Augmenting out-of-plane behaviour of masonry wallet using PP-band and steel wire mesh

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Abstract. Extent of vulnerability of unreinforced masonry (URM) structures during seismic loading is too high in comparison to reinforced concrete structures. Brittle behaviour of URM causes life safety of inhabitants. Out-of-plane strength of masonry structure is much lesser than in-plane strength due to less moment of inertia of the former one. In this context, present study is an attempt to improve the out-of-plane behaviour of URM structures by strengthening with polypropylene band (PP-band) and steel wire mesh (WM). Two types of wall configurations; full scale wall and half scale wall were tested under four-point loading method as per ASTM E518-10 recommendations to investigate the out-of-plane behaviour of URM and reinforced masonry (RM). In both the types of walls, it was observed that due to presence of PP band and wire mesh, the load carrying capacity was enhanced and the failure time was delayed which helps in avoiding the sudden collapse of structure. Failure load and load-displacement behaviour of structures are reported in this study. An analytical formulation has also been developed for validating the experimental results. This study may be beneficial in exploring the low cost strengthening techniques for improved seismic behaviour of masonry structures.

1. Introduction
Masonry is an unavoidable component of housing. Among different types of masonries, brick masonry is one of the most widely used in our country and elsewhere because of low cost, easy availability of raw materials, good strength, easy construction with less supervision, good sound and heat insulation properties, and availability of manpower [1-3]. The behaviour of masonry is dependent on the properties of its constituents such as brick units and mortar separately and together as a united mass [4-7]. Burnt clay bricks are widely used across the globe.

The wall which is perpendicular to the loading direction, subjected to out-of-plane bending is vulnerable during earthquake [8-13]. Recently, strengthening of structure using welded wire mesh has become very popular as it increases significant amount of strength and ductility. Unreinforced brick masonry panels were strengthened by uni-directionally and bi-directionally anchored welded wire mesh and micro-concrete [14]. It was reported that the increase of strength has been achieved by more than 10 times for reinforcement ratio of 0.29%. Strengthening of wallet by tightening the polypropylene band (PP band) has been widely used now-a-days due to its low cost, ease of availability and implementation. PP band is tightened in crisscross manner which improves bending strength and deformation ability [15].

In this study, two different strengthening materials i.e. PP band and welded wire mesh are adopted to improve the out-of-plane behaviour of masonry wallet. Traditional size of clay burnt brick, as well as half scale brick is used to construct the masonry wallet. The reason behind use of half scale brick is to check the adequacy of its use for scale-down models. Finally, analytical model for PP band strengthened wallet has been developed to validate the experimental results.
2. Materials used

Traditional size of standard clay brick (230 × 110 × 75 mm), in addition of, half size of clay brick (112 × 50 × 37 mm) has been chosen to investigate the suitability of half size brick in shake table test. To characterize the mechanical properties of the material, tests for compressive strength and water absorption are carried out in accordance with BIS (1992) [16]. Clay bricks used for the construction are of Class 7.5 as presented in table 1. The compressive strength and permissible tensile stress of mortar are 5 MPa and 0.07 MPa, respectively, which implies the grade of mortar is M1 as per BIS (1989) [17]. Full scale and half scale masonry of clay brick satisfies the minimum requirements of the compressive strength of masonry as per IS-1905-1987 [17] and is also presented in table 1.

| Table 1. Material properties. |
|-------------------------------|
| **Type of brick** | **Property** | **Full scale** | **Half scale** | **Codal provision** |
| Clay brick | Dimension (mm) | 230 × 110 × 75 | 112 × 50 × 37 | 230 × 110 × 70 |
| | (BIS (1992)) | | | [16] |
| | Water absorption (%) | 16.15 | 15.96 | < 20 |
| | (BIS (1992)) | | | [16] |
| | Compressive strength (MPa) | 7.97 | 8.59 | 7.5-10 (Class 7.5) |
| | (BIS (1992)) | | | [16] |
| | Masonry compressive strength (MPa) | 3.30 | 3.69 | > 1.9 (IS-1905-1987) |

3. Strengthening Materials

The specimens are strengthened by using two types of material; polypropylene band (PP band), and welded wire mesh (WM). The properties of PP band and WM, which are presented in table 2, are found to be suitable for strengthening purpose.

| Table 2. Properties of strengthening material. |
|-----------------------------------------------|
| **Type of material** | **Property** | **Numerical value** |
| PP band | Width | 10 mm |
| | Thickness | 0.85 mm |
| | Density | 0.91 g/cm² |
| | Ultimate strength | 142.22 MPa |
| Wire mesh | Size of each rectangle in the mesh | 3.12 mm × 2.54 mm |
| | Diameter of the wire | 0.119 mm |
| | Ultimate strength | 697 MPa |

4. Details of construction procedure

The order of stages of construction of masonry wallet is described here. Full scale of wall of dimension 500 × 500 × 120 mm is constructed using clay bricks, in addition, half scale-walls of size 250 × 250 × 60 mm are also constructed to observe the effect of size on strength properties during flexural test. Both full scale wall and half scale wall are strengthened with PP band and welded wire mesh as shown in table 3. PP band with a spacing of 100 mm has been provided for full scale wall, whereas for half scale wall, PP band are spaced at 80 mm. Firstly, these are oriented in criss-cross manner, later tightened with the help of clip and fasteners. In other hand, wire mesh are cut into pieces of size 400 × 400 mm and 200 × 200 mm for full scale wall and half scale wall, respectively, and pasted over the both side of masonry surface. Each sample contains six layers of bricks, containing two bricks in each layer. After construction of the bed joints, samples are plastered with 10 mm and 5
mm thick mortar (cement: sand = 1:4) layer in case of full scale brick and half scale brick, respectively. After construction of walls, all samples are cured for 28 days before testing.

5. Test setup
Out-of-plane test of both URM and strengthened specimens are carried out as per the standard guidelines of ASTM E518-10 [18]. Four-point test are adopted for all types of specimens as the masonry is brittle in nature. Four LVDTs (linear variable displacement transducers) are placed to measure the deflection of the samples during the test. The test setup and the positions of LVDT are illustrated in figure 1. Three LDVTs are placed on the upper side of wall and one LVDT was kept under the wall. All the LVDTs are connected with data acquisition system as shown in figure 1a.

6. Result & discussion
All the unreinforced and strengthened specimens are tested in flexural testing machine. The failure pattern of the wallet is presented in table 3.

6.1 Unreinforced specimen
The failure of unreinforced specimen was sudden and brittle. For both half scale and full scale brick wallet are broken into two pieces. The failure load of full scale was 8.98 kN, whereas, half scale brick can sustain the load up to 4.38 kN.

6.2 Strengthened specimen
Retrofitted specimens carried larger load compared to unreinforced wallet. Unlike URM, strengthened wallets improved ductility behaviour and sudden collapse has been prevented. Initial stiffness of strengthened wall are similar to that of unreinforced masonry. Failure load has been increased by 70.14% and 76.43% for full scale wall and half scale wall, respectively, due to the tightening effect of PP band. The post peak behaviour was clearly observed in PP band retrofitted full scale wall. Failure was achieved at 15.27 kN because of the propagation of crack between two loading roller which was presented in table 3. Further, the load was taken by PP band only until the ultimate displacement of 20 mm. The crack pattern for half scale wall was similar to the full scale wall though post peak behaviour was not observed due to less number of PP band.
The shear failure was common failure mode for both types of wire mesh retrofitted walls. It has been observed that crack initiated from the roller loading point and propagated through the portions of wall where wire mesh is not covered. Failure of plaster and the exposure of wire mesh have been observed due to further increase of load. Strength of wall has been increased by 173.69% and 198.9% for full scale and half scale wall, respectively compared to unreinforced wall. Wire mesh has more contribution towards the strength compared to PP band as shown in figure 2. It has been observed that wire mesh retrofitted structure can sustain the load 1.69 times and 1.61 times higher than PP band retrofitted structure for half scale and full scale wallet, respectively.

Figure 2. Load-displacement behaviour of wallet: a) full scale wall; b) half scale wall.
Table 3. Specimen details.

| Details of Specimen | Wallet before testing | Failure pattern |
|---------------------|------------------------|-----------------|
| Unreinforced masonry| ![Unreinforced masonry](image) | ![Failure pattern](image) |
| Half scale brick    | ![Half scale brick](image) | ![Failure pattern](image) |
| Full scale brick    | ![Full scale brick](image) | ![Failure pattern](image) |
| Strengthened with PP band | ![Strengthened with PP band](image) | ![Failure pattern](image) |
| Half scale brick    | ![Half scale brick](image) | ![Failure pattern](image) |
| Full scale brick    | ![Full scale brick](image) | ![Failure pattern](image) |
| Strengthened with welded wire mesh | ![Strengthened with welded wire mesh](image) | ![Failure pattern](image) |

Steel wire mesh
7. Analytical approach

Analytical model to predict the flexural behaviour of masonry wall strengthened with FRP has been proposed in various studies [19-23]. Although, PP band is very effective for strengthening purposes, analytical approach towards the failure load of strengthened masonry is rarely available in literature. Current study focuses to develop a theoretical model to predict the failure load for PP band strengthened wallets.

The analytical model is considered based on the section analysis similar to the reinforced cement concrete sections and the behaviour of stress-strain curve for brick masonry blocks is considered under compression as parabolic up to the maximum compressive strength followed by a linear descending branch [22] as shown in figure 3. For simplicity of the calculation, equivalent rectangular stress block is replaced to the actual stress block. The parameters, $\beta$ and $\gamma$ which are defined in equivalent stress block can be taken as 0.88 and 0.8, respectively [24].

To compute the compressive strength ($f_{m}'$) of masonry analytically, parameters involved to evaluate the strength of brick and mortar has to be considered carefully. The compressive strength ($f_{m}'$) can be expressed in the following equation [25].

$$f_{m}' = 0.433 \times f_b^{0.64} \times f_j^{0.36}$$

where, $f_b$ and $f_j$ are the compressive strength of brick and mortar, respectively. The modulus of elasticity of masonry structure can be obtained by solving the equation of 550 $f_{m}'$ [25-27].

![Figure 3. Stress and strain distribution for section analysis [28.]](image)

7.1 Calculation steps

Depth of the neutral axis, $a = \beta \times c = 0.88c$ (c is the depth of neutral axis in actual stress condition)

Compressive force, $C = \gamma \times f_{m}' \times a \times b = 0.8 \times 3.3 \times a \times 500 = 1320a$ (b = width of PP band)

Tensile force due to PP band, $T = n \times T_p \times b_p \times t_p = n \times 142.22 \times 10 \times 0.1 = n \times 142.22$ N

where, $n$ represents the number of PP band, $T_p$ is the tensile strength of PP band, $b_p$ and $t_p$ are the width and thickness of band, respectively.

From equilibrium condition, we know

$$C = T$$
or, $1320a = n \times 142.22$

or, $a = n \times 0.11$ mm

Ultimate moment capacity = $M_u = C \times (h - a/2) = T \times (h - a/2)$

or, $M_u = 1320a \times (h - a/2)$ N-mm = $n \times 142.22 \times (h - a/2)$ N-mm

The moment due to the applied load will be $DW$, where, $W$ is the applied load in each roller and $D$ represents the distance of each loading points from support which is equal to 140mm and 70mm for full scale wall and half scale wall, respectively.

Therefore, moment due to applied load, $M_a = W \times D$

When moment ($M_a$) due to applied load reaches up to the ultimate moment resisting capacity ($M_u$) of specimen, crack will start.

Maximum cracking load from each roller, $W = M_a/D = M_u/D$

$$\frac{W}{D} = \frac{1320a \times (h - a/2)}{D} N$$

$$\frac{W}{D} = \frac{n \times 142.22 \times (h - a/2)}{D} N$$

Table 4. Comparison of experimental results with theoretical value.

| Specimen                        | Maximum load (kN) | Ratio of analytical to experimental load, $P_A/P_E$ |
|---------------------------------|-------------------|-----------------------------------------------|
| [Analytical, $P_A$]             | [Experimental, $P_E$] |                                               |
| Full scale clay brick with PP band | 16.12             | 15.27                                          |
| Half scale clay brick with PP band | 7.898             | 7.4                                            |

Table 4 presents the analytical value of failure load of PP band strengthened wallets. The analytical results are almost similar with the results which are obtained experimentally. The difference between the ratio of $P_A/P_E$ is almost same which confirms that the present study holds good to predict failure load of PP band strengthened structure.

8. Conclusions
A total number of six types of wall were tested in flexural loading among of these two types of structure are unreinforced and rest of that are strengthened structure. The following conclusion can be drawn after observing the type of failure:

i) The unreinforced masonry structure collapse completely at lower load, therefore it is required to strengthen the structure to improve its strength and ductility. The cost effective reinforcing materials which are used in the present study are proved to be effective for strengthening purpose.

ii) Strengthening with welded wire mesh shows most effective in terms of strength and flexural capacity of masonry wall compared to PP band. It can withstand the cracking load more than 1.6 times than PP band strengthened wall.

iii) The load-displacement behaviour of half scale brick becomes almost similar to the full scale brick after introduction of the proper scale factor (2 for the present study). It can be stated that half scale brick can be suitable to construct the scaled down masonry house for the shake table test.

iv) The analytical model which is used in the present study can be used to obtain the maximum load carrying capacity of PP band strengthened full scale and half scale wall.

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