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Contribution of a Special Plaster on the Out-Of-Plane Bending Behavior of Unreinforced Masonry Walls

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ABSTRACT

The present study aimed at investigating the effect of a special plaster on the out-of-plane behavior of masonry walls. A reference specimen, plastered with conventional plaster, and a specimen plastered with a special plaster were tested under reversed cyclic lateral loading. The load was applied with the help of a special loading mechanism, creating a moment diagram similar to the one under uniform distributed out-of-plane loading throughout the wall. The specimens were identical in dimensions and material properties. The special plaster contained an additive, which increased the adherence strength of the plaster to the wall. The amount of the additive in the mortar was adjusted based on the preliminary material tests. The influence of the plaster on the wall behavior was evaluated according to the initial cracking load, type of failure, energy absorption capacity (modulus of toughness), and crack pattern of the wall. Despite having limited contribution to the ductility, the special plaster increased the ultimate load capacity of the wall about 25 %. The failure mode of the wall with special plaster resembled the plastic failure mechanism of a reinforced concrete slab in the formation of yielding lines along the wall. The deflection at failure and the modulus of toughness of the wall with special plaster were measured to be in order of 60 % and 75 % of the corresponding values of the reference wall.

Keywords: Structural strengthening; seismic loading; earthquake-resistant design.

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1. Introduction

The earthquake resistance of masonry structures is a significant cause of concern in many developing and underdeveloped countries since a majority of the building stock in the rural areas of these countries consist of masonry structures. Most of these masonry structures are non-engineered, in other words they are constructed without the supervision of engineers and with poor workmanship. The lack of adequate and proper bond between the masonry units results in significant reductions in the earthquake resistance of these structures, which will have much less lateral strength and rigidity values compared to concrete and steel structures.

Among the three groups of masonry structures, namely the unreinforced masonry, confined masonry and reinforced masonry, unreinforced masonry (URM) buildings constitute the most common type of structural system in rural residential areas. URM structures mainly consist of reinforced concrete slabs and roof, masonry walls and foundation. The masonry walls are the main load-carrying members of these structures, which are also responsible for resisting the lateral and vertical earthquake loads. The lateral loads are generally present at the level of the slab, where a major portion of the structural mass is present. These floor loads induce out-of-plane bending in some of the walls, while resulting in in-plane bending of some others. The URM walls are much weaker in out-of-plane bending compared to the in-plane bending.

Due to the lack of supervision and poor workmanship, masonry structures are liable to brittle failure even under low-to-moderate earthquakes. Failure of these structures is usually initiated in the members subject to out-of-plane bending. Different retrofitting techniques were proposed and investigated by previous researchers for improving the out-of-plane flexural behavior of URM walls. Ehsani et al. (1999) showed that the externally-bonded vertical composite strips are able to contribute to the ductilities of URM walls despite the brittle stress-strain characteristics of both masonry and composite materials. Hamilton and Dolan (2001) found out that unidirectional E-glass fabric increases the out-of-plane flexural strength of an URM wall to a major extent when the fibers of the fabric are oriented perpendicular to the bed joints of the wall. The tests of Ghobarah and El Mandooh Galal (2004) on full-scale URM walls with different opening configurations (windows and doors) indicated that CFRP laminates are effective in improving the out-of-plane bending behavior of these walls. Kanit and Atimtay (2006) observed that the lateral earthquake loads perpendicular to the plane of a wall are conveyed to the neighboring orthogonal walls in diagonal directions. Haddad et al. (2010) revealed the efficiency of sprayed GFRP in improving the resistance of an URM wall to out-of-plane distributed loading. Papanicolaou et al. (2011) found out that the external grids are capable of upgrading the in- and out-of-plane flexural behavior of perforated clay brick and stone walls in the presence of axial loads on the walls. The laboratory and in-situ experiments of Dizhur et al. (2010a&b) showed that the contribution of the near-surface mounted (NSM) CFRP strips to the earthquake behavior of URM walls will greatly increase if debonding of the composite strips and shear failure of the walls can be prevented. Ismail et al. (2011) showed that the crack widths in URM walls under out-of-plane bending can be limited with the help of post-tensioning bars and strands extending through the entire height of a wall. Babaeidarabad et al. (2014) and Babaeidarabad and Nanni (2015) used fabric-reinforced cementitious matrix (FRCM) for strengthening clay brick walls under out-of-plane loading, simulating high wind pressures and earthquakes. FRCM reinforcement, composed of two layers of cementitious mortar and a ply of carbon fabric between them, increased the load capacities of URM walls to 3-9 times the respective capacity of the control specimen. Prota et al. (2006) found out that the cement based matrix-coated alkali resistant glass grid system (CMG) contributes to in-plane diagonal compression behavior of the tuff masonry panels. De Felice et al. (2014) proposed the use of steel reinforced grouts, carbon textile reinforced mortars and basalt textile reinforced mortars for retrofitting brick and stone masonry structures. Basaran et al. (2015) depicted that the polypropylene and steel fibers in the mortar is effective in contributing to the diagonal tensile capacities of blend brick walls.

A great majority of these aforementioned retrofit techniques are cumbersome to apply to numerous structures in the rural residential areas since the application of these techniques require a significant amount of time and effort. Furthermore, the use of composite materials in almost all of these techniques necessitates the use of skilled labor in strengthening applications, which is quite limited in many parts of the globe. The experiments of Kanit and Atimtay (2006) indicated that the out-of-plane flexural strength of a wall depends on its resistance to diagonal tension cracking. Based on this finding, the use of a special type of mortar, whose bond strength to masonry is superior to conventional mortar thanks to the use of an additive, was proposed in the present study for strengthening URM walls under out-of-plane bending. This technique is much easier to apply and requires less time and effort compared to the methods proposed by previous researchers. Two URM specimens, consisting of a main wall and two orthogonal walls, were tested under reversed cyclic out-of-plane loading and significant conclusions were drawn.

2. Experimental Study

Two full-scale URM specimens, made up of 190×190×50 mm solid blend bricks, were tested under reversed cyclic lateral loading. The control specimen (RW) was constructed with conventional mortar, while the mortar with special additive was used in the second specimen (MW). The special additive was used for increasing the bond strength of mortar to masonry to retard the formation of the diagonal tension cracks in the main wall, which eventually formed the failure lines. The specimens only differed in the presence of the additive in the mortar. The mixing proportions of the mortar in RW and MW are illustrated in Table 1.

Table 1. Mixing proportions of mortar

Specimen	Additive (kg)	Water (kg)	Cement (kg)	Sand (kg)
RW	-	1.8	4	9
MW	1.2	0.6	4	9

Each specimen was made up of a main wall (2600x2600 mm), two orthogonal support walls (1100x2600 mm), a slab and lintel beams, supporting the slab. The wall faces were plastered with a 20-mm thick coarse and 10-mm thick fine layers. The bricks were laid in alternative courses and the mortar joints between the bricks had a uniform thickness of 20 mm in both the main and orthogonal walls. Specimens cut from blend bricks were tested based on the British Standards BS EN 772-1:2000 (BS 2000). These material tests indicated that the bricks had a mean compressive strength of 23.2 MPa with a coefficient of variation of 9.5 % and a mean modulus of elasticity of 3000 MPa. The M8 and M12 reinforcing bars used in the concrete members had average yield strength values of 450 and 480 MPa with standard deviations of 15 and 35 MPa, respectively. Finally, the mortar mixtures of RW and MW had mean compressive strength values of 6.6 MPa and 8.5 MPa with standard deviation values 0.3 and 0.6 MPa, respectively.

The specimens were tested with the help of the test setup illustrated in Fig. 1, which consisted of a hydraulic jack connected to a reaction wall at one end and to a steel plate on the exterior face of the wall at the other end. The plate on the exterior face of the wall was connected to another plate on the interior face of the wall with the help of four bolts at the corners of the plates. The bolt holes were filled with epoxy to avoid the formation of weak zones in the wall. The bolt holes were located on the possible failure lines of the specimens to have minimal influence on the behavior of the walls. The distribution of the loads into four points created a moment diagram along the length of the wall, similar to uniform out-of-plane pressure throughout the entire face of the wall. A uniform distributed vertical load of 2 kN/m^2 was applied to the slab with the help of concrete blocks to imitate the uniform design live load of the slab of a residential structure, as given by the Turkish Standard TS 498 (TS 1997). The out-of-plane translation of the main wall was prevented by a lateral restraining system. Transducers with a precision of 0.01 mm were used for measuring the out-of-plane deflections at mid-span and the ends of the main wall. A load cell was connected to the hydraulic jack for measuring the applied load. The deflection and load measurements were acquired with the help of a DAQ system and computer.

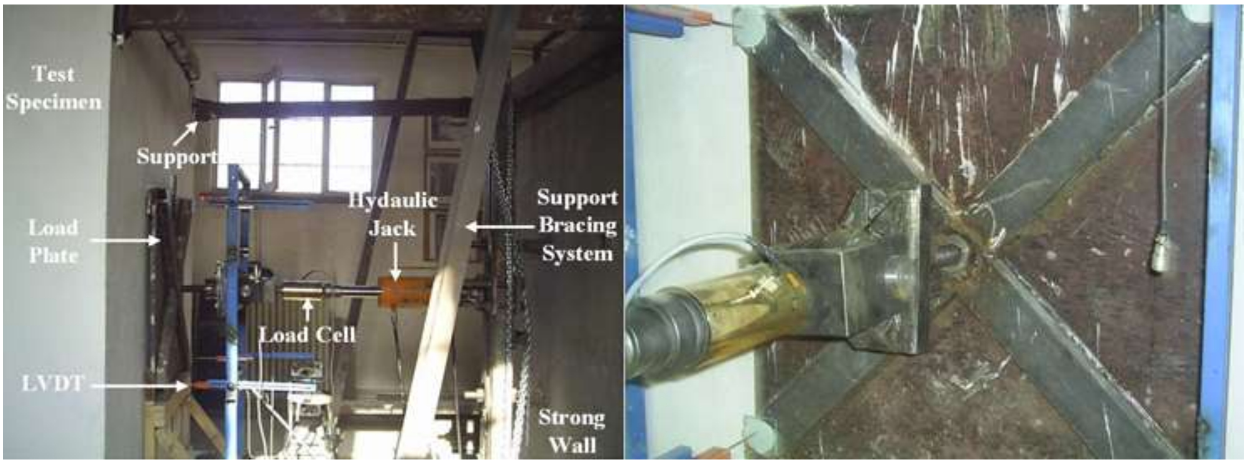

Fig. 1. The test setup

3. Discussion of Test Results

Unlike the control specimen RW, which failed in a brittle manner at an ultimate applied load of 65 kN in the forward and reverse directions of loading, the strengthened wall MW reached an ultimate load of 80 kN in the forward direction of loading. MW had a load capacity about 20 % higher than the capacity of RW. The ultimate load of RW in the reverse direction, on the other hand, was measured to be 60 kN, implying that the special mortar had a greater contribution to the load capacity of the wall in the forward direction of loading (tension on the exterior face and compression on the interior face of the main wall). The initial cracks formed at load values of 40 kN and 55 kN in RW and MW, respectively. The post-cracking rigidities of RW and MW were about 50 % and 60 % of their respective pre-cracking rigidity values. The load-deflection curves of RW and MW are illustrated in Fig. 2&3 and the cracking pattern of MW at the end of the test in Fig. 4.

Specimen RW failed due to the formation of diagonal cracks on the exterior face of the main wall, extending between the loading points and the corners of the wall and horizontal cracks extending between the two supports on the interior face. Several cracks formed along the intersections of the main wall and the orthogonal walls, indicating the presence of considerable interfacial stresses between the neighboring walls. Similarly, in specimen MW, the diagonal cracks on the exterior face of the main wall propagated in horizontal direction in the orthogonal wall segments (Fig. 4). In both RW and MW, the major damage took place in the forward direction of loading.

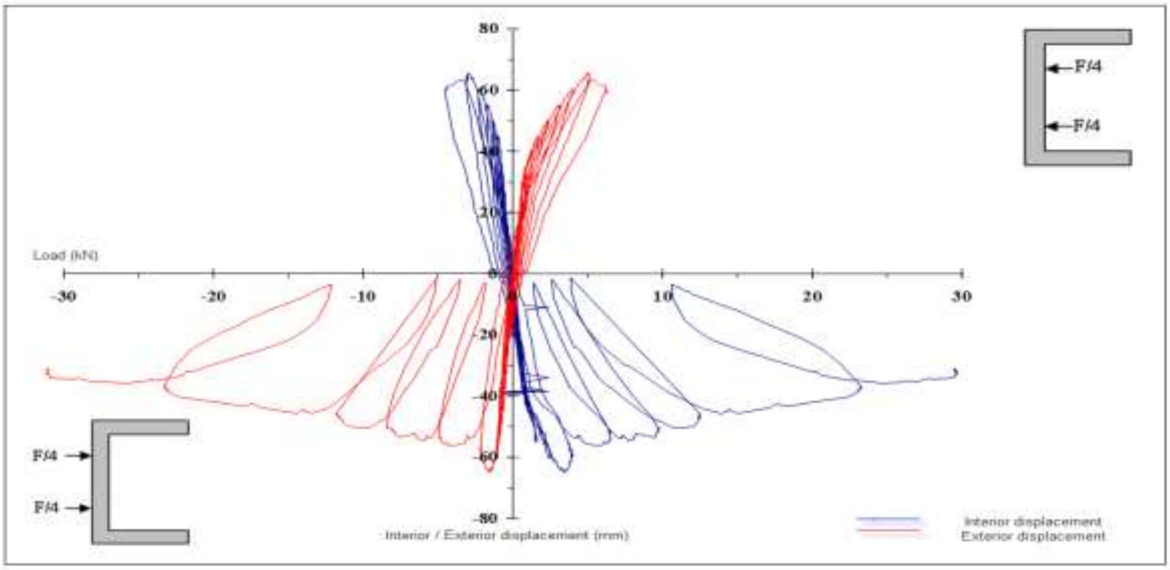

Fig. 2. The load-deflection curve of RW

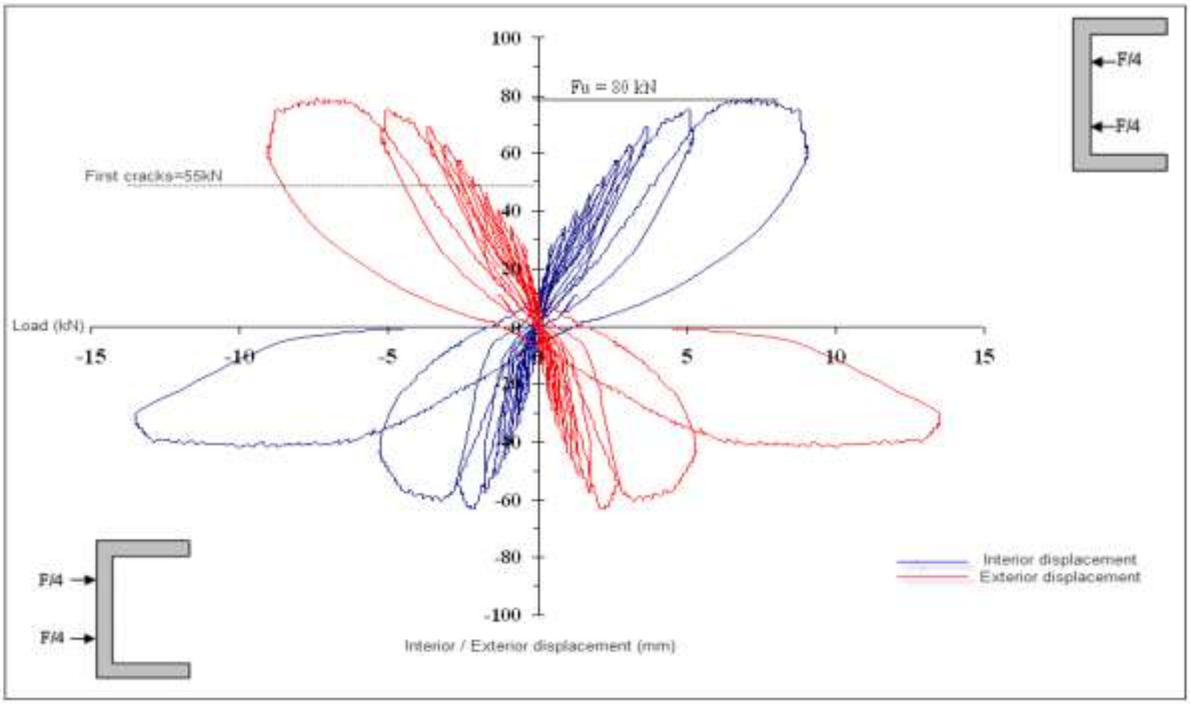

Fig. 3. The load-deflection curve of MW

Fig. 4. The final state of MW

RW and MW had modulus of toughness values of 1080 and 750 kN.mm, respectively. These values correspond to the envelope load-deflection curves of specimens in the reverse direction of loading. The specimens underwent greater deflections in the reverse direction of loading, and thus, the energy absorption capacities of the specimens were calculated for this loading direction. Opposite to the expectations, the additive had no contribution to the energy absorption capacity. Accordingly, the strengthening method contributed to the load capacity, cracking load and post-cracking out-of-plane bending rigidity of the wall, while having no influence on the ductility and energy capacity of the wall.

3. Conclusions

The influence of application of a special mortar on the out-of-plane flexural behavior of URM walls was investigated in the present study with the help of tests on two full-scale URM specimens, each made up of a main wall, two perpendicular walls, a reinforced concrete slab and lintel beams. The mortar contained an additive, improving the bond strength of mortar to masonry. This strengthening technique aimed at retarding the formation of diagonal tension cracks in the wall, and thus, contributing to the out-of-plane flexural capacity of a wall. The additive effectively increased the load capacity and post-cracking rigidity of the URM assembly subjected to out-of-plane loading. Nevertheless, the use of special mortar in replacement for conventional mortar did not have a definite contribution to the ductility and energy absorption capacity. Due to the ease of application with no need for skilled labor and the considerable contribution to the out-of-plane strength and rigidity of an URM wall, the use of the special mortar developed in the present study can be considered as an effective alternative for retrofitting URM walls.

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