Shaking Table Experiment for Philippine Full-Scale Concrete Hollow Blocks (CHB) Masonry Houses

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SUMMARY:
The safety of Non-Engineered Construction is one of most urgent issues especially in seismically active regions because failure of these structures is commonly observed during large earthquake which is one of the main causes of human casualties. Concrete hollow block (CHB) masonry structures have recently become common residential structures in the Philippines. A full-scale shaking table experiment on CHB masonry structures modeled after Philippine residential structures was conducted in Japan. This experiment is part of a joint research study by Japanese and Philippine researchers which aims to better understand the behavior of these structures during large earthquakes, and its results will be used to produce a Simple Seismic Evaluation Method and Awareness Tool and to disseminate information on safer construction of houses in the Philippines.

Keywords: Non-Engineered Construction, Masonry, Concrete Block, Shaking Table Test, Seismic Evaluation,

1. INTRODUCTION

Most of the injuries and loss of lives during large earthquakes were due to varying severity of failure of buildings like residential houses that are constructed using different types of masonry materials. Most of these buildings did not consult a professional engineer and, as such, are not designed to be earthquake-resistant, often referred to as “Non-Engineered Buildings”. Unfortunately, these types of buildings and houses are widely constructed in most of the seismic prone areas.

A review of common housing types in the Philippines shows that many non-engineered houses exist on the ground and are mostly made of concrete hollow blocks (CHB). (Fig.1) With this situation, it is necessary to let the stakeholders and the house owners become aware of the possible behavior and seismic performance of their houses during strong ground shaking.

Figure 1. Typical CHB house in Manila

The National Research Institute for Earth Science and Disaster Prevention (NIED) of Japan and the Philippine Institute of Volcanology and Seismology (PHIVOLCS) of the Philippines, have agreed to cooperate in the implementation of a Joint Research Program named "Enhancement of Earthquake and Volcano Monitoring and Effective Utilization of Disaster Information in the Philippines", under the Japanese program Science and Technology Research Partnership for Sustainable Development (SATREPS) jointly funded by Japan Science and Technology Agency (JST) and the Japan International Cooperation Agency (JICA). Under this program, researchers from both countries investigated the seismic performance of existing houses and will recommend strengthening and retrofitting methods if necessary in order to mitigate disasters due to earthquakes.

2. FULL SCALE SHAKING TABLE EXPERIMENT

2-1. Outline of Specimens

Two house model specimens were built and dynamically tested on a seismic simulator at NIED (shaking table with one horizontal movement) on 23-24 February, 2011.

The overall dimensions of these two models were similar: 3600mm square plan and 2600mm height plus a 1200mm gable wall. The model structure has load-bearing walls with no RC column and the walls consisted of CHBs which were imported to Japan from the Philippines. Both models have the same roof specification of zinc sheet roof. (Fig.2, Fig.3).

One of these structures called "Model A" follows the standards stated in Chapter 7 of Masonry in the National Structural Code of the Philippines (NSCP). The other specimen called as "Model B" represents a non-engineered house which is actually found existing in different places in the Philippines. (Table 1).

Model A was constructed according to the minimum requirements set in the National Structural Code of the Philippines. The walls were made of fabricated 400x200x150mm CHB (also called as #6" CHB in the Philippines). The minimum thickness of load-bearing CHB walls as indicated in NSCP shall be 150 mm and the ratio of width to this thickness shall not exceed 32. For Model A, the ratio would be 3600/150=24 which passed the minimum requirement set in the NSCP on wall span over thickness. The mortar mix used for fill and joint mortar is properly compacted in every CHB hole, assuring proper bonding between joint and hole mortars. The vertical and horizontal reinforcement bars used were 10 mm deformed steel bars (DSB) and spaced at 400 mm and 600 mm respectively.

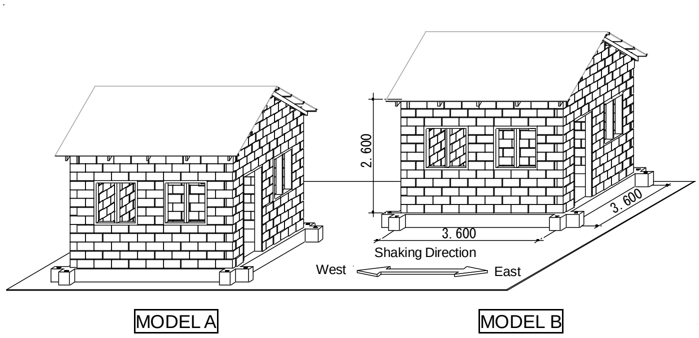

Figure 2. Isometric of two models on the shaking table

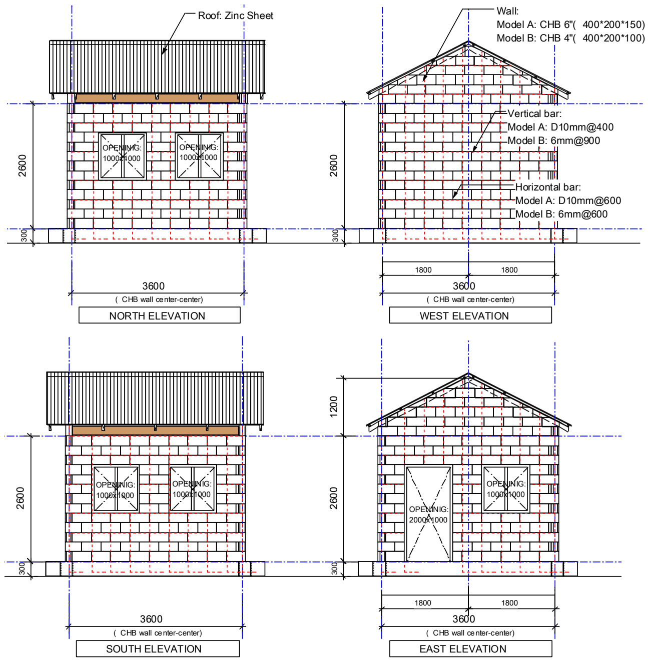

Figure 3. Elevations (N,S,W,E) of two models

Model B represents non-engineered buildings of the Philippines with substandard materials and poor construction implementation. These are houses commonly made either by the owners themselves or by a group of construction workers usually led by foremen or mason leaders. The walls for this model were made of 400x200x100 mm CHB (also called as #4" CHB in the Philippines) and the holes and joints were ruggedly filled with mortar mix with cement-sand ratio of 1:4. During the construction, mortars are not appropriately compacted, leaving possible voids and hollows in the CHB. This mortar mix and its application were observed in simple construction in the Philippines and were revealed by some local construction workers to be commonly practiced in the Philippines. For Model B, the ratio on wall span over thickness would be 3600/100=36; this does not pass the minimum requirement set in the NSCP. This model still used reinforcement steel bars but these bars are smaller (size of 6 mm diameter) than the standard ones. The steel bars used in this model are not DSB and are spaced at 600 mm horizontally and 900 mm vertically.

Table 1. Specification of Models

Specification	Model A	Model B
Wall (CHB)	6" (400x200x150)	4" (400x200x100)
Longitudinal Bar	D10mm@400mm	6mm@900mm
Horizontal Bar	D10mm@600mm (Each 3layers)	6mm@600mm (Each 3layers)
Mortal (Cement : Sand)	1:4 with compress	1:4 without compress
Roof	Zink Sheet	Zink Sheet

2.2. Input motion

This experiment was implemented at different steps, increasing the input motion at every step. The input horizontal motion was based on a strong-motion record of the 17 January 1995 Kobe Earthquake (JMA Kobe N-S Direction). Preliminary shaking tests of up to 50% of JMA Kobe record were conducted on 23 February 2011 for the two CHB house specimens. The final shaking table experiments were conducted on 24 February 2011 using up to 110% JMA Kobe on the shaking table in NIED, Tuskuba. (Table 2).

2.3. Measurement

After each shaking test, the distribution and size of cracks on each of the models were noted and sketched. From these sketches, the formation and stages of development
of the cracks can be inferred as the experiment progresses.

Variations in the performance of each model were measured using ground motion recorded from installed accelerometers (x10 points) and displacements of 3-D observation markers captured by high-resolution cameras (x60 points). (Fig 3)

Table 2. List of main input motions

Input No’	Input	Scale (%)	Displacement (mm)	Acceleration (G)
23rd Feb 2011				
No.2	JMAKobe	20	±35	0.17
No.3	JMAKobe	50	±87.5	0.4
24th Feb 2011				
No.7	JMAKobe	100	±175	0.85
Adding weight (4ton) on Model A				
No.10	JMAKobe	100	±175	0.85
No.12	JMAKobe	110	±200	1
No.14	JMAKobe	110(reverse)	±200	1

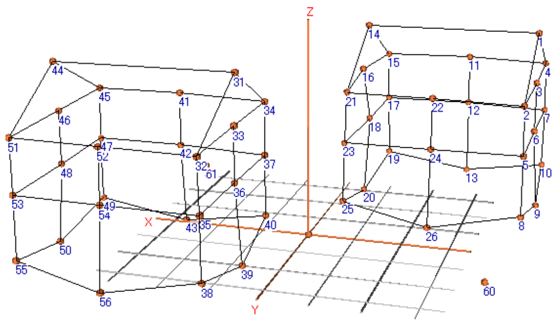

Figure 3. Location of maker for 3D measurement (Left: Model B, Right: Model A)

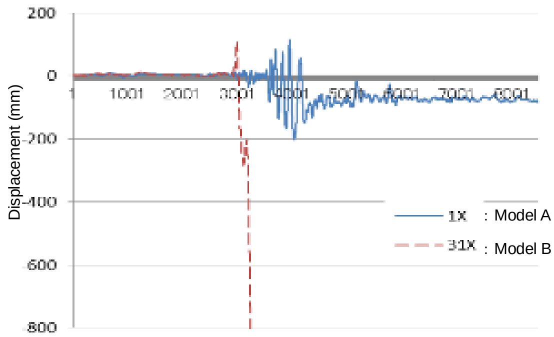

Figure 4. Displacement data of two models on input No’7

2.4. Result

2.4.1. Observations on input No’7 JMA Kobe 100% (Fig.5, Fig6, Fig7)

Model A (Engineered)

・East and West walls reacted to large displacement.

・Horizontal crack was recognized on the bottom of the gable wall.

・East-South corner started to separate.

Model B (Non-engineered)

・East gable wall collapsed. The upper part of opening had large displacement.

・West gable wall and upper part of wall collapsed.

North and South wall was minor diagonal cracks started to appear.

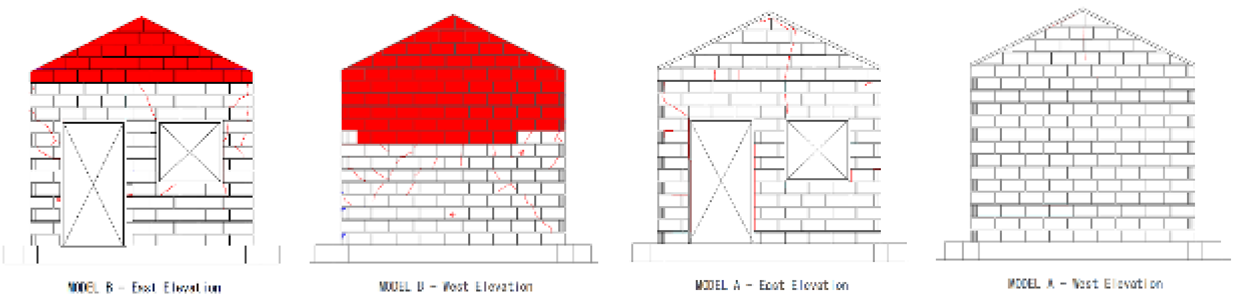

Figure 5. Cracks and fell down parts of Model A and Model B after input No’7

Figure 6. Two models after Input No'7
(Left side: Model B, Right side Model A)

Figure 7. Two models after Input No'7
(Left side: Model A, Right side Model B)

Table 3. Damage of models on main inputs

Input No'	Input motion	Scale	Acceleration	Damage situation	
		%	G	Model A	Model B
23rd Feb, 2011					
No.2	JMAKobe	20	0.17	No damage	No damage
No.3	JMAKobe	50	0.4	No damage	East Wall: There was a horizontal crack on the bottom of gable wall.
24th Feb, 2011					
No.7	JMAKobe	100	0.85	West wall: There was a horizontal crack on the bottom of gable wall. East and West wall had large displacement. The East-South comer (3layers of upper part) separated.	East wall: Gable wall collapsed (fell). Upper part of opening had large displacement. West wall: Gable wall and upper part of wall was collapsed (fell). North and South wall: Miner cracks started to appear in diagonal dimension.
Adding weight (4 tons) on Model A					
No.10	JMAKobe	100	0.85	East wall: Gable wall and upper part of opening wall was collapsed (fell). West wall: Gable wall was collapsed. North and South wall: Miner cracks started to appear in diagonal dimension.	East wall: Opening part had large displacement, and separated from South wall. West wall: large displacement, and wall separation was developed. North and South wall: Diagonal cracks were developed.
No.12	JMAKobe	110	1	North wall: Diagonal cracks were developed.	East and West walls were collapsed, and then This model was totally collapsed.
No.14	JMAKobe	100 (reverse)	1	East wall: Cracks were developed. Upper part of comer on South wall was separated. This model had partial damage, it still standing.	Already collapsed.

2.4.2. Observations CHB masonry structure thought Shaking Table Test

The following findings have been drawn from the observations during full-scale shaking table experiment.(Fig.8):

- Gable walls of Model B (Non-engineered) collapsed easily, and poses danger to its residents.
- Gable walls of both models are the most vulnerable part of the structure, showing strong movement compared to other parts
- The gable wall of Model A (Engineered) did not collapse for input No. 7; using the correct size and spacing vertical steel bar for this model may have a significant effect against bending failure of gable wall.
- Model A survived 100% of JMA Kobe input motion with only minor damage; good compaction of mortar filling improved CHB-mortar bonding and the use of standard size and spacing of steel reinforcement bars improved wall strength and ductility.
- Model B showed consistent failure between joint and upper fill mortar on the next upper level of CHBs, indicating poor bonding in the joints.

- For Philippine CHB masonry structures, the application of mortar is also a critical and important subject and should follow standards of construction. Mortar fill should be properly compacted; mixing and pouring should be homogeneous and properly timed for bonding of mortars; and proper curing of mortar fill should be followed.
- For both model specimens, which span 3600 mm, out-of-plane failure occurred before in-plane failure. It should be follow minimum thickness of load-bearing CHB walls as indicated in NSCP shall be 150 mm and the ratio of width to this thickness shall not exceed 32.

Figure 8. Behavior during collapse of Model B by Input No’19

3. ELEMENTAL TEST OF CHB

Washed river sand are commonly used in making concrete hollow blocks in the Philippines. However, the CHBs imported from the Philippines and used in the construction of the two model houses for the shaking table experiment were made of lahar deposits (volcano pyroclastic materials & debris). These CHBs are generally available in two thicknesses, #4” and #6”. Full and cut CHB specimen samples were subjected to compression strength tests at Mie University (Fig. 9 and 10) and were compared to Japanese concrete blocks. Results reveal a relatively low compressive strength for these Philippine CHB samples, less than 10% of that of Japanese concrete blocks as shown in Table 4, 5 and 6.

Figure 9. Compressive test of FULL BLOCK

Figure 10. Compressive test of CUT-CHB

Table 4. Compressive strength of Full Block

Specimens		Maximum Load (kN)	Compressive Strength(N/mm^2)	Avg. of the Compressive Strength(N/mm^2)
Philippine CHB	4″	24	1.0	1.0
	6″	33	1.0	
Japanese Concrete Block	Type B-10mm	284	11.6	12.0
	Type B-15mm	423	12.9	
	Type C-10mm	476	20.6	19.7
	Type C-15mm	563	18.7	

Table 5. Compressive strength of Cut CHB

Specimens		Maximum Load (kN)	Compressive Strength(N/mm2)	Avg. of the Compressive Strength(N/mm2)
Philippine CHB	4″	0.6	0.9	1.5
	6″	1.1	1.7	
Japanese Concrete Block	Type B−10mm	7.6	12.8	15.9
	Type B−15mm	14.8	19.0	
	Type C−10mm	11.0	25.4	23.6
	type C−15mm	13.1	20.8	

Table 6. Water absorption and Air density

Specimens	Philippine CHB	Japanese Concrete Block	
		Type−B	Type−C
Water absorption rate [%]	17.6	11.5	6.6
Dry air density [g/cm^3]	1.6	1.7	2.2

4. NEXT STEPS

The results of this experiment, appropriate construction and unerring knowledge need was recognized. Therefore practical tools to evaluate Vulnerability/safety of houses and audio-visual materials for raising awareness will be developed in this project.

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