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# Strengthening of Load Bearing Masonry Wall Panels with Externally Bonded Precast Textile Reinforced Concrete Laminate

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Textile Reinforced Concrete (TRC) has gained worldwide popularity as a strengthening material for masonry structures in the recent years. As of today, the application of TRC for masonry strengthening is either by cast-in-place methodology or by spraying method. The present work is a first-of-its kind study, which explores the feasibility of using externally bonded precast TRC laminate for strengthening of load bearing brick masonry wall panels. The binder used in TRC itself is used as adhesive for adhering the TRC laminate to masonry wall panels. Experimental investigations were carried out on unstrengthened and strengthened brick masonry wall panels under axial compression and combined axial compression and shear loading. The influence of TRC strengthening system is assessed by examining the performance indicators such as strength, stiffness and deformation. Based on the investigations, the use of externally bonded precast TRC laminate is found to be a feasible solution to strengthen brick masonry walls to have the required structural adequacy.

**Keywords:** Textile Reinforced Concrete, Brickmasonry strengthening, Precast, Laminate, Compression, Shear Loading

## Introduction

There is staggering demand for the strengthening methods to improve the structural performance of masonry structures to resist the seismic loads. Textile reinforced concrete (TRC) is a relatively novel material, which has shown great promise recently in the area of repair and retrofitting. This is mainly because of the advantage of TRC such as, easy applicability, reversibility, compatibility with masonry substrate, moisture compatibility, etc. The strengthening effectiveness of TRC in masonry strengthening is found to be with respect to shear stiffness, shear strength, ductility under shear and failure mechanisms, which are mainly influenced by the textile layers with different reinforcement densities and configurations[1-5]. It was found that TRC provides substantial increase and effectiveness in terms of strength and deformation capacities for both out-of-plane and in-plane cyclic loads. It is noticed that TRC is one of the most studied strengthening solution for masonry wall panels in recent years and in India it is yet to get its attention[6,7]. In all of the studies reported as of today, the application method used for TRC is by cast-in-place way. Recently a spraying method was also used by an industry; however no research is reported in this direction. Hence there is necessity to find alternative methods, which can improve the competitiveness of TRC as a strengthening material. Towards this objective, a first-of-its-kind precast solution is proposed in the present study for strengthening of load bearing brick masonry wall panel. This is realized by adhering precast TRC laminates to masonry panel as vertical strips by using the same binder of TRC as adhesive. Investigations focused around determining the performance of the strengthened panel under axial compression and also under combined effect of compression and shear loading.

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## Experimental Investigation

The investigation was carried out on unstrengthened and TRC strengthened brick masonry wall panels. The behavior of specimens was investigated under axial compression as well as under the compression along with shear loading.

### Details of Materials

The solid burnt clay bricks used in the investigations of masonry wall panels were of size 220 mm × 110 mm × 70 mm. The compressive strength of brick was determined in accordance with IS 3495-1992: PART 1, and is obtained as 5MPa. The water absorption capacity of the bricks is 18% and was determined according to the test procedure in IS 3495-1992: PART 2. The mortar used in the brick work for joints is of OPC 53 grade cement and fine aggregate is of size 1.18 mm. Joint mortar used for bounding the brick units is chosen with a mix ratio of 1:4 with a water cement ratio of 0.67. The 28 day compressive strength of joint mortar is around 17MPa, and split tensile strength is 2.1 MPa. Textile Reinforced Concrete (TRC) used in the study consists of an alkali resistant glass textile with a mesh type of geometry. The textile characteristics are: mesh size of 25 × 25 mm, tensile strength of 45 kN/m (corresponding to stress of 1340 MPa) and elongation ability of maximum 2%. A commercially available cementitious mortar with 28day compressive strength of around 50 MPa, flexural strength of 7 MPa, and elastic modulus of 23 GPa was used as binder for TRC and also as adhesive for bonding the TRC laminates to brick masonry wall panel. For brick masonry strengthening, TRC Laminate thickness was selected as 12 mm, which is based on the overlay sizes of TRC layers reported in literature in various studies for masonry strengthening. Four number of textile layers were chosen as textile reinforcement in TRC. The number of layers was chosen based on the observations about uniaxial tensile characteristics of TRC. TRC coupons of 500 mm × 60 mm × 12 mm were cast and tested under uniaxial tension. A 7.5Tonne capacity MTS was used to conduct the test ata rate of loading of 0.5 mm/min. The coupons are gripped 50 mm at top and bottom ends. Based on the load versus displacement behaviour, the nominal stress for textile was obtained dividing the load by the textile reinforcement cross-section area of 33.58 $mm^2/m$. The strain was obtained by dividing the displacement of LVDT with gauge length of 350 mm. From the tensile characteristic it is observed that the textile has experienced a stress of 680 MPa, which is only half of its maximum tensile stress.

**Specimen Details**

The brick masonry panels of size 1220 mm × 1220 mm × 220 mm was made using solid clay bricks of size 220 mm × 110 mm × 70mm. Wall panels were constructed in a running bond pattern resembling Flemish bond. Normal mortar with OPC 53 grade cement and 1.18 mm sieve passing sand is used with 1:4 mix ratio and 0.67 w/b ratio to fill the joints. Mortar thickness of 10mm is maintained at both head and bed joints. Bricks were made wet before construction of wall as bricks have high water absorption of 18%, they may absorb water present in cement mortar thus reducing the hydration of cement leading to reducing the mortar strength, adhesion and bonding with individual bricks. After all specimens were build panel was scrapped with brush to remove excess mortar. The specimens were cured with gunny bags for 28 days.

To strengthen brick masonry panel, TRC laminates were precast. It is cast whole to wall the dimensions i.e., 1.2 m × 1.2 m with thickness of 12 mm. The binder was made with a water binder ratio of 0.18. A layer of nearly 6 mm thickness mortar was layed first and then four textile layers were placed and pressed with a metal trowel gently into mortar. An overlap of 200mm is allowed due to insufficient width of textile while casting TRC panel. Finally top layer is smoothened and brushed to remove excess mortar. It is allowed to set in the formwork for 24 hours and then lamina is lifted and placed aside where curing for 24 hours is done. At the day of strengthening lamina is cut into strips of 220 mm width for the full height of panel.

Strengthening is done with TRC laminate strips of 220 mm wide. Strips are bonded to specimen surface by means of the same cementitious binder, which was used as binder in TRC. The TRC strips were bonded at a spacing of 135 mm c/c. First markings were made over the panel to ensure laminae is being placed vertical. Bonding of laminate was carried out after 14 days of masonry construction.The strengthening procedure involves the following steps: first, the panel surface is made wet for applying mortar, and then layer of mortar to the thickness of 10 mm was applied to the masonry. Strips of 12 mm thickness are placed over the mortar applied and pressed slightly. The mortar has to be in fresh state when the strips are placed because it will be bonded properly due to adhesion. Only one face of panel is strengthened in the present study.

**Test set-up and Instrumentation**

The test setup shown in Figure 1 consists of a frame fitted with jack for loading with clear spacing of 1.8 m between jack and floor. Brick panel is placed in such a way that major axis of panel is perpendicular to frame. Test arrangmenst were made to panel such that premature failure will not happen to it. Channels with 2 hooks at its edges were fabricated and placed on both sides of panel with rubber layer sandwiched between panel and channel so that crushing of brick could be prevented. Girder of 10 Tonne capacity is used to lift the panel and place in the poistion. Center of jack and panel is assured in straight using plumbob. Hydraulic jack with with a separate hand pump is fixed on one side of masonry panel to apply lateral loading. Specimen is arrested at bottom to prevent horizontal movement of masonry while application of lateral Load. Steel plates and distributer beams are placed on the masonry for uniform distribution of load. Brick masonry panel is instrumented with 8 Linear Variable Dislacement Transducers (LVDT) to measure axial, shear and lateral deformations along masonry.The positioning of LVDT's are as follows: F1 and F2 are placed at 1/3$^{rd}$ distance from top of panel in load application face and on opposite face respectively; H1 & H2 are placed in horizontal direction at 200 mm from top and bottom of the panel respectively; V1 & V2 are placed in vertical direction at 200 mm from right and left side of panel; D1 & D2 are placed in such a way that its centre coincides with the centre of the panel.These deformations are used to evaluate strains. L-angles are fixed on masonry panels after

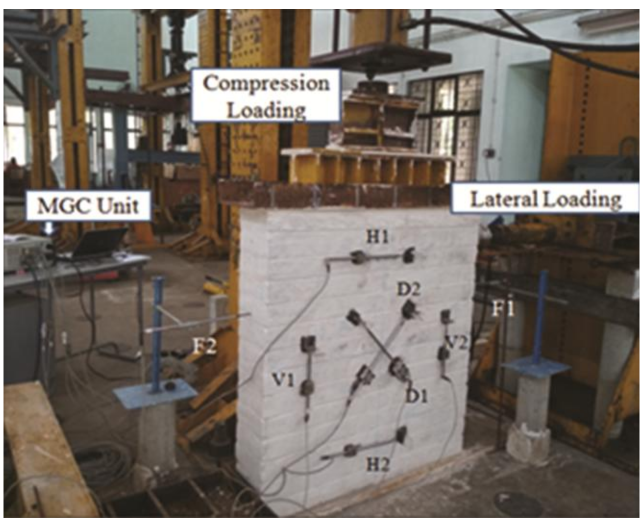


Fig. 1—Test setup

marking guage lenghts using m-seal adhesive. LVDT's are placed in such a way that tip of LVDT is made to touch L-angle. The placement position of LVDT's are chosen based on some of the Literature. All LVDT's are connected to data accqusition system MGC plus. 50 mm LVDT's are used to measure axial deformation and remaning deformations are measured by 100 mm LVDT's. The guage length of 260 mm for (H1, H2), 130 mm for (V1, V2) and for 300 mm (D1, D2) are used during the investigations. Load cells are fixed to the jack at both top and side for aplication of compression and lateral load respectively. Lateral load is applied in such a way that center of load cell touches masonry at a point 115 mm from top of wall.

## Experimental Results and Discussion

### Compression Test

The unstrengthened brick masonry panel is loaded under compressive load and the first vertical crack initiated at a load of 306 kN. At 350 kN of load, crushing is observed at middle of base. Experiment is stopped at load of 420 kN, after reaching the maximum capacity of the load cell used. Hence interpretations are made only up to this load level. Among 8 LVDT's placed only 5 LVDT's are able to show deformation. It is observed that the failure is not observed in region where H1, V2 and D1 are fixed. So deformation is not captured in those particular LVDT's. In case of Strengthened panel, the first crack was observed at a load of 400 kN at the back face of the panel. It is noticed that compared to unstrengthened panel, there is around 23% of increase in the first crack load for the strengthened panel. From Figures 2(a) and 2(b), the

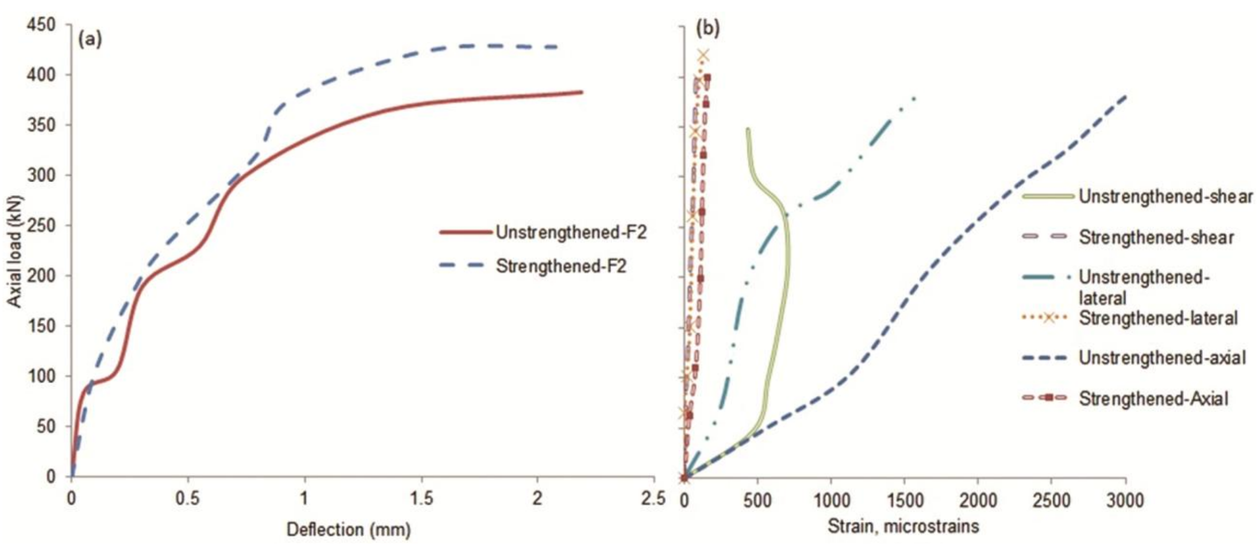


Fig. 2—Response of panels under compressive loading (a)load vs. deflection (b)load vs. strain

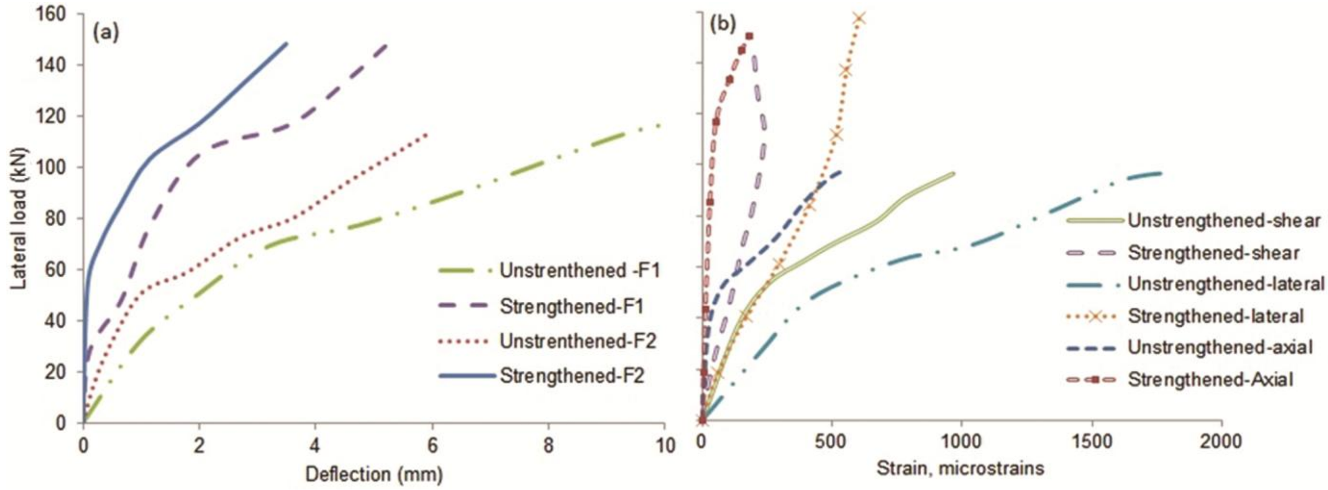


Fig. 3—Response of panels under combined action of compression and shear loading (a) load vs. deflection (b) load vs strain

comparison for strengthened panel and unstrengthened panels indicate that at a load of 306 kN, which is the cracking load of unstrengthened panel, the lateral, axial and shear strains are decreased by 1.92 times, 1.91 times and 1.86 times respectively. Total load taken by unstrengthened panel wall is 420 kN, which is the maximum capacity of the load cell used. It is observed from Figure 2(b) that in shear, lateral and axial directions the strengthened wall is stiffer. There is a reduction in deflection of 1.75 times on load application face for the strengthened panel is witnessed as well. From the results of compressive test it was observed that high compressive strength and strain values were achieved for strengthened panel. The number of vertical cracks had been observed on faces of the panel for unstrengthened panel. Horizontal cracks were observed at back face of strengthened panel which is in contrary to the vertical cracks which was observed in unstrengthened panel. It should be noted that there was no crack formation in the strengthened face of the panel.

**Combined effect of compression and Shear**

Behavior of unstrengthened panel specimen under combined compression allied lateral loading is observed by using 8 LVDT's. Compressive load is applied in increments and is made constant after reaching 130 kN (which is around 10% of the maximum compressive stress of brick) then lateral load is manually applied using jack in increments. In LVDT's fixed for capturing vertical strain F1 is in tension and F2 is in compression. Beacuse of opening of crack at a particular region LVDT in that region may show decrease in deflection and at the same time another LVDT picks up the deflection to be captured. Load is measured from the load cell attached to data accqusition system MGC plus. Since, the test is not conducted upto failure load, no conclusions are derived for the ultimate capacity of the panels. So comparision of strains is made to the maximum lateral load level upto which the test is conducted. In strains measured in 2 LVDT's capturing same defletion i.e., either axial,shear,lateral or vertical one exhibited positive values (compression) and the other which is near to loading face negative values (tension). For the unstrengthened panel, at load 68.47 kN crack at interface of floor and masonry got initiated and started propagating parallel to joint. Spalling of brick at the bottom corner and horizontal crack at middle of back face is observed when load reached 75 kN. For the strengthened panel, at 150 kN, no cracks were observed at strengthened face and few numbers of vertical cracks were observed at unstrengthened face of specimen. No crack in joint was found. From Figure 3(a) it is noticed that the vertical deflection of strengthened panel is reduced by 1.7 times on load application face and 1.83 times on opposite side compared to unstrengthened panel. From Figure 3(b), it is noticed that there is decrease in lateral, axial, and shear strains by 1.47, 1.86 and 1.73 times respectively for strengthened panel compared to unstrengthened panel. An enhancement of 30.7% load is observed for first crack load for strengthened panel compared to unstrengthened panel. From the investigations, it can be concluded that strengthened panels show lesser deflection and high stiffness compared to unstrengthened panels. Number of cracks observed in strengthened panel is also less than unstrengthened panel. Shear strain is less in strengthened panel and it is observed that failure till load applied is due to formation of vertical and horizontal cracks in both specimens. The shear strength of unstrengthened panel was recorded as 105 kN, where as that of strengthened panel were 150 kN showing an increase of 50 percent. More values of lateral displacement are less for strengthened panel compared to unstrengthened panel.

## Conclusion

The feasibility of using externally bonded precast textile reinforced concrete (TRC) laminate for strengthening of load bearing brick masonry wall panels was investigated under axial and combined axial and shear. It was observed that there is around 20% enhancement in first crack by strengthening using TRC laminates. It also helps to reduce the lateral deflection considerably in the service state. The stiffness of the strengthened system is also enhanced by more than 70% in all direction due to the proposed strengthening. Based on the investigations, the use of precast TRC laminate is found to be a feasible solution to strengthen brick masonry walls and further investigations will pave way for incorporation of TRC in Indian standard as a structural strengthening material for masonry structures.

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