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Investigation on Modulus Rigidity of Retrofitted Brick Masonry Panel

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ABSTRACT: *Shear Modulus of a material helps in measuring its stiffness and its response to shearing strain. In this paper Investigation on the modulus rigidity of the retrofitted brick masonry panel is aimed and a low-cost and easy method of retrofitting for the unreinforced brick masonry structures is proposed. To accomplish this, an experimental investigation on retrofitted brick panels with different materials such as Polypropylene packaging strips, Metallic packaging strips, Nylon wire, G I wire under in-plane diagonal loading is carried out. Experimental results showed the modulus of rigidity of the retrofitted brick masonry panel is much more as compared to non-retrofitted panels.*

Keywords: *modulus of rigidity; brick masonry panel; retrofitting; in-plane diagonal loading ; shear stress; shear strain.*

I. INTRODUCTION

Masonry structures are very brittle in nature and their performance during earthquakes is very poor. Many structures which get damaged during earthquakes are un-reinforced brick masonry structures it can be seen from the earthquake in Pakistan in 2005 of magnitude 7.6 [1], the earthquake of Sichuan in 2008 of magnitude 7.9 [2], the earthquake of L'Aquila in 2009 of magnitude 5.8 [3] and this can be prevented by adopting easy methods of retrofitting which improves the seismic behavior of a reinforced brick masonry structure. Past researches have shown the behavior of brick masonry structures can be improved by retrofitting techniques. The shear strength of brick walls can be improved and the behavior of structure can be made ductile by using near surface mounted high strength twisted stainless steel reinforcement (TSNSM) [4]. Un-reinforced masonry structures can be strengthened and their ductility can be increased by increasing their collapse time with the addition of steel reinforcement like ferrocement overlays, reinforced surface plastering, grouted centre core steel insertion [5] and near surface mounted (NSM) steel insertion [6].

In the present paper, investigation of retrofitting technology is specifically aimed at preventing or prolonging the collapse of brick masonry buildings under earthquakes. Not much research has been done on the retrofitting of masonry structures using locally available materials in Northern Karnataka, India. In this research, different type of materials are used such as Polypropylene packaging strips, Metallic (Iron) packaging strips, Nylon wire, G I wire for retrofitting of the brick panels which forms a mesh which in turn prevents brittle masonry collapse. This present research aims at understanding the behavior of these materials with parameters such as shear stress, shear strain, and modulus of rigidity.

II. MATERIALS

Brick masonry panel is a composite material consisting of bricks and mortar. To be able to predict the behavior of this composite under states of shear stress, it is necessary to have a clear understanding of how the component parts act together. The materials used for the construction of panels are cement, sand and bricks. These materials are tested for their individual properties. In order to control the variables for the entire testing program, the materials used were carefully selected and maintained. In this chapter the properties of the materials used are presented. The materials used for construction of brick masonry panels and retrofitting are cement, sand, water, bricks, polypropylene packaging strips, metallic packaging strips, nylon wire and G I wire.

The entire experimental work was carried out in two phases. In the first phase, samples were cast and tested to determine the physical and mechanical properties of masonry and its constituents. And in the second phase, shear tests were carried out on masonry panels. The tests to determine the physical and mechanical properties of masonry and its constituents are discussed in subsequent sections.

2.1 Cement

The Ordinary Portland Cement used in this study is tested to determine the properties like standard consistency, initial setting time, final setting time and compressive strength as per IS 8112-1989 and IS 4031-1968 (Part4) for Testing of Cement. The test results of cement are given in Table 1.

Table 1- Test Results of Cement

SI No	Name of test	Results	IS specifications IS – 8112 (1989) and IS 4031-1968 (part4)
1	Normal consistency	32%	--
2	Initial setting time	55 minutes	Not less than 30 minutes
3	Final setting time	145 minutes	Not more than 600 minutes
4	Compressive strength a) 3 days b) 7days	30 MPa 41 MPa	>23 MPa >33 MPa

2.2 Sand

The quality of sand to be used for masonry building should be carefully maintained. For the present study, sand of zone II (River sand) has been used. The specific gravity and sieve analysis tests are performed as per IS 2386 (Part 3)1963 for Testing of Sand to understand the sand properties. Table 2 shows the specific gravity and sieve analysis report of the sand used for the present study.

Table 2- Results for Specific Gravity and Fineness Modulus

SI No	Particulars	Results
1	Specific Gravity	2.7642
2	Fineness Modulus	3.1

2.3 Bricks

The brick used for the study were well burnt of size 209 x 100x 70mm, of which the average compressive strength was found to be 3.78 MPa. The bricks are tested for their water absorption and compressive strength as per IS 3495-1976 for Testing of Brick. Table 3 shows the compressive strength and the percentage of moisture content report of the bricks used for the present study.

2.4 Mortar

The flow table test and compressive strength tests are performed on mortar for different mix proportions and in the mix proportion of 1:6 which is adopted in the present work are discussed in this section.

Flow table test:

As per IS 5512-1969 an average flow value of about 110%-115% is desirable for masonry construction in the Indian conditions. Finally water cement ratio of 1:6 was adopted to prepare the mortar for brick panels. Table 4 shows the W/C ratio corresponding to 110% flow and Table 5 shows the flow table test on mortar for 1:6 mix proportion used for the present study.

Compressive strength of mortar

The quality of cement for its strength in compression is judged by finding the compressive strength of cement-mortar in different mix proportions and the average compressive strength of the mix proportion of 1:6 which is adopted in the present work is shown in Table 6.

Table 3-Compressive Strength and Percentage of Moisture Content

Sl No	Dry weight W_1 (gms)	Wet weight W_2 (gms)	% Moisture content	Size of brick (mm)	Load at failure in kN	Compressive strength MPa
1	3050	3506	14.95	209 x 100x 70	65	3.11
2	3040	3510	15.46	209 x 100x 70	80	3.82
3	3058	3550	16.08	209 x 100x 70	75	3.58
4	3076	3552	15.47	209 x 100x 70	65	3.11
5	3088	3556	15.15	209 x 100x 70	95	4.54
6	3026	3484	15.13	209 x 100x 70	95	4.54
			Average=15.37			Average=3.78

Table 4- W/C Ratio corresponding to 110% Flow

Mortar type	Water cement ratio corresponding to 110% flow
1:6	1.18

Table 5- Flow Table Test on Mortar

Mix Proportion	W/C Ratio	Diameter of flow (mm)	Average diameter (mm)	Average percentage flow
1:6	0.92	**i.** 154 **ii.** 150 **iii.** 145	149.66	49.66
	1.2	**i.** 207 **ii.** 216 **iii.** 218	213.66	113.66

Table 6- Compressive Strength of Mortar

Mix proportion	Size of cube (mm)	W/C Ratio	No. of days	Failure load in kN	Compressive Strength (MPa)	Average
1:6	70.6 x 70.6 x70.6	1.18	7	20	4.01	3.67
			7	20	4.01	
			7	15	3.00	
			28	25	5.01	6.01
			28	35	7.02	
			28	30	6.01	

III. OBJECTIVES AND METHODOLOGY

Following are the objectives of the present study-
Investigation on Modulus Rigidity of Retrofitted Brick Masonry Panel
Proposing a low cost and easy method of retrofitting of the brick masonry building.
To investigate the behavior of retrofitted brick panels under in-plane diagonal loading.

Methodology

For investigation on the modulus of rigidity, experimental work is carried out by constructing brick panels of size 0.6mx0. 6m and curing for 28 days. The panels are tested placing diagonally in loading frame with some attachments at the top and bottom. The shear behavior of masonry panels is observed while testing. The constructed panels retrofitted with different material such as Polypropylene packaging strips, Metallic packaging strips, Nylon wire, G I wire is tested. Table 7 shows the sizes of Retrofitting Materials. The behavior of panels with these materials is observed. The observation includes the parameters such as shear stress, shear strain, modulus of rigidity, and modulus of elasticity. The load is applied with the help of hydraulic jack which was placed below the loading cell. The loading cell and LVDT were connected to the computer to measure the horizontal extension and vertical shortening as shown in Figure 1. Spacing of all the retrofitting materials to the masonry is kept same (80mm).

Figure 1- Retrofitting of Specimens and Test Setup

IV. RESULT AND DISCUSSION

In this chapter, the results obtained after the experimental investigations are discussed in detail. The results obtained were significant. Metallic strips took higher loads as compared to other materials followed by Nylon wire.

Results showed the behavior of retrofitted panels is far better than non-retrofitted panels. It was found by studying the behavior of each brick panel that all failures of non-retrofitted panels were brittle with no further load being maintained whereas retrofitted panels continued to carry the load after initial failure and vertical deformation is much more than non-retrofitted panels.

4.1 Parameters for the Study

Following parameters are taken for the study, the details of which are discussed in the subsequent sections.

Shear Stress
Shear Strain
Modulus of Rigidity
Modulus of Elasticity

Testing of Brick Panels

Brick panels were made of size 0.6mx06mx0.1m as a square brick panel, as suggested by ASTM E519-02-2002 (American Society for Testing and Materials) [7], E72-1995 (Euro Code) [8], Standard Test Methods of Conducting Strength Tests of Panels for Building Construction. Different panels of non-retrofitted and with materials such as Polypropylene packaging strips, Metallic (Iron) packaging strips, Nylon wire, and G I wire were tested for diagonal tension (Shear). In this section, all the calculations for obtaining the parameters are shown for one panel. And remaining values are summarized in Table 7- Table 11.

Non retrofitted Brick Panels

Shear Stress - The vertical load applied at the top end of the prism produced shear stresses in the prism along its vertical diagonal plane. These stresses, using the equation recommended by ASTM E 519 – 02 specifications, were calculated as follows:

$$A_n = \left(\frac{W+n}{2}\right)tn \quad = 0.110\text{MPa} \qquad (1)$$

$$S_s = \frac{0.707P}{A_n} \quad = 60000 \text{ mm}^2 \qquad (2)$$

Where, Ss = Shear Stress in MPa

P=Compressive Load in N i.e. P=10000 MPa

An= Net area of the specimen in mm².

W= width of the specimen in mm i.e. W=600 mm

h= height of the specimen in mm i.e. h=600 mm

t= total thickness of the specimen in mm i.e. t=100mm

n= percent of the gross area of the unit that is solid i.e. =1

Shear Strain - Shear strain is given by,

$$\gamma = \frac{\Delta V + \Delta H}{g} \qquad (3)$$

$= 6.8x10^{-4}$

Where, γ= shearing strain

g=vertical gage length in mm i.e. =250mm

ΔV=vertical shortening in mm i.e. =0.08mm

ΔH= horizontal extension in mm i.e. =0.09mm

Modulus of Rigidity -

$$G = \frac{S_S}{\gamma} = 161.76 \text{ MPa} \tag{4}$$

The Modulus of Rigidity is usually low for bricks having lower compressive strength. Hence in the present study, the value of G is comparatively low.

Modulus of Elasticity (As per Euro Code 72)

$$E = \frac{G}{0.4} = 404.40 \text{ MPa} \tag{5}$$

Retrofitted Brick Panels With G I Wire - For brick panels retrofitted with GI wires, it was observed that it carried loads up to 17.60 kN and failed but even after the failure, further it carried the load up to 23.00 kN because of mesh provided by the GI wires. Table 8 shows the different values of parameters for brick panels retrofitted with GI wires.

Retrofitted Brick Panels with Polypropylene Packaging Strips- For brick panels retrofitted with Polypropylene packaging strips, it was observed that it carried loads up to 21.36 kN and failed but even after the failure, further it carried the load up to 29.00 KN. Table 9 shows the different values of parameters for brick panels retrofitted with Polypropylene packaging strips. The failure of brick specimen is shown in Figure 3.

Retrofitted Brick Panels with Nylon Wire- For brick panels retrofitted with Nylon Wire, it was observed that it carried loads up to 24.63 kN and failed but even after the failure, further it carried the load up to 32.00 kN. Table-10 shows the different values of parameters for brick panels retrofitted with Nylon wire. Failure of panel retrofitted with Nylon Wire is as shown in Figure 4.

Figure 3-Failure of panel retrofitted with (a) Polypropylene Strips (b) Nylon Wire

Retrofitted Brick Panels with Metallic Packaging Strips

For brick panels retrofitted with Metallic packaging strips, it was observed that it carried loads up to 31.76kN and failed but even after the failure, further it carried the load up to 41.00 kN. Table-11 shows the different values of parameters for brick panels retrofitted with Metallic packaging strips.

Table 7- Summarized Values of Parameters for Non-Retrofitted Brick Panels

SI No	Shear Stress (N/mm)	Shear Strain X10^{-4}	Modulus of Rigidity (MPa)	Modulus of elasticity (MPa)	First Crack Load (kN)
1	0.110	6.8	161.76	404.40	10.00
2	0.118	7.2	163.88	409.70	10.30
3	0.114	08	142.50	356.25	09.70
Average	0.114	7.3	156.04	390.10	10.00

Table 8- Summarized Values of Parameters for Retrofitted Brick Panels with GI Wires.

SI No	Shear Stress (MPa)	Shear Strain X10^{-3}	Modulus of Rigidity (MPa)	Modulus of Elasticity (MPa)	First Crack Load (kN)
1	0.223	1.20	185.83	464.57	19.00
2	0.188	1.10	170.90	427.25	16.00
3	0.209	1.20	174.16	435.40	17.80
Average	0.206	1.16	176.96	443.96	17.60

Table 9- Values of Parameters for Brick Panels Retrofitted with Polypropylene Strips

SI No	Shear Stress (MPa)	Shear Strain X10^{-3}	Modulus of Rigidity (MPa)	Modulus of Elasticity (MPa)	First Crack Load (kN)
1	0.240	1.12	214.85	537.12	21.00
2	0.256	1.16	220.68	551.70	21.08
3	0.261	1.08	241.66	604.15	22.02
Average	0.252	1.22	225.73	564.32	21.36

Table 10- Values of Parameters for Brick Panels Retrofitted with Nylon Wire

	Shear Stress (MPa)	Shear Strain X10^{-3}	Modulus of Rigidity (MPa)	Modulus of elasticity (MPa)	First Crack Load (kN)
1	0.280	1.32	212.12	530.30	24.00
2	0.290	1.24	233.87	584.67	25.30
3	0.289	1.08	268.39	670.97	24.60

Average	0.283	1.2	238.12	4711.10	24.63

Table 11- Values of Parameters for Brick Panels Retrofitted with Metallic Packaging Strips

SI.NO	Shear Stress (MPa)	Shear Strain $X10^{-3}$	Modulus of Rigidity (MPa)	Modulus of Elasticity (MPa)	First Crack Load (kN)
1	0.395	1.28	308.59	771.47	33.60
2	0.348	1.16	300.00	750.00	29.60
3	0.378	1.24	304.83	762.07	32.10
Average	0.373	1.22	304.47	761.18	31.76

V. CONCLUSION AND SUMMARY

This research was aimed at finding the behavior of retrofitted brick panels by knowing their properties such as shear stress, shear strain, modulus of rigidity, and modulus of elasticity. It can be seen that the mesh provided by different retrofitted materials made the brittle material to act as a ductile material and panels carried load even after failure of masonry. The ultimate load is taken after the first band gets fail. These kind of retrofitting are still under active research and currently have application in Nepal, Pakistan and Kathmandu.

As we can see from Table-11 Metallic (Iron) packaging strips gives higher strength i.e. 75% more than non retrofitted brick panels but it costs twice the Nylon wire which gives 68% of strength, enough for a moderate earthquake. GI wire and Polypropylene packaging strips have lower Strength as compared to Nylon wire and Metallic (Iron) packaging strips. It is possible to provide reinforcement to brick masonry buildings in order to improve their structural performance and to increase their collapse time during earthquakes.

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