EXPERIMENTAL STUDY OF SEISMIC BEHAVIOR OF SCALED NON-ENGINEERED MASONRY STRUCTURES RETROFITTED BY PP-BAND MESH

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ABSTRACT: Most residential structures in developing countries are masonry structures which are highly vulnerable to earthquake and increase the structural damage and the death toll. This paper discusses the seismic capacity of non-engineered common masonry structures in Pakistan, which having more tendency to collapse due large weight of slab, by experimental approach using 1/12 miniature models. These models were constructed using acryl blocks which can be used several times. This paper also includes the comparison of retrofitted masonry model by PP-band, a method proposed by Meguro Laboratory, IIS, the University of Tokyo, with non-retrofitted one. The PP-band retrofitted masonry model showed almost 4 and 16 times greater seismic capacity than the non-retrofitted one in terms of ground acceleration and arias intensity, respectively.

Key Words: Masonry structure, seismic retrofitting, PP-band meshes, shake table test

INTRODUCTION

Pakistan is one of the developing countries in South Asia where most residential structures are non-engineered masonry structures. The 2005 Kashmir Earthquake of magnitude 7.6 (Mw) (US Geological Survey) caused a significant failure of these masonry structures which yielded a death toll of 79,000 people [1]. These masonry structures are highly vulnerable to earthquake. This vulnerability can be reduced by retrofitting using some locally available, affordable, and easily applicable method like PP-band mesh retrofit proposed by Meguro Lab, IIS, the University of Tokyo [2, 3, 4, 5, 6].

These structures are usually built up by fully or semi burned bricks with RCC (reinforced cement concrete) or BRCC (brick RCC) slab as roof. The clay soil and brick tile are also placed on RCC or BRCC slab for heat isolation and floor finishes, respectively. This concrete slab is usually cast in-situ without any shear connection with walls. The excessive weight of slab and absence of shear connection increase the probability of collapse of these structures during seismic events.

These masonry structures were modeled using 1/12 scaled specimen with acrylic blocks, cement lime sand mortar for experimental studies [5]. These models were prepared under the different scenarios, i) non-retrofitted, ii) retrofitted without shear connection between slab and walls, and iii) retrofitted with shear connection between slab and walls as shown in Figure 1. All three models were constructed under the same conditions of materials, strength and dimensions. The input motion applied to all three structures was also the same. The both retrofitted and non-retrofitted models were tested using shake table to asses their seismic performance. The results obtained from shake table tests were compared with each other and an excellent improvement of seismic capacity of PP-Band retrofitted

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masonry structure was observed. It was also observed that the shear connection between the slab and walls increased the seismic capacity of structure.

EXPERIMENTAL DETAILS

Model Characteristics

Three 1/12 scaled single room models were constructed for shake table test as shown in Figure 1. The characteristics of prototype were incorporated as much as possible in the models as shown Table 1. The size of the model was determined on the basis of permissible payload of shake table [i-e $\simeq$ 18 Kg]. The plan size of the models was approximately 290mm x 290mm. The model height and wall thickness were 240mm and 20mm, respectively. The door was placed on the one side of the model and window was placed opposite to it. The dimension of the door opening was 84mm x 156mm in horizontal and vertical direction, respectively. The dimension of the window opening was 84mm x 84mm.

The concrete slab of prototype structure was modeled by using wood plate and additional steel plates were attached to make the weight of slab proportional to 1/12 scaled concrete slab weight. The slab was placed on the walls without any connection between wall and slab in case of NR-XSC and R-XSC models as shown in Figures 1(a) and 1(b), while, in case of R-SC model, the slab was connected to walls by the PP-band as shown in Figure 1(c). The model was placed on the shaking table and input motion was applied to the model parallel to the walls having openings.

Materials

For the construction of 1/12 scaled masonry structure model, the two sizes of the acryl blocks, 40 x 20 x 10 mm^3 and 20 x 20 x 10 mm^3, were used as shown in Figures 2(a) and 2(b). The half blocks were used for break of joints among the layers. The major reason of the use of acryl blocks were their reusability [5].

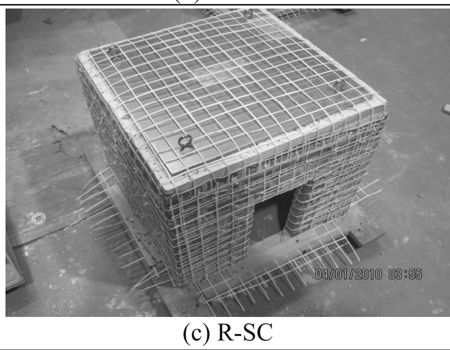
The surface of acryl blocks was very smooth and inefficient to provide required friction, we used sandpapers to solve this problem. Two basic tests, 'Friction Coefficient Tests' and 'Direct Shear Tests' were conducted as shown in Figures 3(a) and 3(b), by using acryl blocks with sandpapers pasted on the both sides by double sided tape as shown in Figure 2(c). For the selection of appropriate sandpaper, the more weightage was given to shear test. The shear test demonstrated the sandpaper of Grit# 80 as

Model Name	Description
NR-XSC	Non-retrofitted model without slab connection to walls [Figure 1(a)]
R-XSC	Retrofitted model without slab connected to walls [Figure 1(b)]
R-SC	Retrofitted model with slab connection to walls [Figure 1(c)]

NR = Non-Retrofitted, R = Retrofitted
XSC = Slab without connection
SC = Slab with connection

(a) NR-XSC

(b) R-XSC



(c) R-SC

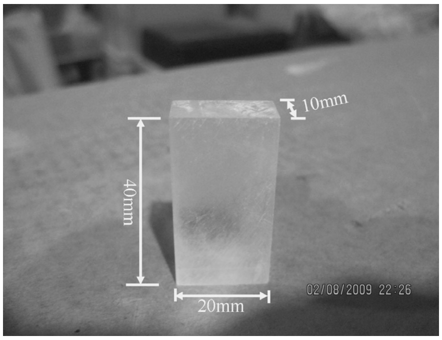
Figure 1: Structure models used

the most appropriate sandpaper to achieve the require shear strength as shown Figure 3.

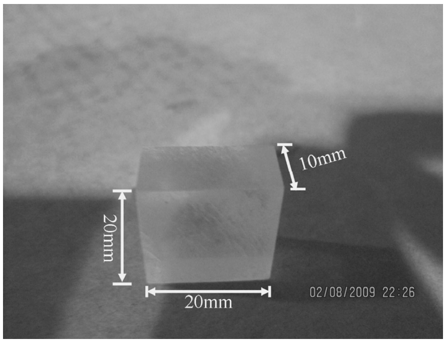
Table 1: Characteristics of prototype and corresponding values of model

Quantity	Equation	Theoretical Factor	Prototype	Model	Actual Factor
Length (L)	$S_L = \frac{L_P}{L_M}$	12	228 mm	20 mm	11.40
Stress (τ)	$S_\tau = \frac{\sigma_P}{\sigma_M}$	12	0.2400 MPa	0.0192 MPa	12.50
Weight (W)	$S_W = S_L{}^2 S_\tau$	1,728	7,010 Kg	4.05 Kg	1,728

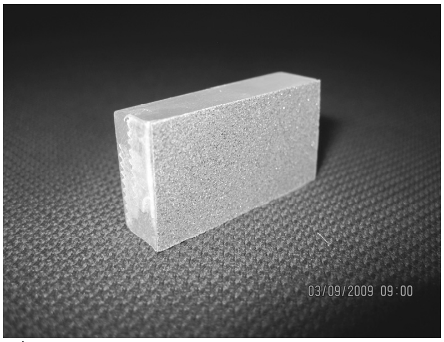
S = Scale Factor, τ = Shear Stress



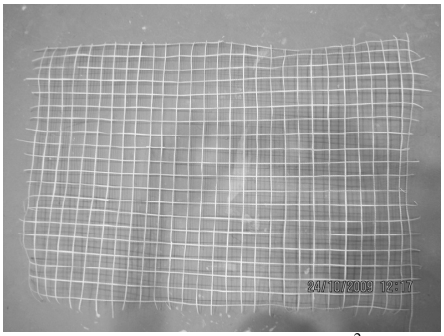
(a): Full size acryl block



(b): Half size acryl block

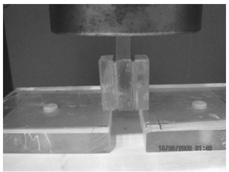


(c): Acryl block with sandpapers pasted on both sides by double sided tape



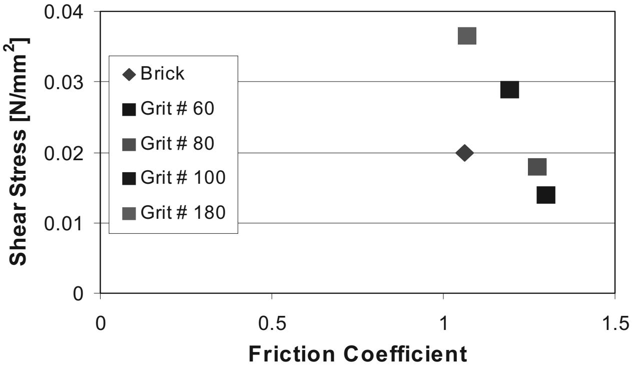
(d): PP-band mesh (20 x 20 mm^2 pitch)

Figure 2: Material used for the models preparation



(a): Shear test

(b): Friction Coefficient Test



(c): Shear test and friction coefficient test results

Figure 3: Selection of appropriate sandpaper

After the various trials with different mixture ratios of mortars, the mortar with the mixture ratios of cement: lime: sand: water = 1:8:30:10 [by weight] were finally selected based upon the shear strength. The above described mortar gave the shear strength nearest to the target shear strength of brick proportional to 1/12 scaled model as shown in Figure 3(c).

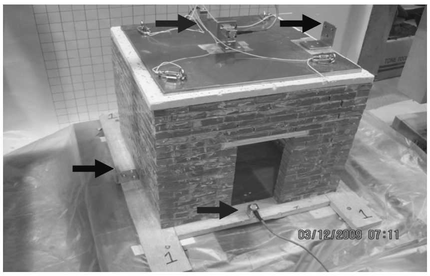
The cross sectional area of the PP-Band was approximately 1mm x 0.3mm. These PP- bands were placed with a pitch of 20mm from center to center to make meshes as shown in Figure 2(d). The pitch of 20mm was selected so that each acryl block was covered by two PP-bands. The PP-Band meshes were connected across the wall by using threads at a grid of 40 and 20mm in horizontal and vertical direction, respectively.

Experimental Setup and Input Motion:
The models were constructed on the rectangular wooden frames which were placed on the shake table and connected by shear keys. The first layer of acryl blocks was permanently fixed with wooden frame. The one dimensional sinusoidal wave motion was applied to shake the specimen. The models were placed on the shake table and the input motion was applied parallel to walls having openings.

The shake table used can apply sinusoidal motion of two amplitudes, 5 and 15mm, and the frequencies from 2 to 66 Hz. In the experiment, sinusoidal motions of frequencies from 2 to 6Hz with 5 and 15mm amplitudes were applied to the specimen in the pattern shown in Table 2. The duration of motion of each frequency applied was 30 Sec. Arias Intensity, I_A, was also calculated from the input motion by Eq. 1 [7]. Acceleration and displacement at the base and slab of the structure were measured by using accelerometer and laser displacement measuring system as shown in Figure 4.

Table 2: Input motion used in experiment

Amplitude (mm)	Frequency (Hz)				
5	2	3	4	5	6
15	2	3	4	5	6

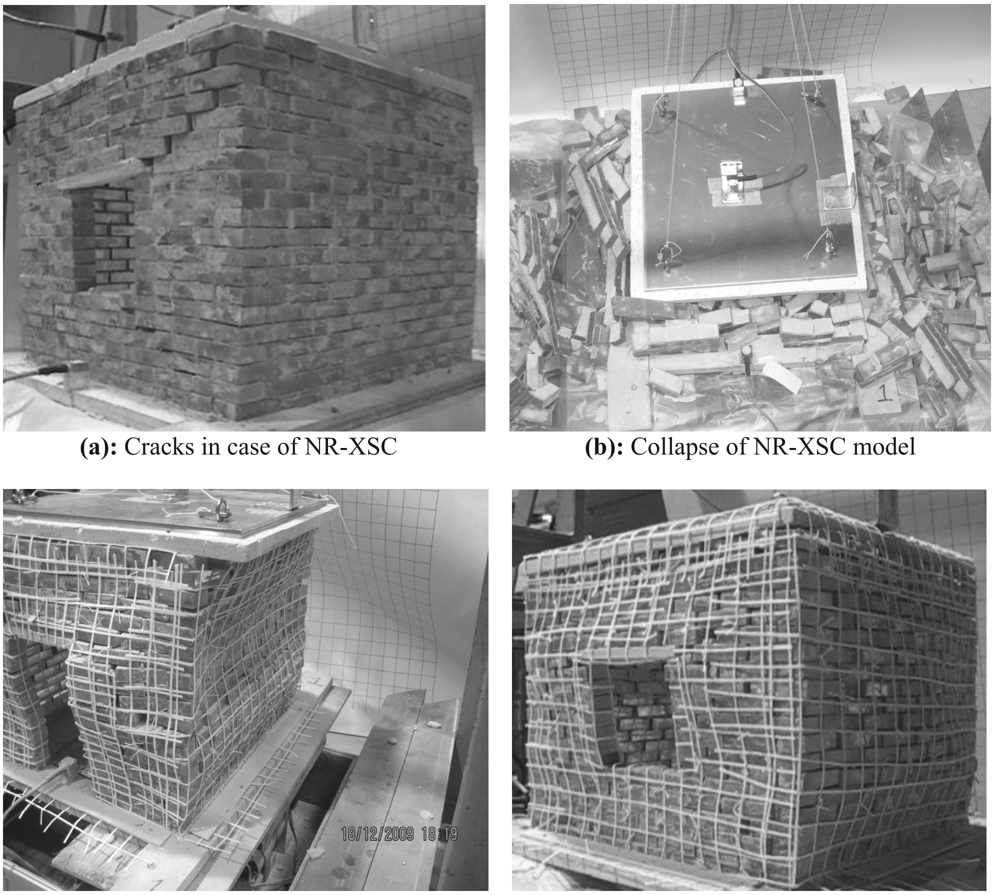


➡ Acceleration ➡ Displacement
Figure 4: Location of sensors

$$I_A = \frac{\pi}{2g}\int_0^\infty a^2(t)dt \quad \text{Eq. (1)}$$

RESULTS DISCUSSION

The first model tested by the shake table was NR-XSC. The model performed well and it did not show any considerable damage until the input acceleration was below 141 gal [I_{JMA} < 5.0]. During this stage, the acceleration observed at the base was almost same as that of slab acceleration. When the base acceleration was increased to 200 gal [$I_{JMA} \simeq 5$], the slab displacement was amplified and became much larger than base displacement. But meanwhile the slab acceleration observed became smaller than the base acceleration due to cracks in masonry walls as shown in Figure 5(a). But when the acceleration was further increased, the collapse of structure occurred suddenly at an acceleration of 300 gal [I_{JMA} > 5] as shown in Figure 5(b).



(a): Cracks in case of NR-XSC

(b): Collapse of NR-XSC model

(c): Movement of slab in R-XSC

(d): R-SC after shake table test

Figure 5: Results of shake table test

On the other hand, the retrofitted model, R-XSC, showed higher seismic capacity. The PP-band effect became more prominent after appearance of large cracks. Due to appearance of cracks and holding effect by PP-Band mesh, the energy dissipation capacity was improved which thwart the complete collapse. But when the amplitude of input motion was changed to 15mm [at which acceleration was 903 gal, $I_{JMA} \simeq 6$], the slab of model started sliding because slab was not connected with walls as shown in Figure 5(c).

The retrofitted masonry model, R-SC, whose slab was connected with walls, was tested by shake table under the same motion used for NR-XSC and R-XSC. In this model, as the slab was covered by PP-band meshes to prevent its movement, the slab did not move during the shake table test as shown in Figure 5(d). The collapse point of each type of model was recorded in terms of JMA Intensity [8], Arias Intensity and time except R-SC which did not collapse completely even an input motion of more than 1,000 gal was applied [$I_{JMA} > 6$]. These observations are shown in graphical form in Figure 6. It is also important to note that the R-SC did not fail completely like NR-XSC and also did not slide like R-XSC. The lateral sway displacements recorded at slab level of all models are shown in Figure 7.

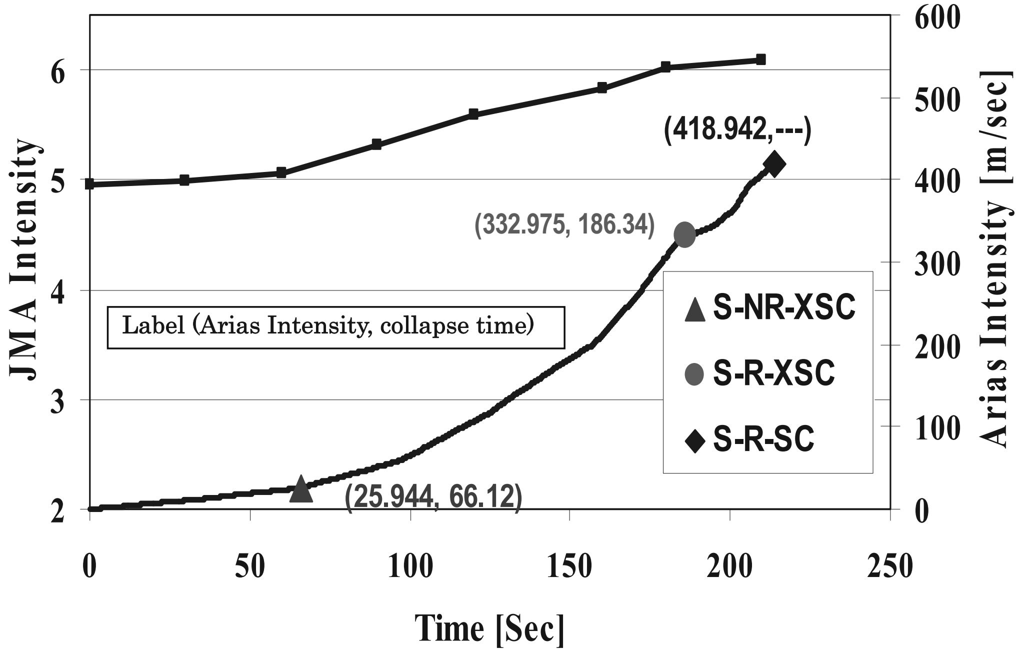


Figure 6: Comparison of collapse point

The European Macro-seismic Scale (EMS) Grades were used for damage level definition as shown in Figure 8(a). The EMS Grades were carefully observed and corresponding time was recorded during the shake table test. The damage level of each model, EMS Grades and corresponding Arias Intensity are shown in Figure 8(b). The EMS Grade 1 and Grade 2 occurred at almost same Arias Intensity [time] for all three models. However after EMS Grade 2 [considerable cracks], the PP-Band became effective and a considerable seismic capacity was observed in retrofitted model as compare to non-retrofitted one. The retrofitted model (R-SC) didn't collapse completely and maximum EMS grade obtained was 4 even at the peak acceleration of over 1,000 gal [$I_{JMA} > 6$].

CONCLUSIONS

It was clearly observed that PP-Band retrofitted masonry house could have much higher seismic capacity as compare to non-retrofitted one. The seismic capacity improved by PP-Band retrofitting was almost 4 and 16 times higher than non-retrofitted model in terms of ground acceleration Arias Intensity, respectively. The retrofitted model can tolerate 8 times larger lateral sway displacement than non-retrofitted one.

The heavy slab of structure accelerated the crack generation in walls but if the structure retrofitted properly by PP-band, the energy dissipation capacity could be improved and complete collapse can be thwarted. Furthermore, the shear connection between slab and walls of the structure further could increase seismic capacity.

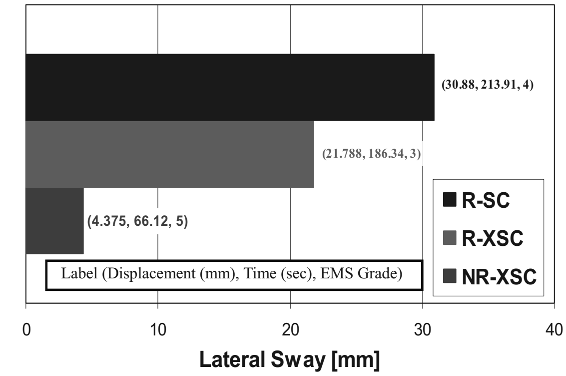
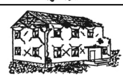
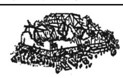
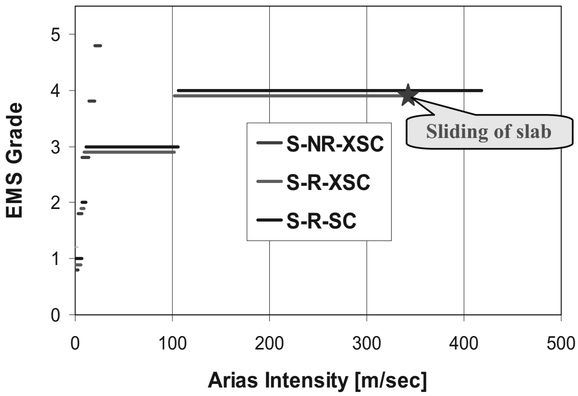


Figure 7: Lateral sway displacement (in case of R-XSC Model: just before slab sliding)

Grade	Description	Picture
1	Hair-line cracks in very few walls	
2	Cracks in many walls	
3	Large cracks in most walls	
4	Very heavy damage	
5	Total or near total collapse	

(a): EMS grades of damage



(b): EMS grades and corresponding Arias Intensity

Figure 8: Experimental Results

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