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Out of Plane Behavior of Calcareous Masonry Panels Strengthened by CFRP

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Abstract

This paper presents the results obtained by an experimental program carried out to evaluate the influence of externally bonded FRP composites on the out of plane behavior of masonry. To this aim two groups of samples were tested for static out-of-plane loads under different vertical load applying orthogonally to the mortar beds. Three panels Carbon fiber-Reinforced Masonry (CRM) were reinforced by one layer of carbon fiber-reinforcing system attached to the tension side of the wall, while the remaining unreinforced three (URM) were used as referring samples. The failure loads, collapse mode, mid-span deflection and fiber-debonding were measured. Based on the data obtained from the experimental program, it appears that the out-of-plane CFRP reinforcement tends to deeply decrease the out-of plane deflection, change the collapse mechanism, and increase enormously its out of plane resistance up to seven times respect to the URM panel.

Keywords: C-FRP, masonry, experimental tests, out of plane loads, retrofitting, historical buildings

1. Introduction

The latest earthquakes have shown the vulnerability of existing Un-Reinforced Masonry (URM) buildings, many of which have historical and cultural importance, This has brought to light the urgent need to improve and develop better methods of retrofitting for existing seismically inadequate URM buildings. For this reason there is significant potential for the application of Fiber Reinforced Polymers (FRP) in the masonry [1,2,3,4]. In fact, FRPs can improve not only the strength capacity of the material, but also the ability to resist crack

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propagation and retain structural integrity through increased toughness. The range of testing needs to be increased to determine whether other unknown modes of failure might occur according to different scheme of loads as well as of different mechanical properties of the masonry units used in the masonry heritage. The stability of the wall under dead load depends on the boundary conditions, wall compressive strengths, joint tensile strengths, wall stiffness, and after cracking if they are within the specified height-to-thickness ratio. In this paper we analyzed the effects of the masonry panel well connected to the extremities but under the out of plane actions caused by the presence of roofs located at different levels (Fig.1). Under these conditions, the produced collapse mechanism is that reported in Fig. 2.

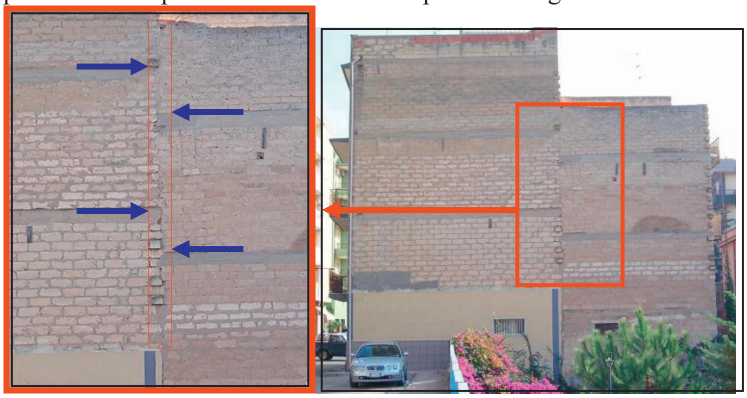

Fig. 1. Collapse mode for combined normal and bending actions

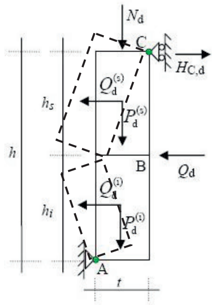

Fig. 2. Out of plane collapse mechanism

2. The constituent units of the masonry

To this scope two groups of panels with the same geometry (55x55x7 cm^3) were selected. The first group was constituted by URM unreinforced specimens (Fig. 3), the second group was CRM constituted by CFRP strengthened specimens (Fig. 4) Both the groups were single thickness wall scaled in size 1:2, keeping the ratio between the mortar joints and the height of the bricks equal to 11 as commonly used in practice.

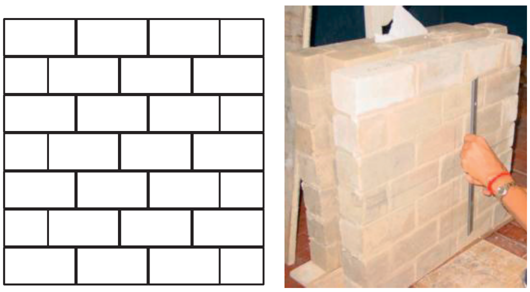

Fig. 3. URM specimen

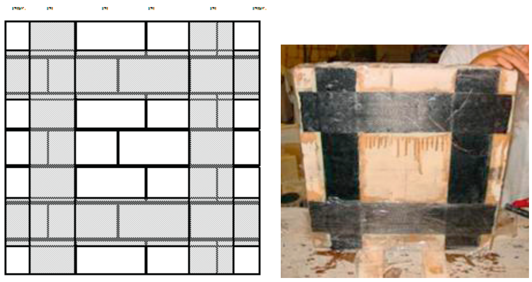

Fig. 4. CRM specime

The mechanical features of the materials used were previously tested by the same authors; they are discussed in [5, 6, 7]. Deeper experimental tests were carried out to determine the mechanical proprieties of the masonry-CFRP composite as well as of the CFRP-masonry bond. The latter are referred in Anania et al. 2013 [8] The main parameters so obtained, are reported in Table 1 and 2:

Table 1. Mechanical properties of materials of URM

Materials	Tensile Strength f_{mtm} (N/mmq)	Compressive Strength f_{mk} *(MPa)*	*γ (kN/m³)*	*E (Mpa)*
Mortar	-	0.795	15	675
Brick	1	12.6	20	12190
Panel	-	4.76	16.5	3500

Table 2. Mechanical properties of materials of reinforced specimens

Material	Tensile Strength f_{mtm} (N/mmq)	Com. Strength f_{mk} (N/mmq)	E (N/mmq)	Sub. Adhesi. (N/mmq)	Equiv. Thickn. (mm)
Composite Panel	-	5.76.60	5700	-	-
CFRP Uniaxial 300	4.830	-	230.000	>3	0.166
CFRP Bi-axial 230/20	4.800	-	230.000	>3	0.1
Epoxy resin	40	40	3.000	>3	-

3. Test set up

The statical scheme employed is the typical scheme of a four points bending tests shown in Fig. 5. So a constant bending moment is obtained in the mid portion as well as a constant shear is obtained at the extremities near the supports.

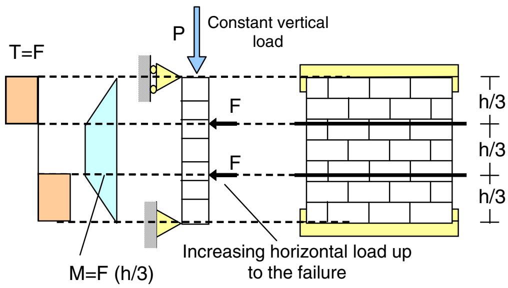

Fig. 5. For points bending test

Fig. 6. Testing equipment

Loads were applied cyclically to failure. To reproduce the typical load-bearing walls found in Southern Italy heritage, a uniformly distributed vertical load capable of simulating the gravity service loads typically acting at the lowest storey, was applied. Fig. 6 shows the test apparatus with a specimen ready for testing. A vertical load was applied by a hydraulic jack connected to a tilting beam, restrained in the plane of the rigid frame used for the test, and capable of transferring the load uniformly. The uniform horizontal action was applied on the faces of the specimen by means of two parallel circular profile points spaced h/3 from the supports welded onto a rigid bucket as shown in fig.7. The Ω transducers, LVDTs, strain gauges and a load cell were used to monitor the response of the specimens to the applied loads: mid-span deflection, strains on the panels ect.. Readings of load, displacements and deflections were recorded by a computerized UPM60 data acquisition system and stored in an Excel spreadsheet file.

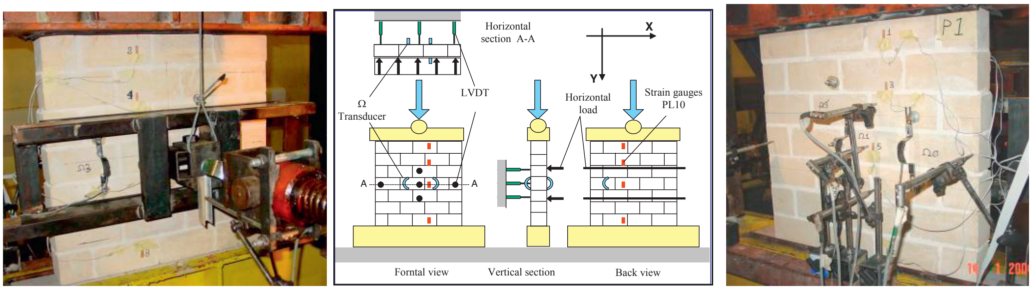

Fig. 7. Instruments disposition in the URM panels

In the strengthened specimens, the CFRP layer were applied as a grid of single layer uniaxial carbon/epoxy composite laminate 100 mm wide with a step, in both the directions, chosen, according to the CNR-DT 200/2004 Italian code, by the formula (1), where “b_f” is the width of the adopted strengthening system and “t” is the thickness of the panel. The CFRP was applied on each side of the wall. The panel was instrumeted similarly to URM sample. Testing equipment is shown if fig. 8.

$$p_f \leq 3\ t + b_f, \tag{1}$$

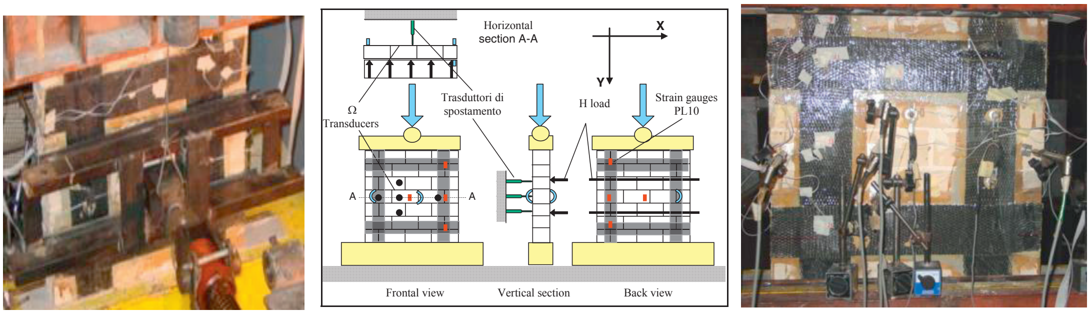

Fig. 8. Instruments disposition in the strengthened panels

4. Tests results

One of the principal focuses of this investigation was on the collapse mechanism occurring for the masonry as well as on the load deformation characteristics of the fiber reinforced concrete masonry wall systems. A small initial load was applied to ensure complete contact of the specimen with the two supports and to the load system. Then, the load was released and an initial reading of loads and deflection was recorded. Then, the loading was re-applied at a steady rate at displacement controlled. The testing program evaluated three different values of the constant vertical load applied “F_v”: 12 kN, 6 kN and 3 kN.

4.1. URM test result

In the case of a higher vertical load, which acts as a stabilizer, the load displacement curve (Fig. 9) gives an apparent high ductility with an ultimate displacement up to 40 mm and a horizontal reagent load of 5kN; when the stabilizing load decreases the panel shows its weakness. The collapse occurs for very low out plane loads. In fact, the restrain conditions at the extremities and the magnitude of the stabilizing load produce the formation of a three-hinged arch, of variable position in the thickness of the masonry, which must be aligned so as to form a mechanism (Fig. 10). By considering a vertical load corresponding to a real vertical load acting on the structure, in the reduced scale, equal to 3 kN, the panels fails under a very low ultimate bending equal to 0,28 kNm. (Fig. 11).

4.2. Strengthened panel by means of CFRP layers

Three specimens were tested under a vertical constant load of 3,0 kN, corresponding to the real load acting on a masonry. The tests were carried out cyclically up to the collapse. The stiffness in the load displacement curve (Fig. 12) slowly degrades up to a peak of the collapse moment. This behavior is mainly due to the failure mode of the specimen; in fact collapse does not occur in the central area because of the achievement of the ultimate bending in this section, but near the supports where the slip between the bricks and a debonding of fibers occurs (Fig. 13). The shear failure is a fragile collapse mode, that occurs before the more ductile flexural mode, is due to the presence of the applied CFRP reinforcement. The elastic flexural behavior can be analyzed in Moment curvature plot of Fig. 14 where it is possible to note the cycles overlapping under an out plane action of 20 kN (2/3 of the ultimate load).

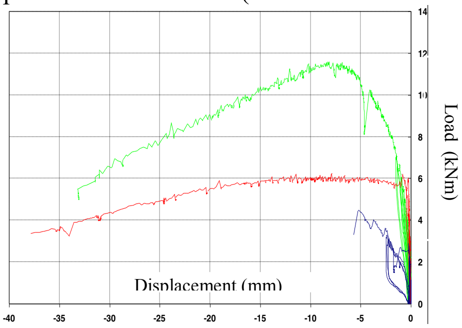

Fig. 9. Load vs dispacement URM panels

Fig. 10. Collapse load URM

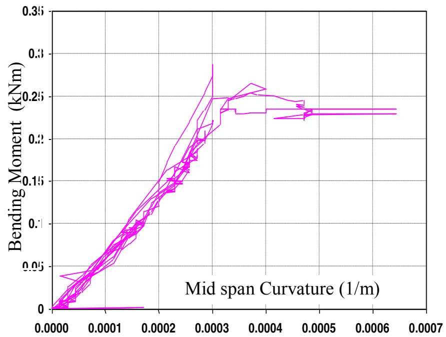

Fig. 11. Bending vs Curvature URM

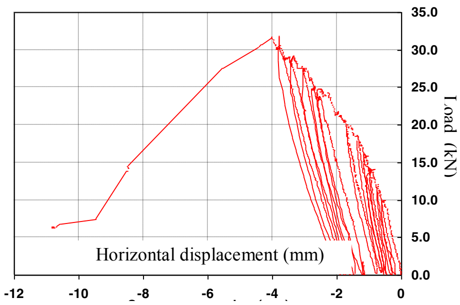

Fig. 12. Load vs dispacement CRM panels

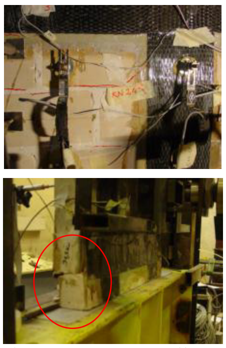

Fig. 13.CRM collapse mode

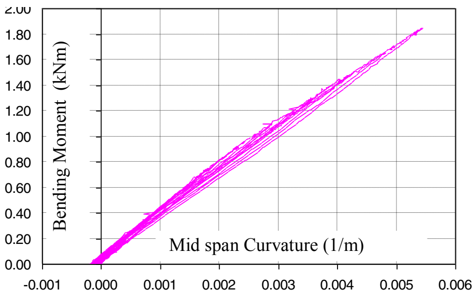

Fig. 14 Bending vs Curvature CRM

Table 3. Data comparison between URM and CRM panels (Fv=3kN)

Materials	Yielding Force (kN)	Yielding displacement (mm)	Collapse Load (kN)	Final disp. (mm)
URM	2,1	0,7	4,5	6
CRM	24,23	1,53	33,33	2,88

5. Conclusions

The tests results made possible to identify the different failure mode between URM and CRM panels. In the URM collapse occurs with the formation of hinge in the mid span of the specimen due to the failure of the parent materials, while in the strengthened specimens failure is associated to the reinforced material. In fact, in the latter case cracks along the bricks occurred firstly, then a deboning of the fiber in the extreme parts is observed; deformations are very small so as to preserve the structural integrity of the wall. The CFRP reinforcement causes the increase of both the elastic limit and of the ultimate load up to 7 times (table 3). Besides, the final deflection is deeply smaller. The proposed strengthening method described in this paper, offers a good rational attempt for consideration by engineers and technicians interesting in out plane masonry reinforcement. The data obtained were very useful for the mechanical characterization of masonry panels wall with openings studied and tested by the same authors [9].

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