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IN PLANE CYCLIC BEHAVIOR OF MASONRY WALLS JACKETED WITH FIBER REINFORCED MORTAR AND FIBER GRIDS

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Abstract: Masonry buildings represent the most vulnerable part of the building stock to seismic action in Romania. The main goal of this experimental research program is to investigate the efficiency of several retrofitting solutions using fiber reinforced polymers. Research focused on the lateral strength and displacement capacity of the retrofitted specimens. The masonry walls were built using solid bricks. Glass or carbon fiber reinforced polymers (GFRP or CFRP) embedded in a fiber reinforced mortar layer were used for jacketing. Seven specimens having essentially 25cm width, 1,75m height and 2,10m length were tested in the experimental research program. These specimens were subjected to a constant vertical compressive stress of 1,2MPa. A quasi-static load protocol was considered for the horizontal loading. This paper presents the layout of the experimental research program and some preliminary results.

Keywords: seismic, fiber reinforced mortar, glass/carbon fiber grids

1. Introduction

The most seismic vulnerable buildings in Romania are masonry structures. To reduce the earthquake social and economic impact, retrofitting of these structures needs to be prioritized. Adding new reinforced concrete (RC) shear walls and RC jacketing represents the traditional retrofitting techniques in Romania. These good technical solutions usually imply a long construction time, building operation interruption, temporary relocation of the inhabitants, alteration of the finishing or building facilities [1,3].

FRP jacketing represents an alternative option for retrofitting the existing masonry buildings. The main advantages are the relatively high strength to weight ratio, short construction time and the natural corrosion resistance [2].

FRP sheets are usually bonded on structural elements using epoxy resin. Poor fire resistance, alteration of the resin behavior at high temperatures and UV sensitivity represent the main shortcomings of this solution [5]. Moreover, poor permeability to moisture vapors that might cause moisture accumulation in the walls presents a particular importance in case of historic or architectural monuments.

The use of glass or carbon fiber grids embedded in a cementitious matrix represents an alternative solution. The advantages of this solution are [5]: fair fire resistance, good compatibility with the support, good permeability to moisture vapors and easy installation by medium skilled workers. The efficiency of the retrofitting work can be further improved if fiber reinforced mortar (FRM) is used.

Experimental research on this retrofitting technique was performed within the project “Conventional and unconventional experimental methods to determine the performance level for materials, elements and structures – METEX”. Some of the obtained results are reported here.

2. Experimental Program

Seven masonry specimens with different retrofitting solutions were considered in the test plan.

All specimens were 1,75m in height with a rectangular cross-section of 2,10m x 0,25m except for specimen WMET6. Specimen WMET6 had an asymmetric cross-section with a rectangular end zone of 0,25m x 0,25m at one end and a rectangular web of 0,125m x 1,85m. Full bricks recovered from a demolished building having average compression strength of 1,45MPa were used. Two reinforced concrete boundary ties, located at the top and bottom end of the masonry walls, with cross-section of 0,30 m x 0,30m, were used for each specimen to ensure the load transfer. These were attached to the reaction frame such as only their translation in the longitudinal and vertical direction was allowed.

Retrofitting solutions based on Carbon Fiber Reinforced Polymers (CFRP) and Glass Fiber Reinforced Polymers (GFRP) grids were implemented for all specimens. The polymeric grids were embedded in a 15-25mm think Fiber Reinforced Mortar (FRM) layer. The effectiveness of the retrofitting work considering different jacketing solutions applied on both faces of the walls or on a single face was investigated. Two reference specimens were tested: WMET1 – un-retrofitted masonry wall and WMET8 – retrofitted masonry wall just by FRM jacketing on both sides.

The characteristics of the repairing and retrofitting materials are presented in Table 1 and Table 2. The main characteristics of the specimens are presented in Figure 1 and Table 3.

Table 1

Mortar characteristics (MAPEI Planitop HDM Maxi)

	Testing method	Requirements according to EN1504-3, Class R2 mortars	Product performance
Compression strength (MPa):	EN 12190	≥15 (after 28 days)	>3 (after 1 day) >15 (after 7 days) >25 (after 28 days)
Bending strength (MPa):	EN 196/1	Not required	>2 (after 1 day) >6 (after 7 days) >8 (after 28 days)
Elasticity modulus in compression (GPa):	EN 13412	≥20 (after 28 days)	11 (after 28 days)
Concrete bond (MC 0.40) – water to cement ratio of 0.40 according to EN 1766 (MPa):	EN 1542	≥0.8 (after 28 days)	>2 (after 28 days)

Table 2

Fiber grids characteristics

Glass fiber grids (Mapegrid G 120)	
Fiber type:	Alkali resistant fiberglass
Weight (g/m2):	125
Grid spacing (mm):	12.7 x 12.7
Maximum load per unit length (kN/m):	>25
Ultimate tensile strain (%):	<3
Carbon fiber grids (Mapegrid C 170)	
Fiber type	High-strength carbon fiber
Weight (g/m2):	170
Grid spacing (mm):	5 x 5
Maximum load per unit length (kN/m):	>225
Ultimate tensile strain (%):	2

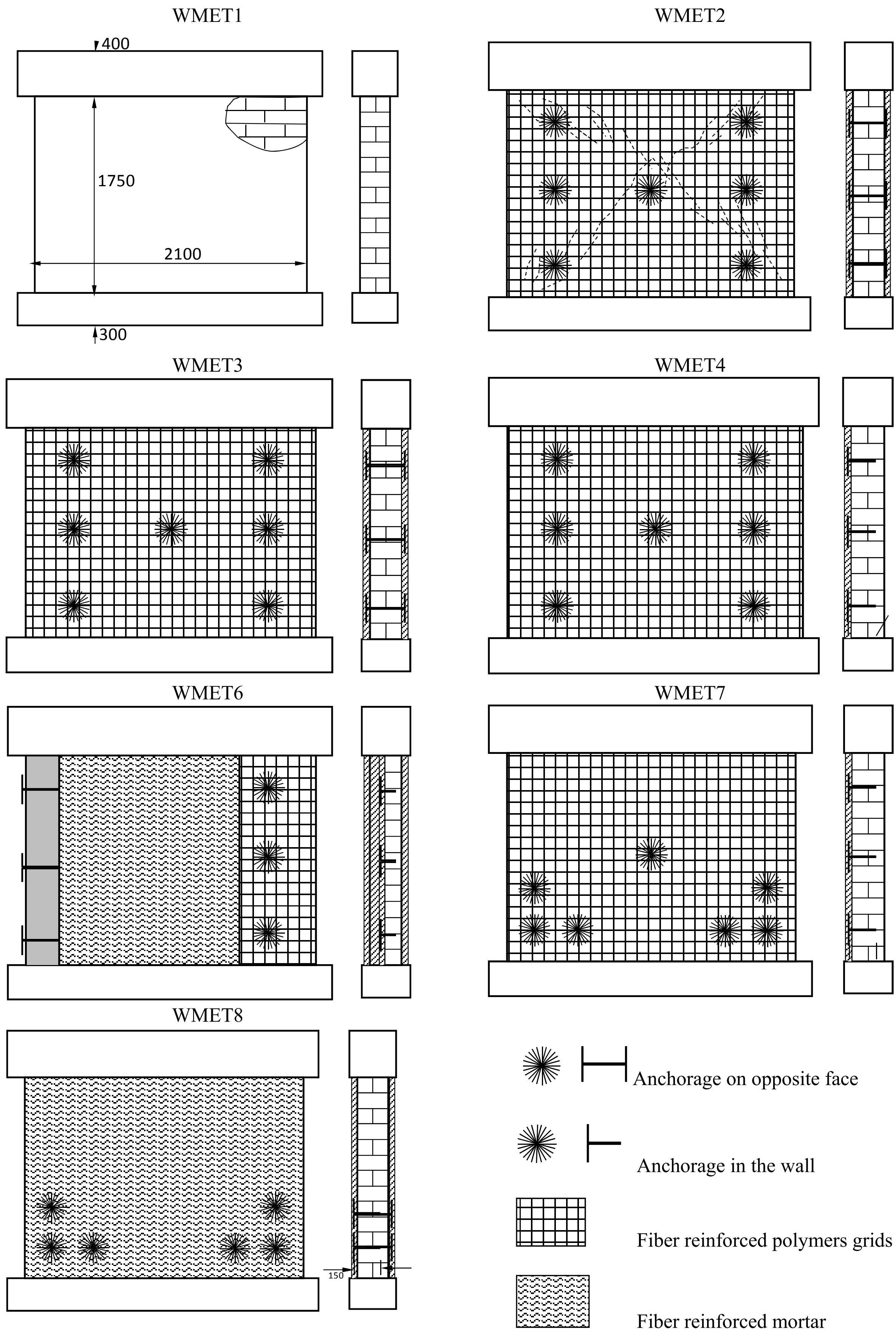

Fig. 1 - Simplified representation of the specimens

Table 3

Specimen characteristics

	WMET1	WMET2	WMET3	WMET4	WMET6	WMET7	WMET8
Repaired:	NO	YES	NO	NO	NO	NO	NO
Retrofitted:	NO	YES	YES	YES	YES	YES	YES
FRM	NO	YES	YES	YES	YES	YES	YES
CFRP :		NO	NO	2 layers	2 layer	2 layer	NO
GFRP		2 layers	2 layers	NO	NO	NO	NO
Applied on:		Both faces	Both faces	One face	One face	One face	Both faces

Displacement controlled quasi-static cyclic loading was performed. The specimens were subjected to a cyclic, statically applied, lateral force under a constant axial load. The lateral force was applied using two horizontal 100t hydraulic jacks. The lateral loading protocol included one cycle at ±0,25% lateral drift and two cycles for each peak at ±0.05%, ±0.1%, ±0.2%, ±0,4%, ±0,6%, ±1,0%, ±1,5%. After 1,5%, the lateral displacement was increased up to failure ("pushover" loading). The lateral load protocol is presented in Figure 2.

The axial load was applied using one 200t vertical jack. A mean axial stress of 1,2MPa was applied at the beginning of the test and maintained constant up to failure. The corresponding axial force was 750kN for all specimens except for WMET6 where the axial force was 420kN to take into account for the smaller width of the web. Tests were stopped when the loss in the axial force carrying capacity occurred. The reinforced concrete boundary ties at both ends of the specimen were fixed against rotation. A simplified representation of the measurement system is presented in Figure 3.

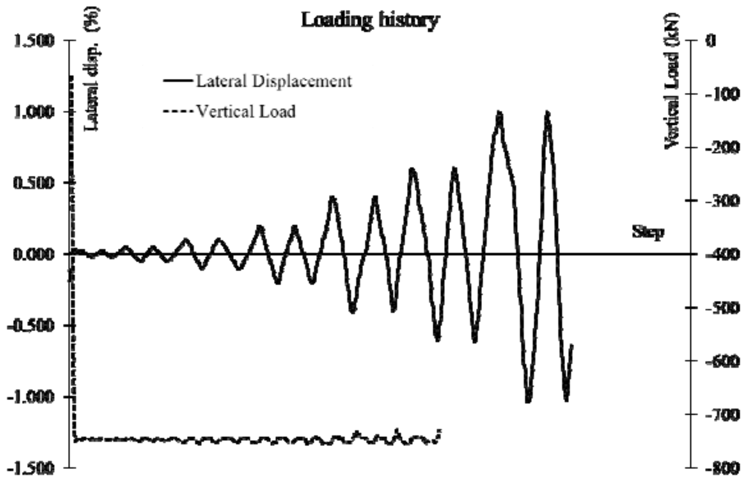

Fig. 2 - Loading protocol

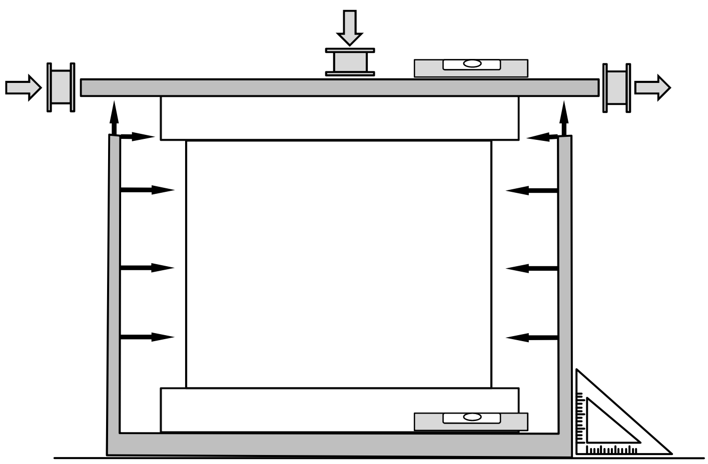

Fig. 3 - Loading and measurement

3. Failure Patterns

Simplified representations of the failure modes are given in Figure 4.

In case of WMET1 a diagonal failure was noticed. At the first deformation cycle at 0,4% lateral drift, the diagonal cracking process initiated. In the subsequent cycle, cracks developed along the other diagonal. Considering the damage state of the specimens, after two loading cycles at ±4% lateral drift, loading was stopped.

After the loading test, WMET1 was repaired and retrofitted. This retrofitted specimen was called WMET2. FRM jacketing with one layer of GFRP grids on each side of the wall was applied. The first diagonal cracks at the surface of the mortar jacket were noticed at the second loading cycle at -0,4% drift. These cracks had different orientation in comparison with WMET1 starting from the midpoint of the upper side to the right corner at the bottom side. In the following cycle a symmetrical crack starting from the left-bottom corner appeared. Subsequently, at the following cycles at 0,6% and 1,0% inclined cracks along the main diagonals appeared. At 1,36% drift slip was noticed in the horizontal joint between the masonry wall and the bottom concrete boundary tie and the loading test was stopped.

Specimen WMET3 was obtained by retrofitting an undamaged masonry wall using the same techniques as for specimen WMET2. At 1% lateral drift slip at the horizontal joint between the masonry wall and the bottom concrete tie was noticed. The corresponding lateral force was approximately 500kN indicating an equivalent friction coefficient of 0,7. No cracks at the surface of the mortar jacket and no damage to the bottom corners of the masonry wall were noticed.

Specimen WMET4 was obtained by retrofitting an un-damaged masonry wall by applying a FRM jacket embedding 2 layers of CFRP grids on one face of the wall. Loading was stopped at 0,8% lateral drift, during the first loading cycle to +1%. At +0,6% drift a sudden decrease of the lateral strength followed by a severe increase of the vertical deformation was recorded. No cracks could be seen at the surface of the FRM jacket. On the opposite side, at the second loading cycle at +0,4% lateral drift inclined cracks starting from the midpoint of the upper side to both bottom corners were noticed. After two loading cycles at 0,2% splitting cracks at the bottom corners of the masonry walls appeared.

In case of WMET6, a vertical crack separating the web from the end zone of the wall was noticed at 0,3..0,4% lateral drift. Subsequently, a sudden decrease of the lateral force of approximately 30% from the maximum one was recorded. Further loading up to 0,6% drift increased the wall damage until the loss of the vertical load carrying capacity. Retrofitting at one end on the cross-section by FRP wrapping prevented the deterioration of this end under the applied compression stress.

In case of WMET 7, during the first loading cycle to -1%, at 0,6% lateral drift, the first major fracture occurred. A lateral force decay of app. 30% was recorded. After this event, loading to 1% lateral drift was continued. As failure to vertical load was observed, after the first loading cycle to 1% lateral drift lateral loading was stopped.

WMET8 responded essentially elastically up to 0,4-0,6% lateral drift. At the peak of the first loading cycle to -0,6% drift first diagonal cracks were noticed. At the peak of the second cycle to -0,6% drift, failure of the wall by a diagonal crack developed from the midpoint of the upper side to the bottom-left corner was noticed.

Maximum recorded values for loads and displacements in tests for each specimen are given in Table 4.

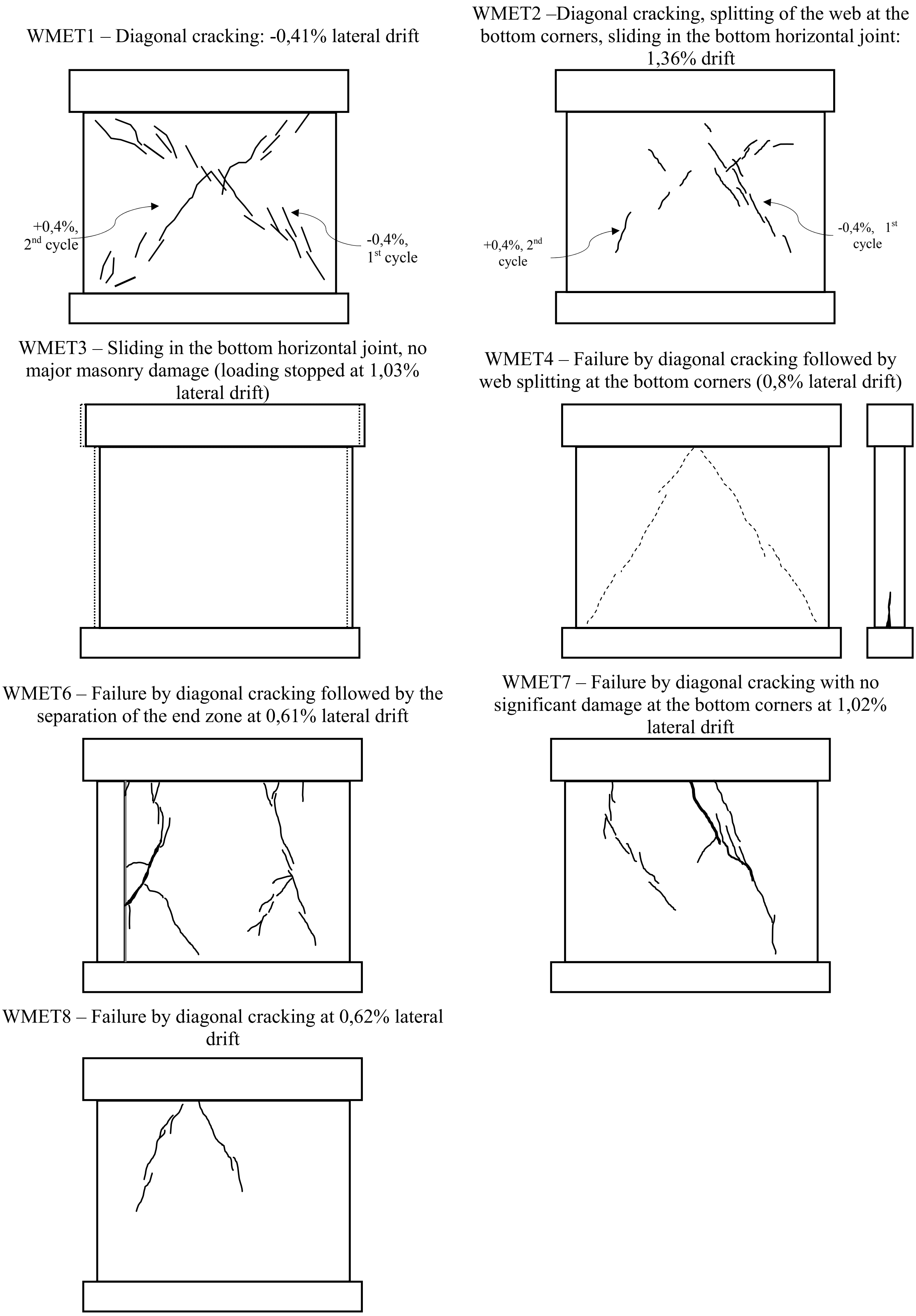

Fig. 4 - Failure patters and peak lateral displacements

Table 4

Peak forces and displacements

	WMET1	WMET2	WMET3	WMET4	WMET6	WMET7	WMET8
Peak lateral displacement	-0.41%	1.36%	-1.03%	0.8%	0.61%	1.02%	0.62%
Peak lateral force (positive)	452	534	539	494	258	409	467
Peak lateral force (negative)	-415	-555	-470	-478	-206	-419	-491

4. Conclusions

The failure mode of the retrofitting masonry walls strongly depends on the retrofitting details. All the specimens were retrofitted using the same general jacketing solution but different details were considered. The failure modes were different.

Jacketing both sides of the masonry wall with a moderate amount of glass or carbon fibers resulted in the best behavior.

The failure mechanism of the jacketed masonry walls strongly depends on the jacketing details. Two faces jacketing with a moderate amount of fibers gives the best results. In case of WMET3, sliding in the horizontal joint at the interface with the RC support element was observed. After the occurrence of sliding, the lateral force was constant and the damage state was stable.

FRP jacketing improved the capacity of diagonal compression strut. The increased diagonal compression force led to the failure of the web at the corners under compression. The diagonal strut had the smallest width at the corners so a high diagonal compression stress developed in this area. While failure of the web by diagonal cracks is prevented by FRP, a splitting crack appeared in the midplane of the wall (Figure 5). This crack was parallel to the compression stress in the diagonal strut. In case of specimens WMET2 and WMET4 this failure mechanism was observed. If the FRP jacket is bended around the corners of the wall and anchored on the opposite face (Figure 6,a), the efficiency of the jacketing is highly improved. This is not possible in many practical situations, as the wall is usually confined by other walls or columns. To obtain a proper anchorage of the fiber grids to the masonry walls steel wire anchors (Figure 6,b) were also used. A lower efficiency of this anchorage system was observed during the tests.

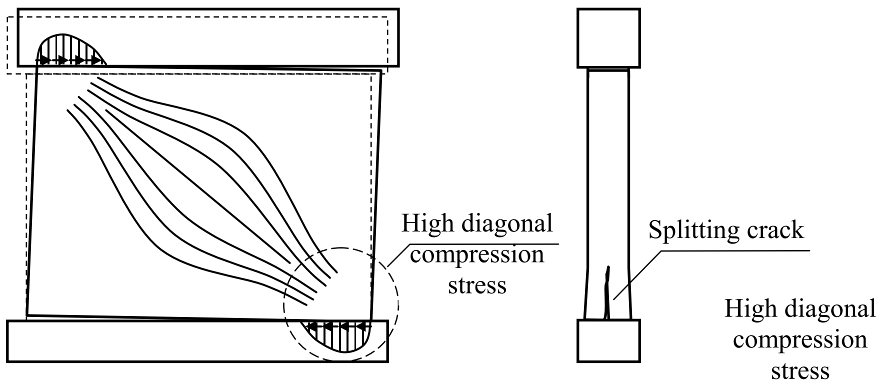

Fig. 5 - Failure by splitting of the web at the bottom corner

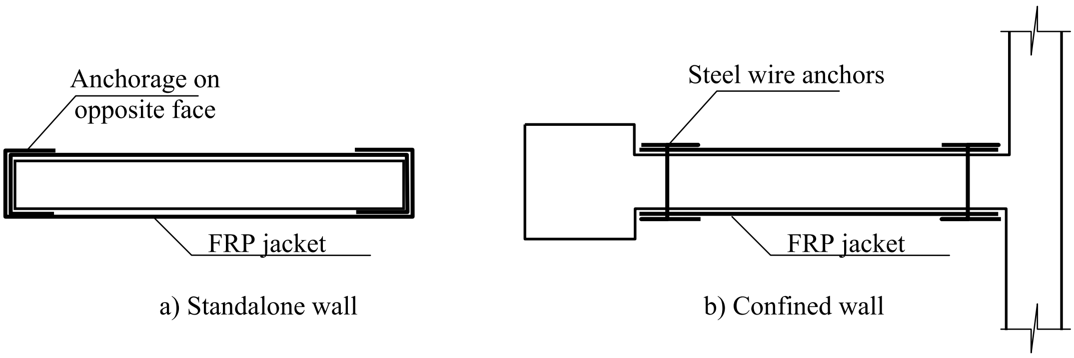

Fig. 6 - Anchorage options for FRP jackets

A comparison between the tested specimens and similar un-retrofitted masonry walls, previously tested in the laboratory [6,7], shows that the displacement capacity and lateral strength are not necessarily improved in a satisfactory manner by FRP jacketing. For un-retrofitted masonry walls ultimate lateral drift angles of app. 0,6% were obtained. For retrofitted specimens values between 0,8% and 1,4% were observed. In case of specimen WMET4, retrofitted by FRP jacketing on one face with no proper confinement of the corners in transversal direction, an insignificant increase of the lateral displacement capacity was observed. The strength improvement of app. 20% cannot compensate the insignificant increase of the displacement capacity.

The results of this testing program will be further analyzed and reported.

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