STRENGTHENING OF UN-REINFORCED BRICK MASONRY WALLS USING EPOXY MORTAR

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Abstract:

This study is carried out to investigate the effectiveness of using externally applied epoxy mortar on joints of masonry wall panels to enhance their load carrying capacity under axial compressive and lateral loads. A total of six 113 mm thick masonry wall panels of size 1200 x 1200 mm were constructed for this study. Four out of six walls were strengthened using locally available CHEMDUR-31 epoxy mortar on joints. The remaining two walls were tested as control specimens. The control and strengthened wall panels were tested under axial compression and lateral loads. In axial compression test, out of plane central deflection and vertical strain at the center of wall panel were recorded while in lateral load test, in-plane lateral displacement of wall and horizontal strain at the center were recorded at each load increment. Failure pattern of each wall panel is also studied to notice its structural behavior. The results of this experimental study showed an increase of 45% and 60% in load carrying capacity under axial compression and lateral bending, respectively by the use of strengthening technique employed in this study.

1. INTRODUCTION

As a building technique, masonry has a long history. Even if reinforced concrete (RC) and structural steel are prevailing these days as construction materials in modern structures, masonry units are also being used (Bui et al, 2015). Up to two storeys, masonry construction is generally economical as compared to RC frame structures because of the availability of materials used in masonry construction at relatively lower cost and due to simple method of construction. However, experiences show that under seismic excitation masonry buildings demonstrate poor performance and are likely to develop structural cracks resulting ultimately to their failure.

In Pakistan, masonry buildings cover a large portion of the building stock and more than 80 percent of the population lives in such buildings. Recent earthquakes in Pakistan have shown that most of the masonry structures are seismically vulnerable to the lateral forces. In 2005 and 2015, northern region of Pakistan was hit by an earthquake of magnitude 7.6 and 7.8 on Richter scale, respectively which resulted into huge property losses and thousands of casualties due to collapse of most of the masonry structures. Along with seismic excitation, environmental effects are also the reasons of deterioration and damage of existing masonry buildings.

Strengthening and rehabilitation of masonry buildings affected by the above-mentioned factors is always of primary importance for their safe use. In some cases, alteration/modifications in existing masonry structures due to change in purpose and usage of building also demand strengthening of masonry walls subjected to increased gravity loads. Strengthening / retrofitting of existing masonry structures may be done by many well-known techniques such as using Fiber- Reinforced Polymer (FRP) composite (ElGawady et al, 2006; Marcari et al, 2007 ; Wei et al, 2007; Mahmood and Ingham, 2011; Bui and Limam, 2014; Mazzotti et al, 2015; Ramaglia et al, 2020), steel strips and bars (Farooq et al, 2014; Triwiyono et al, 2015; Ferretti et al, 2020; El-Salakawy et al, 2020; Yao et al, 2021), shotcrete (Lin et al, 2015; Ghezlbash et al, 2020) and fiber reinforced cement plastering (Luccioni and Rougier, 2011; Arisoy et al, 2015; Deng et al, 2019; Codispoti et al, 2015). Although these common methods of strengthening masonry have many successful application cases, most of these techniques have some disadvantages such as time consumption in application, reduction in available space, disturbance of occupancy, adverse effects on aesthetics. Moreover, the use of steel in strengthening makes structure heavier which results in increased earthquake-induced inertia forces and may require strengthening of the

foundations as well (Zhou et al, 2013).

Strengthening techniques based on FRPs system offers many advantages such as easy handling and installation, low architectural impact, high strength-to-weight ratios, corrosion and fatigue resistance and negligible influence on global structural mass (Ascione et al, 2005; Valluzzi et al, 2002; Prota et al, 2008). In terms of structural performance, the use of FRP materials has the capacity to improve tensile strength and ductility of masonry structural elements; however, there are also some drawbacks related to this kind of reinforcing system, including poor fire resistance, relatively high cost, environmental impacts and compatibility with masonry structures (Bisby and Kodur, 2007; Bisby et al, 2005; Menna et al, 2013). Moreover, in most of the cases, the failure type of FRP-strengthened masonry elements is an early de-bonding of the FRP materials from the masonry substrate without reaching ultimate strength of FRP material (Triwiyono et al, 2015).

Keeping in mind the restrictions of all above mentioned masonry strengthening techniques, design and development of cost-effective strengthening technique is significantly important. This paper presents a technique to strengthen masonry walls by the use of externally applied epoxy mortar on joints.

2. EXPERIMENTAL PROGRAM

Preparation of test specimens

Square wall panels of size 1200 x 1200 mm with thickness of 113 mm as shown in Figure 1 were prepared as test specimens. First class bricks available in local market were used to construct test specimens. Total six wall panels were prepared. Cement sand (C/S) mortar with mix ratio of 1:4 was used to construct all wall panels. Locally available Ordinary Portland Cement (OPC) and river sand were used to prepare mortar.

Figure 1. Test specimens (masonry wall panels)

Out of six walls, four were strengthened and remaining two walls were kept as control specimens. For strengthening purpose, groove of about 10 mm depth was made with the help of cutter on joints of four walls as shown in Figure 2.

These grooves were then filled with epoxy mortar commercially

named as CHEMDUR-31 with the help of commonly used tool called trowel as shown in Figure 3.

Figure 2. Provision of grooves on joints using cutter

Figure 3. Filling of grooves with epoxy mortar

Chemdure-31 is a solvent free, thixotropic, epoxy mortar, based on combination of epoxy resin and specially selected fillers. Properties of Chemdure-31 are given in Table 1 and it offers following advantages (Constr. Chemicals, 2020):

- Easy to apply
- Suitable for use on both dry and damp surfaces
- Non-sag product, even at high temperature
- Hardens without shrinkage
- Excellent mechanical strength
- High early strength
- High abrasion and impact resistance
- Solvent free

Material	Density	Modulus of Elasticity	Compressive Strength	Flexural Strength	Tensile Strength
	kg/Lit	MPa	MPa	MPa	MPa
Chemdure -31 (Epoxy Mortar)	1.65	4300	60-70	30-40	15-20

Table 1. Technical data of Chemdure-31(Constr. Chemicals, 2020)

In order to check the quality of materials used to construct test specimens, compressive strength test was performed on bricks and mortar cubes. Water absorption of bricks was also determined. The results of these basic tests revealed that the compressive strength of bricks and mortar cube was 18.50 MPa and 5.90 MPa, respectively. The water absorption of bricks was 12.5%.

Testing of masonry wall panels

The control and strengthened masonry walls were tested under axial compression and lateral loads. Procedure of these tests is described in the following subsections.

1) Axial compressive load test:

In order to check the effectiveness of proposed strengthening method for masonry walls to enhance axial compressive load carrying capacity, two out of four strengthened walls were subjected to vertical axial compressive load. The testing setup is shown in Figure 4, where it is shown that vertical axial compressive load was applied on wall with the help of reaction frame and load cell. Steel beam was placed on top of wall to transfer the point load from load cell into uniformly distributed load over the wall. A deflection gage was mounted at mid height of wall to measure central lateral deflection of wall. Two DIMMIC points with gage length of 200 mm were attached to the wall at center in vertical direction as shown in Figure 4. These points were used to measure vertical strain. Vertical load was applied with the help of hydraulic jack and gradually increased up to failure of wall panel. At each increment of load central lateral deflection and vertical strain were recorded.

Figure 4. Wall subjected to axial compressive load

2) Lateral load test:

Testing setup for lateral load test is shown in Figure 5. Deflection gage was mounted at top of the wall to measure the horizontal lateral deflection under application of lateral load. A constant vertical load of 176 kN (Farooq, 2010) was applied in lateral load test with the help of load cell and roller bearing and the load was converted into UDL of 146.67 kN/m with the help of steel beam. This constant uniformly distributed load on wall panels represents the load of concrete slab which is transferred to walls in real situation. To apply lateral load gradually, hydraulic jack along with load cell was used as shown in Figure 5. In order to produce maximum overturning effect in wall panel under the application of lateral load, the load was applied near the top of wall panel as shown in Figure 5. Two DIMMIC points were attached to the wall at mid height in horizontal direction with gage length of 200 mm to measure horizontal strain developed in wall panel. Lifting of the base, on which wall panels were constructed, was prevented with the help of properly designed steel plates fixed with floor through bolts as shown in Figure 5.

Figure 5. Lateral load testing setup

3. RESULTS AND DISCUSSION

Axial compression load test

Maximum load carried by control and strengthened walls when subjected to axial compressive load are presented in Figure 6 where significant increase in load carrying capacity is achieved by the strengthening methodology used in this study. The values presented in Figure 6 are average of two test specimens.

Figure 6. Failure load

A graph (Figure 7) is plotted between load and central lateral deflection which indicates that in comparison to control wall significant reduction in central lateral deflection is achieved by the strengthening methods employed in this study. Reduction in central lateral deflection at any given axial compressive load shows improvement in out of plane bending stiffness of wall.

Figure 7. Load versus central lateral deflection response

Vertical strain values at center of wall corresponding to each load increment were plotted and are shown in Figure 8 where it is quite apparent that in comparison to control wall significant reduction in vertical strain is achieved by the strengthening. Reduction in strain values at any given load shows improved axial stiffness of masonry wall panel.

Figure 8. Load versus vertical axial strain response

Failure pattern of both control and strengthened masonry walls when subjected to axial compressive load are provided in Figure 9 and Figure 10, respectively. It may be noticed in Figure 9 that in case of control wall, distributed cracking through joints and minor crushing of bricks was occurred. However, in case of strengthened walls localized failure plane not only passed through joints but also through bricks which shows splitting failure in tension due to strengthening of joints by the use of epoxy mortar. As a result of joint strengthening by employing the proposed strengthening technique, failure of wall panel occurred due to crushing of bricks at significantly higher load.

Lateral load test

Maximum load carried by control and strengthened walls when subjected to lateral load is presented in Figure 11 where it is obvious that in comparison to control wall, strengthened wall carried 60% more load. Horizontal lateral displacement at top corresponding to each load increment was recorded and graphically shown in Figure 12 which indicates that in comparison to control wall reduction in horizontal displacement is achieved by the strengthening methods employed in this study. Smaller value of horizontal displacement at a particular load level shows appreciable improvement in in-plane

lateral bending stiffness of wall.

Figure 9. Failure pattern of control wall

Figure 10. Failure pattern of strengthened wall

Figure 11. Failure pattern of strengthened wall

Strain developed in horizontal direction corresponding to each load increment was recorded and plotted in Figure 13 where it can be observed that in comparison to control wall, significant reduction in horizontal strain value is achieved by the proposed strengthening technique.

Figure 12. Load versus horizontal displacement (at top of wall) response

Figure 13. Load versus horizontal strain

Failure pattern of both control and strengthened masonry walls subjected to lateral load are shown in Figure 14 & Figure 15, respectively.

Figure 14. Failure mode of control wall (lateral load test)

Figure 15. Failure mode of Strengthened wall (lateral load test)

Figure 14 shows that in case of control wall, diagonal failure plane passes through joints which indicate joint failure, while in case of strengthened wall, crack initiated at the junction of wall and base without any cracking within the wall (Figure 15). This reveals that joints in masonry become strong region by the application of the proposed material which made it possible to avoid development of diagonal cracks within the wall panel under the application of lateral load. At ultimate load value, failure initiated at the level of connection between base and masonry.

4. CONCLUSIONS

For already constructed masonry walls, use of Chemdur-31 epoxy on joints was investigated as strengthening methodology in this study. Following conclusions are drawn based on the experimental results obtained:

- Under axial compressive load, an increase of 45% in load carrying capacity of masonry walls is possible by the use of proposed strengthening technique.
- An increase of 60% in load carrying capacity of masonry walls when subjected to lateral loads is possible by the use of proposed strengthening technique.
- Significant reduction in the values of vertical and horizontal strain in masonry wall panels is possible by employing the proposed strengthening methodology, which shows notable enhancement in stiffness of masonry wall panels.
- At a particular load level in case of strengthened masonry wall panels, central lateral deflection under axial compressive vertical load and horizontal displacement under lateral load (with a constant vertical load value) are significantly decreased compared with the un-strengthened masonry wall panels. This further provides significant improvement in the bending stiffness of masonry walls.
- Due to weak joints in un-strengthened masonry, vertical cracks in walls subjected to axial compressive load and diagonal cracks in walls subjected to lateral load were developed and passed through joints at a lesser load value which indicates joint failure; whereas in case of strengthened walls, splitting of bricks in tension occurred and cracks passed within the bricks at a significantly greater load values.
- The proposed technique of strengthening of masonry walls is better than the techniques already in use because of following benefits;

- ✓ Ease of Application
- ✓ Causes no congestion
- ✓ Causes no disturbance to aesthetics
- ✓ No requirement of skilled labor
- ✓ Light weight
- ✓ Causes no additional mass to structure

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