. The τ_0 is similar for the two tests (average value 4.65 N/cm^2). The first test showed a more rigid behavior, providing G of 645 N/mm^2, at least the double of the G result of CD2 test. Figure 8 represents the panel CD1 (both sides front and cross section) at the end of the test with the individuation of the crack patterns that happened for collapse of compressive beam. The mechanism collapse is influenced by the metallic hooks stiff element (in grey in Figure 8), that represented the starting point of the cracking that afterwards, unlike in the case of the compression test, developed along the mortar joints (horizontal and vertical) which represented the lower resistant elements for those masonry panels.

Table 3. Results of the diagonal compression test.

Specimen	F_U	f_{tu}	τ_0	G	$G_{1/3}$	G_u
	kN	N/cm^2	N/cm^2	N/mm^2	N/mm^2	N/mm^2
CD1	78.05	6.45	4.30	645	721	437
CD2	90.63	7.49	4.99	375	501	134

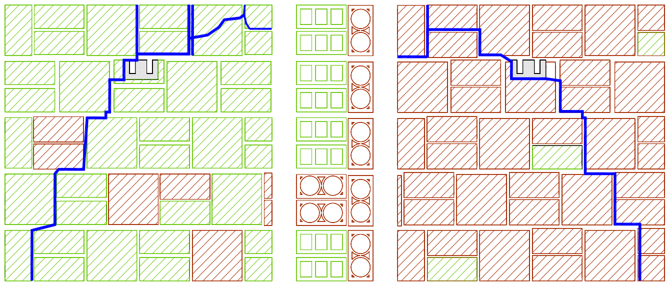

Figure 8. CD1 diagonal cracking after diagonal test (from left, front, section and rear sides of the panel).

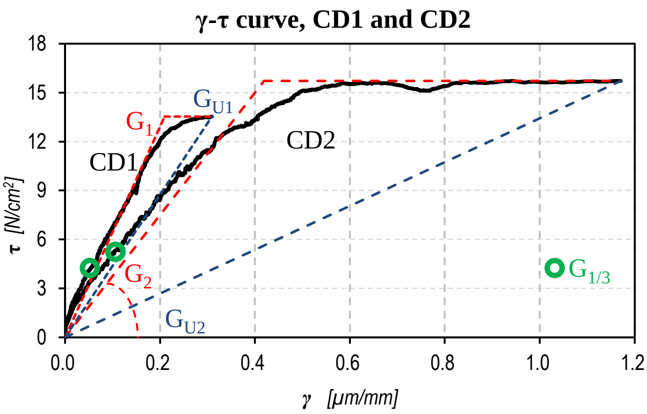

Figure 9. CD1 and CD2 in situ test results (τ-γ curves).

An experimental campaign was carried out in a part of an historic building in Umbria (Borri et *al.*, 2009), rebuilt after the II World War with "occhialoni" one leaf masonry walls. The tested panels, of 26 cm thin with elements disposed with horizontal holes' axis, were walled with weak cementitious mortar type. The campaign cover two double flat jack tests and one diagonal compression test. The double flat jacks showed 98 and 78 N/cm^2 compressive resistance and E moduli enter 1650 and 2470 N/mm^2. The diagonal compression test provided τ_0 = 14.3 N/cm^2, while $G_{1/3}$ 460 N/mm^2. The stiff values (G, E) are comparable with those here reported, while the τ_0 was significantly higher.

3.3 *Results of the "masselli" masonry tests*

The experimental campaign on "masselli" masonry consisted in the execution of:

- n°4 compression tests in laboratory on blocks extracted from the structure in Brozzi. In particular, n°3 tests on specimens (C1, C2 and C3 of 2013) of dimensions of 38x20x18 cm (Figure 10) and 1 on specimen (C4) of dimensions of 38x29x18 cm extracted from the panel on which the diagonal in-situ test was performed;
- n°1 in situ diagonal compression test.

In addition, the results of a laboratory experimental campaign of 1986 carried out for an agreement between the Tuscany Region and the DICEA (Angotti et *al.*, 1986) are reported. The test refers to:

- n°5 compression tests on blocks extracted from a building in Firenze province ($C1_{1986}$ - $C5_{1986}$) of dimensions of 38x16x17 cm, but tested with cubical shape;
- n°3 diagonal compression tests on laboratory made panels composed of extracted blocks of the building in the Firenze province.

3.3.1 *Compression tests on the blocks*

The test results carried out on "masselli" blocks in 2013 are shown in Table 4, while those of the 1986 are reported in Table 5.

Table 4. Results of the compression of 2013.

Specimen	Area	Average density	P_{max}	Compression strength	Average compression strength
	cm^2	kg/m^3	kN	N/mm^2	N/mm^2
$C1_{2013}$	430	2364	183.9	4.27	
$C2_{2013}$	380	2455	147.9	3.89	4.25
$C3_{2013}$	389	2455	164.8	4.23	
$C4_{2013}$	460	2431	211.1	4.59	

Table 5. Results of the compression tests of 1986.

Specimen	Area	Average density	Compression strength	Average compression strength
	cm^2	kg/m^3	N/mm^2	N/mm^2
$C1_{1986}$	297		1.7	
$C2_{1986}$	210		1.5	
$C3_{1986}$	240	2130	1.3	1.5
$C4_{1986}$	232		1.3	
$C5_{1986}$	232		1.5	

The specific density is very different for the two samples: the Brozzi blocks (2013) demonstrated to be more compact, with the density similar to unreinforced concrete (2426 kg/m^3) while the blocks of 1986 experimentation, more porous, have density about 20% lower. The compression strength is 3 times minor for the 1986 blocks, probably due to the their mixture composition and to the used mortar type, since it should be noticed that the realization of these blocks is generally done within the work site, without following specific rules and for this reason, it is very sensitive to the external in situ conditions.

Figure 10. Masselli blocks.

3.3.2 *Diagonal compression tests*

The in situ test has been performed on one panel (CD_{2013}) of the Brozzi building of dimension 119x120x34 cm (plaster included). The laboratory tests (1986) have been performed on 3 laboratory-made panels, CD_{1986} (dimension of 112x124x15.5 cm) composed of extracted blocks from the building in Province of Firenze and walled with three different mortar mix design:

- $CD1_{1986}$_Model 1: cement based mortar, in volume: 1cement, 3 sand;
- $CD2_{1986}$_Model 2: cement based mortar, in volume: 1cement, 4 sand, 0.5 hydraulic lime;
- $CD3_{1986}$_Model 3: mixed mortar, in volume: 1cement, 9 sand, 2 hydraulic lime.

The results of the tests are shown in Table 6. For all the panels the occurred collapse is related to the compressed diagonal cracking. Figure 11 represents the curve shear stress-strain, with the individuation of the calculated G moduli.

Table 6. Results of the diagonal compression test of the specimens CD_{2013}, $CD1\text{-}2\text{-}3_{1986}$.

Specimen	F_u	f_{tu}	τ_0	G	$G_{1/3}$	G_u
	kN	N/cm^2	N/cm^2	N/mm^2	N/mm^2	N/mm^2
CD_{2013}	107.4	13.2	8.81	496	688	174
$CD1_{1986}$	47.0	12.8	8.56	-	-	-
$CD2_{1986}$	52.5	14.3	9.57	-	-	-
$CD3_{1986}$	27.0	7.4	4.92	-	-	-

The result of shear resistance test of Brozzi (τ_0 = 8.8 N/cm^2) is in line with the results of the first two tests of 1986 (average value τ_0 = 9.1 N/cm^2), characterized by a cementitious mortar, while the 1986_Model 3, constituted by mixed mortar, provided shear strength about 45% lower. The elastic shear stiffness is provided by one single test and is worth G = 496 N/mm^2. From the elaboration of the results, the mechanical characteristics found for the "masselli" masonry are comparable with those of the cementitious hollow blocks masonry (φ enter 45 and 65%) described in the Standards (Circ.617/09), which are characterized by a shear strength enter 9.5 and 12.5 N/cm^2 and a G modulus between 300 and

400 N/mm^2. It should be noticed that the number of test carried out could not be considered sufficient to provide characteristic mechanical parameters for this masonry type. It is recommended to carry out other in situ experimentations.

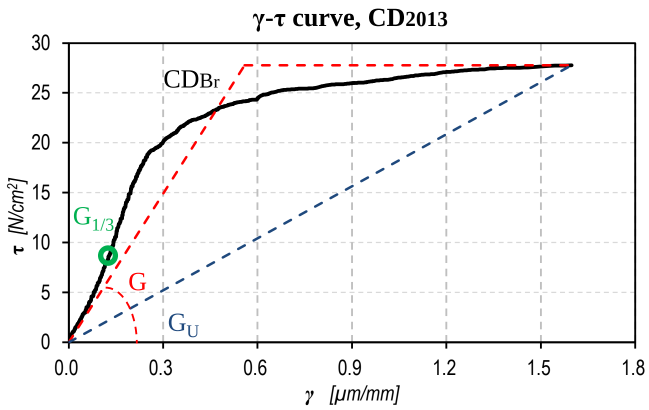

Figure 11. CD_{2013} in situ test results (τ-γ curve).

4 CONCLUSIONS

In this paper, some results of experimental tests on particular masonry categories, which differ from those provided in the Italian Structural Code, are reported. In particular the presented masonry types, identified in the Tuscan buildings but common even in other areas, are composed of hollow brick blocks with holes percentage higher than 40-45% ("occhialoni" and "foratoni" element) and hand-made and built-on-work-side concrete blocks, the "masselli".

The experimental campaign included in situ diagonal compression and compression tests for hollow brick panels in and in situ and in laboratory diagonal compression tests for "masselli" ones. For both masonry types, blocks specimens extracted from buildings have been tested in compression in laboratory.

The results provided that the hollow brick blocks are examples of stiff and fragile masonry types since they expressed a Young modulus of about 1750 N/mm^2 from the compression test but a premature collapse of out-of-plane mechanism with first cracks starting from the circular blocks, that, as showed also from the blocks compression results (f_{bm} = 3.20 N/mm^2), represents the weakest elements of the panels. The ratio among the E and the G moduli provided by the tests is about 3.3, as for the hollow brick masonry defined in the Code (Circ. Min. 617/09).

About the "masselli" masonry, the results of blocks compression tests showed the high variability of blocks specific density and compression resistance (f_b), due to the particular composition and porosity of the mortar's mixture and the type, shape and dimensions of the used aggregates. Moreover, these blocks are particularly sensitive to the condition of the work-site in which they were realized. From the elaboration of the results, shear resistance and the G modulus found for the "masselli" masonry are comparable with those of the cementitious hollow blocks (φ enter 45 and 65%) masonry described in the Standards (Circ.617/09).

It would be useful to implement the experimental campaign for these particular masonry types to characterize from a statistical point of view the obtained results being able to upgrade the Code classification.

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