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Investigation of seismic performance of in-plane aligned masonry panels strengthened with Carbon Fiber Reinforced Polymer

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HIGHLIGHTS

- Diagonal compression test on masonry panel strengthened with CFRP.
- Improvements in resistance and dissipative capacity of reinforced walls.
- Strengthening techniques in masonry panels.
- In plane behavior.

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ABSTRACT

Masonry structures are economical, easy to construct and has important advantages such as the use of natural materials. In Turkey, these structures have been heavily built especially with traditional construction methods and nowadays they are popular as well. Therefore, the reinforcement of masonry structures and seismic safety are of paramount importance. Masonry walls are not naturally stable and cannot be considered as homogeneous structures so it is difficult to predict their behavior under load by using numerical methods. Supportive framework of the mathematical model and the data of the experimental studies are required. In this study, 36 wall blocks were prepared in 900 × 900 × 200 mm using hollow masonry brick, blend brick and aerated concrete and these blocks are reinforced with Carbon Fiber Reinforced Polymer in both directions by using three different methods. For the analysis of retrofit brick walls produced and reinforced with different materials, ASTM E591 test method was used. At the end of the experiment period; shear strength performances of the reinforcement methods of the elements, their deformation and energy dissipation capacities were evaluated. According to results, maximum shear strength performance was observed at the masonry panel strengthened by two face. Maximum load value was 172.63 Kn. Also maximum dissipation capacity was observed at the masonry wall reinforced with CFRP covered diagonally. Maximum energy dissipation capacity was 317.1 J.

1. Introduction

Reinforcement of walls used in masonry buildings and in the ferro-concrete framework against seismic movements is a contemporary research topic. Turkish Earthquake Regulation (TDY) [1] suggests reinforcement methods for brick wall filled frameworks and presents information devoted to calculation and practice. In contrast to the ferro-concrete buildings, brick walls in the buildings, carrier system of which is masonry, are carriers supporting the building in order to provide certain strength to vertical loads. Performance of this type of buildings against seismic powers which act in horizontal direction is very low since masonry carrier system is heavy and shear behavior of carrier walls which are designated according to axial loads is moderate. Even if masonry buildings are not manufactured in the areas with high earthquake risk, it is well known that 60% of building stock in our country are formed by buildings having masonry carrier system. It was also reported by the building census in 2000 [2] that brick is used at 60% of the building stock of our country. In order to prevent mortalities by earthquakes without considering carrier systems, strength of the bricks and walls and performance of the buildings against horizontal loads should be increased. Brick walls are manufactured by combining of brick units with connective mortar. Although the walls are seen as a whole, they do not form a continuous setting for carriage. Therefore, it is convenient to reveal their behavior under loads with experimental methods. Different techniques have been developed using composite materials for long years to reinforce masonry walls and increase their seismic performances.

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Ceroni et al. Proposed a set of design criteria to ensure that the bond between FRP and masonry elements is safe [3]. Capozucca studied the strengthening of historic brick masonry walls with GFRP through pull–push shear tests. Experiments conducted have shown that the increase in anchorage strength due to retrofitting depends on the tensile capacity of the bricks [4]. Corbi, has extensively sequenced and tested both experimentally and analytically the methods of masonry wall reinforcement with FRP in his work [5]. D'ambrisi et al. have experimentally and analytically investigated the bond between the masonry wall and the fiber reinforced cementitious matrix that containing carbon nets. The results of study confirm that this strengthening method is very effective for masonry structures [6]. In the study done by Parisi et al., Mortar based composites were subjected to diagonal compression tests to strengthen the masonry walls. The walls tested were evaluated for shear strength and ductility [7]. Marcari et al. have worked on strengthening the masonry walls with diagonal FRP from the outside. The analytical and experimental data obtained confirm the existing regulations and practical applications [8]. Darbhanzi et al. have worked on strengthening the masonry walls with steel ties. As a result, significant increases in the seismic capacity of the walls were observed [9]. Mahmood and Ingham have carried out some researches on strengthening brick walls with FRP. In the experiments carried out, the achievements provided by the FRPs in different geometries were examined. As a result of the study, it has been observed that the masonry walls reinforced with FRP in general have increased in shear capacities, pseudo-ductility and toughness [10]. In recent years, with the advancing technology, methods for reinforcement of carrier systems by using Carbon Fiber Fabric (CFRP) have been developed. It is desired to increase shear strengths of brick walls using CFRP with different geometries since they are easy to use and have much higher tensile strength levels as compared to other materials.

The aim of this study is to develop a rapidly applicable and effective reinforcement technique for walls which shear insurance and are built from cavity brick (masonry brick), solid brick (clay brick) and aerated concrete and do not have enough horizontal rigidity. Experiment items were produced with the materials and standard workmanship quality commonly encountered in our country.

In the planned experimental study, 36 experiment items were used. Each experiment were repeated three times. Therefore, it was aimed to minimize the negations resulted from experimental measurement system or building materials used. Using the data obtained from experiments, effects of suggested reinforcement technique on general behavior, strength and rigidity of experiment items were investigated. As a result of the present experimental study, it is targeted not only to close a gap in the national and international literature but also to give new information related to the walls which will be reinforced with the suggested techniques and designation principles of real buildings.

2. Material and methods

2.1. Experiment items and materials

Experiment items were manufactured using three different materials (masonry brick (MB), blend brick (BB) and aerated concrete (AC)). The MB, BB and AC masonry panels were constructed in dimensions of 135 × 190 × 290 mm, 50 × 90 × 190 mm, 50 × 90 × 190 mm (height x width x length), respectively. N type mortar was used at MB and BB panels.

As connective mortar for wall items bonded with the bricks, masonry mortar which is defined as normal mortar (N type) in ASTM C270 [11] was used. Ratio of cement, lime, sand and water in the mortar mix was 1:1:6:1.5 in volume. Fabricated mortar was used at AC panels. Special connective mortar suggested by the manufacturer was used in the wall items bonded with aerated concrete. The value of the compressive strength of fabricated mortar was taken as 5 MPa from catalogue. Prismatic pressure strength tests which is preferred by ASTM E447 were performed in order to measure compressive strength of all panels. Prismatic pressure strength test stipulated in ASTM E447 [12] was also performed on identical size wall prisms. Expression of the all walls with identical axial pressure strength was achieved by normalization of wall material in terms of bonding style and workmanship quality. For prismatic pressure test, total 9 items (3 from each material) were manufactured at the cross sections of 190x200 mm, 210x300 mm and 190x300 mm using masonry brick, clay brick and aerated concrete, respectively. Prismatic pressure strengths of the wall units are presented in Table 1.

Photograph aid to element of each wall material obtained during prismatic pressure test is shown in Fig. 1. Experiment elements were reinforced by adhering of epoxy resins with two compounds (2-part epoxy impregnation resin) and material with carbon fiber [15,16]. Reinforcement was performed in two steps. In the first step, CFRP shape was adhered to the both surfaces of the wall. In the second step, anchor hole with 10 mm diameter was bored in places marked previously. The holes were cleaned with forced air. Epoxy resins were injected to the holes bored. And then the holes were anchored with CFRP with roll shape produced as shown in Fig. 2. Before CFRP application the both surfaces of panels were cleaned with pressured air. CFRP was strengthened by adhering in 3 different design. Catalogue values of the CFRP and epoxy resins acquired from producer firm are given in Table 2 [15,16]. Produced and analyzed experiment elements in the scope of the study are summarized in Table 3. Short name of the experiment elements defined in Table 3 is composed of three letters. First two letter states building material used in wall and the latter states method of being reinforced with CFRP.

2.2. Method

In ASTM E591, sizing of the experiment elements was not restricted considering thickness. It was proposed as sample in square shape with 1200 mm dimension of each side. Optimum identical wall dimension was 900 mm element which has square shape due to different sizes of the bricks to be used in the study. In order to eliminate differences between wall thicknesses of the elements, smooth arrangement was preferred in the walls put up with aerated concrete and brick masonry; and closure arrangement was preferred in the walls put up with blend brick (Fig. 3). Panels were tested 28 days after construction. Experiment elements were tested according to envisaged method as described in ASTM E591 [12]. Experiment elements were tested in closed steel frame shown in Fig. 4. which has 750 kN axial load capacity. The load was applied with bidirectional hydrolic jack with 1000 kN load capacity and hydrolic pump which commanded manually. Strain and vertical load was measured over the experiment element located diagonally in loading

Table 1
Compressive Strength of Masonry Prisms.

	Sample No	Prismatic Strength (kN)	SD	Average Prismatic Strength (kN)	Corrected(*) Prismatic Strength (kN)	Cross-Sectional Area (mm^2)	Compressive Strength (MPa)
Masonry Brick (MB.)	MB-1	179.96					
	MB-2	175.85	2.06	177.93	167.31	55,100	**3.04**
	MB-3	177.97					
Blend Brick (BB.)	BB-1	254.03					
	BB-2	249.04	3.58	250.05	250.05	63,000	**3.97**
	BB-3	247.08					
Aerated Concrete (AC.)	AC-1	237.04					
	AC-2	235.50	0.77	236.19	207.85	57,000	**3.65**
	AC-3	236.24					

* Correction coefficients at the ASTM E447 [13].