Seismic simulation of ¼ scale unreinforced masonry models retrofitted with PP-band meshes

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1. Introduction

Human casualties due to earthquakes are mostly due to structural collapse mainly that of unreinforced masonry buildings including earthen structures [1] (Figure 1). The existing world housing stock is mostly composed of this type of seismically vulnerable dwellings [2]. Retrofitting of low earthquake-resistant masonry structures is the key issue to significantly reduce casualties. In addition, it decreases the costs of rescue and first aid activities, rubble removal, temporary residence building, and permanent residence reconstruction to re-establish normal daily life [3] contributing to the sustainability of the affected countries' development.

Several masonry retrofitting techniques are available. However, the above stated problem poses special challenges. Not only should the proposed methodology address the technical issues, i.e. improve the seismic resistant characteristics of the structure, it should also be simple and inexpensive so that the people with limited resources, who usually live in this type of constructions, can implement it. This can be achieved by using widely available and inexpensive materials as well as considering simple installation methods as self construction is predominant for these structures [4]. In this context, the use of PP-band meshes for retrofitting unreinforced masonry has been introduced [5].

To verify the dynamic performance of masonry structures retrofitted with PP-band meshes, shaking table tests were carried out. This paper briefly discusses these tests' results.

Fig. 1 Collapsed adobe house as a result of the 2003 Bam earthquake

Fig. 2 Test setup

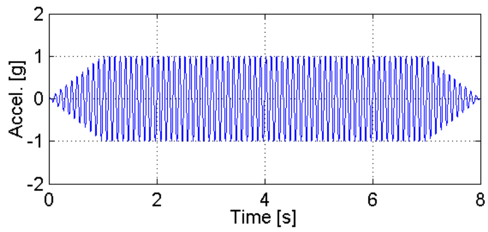

Fig. 3 Input motion waveform (f=10Hz, A=1g)

2. Model preparation and test conditions

Two identical ¼ scale models were built using bricks and cement, lime and sand (1:8:20) mortar. Both models represented a one-storey box-like building without roof (Figure 2). The model dimensions were 950(L) x 950(W) x 720(H) mm^3 and wall thickness was 50mm. A window (243x485mm^2) and a door (325x245mm^2) were provided at two opposite walls. The masonry mechanical properties, compatible with the typical materials found in developing countries, are shown below.

Table 1. Masonry mechanical properties (all in MPa)

Property	NR-40	R-40
Compression	20.96	20.30
Direct shear	0.074	0.075
Bond	0.085	0.074
Diagonal shear	0.173	0.181

NR-40: Non-retrofitted model; R-40: Retrofitted model

One model was retrofitted with PP-band mesh after construction. The details of the installation process may be found elsewhere [6]. The mesh bands cross section dimensions were 6(W) x 0.24(T) mm^2 and the pitch was 40mm. These characteristics are equivalent to a typical 15.5(W) x 0.6(T) mm^2 PP-band (widely available commercially) arranged at 100mm pitch in the prototype domain.

The models were subjected to unidirectional sinusoidal excitations (parallel to the walls with openings) with amplitudes and frequencies varying from 0.05 to 1.4g, and from 35 to 5Hz, respectively. Figures 3 and 4 show the typical input waveform and

Amplitude [g]	Frequency (Hz) 2	5	10	15	20	25	30	35
1.4		59	58	57				
1.2		56	55	54	53			
1.0	62	52	51	50	49			
0.8	61	47	44	41	38	35	32	29
0.6	60	46	43	40	37	34	31	28
0.4	48	45	42	39	36	33	30	27
0.2	26	25	24	23	22	21	20	19
0.1	18	17	16	15	14	13	12	11
0.05	10	09	08	07	06	05	04	03
Sweep	01, 02							

JMA Intensity	-4	5-	5+	6-	6+	7

Fig. 4 Loading program and corresponding JMA intensities (Non-retrofitted and retrofitted models surrounded by red and blue lines, respectively)

Key Words: Shaking table, brick, unreinforced masonry, seismic vulnerability, building damage, retrofitting, PP-band
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loading sequence, correspondingly. The latter also shows the JMA intensities for each input. The sinusoidal waveform was used for simplicity as the experiment results will be used for the validation of numerical models. The structural response was captured with accelerometers and laser displacement meters.

3. Results and discussion

Both specimens were loaded following exactly the same sequence. In the elastic range and initial cracking stage, both models behave similarly, which is consistent with the results of static tests [7]. Until Run 41, walls parallel to the shaking exhibited tension cracks at the lower most mortar joint, next to the openings, and diagonal shear cracks at the opening corners. Walls perpendicular to the shake only had tension cracks along horizontal joints. After this run, the specimen NR-40 rapidly degraded, the existing cracks widened and a few new ones appeared. It completely collapsed during Run 46 (Figure 5).

On the other hand, new cracks appeared in the model R-40 as loading progressed. After Run 46, it did not exhibit considerable residual deformations (Figure 6). Specimen R-40 was loaded 16 more times with shakes of increasing intensity, 6 of them with JMAI 6- or more. Even after these severe demands, the structure did not collapse (Figure 7). Figure 8 shows crack patterns of two model walls. R-40 experienced input velocities and deformations four and ten times larger than NR-40, respectively.

In terms of damage level, NR-40 exhibited Total Collapse [8] during Run 46. On the other hand, R-40 had Life Safety damage level up to Run 61, which had a JMAI 6+. It is worth noting that before the structure cracked there were no major differences in the models' behavior. However, after cracking it was clear that the structural ductility was considerably increased. During the test, sliding along cracked mortar joints was notorious and it is considered to be one of the major mechanisms of energy dissipation of the proposed retrofitting method.

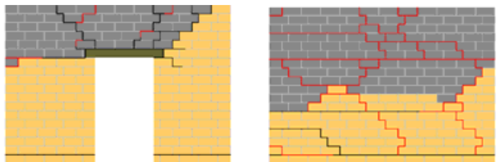
4. Concluding remarks

Two identical masonry models were constructed and one was retrofitted with PP-band mesh. Both specimens were tested on a shaking table under identical conditions to study their dynamic behavior. Cracks patterns were analyzed and failure behavior and performances were evaluated. The experiments showed that the PP-band retrofitting technique significantly enhanced the structural seismic performance. Specifically, the retrofitted specimen exhibited Life Safety damage level up to shaking intensities of JMA6+. Although the specimen did not have roof, if provided, it would have enhanced the structure behavior by providing restrain to the wall deformations.

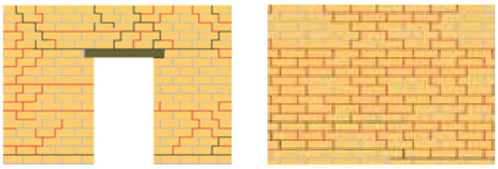
Fig. 5 Non-retrofitted model after Run 46

Fig. 6 Retrofitted model after Run 46

Fig. 7 Retrofitted model after Run 61



(a) Non-retrofitted model



(b) Retrofitted model

Fig. 8 East and south wall **c**rack patterns (Cracks before Run 41: Black; Cracks after Run 41: Red)

Acknowledgements

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