SHAKING TABLE TEST ON SEISEMIC RESPONSE BEHAVOIR OF 2-STORY MASONRY HOUSE MODEL WITH PP-BAND MESH RETROFITTING

Navaratnarajah SATHIPARAN[1], Kotaro SAKURAI[2], Muneyoshi NUMADA[3] and Kimiro MEGURO[4]

ABSTRACT: This report is the study on the dynamic properties and seismic performance of the two-story masonry house model by the 1/4-scale shaking table test. The specimen is an ordinary dwelling house in south Asia. The shaking table test was carried out by the sinusoid input wave of the one direction in the horizontal direction. Acceleration and displacement are measured. The dynamic response properties and comparative study of one-direction excitation were explained.

Key Words: two-story masonry, polypropylene band, shaking table test, arias intensity

INTRODUCTION

Unreinforced masonry structure is one of the most popularly used constructions. It is also unfortunately the most vulnerable to the earthquakes. It would collapse within a few seconds during earthquake movement, and does become a major cause of human fatalities. Therefore, retrofitting of low earthquake-resistant masonry structures is the key issue for earthquake disaster mitigation to reduce the casualties significantly. When we propose the retrofitting method in developing countries, retrofitting method should respond to the structural demand on strength and deformability as well as to availability of material with low cost including manufacturing and delivery, practicability of construction method and durability in each region. Considering these issues, a technically feasible and economically affordable PP-band (polypropylene bands, which are commonly utilized for packing) retrofitting technique has been developed, and many different aspects have been studied by Meguro Laboratory, Institute of Industrial Science, The University of Tokyo (Yoshimura 2004).

Single-story masonry house made of a regular shape brick units have been widely studied both from experimental and numerical point of view, and based on previous experimental results, it was concluded that in single-story high houses with timber roofs, PP-band meshes were not demanded to their full capacity. This is because the band itself is very strong. Therefore, it is expected that PP-band meshes can also be efficient to retrofit two-story high residences. Therefore, the present work aims at increasing the insight about the behavior of the two-story masonry house model under dynamic loading.

A real scale model test makes possible to obtain data similar to real structures. However, it requires large size testing facilities and large amount research funds, so it is difficult to execute parametric tests by using the full scaled models. Recently, structural tests of scaled models become

1 Post Doctoral Research Fellow
2 Graduate Student
3 Assistant Professor
4 Professor, Director of International Center for Urban Safety Engineering (ICUS)

well-known as the overall behavior of the system can be also understood from the scaled model. In these experimental program ¼ scale models was used to investigate the static and dynamic behavior of masonry walls.

DESIGNING AND CONSTRUCTING THE MODELS

Considering the shaking table size and allowable loading condition, the model scaling factor adopted was 1:4 as shown in **Figure 1**. Two models were used for shaking table test. The dimensions of both building models were 930mm×930mm×1440mm with 50mm thick walls. The sizes of door and window in opposite walls were 243mmx480mm and 325mmx240mm, respectively. Both models were represented two-storey box-like building with timber roof; one model was the non-retrofitted and other model was retrofitted with PP-band mesh after construction.

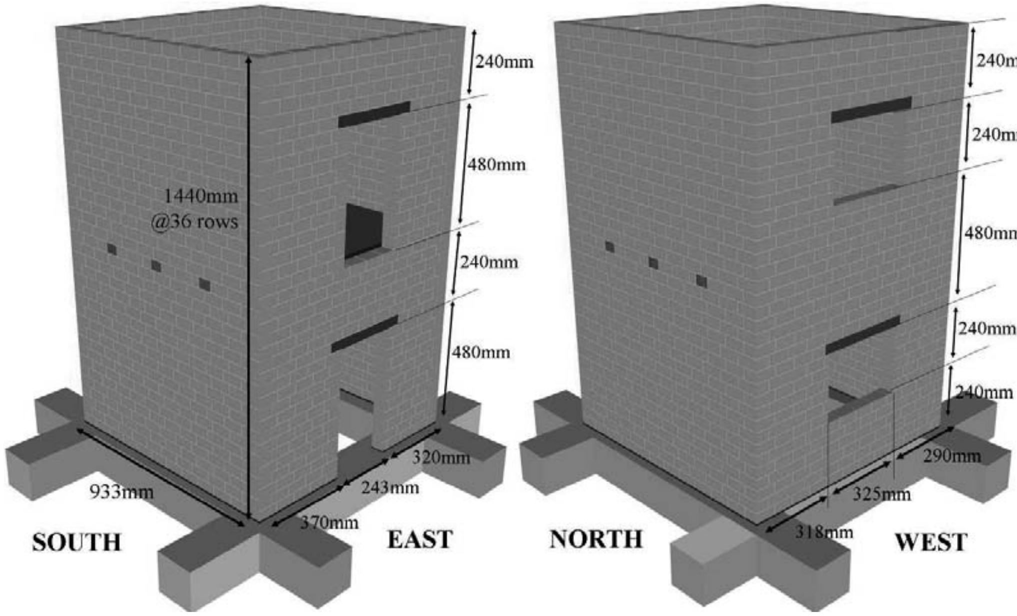


Figure 1. Model dimension

Specimens are consisted of 36 rows of 44 adobe unit in each layer except openings. It took two days for construction of first story. The first 11 rows were constructed in first day and remaining rows were done in following day. Second story construction takes place after 14 days of first story construction. The geometry, construction materials and mixture proportion, construction process and technique and other conditions that may affect the strength of the building models were kept identical for better comparison. The cross-section of the band used was 6mm×0.32mm and the pitch of the mesh was 40mm. The mortar with the mixture ratio of cement, lime and sand=1:2.8:8.5 and Cement/Water ratio=0.33% was used for adobe unburned brick masonry to simulate adobe masonry buildings in developing countries. Surface finish of 7mm mortar mix was applied covering the inside and outside of walls.

INPUT MOTION

Simple easy-to-use sinusoidal motions of frequencies ranging from 2Hz to 35 Hz and amplitudes ranging from 0.05g to 1.4g were applied to the specimens to obtain the dynamic response of both retrofitted and non-retrofitted structures. This simple input motion was applied because of its adequacy for later use in the numerical modeling. **Figure 2** shows the typical shape of the applied sinusoidal wave input motion.

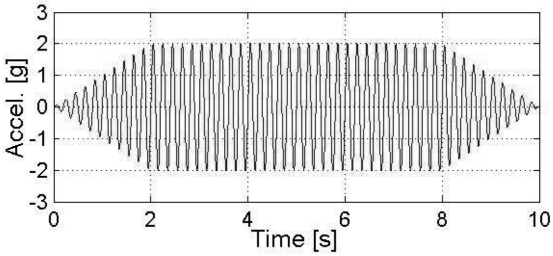


Figure 2. Typical Shape of Input Sinusoidal Motion

Loading was started with a sweep motion of amplitude 0.05g with all frequencies from 2Hz to 35Hz for identifying the dynamic properties of the models. The numbers in **Table 1** indicate the run numbers. General trend of loading was from high frequency to low frequency and from lower amplitude to higher amplitude. Higher frequency motions were skipped towards the end of the runs.

Table 1. Loading Sequence

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

To assess the global and local behavior, specimens were instrumented to measure accelerations and displacements. During the tests, twenty four accelerometers, eighteen on house and six on the roof were installed at the location shown in **Figure 3**. The number of accelerometers was 16 and 5 in the exciting and transverse direction respectively.

Four lasers, in N-S direction were used to measure displacements. The locations of laser measuring instruments are shown in **Figure 3**. L1, L2 aimed at obtaining the wall deformation at the top level in the direction of shaking. Laser L3 recorded the facade wall deformation at the centre. Laser L4 recorded the deformation at the base. The measured data were recorded continuously throughout the tests. The sampling rate was 1/500 sec in the all runs.

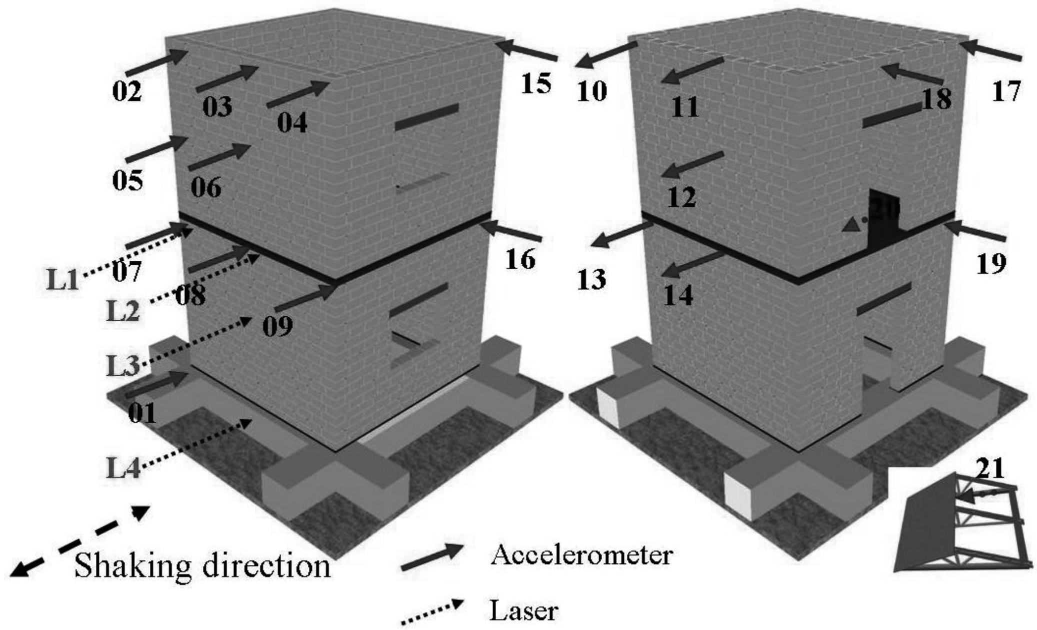


Figure 3. Location of accelerometers and lasers

CRACK PROPAGATION

For both specimens, up to Run 23, no major crack was observed. Major cracks were observed from Run 24. **Figure 4** shows the crack patterns for non-retrofitted and retrofitted after run 24. Non-retrofitted case, diagonal cracks initiating at the corner of the opening on the second story east wall, where the door is located, and it reached the top and bottom border of the model. In the south wall, the inclined cracks were accompanied by vertical cracks that reached from top to the first story wall. In case of retrofitted model, only minor crack on west wall was observed.

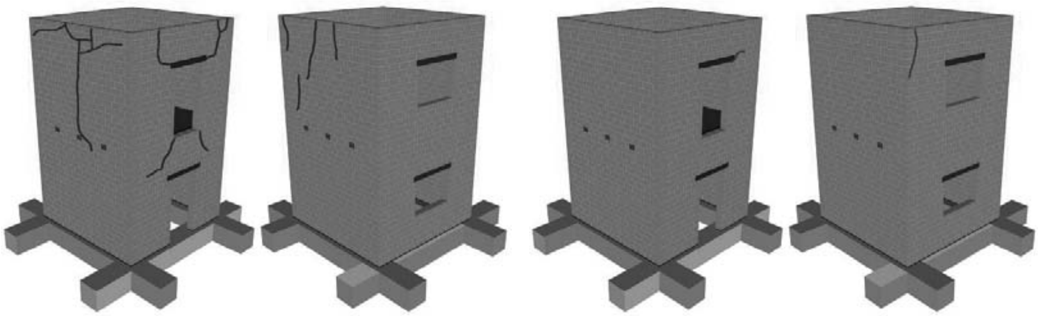
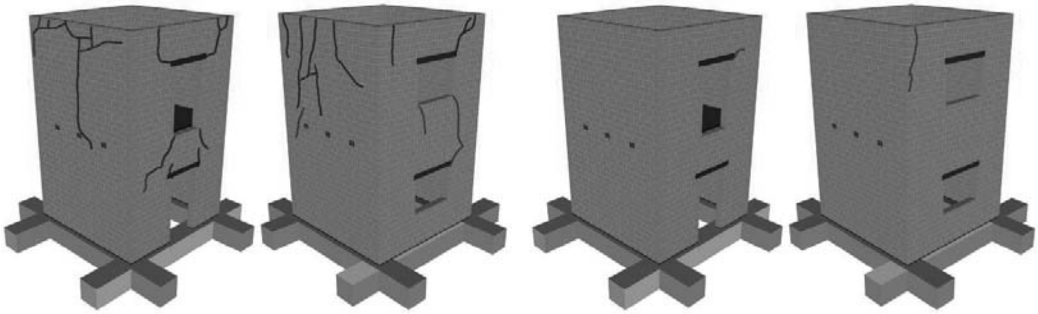
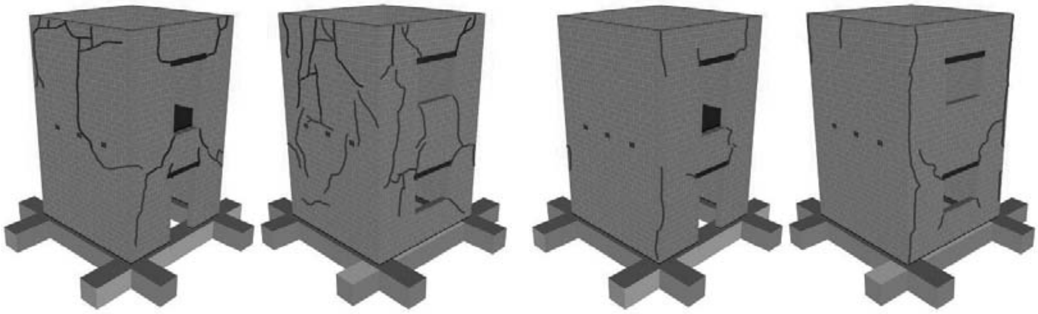


Figure 4. Crack patterns observed on non-retrofitted and retrofitted model after Run 24



Non-retrofitted model Retrofitted model

Figure 5. Crack patterns observed on non-retrofitted and retrofitted model after Run 33



Non-retrofitted model Retrofitted model

Figure 6. Crack patterns observed on non-retrofitted and retrofitted model after Run 40

Figure 7. Non-retrofitted model after Run 43

Although in case of Non-retrofitted model, cracks widened with each successive run after Run 24, Run 43 was critical. **Figure 7** shows the non-retrofitted model after run 43. There were large amount cracks observed in walls in the direction of shaking and exciting cracks widened and connection between adjacent walls was become weak. At the end of this shake, as shown in **Figure 7**, some top portion of the north and south walls above totally separated and removed from the model before resuming the testing program. Now the roof only supported by two walls, which were in the opposite direction of shaking. Therefore, they were bursted outwards in shaking direction. This finally led to the structure collapse. Run 44 was corresponded to base velocity and displacement equal to 125mm/s and 4mm, respectively.

Figure 8. Non-retrofitted model after Run 44

In case of retrofitted, each successive shake caused new cracks after Run 33. In each loading, cracks widen and sliding along mortar joints could be clearly observed. At the final stage of the test, run 52 virtually, all the brick joints were cracked, and the model had substantial permanent deformations. This input motion corresponds to a velocity and displacement equal to 467.5mm/s and 37.3mm, respectively, 3.7 and 9 times larger than the motion that caused the failure of Non-retrofitted model. However, building did not lose the overall integrity as well as stability and collapse were prevented in such a high intensity of shaking.

Figure 9. Non-retrofitted model after Run 52

At the final stage of the test, Run 53, with 50.6 mm base displacement, 12 times larger input displacement and 5 times larger input velocity than the Run 44 was applied. At this stage, most of the brick joints were cracked and the building had substantial permanent deformations. However, building did not loose the overall integrity as well as stability and collapse was prevented in such a high intensity of shaking. Thus, we could say that, PP-band retrofitting technique could maintain the integrity of the structural elements. Further, the retrofitted model showed the better energy dissipation mechanism as many new cracks were propagated without loosing the overall integrity and stability of the structure.

ANALYSIS ON TEST RESULTS

The performances of the models were assessed based on the damage level of the buildings at different levels of shaking. Performances were evaluated in reference to five levels of performances: light structural damage, moderate structural damage, heavy structural damage, partially collapse, and collapse.

Table 2. Damage categories

Category	Damage extension
D0: No damage	No damage to structure
D1: Light structural damage	Hair line cracks in very few walls. The structural resistance capacity did not decrease noticeably.
D2: Moderate structural damage	Small cracks were observed on masonry walls. The structure resistance capacity decreased partially.
D3: Heavy structural damage	Large and deep cracks were observed on masonry walls. Some bricks are fallen down. Failure in connection between two walls.
D4: Partially collapse	Serious failure and Partial structural failure were observed on walls and roofs, respectively. The building was in dangerous condition
D5: Collapse	Structure is totally or partially collapsed.

Based on JMA Scale

The Japan Meteorological Agency seismic intensity scale (JMA) is a measure used in Japan to indicate the strength of earthquake ground motions.

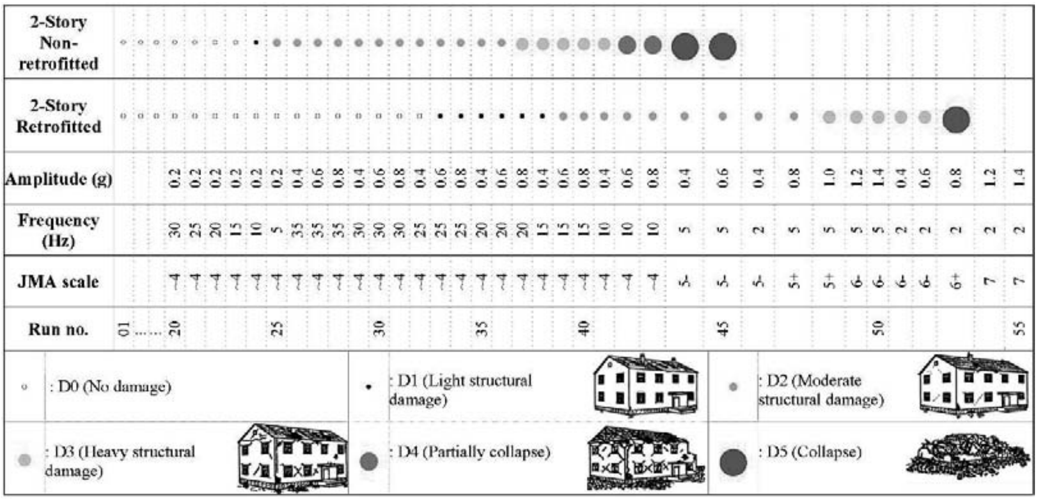


Figure 10. Performance evaluation based on input motion intensity by JMA scale

Figure 10 shows the performances of model houses with different JMA intensities. Collapse of the non-retrofitted building was observed at the 44th run at intensity JMA 5-. The retrofitted building performed moderate structural damage level at the 44th run at which the non-retrofitted building was collapsed. Moreover, moderate structural damage level of performance was maintained until the 47th run. It should be noted again that this model survived 8 more shakings in which many runs were with higher intensities than JMA 5- at which the non-retrofitted building was totally collapsed before reaching to the final stage at the 53rd run.

From these results it can be concluded that a structure retrofitted with PP-band meshes would be able to resist against strong aftershocks. Moreover, it proves that even though houses retrofitted with PP-band were cracked due to strong earthquake, it could be repaired and be expected to withstand subsequent strong shakes.

Based on Arias Intensity Scale

The Arias intensity was initially defined by Arias (Arias A., 1970) as

$$I_a = \frac{\pi}{2g}\int_0^t a^2(t)dt \qquad (1)$$

and was called scalar intensity. It is directly quantifiable through the acceleration record a(t), integrating it over the total duration of the shaking. The arias intensity is claimed to be measure of the total seismic energy absorbed by the ground.

Figure 11 shows the performance levels of each specimen against the dynamic motion based on arias intensity scale. Form the results, retrofitted model damage level performance was at least 4 times better than that of the non-retrofitted model.

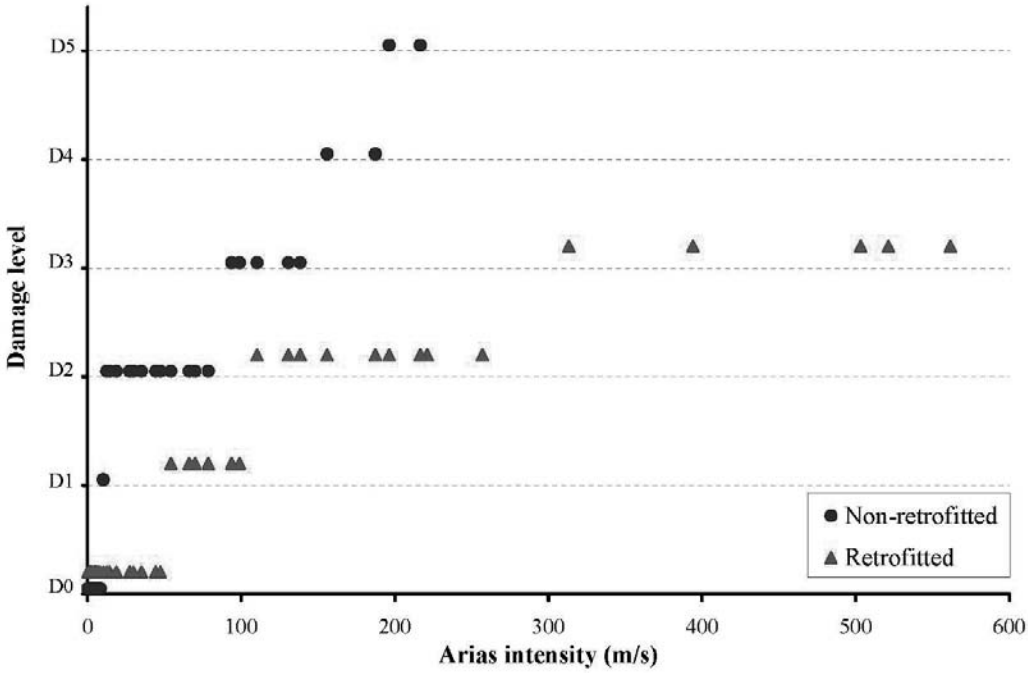


Figure 11. Performance evaluation based on arias intensity scale

CONCLUSION

This paper discusses the results of shaking table tests that were carried out using non-retrofitted and retrofitted two story masonry house by PP-band meshes. From these results, it can be concluded that a structure retrofitted with PP-band meshes would be able to resist against strong aftershocks. Moreover, it proves that even though houses retrofitted with PP-band were cracked due to strong earthquake, it could be repaired and be expected to withstand subsequent strong shakes.

From the experimental results, it was found that PP-band retrofitting technique proposed can enhance safety of both existing and new masonry buildings even in the worst case scenario of earthquake ground motion like JMA 7 intensity. Therefore, proposed method can be one of the optimum solutions for promoting safer building construction in developing countries and can contribute earthquake disaster in the future.

REFERENCES

Mayorca P., and Meguro K., (2004). "Proposal of an efficient technique for retrofitting unreinforced masonry dwellings", *13th World Conference on Earthquake Engineering*, Vancouver, Canada, Paper No.2431.

Sathiparan, N., (2008). "Experimental Study on PP-Band Mesh Seismic Retrofitting for Low Earthquake Resistant Masonry Houses", Ph.D. Dissertation, The University of Tokyo, Japan.

ASTM, E72, (1997). "Standard Test Methods of Conducting Strength Tests of Panels for Building Construction", *American Society for Testing and Materials*, Philadelphia, Pa.

Roko Zarnic, Samo Gostic, Adam J. Crewe and Colin A.Taylorm, (2001). "Shaking Table Tests of 1:4 Reduced Scale Models of Masonry Infilled Reinforced Concrete Frame Buildings", *Earthquake Engineering and Structural Dynamics*, Vol.30, 819-834.

Alidad Hahemi and Khalid M.Mosalam, (2006). "Shake-table Experiment on Reinforced Concrete Structure Containing Masonry Infill Wall", *Earthquake Engineering and Structural Dynamics*. Vol 35, Page 1827-1852.

Arias, A. (1970). "A Measure of Earthquake Intensity", R.J. Hansen, ed. *Seismic Design for Nuclear Power Plants*, MIT Press, Cambridge, Massachusetts, Page 438-483.