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Retrofitting of Masonry Wall Panels Against Out-of-Plane Bending: An Experimental Study

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Abstract: The authors conducted an experimental study of brick masonry wall panels adopting a linear scale factor of 3. Unreinforced masonry walls tend to have sudden brittle failure under out-of-plane bending caused due to earthquake. Wall panels of size 450×450×70 mm are built in C.M 1: 5 using miniature bricks of size 70×35×25 mm adopting English bond. The thickness of mortar was maintained around 6 to 7 mm. Wall panels are retrofitted against out-of-plane bending with 2 strips and 3 strips of GFRP bonded with polyester resin and tested with a hydraulic jack inducing lateral load. When masonry wall is subjected to out-of-plane bending in a built environment, the middle one third heights will undergo lateral bending causing horizontal crack along the bed joint leading to sudden collapse. Hence, it is decided to retrofit the wall panels against lateral bending with GFRP lamination set in polyester resin. The lateral load is induced using a hydraulic jack with pressure gauze fitted with it. The jack was calibrated in the UTM to get the corresponding loads for the pressure. The load carrying capacities of retrofitted specimens were compared with that of the unretrofitted specimen, taken as control specimen. The results are arrived at a logical sequence and analysed in a lucid manner.

Key words: Masonry wall panels, out-of-plane loading, GFRP laminations, polyester resin coating, retrofitting

INTRODUCTION

Brick as a building material and brick masonry as a structural Component have proved themselves durable and weather resistant. Many ancient masonry structures remain as standing engineering marvels to substantiate this fact. In India about a major portion of the construction is based on brick masonry structures due to economy. But in the event of extreme loading like earthquake, masonry structures attain severe damages leading to partial to total collapse. Masonry structures are brittle in nature and attain sudden failure without much warning for the occupants to escape to safety and hence it is essential to impart ductile behaviour to masonry by effective strengthening. Of the 3 components of a masonry building (roof, wall and foundation), the walls are most vulnerable to damage caused by horizontal forces due to earthquake. A wall topples down easily if pushed horizontally at the top in a direction perpendicular to its plane (termed weak direction). Earthquakes produce forces which are three dimensional and complex in nature as the ground shakes simultaneously in the vertical and two horizontal directions during earthquakes. Hence, suitable retrofitting techniques are to be studied for brick masonry. Here the authors make a sincere attempt in imparting ductile behaviour to masonry wall panel and to enhance the load carrying capacity adopting an innovative retrofitting technique using GFRP laminations set in polyester resin coating on the external surface of masonry wall (Fig. 1-4). Much research works were not done in brick masonry wall panels and there were studies on block masonry (Hamilton *et al*., 2001).

Fig. 1: Wall panels getting ready for GFRP laminations

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Fig. 2: Polyester resin coating is applied to fix GFRP lamination

Fig. 3: Wall panels retrofitted with 2-strip and 3-stripGFRP laminations

Fig. 4: General view of masonry wall panels under curing

MATERIALS AND METHODS

The wall panels which are held in between two window openings and which will span vertically between sill and lintel level remain as highly critical. Normally such a panel will measure approximately 135×135 cm as seen from built-in environment. Hence, it is decided to have

Fig. 5: Experimental set-up with pre-calibrated hydraulic jack

scaled down masonry wall panel measuring 45×45 cm using a linear scale factor of (1:3) using miniature bricks. Cement mortar of 1:5 mix was adopted with about 7mm thick. When earthquake strikes, there will be inertia force which will tend to collapse the wall under out-of -plane bending. Hence, the imaginary maximum inertia force felt by the structure is simulated by a horizontal load applied at mid height of the model wall panel, using a hydraulic jack as shown in Fig. 5. The imaginary seismic force is simulated by a hydraulic jack with a capacity of 20 kN, fitted with a horizontal rectangular rod as loading frame and a pressure gauge to find out the pressure of the jack during loading (Hamoush *et al*., 2001).

- The hydraulic jack is fixed horizontally in a loading frame as half of the height of the brick masonry i.e. at the centre (at 225 mm).
- The imaginary inertia force is simulated by horizontal load at the centre span of the brick masonry is provided by means of hydraulic jack (Page, 1982).
- The wall panel is held at the top and bottom by angle support as simply supported to simulate the lintel concrete and sill level masonry support. Incremental loading was given from minimum to collapse load.
- The pressure gauge of 300 kg cm^{-2} capacity is fixed on the hydraulic jack to show the pressure reading during loading.
- The jack was pre-calibrated for the loading against the oil pressure.

Retrofitting technique: The retrofitting methods suggested by Indian codes involve ferro cement lining and welded fabric reinforcement adopting Splint and Bandage technique. Steel reinforcement that remains exposed to environmental attack due to moisture absorption of masonry walls. Therefore, they are vulnerable to corrosion that limits their lives. Moreover, the quality of strengthening depends heavily upon the skills of personnel. Recent developments in fibre reinforced composites can solve many of these problems. These materials are extremely strong, with high load carrying capacity. They are chemically inert and corrosion resistant. Moreover, they are very light and that facilitates easy implementation at site with less supporting structures. These methods are cleaner, simpler and the materials used cure very quickly. This leads to shorter down time of the damaged structure and requires skilled labour with close supervision. The authors have used E-glass fibre sheets that have a minimum tensile strength of 1900 Mpa and elastic modulus of 75000 Mpa with a density 450 $g\,m^{-2}$ are used. GFRP strips of 75 and 100 mm width are laminated on the masonry wall panel coated with polyester resin, which remains as the binding material between the fibre strip and the masonry surface (Fig. 3). One of the important properties regarding the workability of resin is optimum viscosity that simultaneously enables impregnation in to the fibres and keeps the fibres in place to have proper bonding with masonry.

Fibre sheets are cut tot required size. The cut GFRP fibre sheet is made as a roll on a circular spindle to make them easy for wrapping. It is very important to choose the right resin for wrapping applications as the resin must be viscous enough to hold the fibre in place. On the other hand, the resin must keep the fibre wet thoroughly and there should not be a dry pockets. The viscosity of the resin, therefore, is a trade off between these two contradicting requirements. The resin is usually a 3-part mix namely the resin, accelerator and hardener. The resin should not entrap air.

There are two methods of laying namely dry lap and wet lap, the dry fibre sheet is applied on the masonry surface coated with epoxy resin. In the wet lay up, the fibre sheet is kept wet with the resin before wrapping. Although wet lay up ensures a better bonding, it is not always convenient to use wet lay up, especially in the hot climate like India. The sheet should not be slack at the time of wrapping and care must be taken to maintain the intended fibre direction. Rolling must always be in the direction of fibre. The lapped ends must be pressed thoroughly to avoid any defects must be completed within the pot life period of the resin which is usually 10-15 min depending upon the quantity of accelerator added. Therefore, it is advisable to mix small quantities of resin at a time. Care must be taken to use proper gloves during work. After the resin is completely cured (usually 2 h), the wrap is inspected to rule out any defect. The wrapped brick masonry is shown (Fig. 3). The retrofitting of masonry wall specimens is done by providing glass fibre sheet lamination treatment. The sheet is wrapped on both the sides with two different sizes as given below.

- Treatment with 3 strips = 75 mm width each.
- Treatment with 2 strips = 100 mm width each.

RESULTS AND DISCUSSION

The retrofitted specimens and the control specimens are tested against out-of-plane bending to arrive at the maximum load carrying capacity and maximum mid-span deflection. Masonry design codes are silent about out-of-plane forces (Drydale *et al.*, 1999) created due to earthquake and it is mandatory for the structural engineer to find an effective retrofitting technique for brick masonry to withstand against the lateral forces (Anonymous, 2008).

Control specimen: The control specimen had a brittle and sudden failure immediately after the development of horizontal crack without any warning (Fig. 6). The collapse load was found as 2.5 kN. The load Vs Deformation chart (Fig. 7) gives almost linear behaviour and there is no plastic deformation beyond yield point.

Fig. 6: Untreated Specimen at collapse

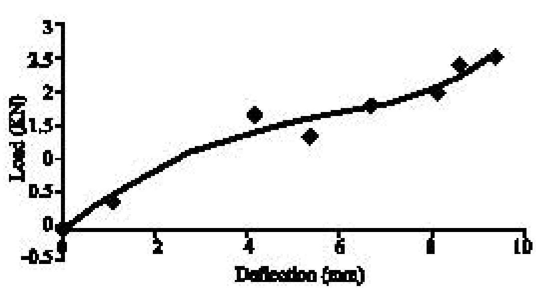

Fig. 7: Load Vs Deflection Untreated specimen

Fig. 8: Specimen treated with 2 strips

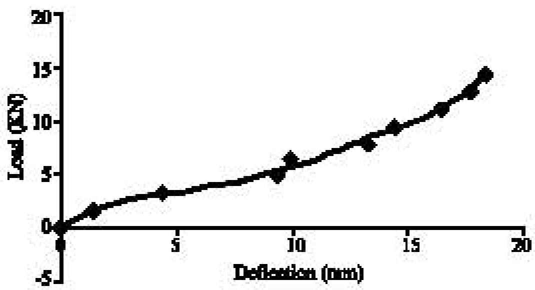

Fig. 9: Load vs deflection-2 strips

Fig. 10: Specimen treated with 3 strips

Specimen retrofitted with 2 strips of 100 mm wide GFRP laminations: As compared to control specimen the crack formation in the retrofitted specimen is less and the horizontal failure occur at maximum loading to collapse load of 14.4 kN (Fig. 8). The load Vs deformation chart shows plastic non-linear deformation beyond yield point, thus exhibiting ductile behaviour (Fig. 9).

Table 1: Comparison of load carrying capacity of different specimens

Specimens	Collapse load at failure	Defelection at 1/3 height mm	Defelection at mid height- mm
Control Specimen	2.5 kN	8.21	9.68
Treatment with 2 strips	14.4 kN	16.96	18.33
Treatment with 3 strips	16.8 kN	21.42	26.63

Fig. 11: Masonry exhibits ductile behavior

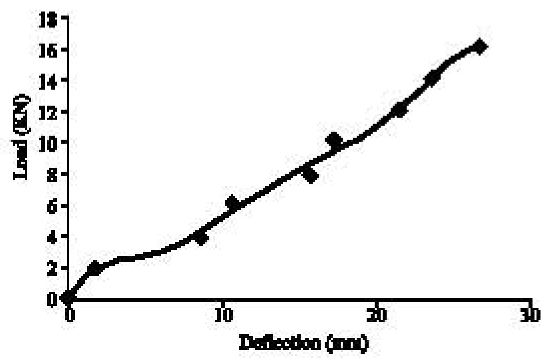

Fig. 12: Specimen treated with 3 strips

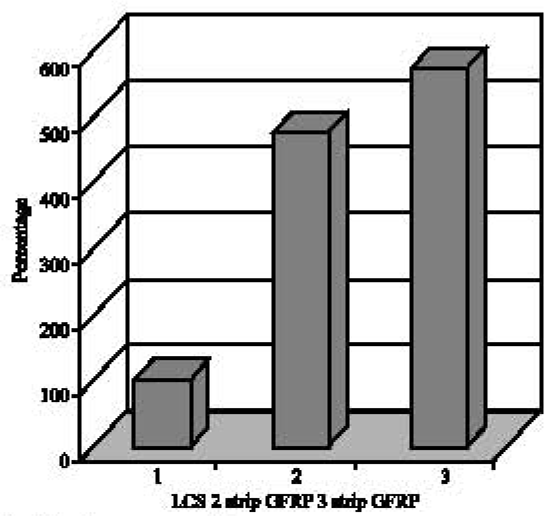

Fig. 13: Percentage difference

Specimen retrofitted with 3 strips of 75 mm wide GFRP laminations: The specimens retrofitted with 3 strips exhibited very high strength than control specimen and the failure occurred at 16.8 kN (Fig. 10, 11 and Table 1). The load vs. Deformation chart shows excellent ductility (Fig. 12).

The critical wall panel held in between two window openings, spanning vertically between sill level and lintel bottom is taken for study using linear scale factor of 1: 3.

CONCLUSION

- Masonry wall samples retrofitted with GFRP laminations set in polyester resin exhibited excellent ductile property. Ductility is numerically approximated as the ratio of deformation at collapse to deformation at yield taken from the experimental observation. The wall panels retrofitted with 3 strips of GFRP laminations have performed well and shown ductility about 2.5-3.7 and where as the control specimen had almost a ductility of unity as the specimen failed at yield point.
- Three control specimens unretrofitted, built in cm 1:5 had uniform mode of failure. The failure was sudden with a linear horizontal crack along the mortar joint.
- The wall specimens retrofitted with two strips of GFRP fibre wrapping yielded good results with ultimate load capacity 476% more than the control specimen.
- The wall specimens retrofitted with three strips of GFRP fibre wrapping yielded excellent results with ultimate load carrying capacity 572% more than the control specimen.
- It is concluded that this sort of strengthening method will greatly help in avoiding sudden failure of masonry buildings due to extreme loading conditions like earthquake loads. The major advantage in GFRP lamination is that it will not disintegrate due to ageing and is anti corrosive in nature.

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