Cyclic in-plane testing for evaluation of shear capacity for ceramic block walls

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***Abstract*—**This experimental research aims to provide valuable informations regarding the behavior and shear capacity of ceramic block structural walls, subjected to in-plane horizontal loads. A number of six shear walls are subjected to cyclic horizontal loading in order to observe the response of this type of structural walls. The experimental specimens are built up using brick with vertical hollows which represents a very common system for low-rise buildings (up to 4 stories, depending on the seismic acceleration of the site). Two Fiber Reinforced Polymers (FRP) based strengthening solutions are applied on the six walls specimens, after testing them in bear state (only as brick masonry walls without any FRP components). The main objective of the strengthening solutions is to obtain increased shear capacity for the strengthened elements. However, the efficiency of the provided strengthening techniques is assessed through several parameters that are of outmost importance for applications in seismic areas, such as ductility, stiffness and energy dissipation.

***Keywords*—**ceramic block with hollows, shear walls, FRP materials, strengthening.

I. Introduction

Masonry structures are a significant portion of the world's heritage buildings and a significant component of the modern residential building stock. Particularly this type of structures are susceptible to damage from seismic horizontal loading [1]. In Romania, many of these structures, located in seismic area are built without any reference to seismic design rules. Therefore the need for new strengthening technologies is essential [2].

The traditional strengthening methods available today, such as steel plate bonding, steel frame works, welded mesh, shotcrete jacketing, have disadvantages such as adding considerable mass to the structure, are labor intensive, need creating work space and access limitations, and the most important disadvantage is the aesthetics of the building. Therefore, the use of fiber reinforced polymers (FRP) has gained much attention [1].

The advantages of FRP retrofitting solutions are high strength at low weights, ease of application, requires minor preparation, preserves the material integrity and has high resistance to corrosion over existing conventional techniques [3]. However, external chemically bonding involves complex mechanical and strength phenomena, such as: the possible peeling off of the brick surface, the brittle behavior of FRP both in shear and tension, the effective resisting response of the reinforcement with respect to its theoretical capacity, the influence of friction and dilatancy in the brick-mortar interface on the response of the strengthening and the coupling difference strength mechanisms activated by the reinforcing, which include an increase friction due to the generation of normal anchoring forces and the contribution of the shear strength of the laminates [4].

The present experimental study is focused on masonry walls built with ceramic blocks with hollows, which is a very common system in our country for low-rise buildings, up to 4 stories, depending on the seismic ground acceleration. The strengthening was made using FRP solutions, after testing the masonry walls in bear state.

II. Experimental Program

A. Test plan

The experimental tests were performed on two masonry walls subjected to a constant vertical load and horizontal cyclic loading. Each wall had the length and height of 1,50 m and the thickness of 25 cm. The horizontal load was increased until the collapse mechanism was activated, then the applied load was removed and each wall was strengthened with FRP materials. The strengthening solutions were applied on the damaged structures and the results allow us to evaluate the enhancement of the structural response of the masonry walls due to the application of the FRP [5].

The test frame considered, is built of three main parts: a reaction frame for the horizontal load, a reaction frame for the vertical load and a sliding frame as seen in Fig. 1. The horizontal load was transferred through the sliding frame to the test units. A dynamic actuator was used to carry out displacement control tests.

Instrumentation consisted in 12 displacement traducers and 2 pressure traducers in order to determine the drift of the wall, the forces applied and to determine if there is any out of plane displacement, as seen in Fig. 1.

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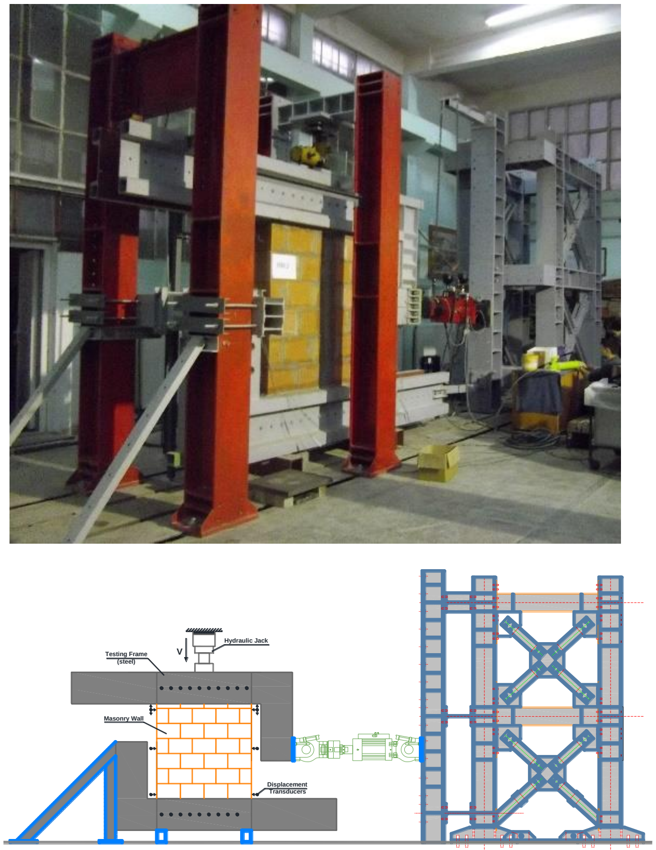

Fig. 1 Experimental stand and loading scheme

B. *Test specimens*

The masonry wall specimens, where built using ceramic blocks with hollows and as seen in Fig. 2. the first specimen was unreinforced masonry (URM1), the second was reinforced masonry with two concrete columns on sides (RM1) and the third was reinforced masonry with one central concrete column (RM2). The position of the reinforcement can be seen in Fig. 4. The FRP mesh and the FRP carbon plate, were applied in diagonal sections. The URM1 specimen was strengthened using FRP carbon plates and for the RM1 and RM2 specimens was used a FRP carbon mesh material. The strengthening configurations were applied on both faces of the walls. The FRP materials were applied only after the surface of the masonry walls was levelled with a thixotropic epoxy resin as seen in Fig. 3.

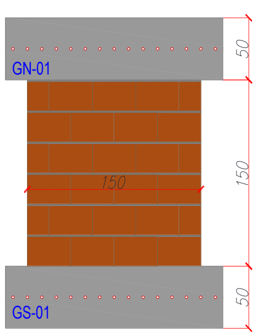

Fig. 2 (a) Test specimen URM1-unreinforced masonry wall

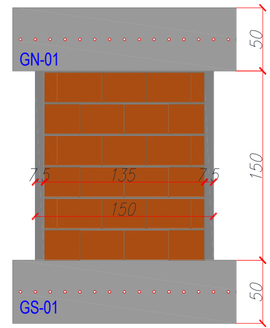

Fig. 2 (b) Test specimen RM1-reinforced masonry

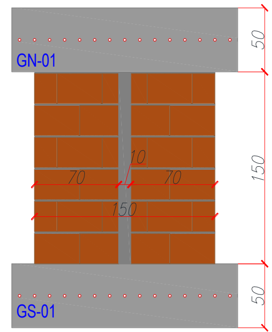

Fig. 2 (c) Test specimen RM2-reinforced masonry

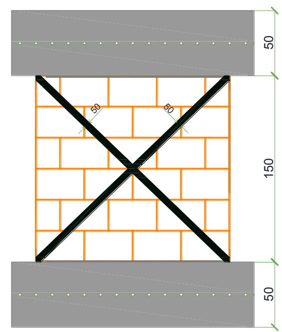

Fig. 3 (a) Strengthened test specimen URM

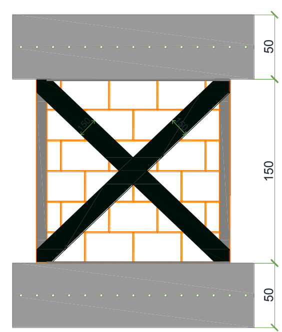

Fig. 3 (b) Strengthened test specimen RM1

C. *Material properties*

The material properties for masonry walls and CFRP mesh and the carbon plate are given in Table 1. The masonry properties were determined from material tests conducted. The walls were constructed by a qualified brick layer using brick hollowed units and general purpose mortar, consisting of cement, hydrated lime and sand. The FRP material properties shown in Table 1 were obtained from the manufacturer's data sheets.

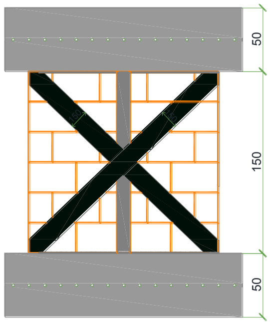

Fig. 3 (c) Strengthened test specimen RM2

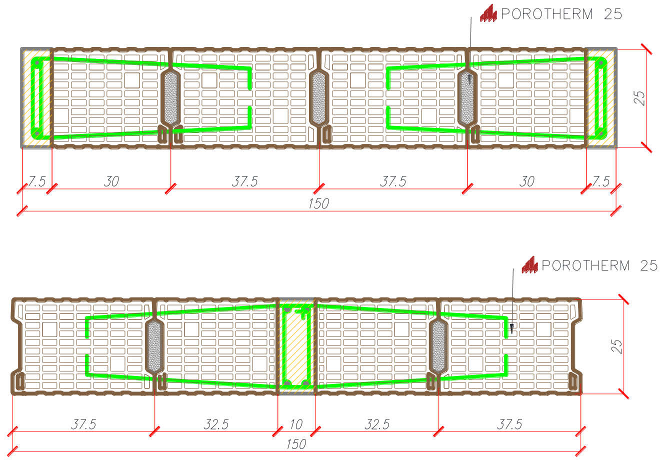

Fig. 4 Reinforcement position for the masonry walls RM1 and RM2

III. EXPERIMENTAL RESULTS

As mentioned before, the specimens were subjected to a lateral horizontal load. The vertical load applied was constant.

Table 1 – Material properties for wall test specimens

Parameter	Thickness mm	Density g/cm^3	Tensile strength N/mm^2	Viscosity MPas	Shear strength N/mm^2	Compressive strength N/mm^2
Primer	-	1.1	-	300	-	-
Thixotropic epoxy	-	1.70	-	800000	-	-
Medium viscosity epoxy resin	-	1.06	40	7000	-	70
Carbon plates	1.4	0.00161	3100	-	77	-
Carbon mesh	0.166	1.8	4830	-	-	-
Parameter	**Flexural tensile strength N/mm^2**		**Compressive strength N/mm^2**		**Elastic modulus masonry N/mm^2**	
Masonry	0.14		3.98		2350	

As mentioned before, the specimens were subjected to a lateral horizontal load. The vertical load applied was constant. The two masonry specimens failed in the classical failure mode: diagonal cracking. Due to the great irregularity in the masonry texture, the strengthening of the panels was carried out only after spreading a layer of thixotropic epoxy resin, to create a sufficiently plane, uniform surface on which the FRP material was then applied. The maximum load increased with 15% at the reinforced wall RM1, compared with the unreinforced wall URM1, and the maximum displacement also increased with 10%. The difference is not very important, but RM1 supported much more loading cycles, therefore has a higher ductility.

The first retrofitting solution, using FRP carbon plates, even though involves higher costs, had a very good result. The maximum load increased with 85%. The failure mode was very fragile, the disadvantage been the splitting of the carbon plates with the peeling of the ceramic blocks, as seen in Fig. 5.

For the second masonry wall RM1, the retrofitting solution was with CFRP mesh. The surface was uniformed also a thixotropic epoxy resin and after drying, the mesh was applied using a glued resin. The results were not so spectacular, but the wall was able so support a horizontal maximum load similar with the initial wall, which proves the efficiency of this type of retrofitting solution. The failure mode was also fragile, with the splitting of the CFRP mesh with the peeling of the ceramic block as seen in Fig. 6 [6].

For the third masonry wall RM2, the retrofitting solution was also with CFRP mesh. The results were very good due to the fact that the strengthened wall regained the capacity to support the same horizontal force with the wall in bear state. The failure mode was also with the splitting of the CFRP mesh with the peeling of the ceramic block as seen in Fig.7.

The Displacement-Load diagrams for the 3 walls can be seen in Fig. 8.

IV. CONCLUSIONS

The experimental program was conducted to identify the effectiveness of retrofitting damaged URM and RM shear walls with FRP carbon plates and CFRP mesh. The following conclusions can be drawn from this experimental study:

Fig. 5 Failure mode for URM1-C (URM1-strengthened)

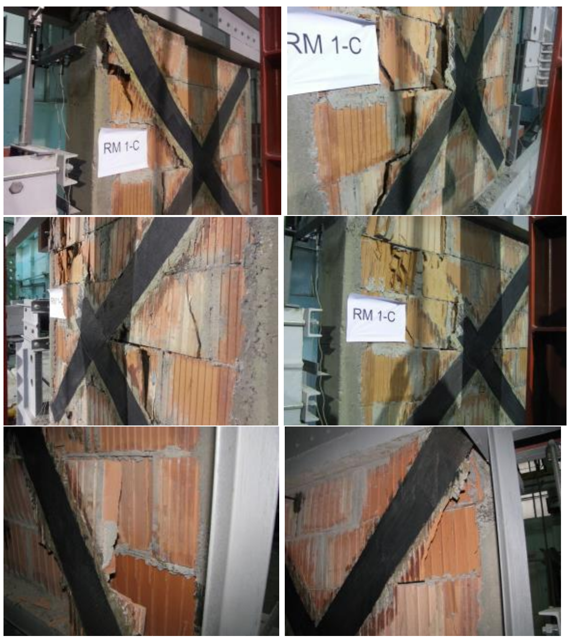

Fig. 6 Failure mode for RM1-C (RM1-strengthened)

- The displacement capacities of the walls increased once due to the reinforcement of masonry and second due to the retrofitting solutions applied.
- The maximum load was significant increased in the first retrofitting solution with FRP carbon plates, but in the second retrofitting solution the load was at 90% from the initial load and for the third wall the load was at 100% from the initial load. However, the retrofitting was successful in restoring the maximum load and even increasing it substantially during the test and allowing a larger maximum displacement for all the walls tested until now.
- The retrofitted walls displayed greater energy dissipation ability compared with the walls in bear state [7].
- If we compare the experimental tests of the walls in bear state with the strengthened walls we can observe the following differences, as seen in Fig. 9.

Fig. 7 Failure mode for RM2-C (RM2-strengthened)

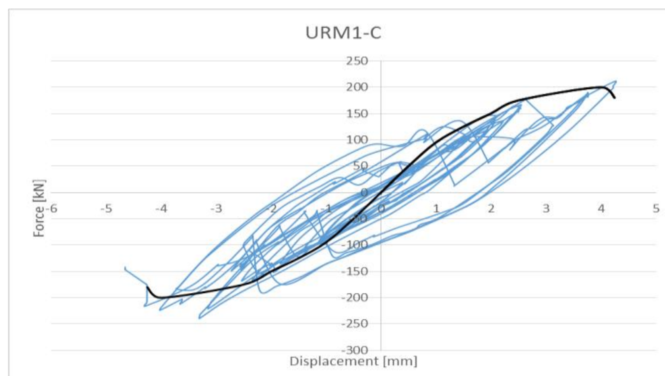

Fig. 8 (a) Force-Displacement Diagrams for URM1-C

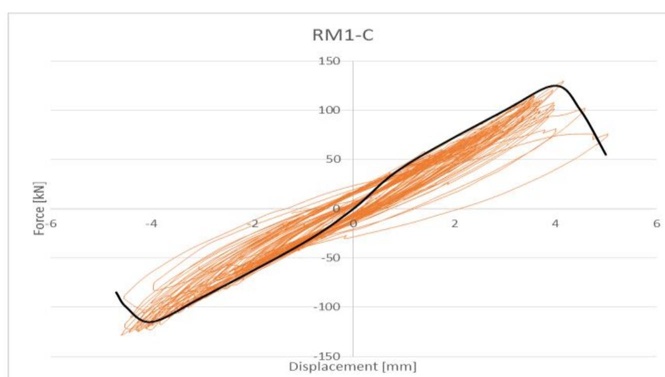

Fig. 8 (b) Force-Displacement Diagrams for RM1-C

The results highlight the effectiveness of the FRP carbon plate and CFRP mesh in improving the performance of masonry walls under cyclic in-plane shear loading. Future

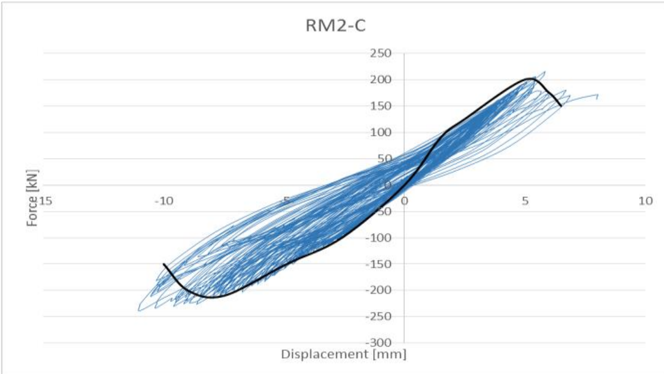

Fig. 8 (c) Force-Displacement Diagrams for RM2-C

Future work will focus on further experiments of this type of wall, with this type and other retrofitting solutions.

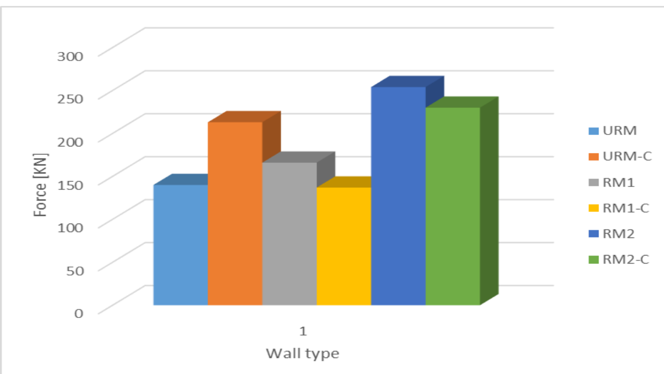

Fig. 9 Maximum horizontal load applied for the six experimental tests

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