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SEISMIC VULNERABILITY EVALUATION FOR NON-ENGINEERED HOUSING IN DEVELOPING COUNTRIES

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SUMMARY

The RC frame with masonry wall structure is widely used not only for the residential houses but also for the commercial buildings around the world. In the past such earthquakes in Taiwan, Turkey, and Algeria, this type of structure is proved to be seismically vulnerable to cause a number of causalities due to the collapse of the structure. Since the method for the standardized structural design has not been established yet for this structure, the quality of construction varies from one construction worker to other. This is one of the key factors that this type of structure is still seismically vulnerable for earthquakes. This project is focusing on such structure for improving the quality of construction of the RC frame with masonry wall structure in the City of Marikina, Philippines. At first, this study investigates the current construction method and structural details by constructing two new houses with current construction method by the local construction workers, and the loading experiments are carried out for estimating the seismic capacity of current construction. Then, based on the experiment results, a better construction method is developed to improve their seismic capacity. And finally, the effect of the improvement is demonstrated by the loading experiment and confirmed it.

INTRODUCTION

The RC frame with masonry wall structure is widely used not only for the residential houses but also for the commercial buildings around the world. In the past earthquake disasters such as Baguio 1990, Turkey 1999, Taiwan 1999, and Algeria 2003, this type of structure is proved to be seismically vulnerable to cause a number of causalities due to the collapse of structure. Despite such experiences, the RC frame with masonry wall structures, especially non-engineered housings, keep constructing in the urban area for Asian-Pacific countries.

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In the field of international aids and supports to the developing countries, lots of efforts have been done for the disaster mitigation. However, they are mainly focusing on the engineered structure, not focusing on the non-engineered structure such as adobe, wood, and RC frame with masonry wall structure. Since the method for the standardized structural design has not been developed yet for such structure, the quality of construction varies from one construction worker to other. This is one of the key factors that this type of structure is still seismically vulnerable for earthquakes.

The objectives of this research are to improve the construction quality of the RC frame with masonry wall structure against the earthquake disaster by

1) identifying the current construction process by interviewing to the local construction workers and residents,
2) investigating the current construction method and structural details by constructing two new houses with the current construction method,
3) estimating the seismic capacity of the house with the current construction method by loading experiments,
4) developing and disseminating a better construction method to improve the seismic capacity with minimum cost increase and applicable for the local worker’s skills and techniques,
5) demonstrating the effects of the improvement by the loading experiment.

The research field of this project is the resettlement site in the city of Marikina, Philippines, which is located in the northeastern part of Metro Manila. The West Valley fault is located nearby the city. The location and its earthquake threat is shown in Fig. 1

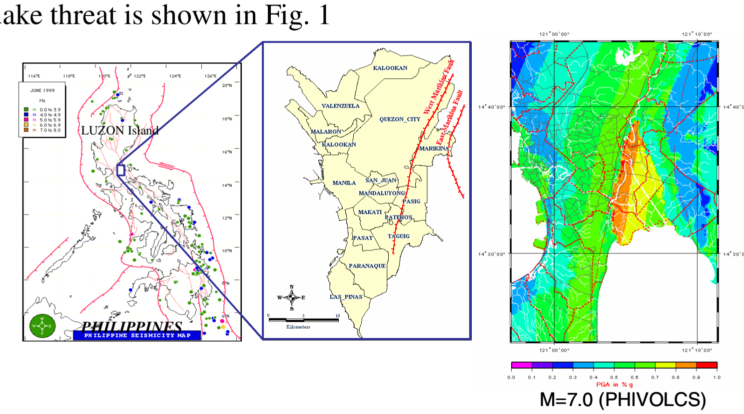


Fig. 1 Marikina City and Its Earthquake Threat

The standard size of the house in this area is 3m x 8m, and 2-3 stories non-engineered RC frame with masonry wall structure as shown in Fig. 2.

Fig. 2 RC Frame with Masonry Wall Structure in the Resettlement Site of Marikina

INTERVIEW SURVEY

The schematic model of the housing construction process is depicted in Fig. 3. It covers all stakeholders such as customer sector, financial sector, government sector, and professional sector, etc. Since it is not clear to us for the relationship of the stakeholders in the housing construction process at this site, the interview survey is carried out to the local stakeholders (Fig. 4). It is a structured interview using the questionnaire sheet, and takes about 40min per person.

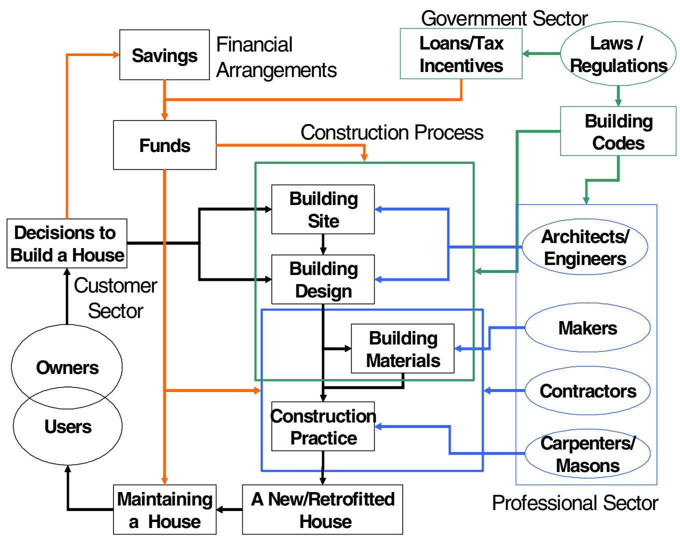


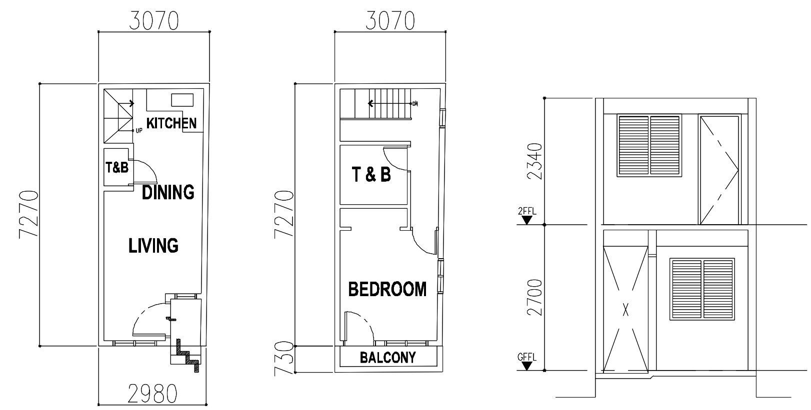
Fig. 3 Process of the Housing Construction

Fig. 4 Interview Survey

CURRENT CONSTRUCTION METHOD AND STRUCTURAL DETAILS

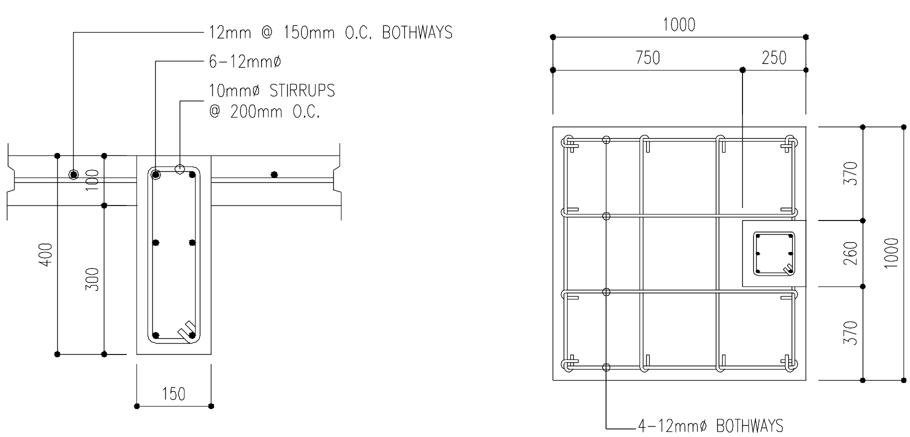
Based on the survey of the housing structure in this area, a typical house, named House E shown in Fig. 5, is selected for investigating the current construction method and structural details. House E is 2 stories non-engineered RC framed with masonry wall structure and is constructed about 2 years ago. The plan, cross section and structural details of House E is shown in Fig. 6 and Fig. 7, respectively. To obtain the information for the construction method and structural details of House E, two new houses are constructed, which named House N1 and House N2. House N1 and N2 are constructed by the same construction foreman, and take the same design, structural details, and material as House E. Therefore, House N1 and N2 are expected to have the same seismic capacity as House E.

Fig. 5 House E



1F 2F Cross Section

Fig. 6 Plan and Cross Section of House E



Beam **Column-Footing**

Fig. 7 Structural Details of House E

The construction for these two houses was started on September 29, and finished on October 31. During the construction, the construction method and structural details are monitored, measured and recorded by the research team (Figs.8-9).

Fig. 8 Structural Details and Method of the Construction for House N1 and N2

Fig. 9 Monitoring the Construction Works for House N1 and N2

ESTIMATION OF THE SEISMIC CAPACITY

To estimate the seismic capacity of the non-engineered RC houses with the current construction method, the lateral loading experiments are carried out for 3 houses, House E, House N1, and House N2. The experiments are carried out at Camacho and Balubad Resettlement Site in Marikina. The loading direction is shown in Fig. 10.

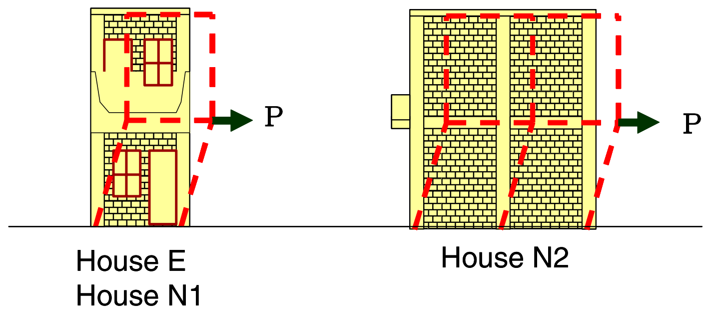


Fig. 10 Loading Direction

The loading method is to pull the second floor slab by jacks as shown in Fig. 11. The applied load and displacement of the second floor are monitored during the experiment. In addition, for House N1, N2, the strain gauges installed on the beam and column rebar are also monitored.

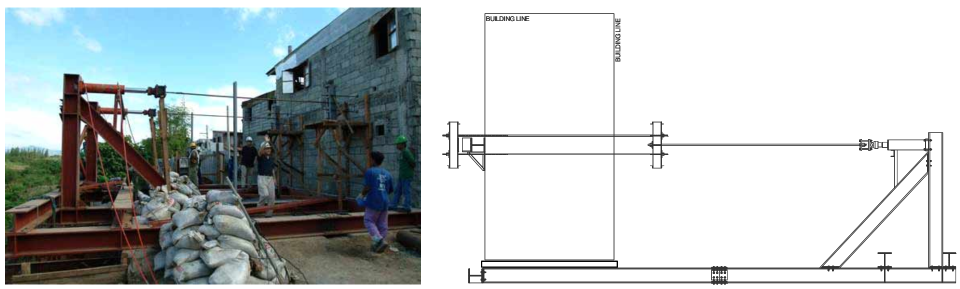


Fig. 11 Loading Method

The result of the loading experiments for the 3 houses and its P-δ relationship are shown in Fig. 12 and Fig. 13, respectively.

Fig. 12 Results of the Loading Experiment for House E, N1, and N2

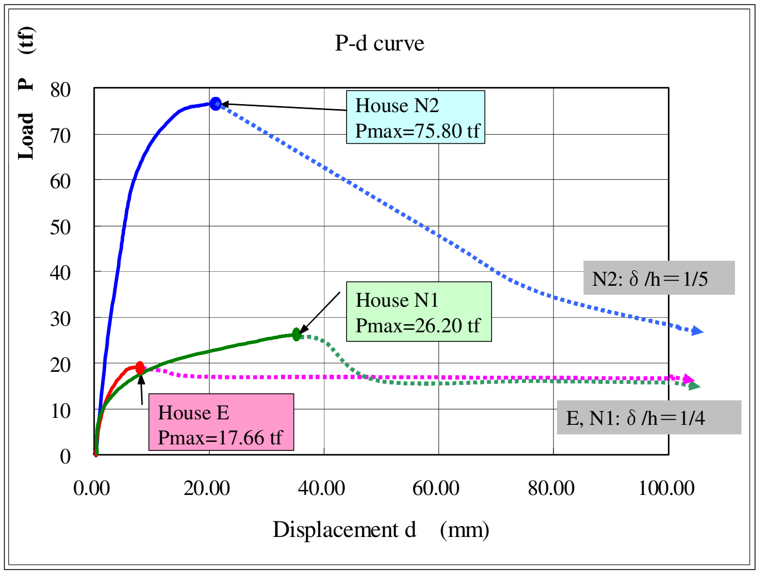


Fig. 13 P-δ Relationship for House E, N1, and N2

The maximum load of House E, N1, and N2 are 17.6 tf (δ/h=1/348), 26.3 tf (δ/h=1/74), and 75.8 tf (δ/h=1/135), respectively. The maximum displacement (δ/h) of House E, N1, and N2, which is recorded just before the collapse, are 1/4, 1/4, and 1/5, respectively. As for the failure mode, a combination of various mechanisms is observed in the failure process. House E and N1 show a similar failure process. Table 1 shows the detail of the failure process for House N1. At the entrance side, the shear cracks appear the wall section first, then shear failure of the column is observed. At the back side, the share cracks appear in the external CHB wall, then bending and shear failure of the column is observed.

For House N2, the shear cracks appear on the side CHB walls first, then the cracks propagate to the beam section. After the collapse, the second floor still kept in the shape.

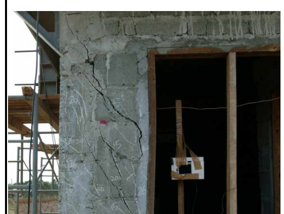
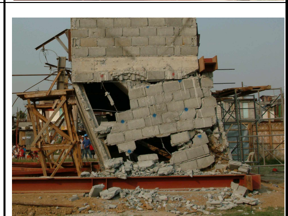
DEVELOPMENT OF THE IMPROVEMENT

Based on the information obtained from the results of the investigation and experiments, the points of improvement to upgrade the seismic capacity of the house are identified. The concept of the improvement is to reinforce the strength of the RC frame of the house with minimum cost increase. The proposed improvements are listed in Table 2.

Table 2 List of Improvements

Item	Part	Current Situation	Improvement
Design Details	External Wall		Install within beam and column frame
	Beam Starlap	90°hook, @200mm	135°hook, @200mm
	Column Hoop	90°hook, @200mm	135°hook, @100mm
	Anchorage of Column Rebar	insufficient	35d
	Anchorage of Beam Rebar	insufficient	35d
	Rebar Lapping Length	insufficient	40d
	Size of Column	250 x 170	300 x 250
	Size of Beam	B=160	B=180
	Size of CHB	t=100	t=150
Construction Works	Concrete Mixture (Cement : Gravel : Sand)	1:3:3	1:2:3
	Joint Mortar for CHB	about	Fill up completely
	Concrete Covering	about	40mm
	Column Concrete Placing	Pouring at once	Placing separately

Table 1 Failure Process of House N1

Damage State	Loading Step No.	Horiz. Force (ton)	Drift (mm) (Drift Angle)	Note	Entrance Side	Back Side
Elastic	1 ~ 20	0 ~ 15	0 ~ 5 (0 ~ 1/500)	・ Loading under force control ・ No crack can be observed. ・ Displacement at back side is larger than that at entrance side.		
Cracks on CHB Walls	21 ~ 30	15 ~ 20	5 ~ 11 (1/500 ~ 1/227)	・ Loading under force control ・ Shear cracks of short column occurred at entrance side. ・ No crack can be observed on back side CHB wall.		
Stiffness Reduction	31 ~ 40	20 ~ 26	11 ~ 34 (1/227 ~ 1/74)	・ Loading method is changed to displacement control. ・ Shear cracks occurred on back side CHB wall. ・ Shear cracks of short column at entrance side are enlarged.		
Maximum Load	40	26	34 (1/74)	・ Loading under displacement control ・ Cracks on back side CHB wall are extended at all over the wall. ・ Hinge of short column at entrance side		
Strength Reduction	41 ~ 75	26 ~ 6	34 ~ 550 (1/74 ~ 1/5)	・ Loading under displacement control ・ Large horizontal crack pass through back side CHB wall. ・ Loading capacity decreases with displacement increase.		
Just Before Collapse	–	Almost 0	Approx. 700 (1/4)	・ Loading under displacement control ・ Back side CHB wall isolates from RC frame.		
Collapse	–	–	–	・ First story collapsed. ・ Second story remains its configuration.		

Although it refers to a wide range of the structural details and construction works, the key points of the improvement are as follows;

1) Enlarge the size of the column
2) Increase the strength of the concrete by controlling the concrete mixture and the amount of water
3) Modifying the rebar arrangement for the beam-column joint section
4) Placing the column concrete separately and well compaction
5) Adequate rebar joint lapping length
6) Use 12mm rebar to minimize the cost increase

These improvements are applied to the construction of a new house named House R. The construction of House R is started on November 28 and finished on December 22. During the construction time, any major troubles were not reported to apply the improvements.

Fig. 14 Construction Process for House R

As for the cost of the construction, the construction foreman calculated the direct construction cost for both House N and House R (Fig. 15).

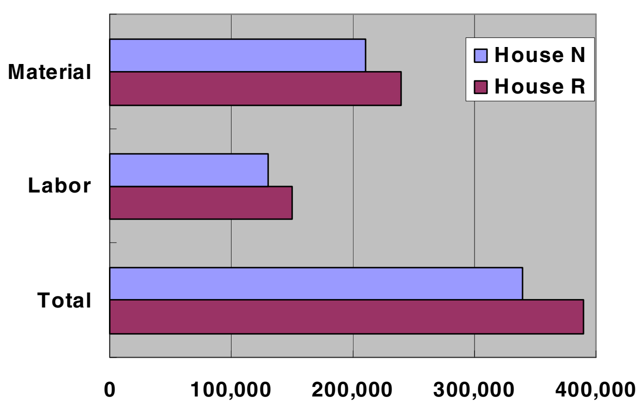


Fig. 15 Comparison of Direct Construction Cost of House N and R

Figure 15 shows that the cost increase is about 15%. According to the interview to the local residents, some of the people answered that 15% cost increase is in the acceptable level. It means that the more cost reduction is necessary for promoting a seismically better construction. This is one of the future research topics.

To demonstrate the effect of the improvements, the loading experiment is carried out for House R. The result of the experiment is shown in Fig. 16, and the comparison of P-δ relationship between the current construction and improved construction is shown in Fig. 17.

Fig. 16 Loading Experiment for House R

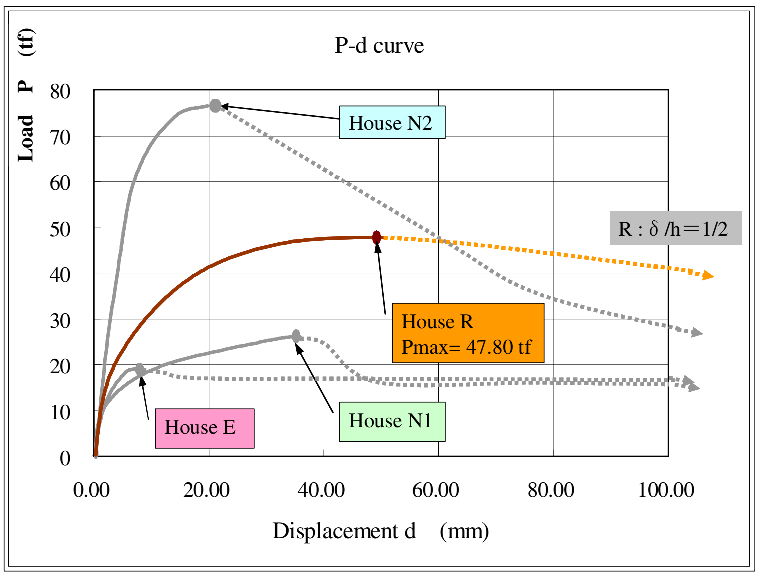


Fig. 17 Comparison of P-δ Relationship between the Current and Improved Construction

The result shows that the maximum load of House R is 47.8 tf (δ/h=1/59), and the maximum displacement (δ/h) is 1/2. These values are almost twice as much as House N1. The failure mode is almost the same as House E and N1. This clearly indicates that the seismic capacity of this house is upgraded by the improved construction method.

CONCLUSION

This paper presents the seismic vulnerability evaluation for non-engineered housing in developing countries. Taking the RC frame with masonry wall structure as an example, the loading experiment for the non-engineered houses are carried out in Marikina City, Philippines to evaluate the seismic capacity. Based on the result of the investigation and experiments, the points of improvement to upgrade the seismic capacity are proposed. The effect of the improvements is demonstrated by the loading experiment and it shows that the improved house has a better seismic capacity than the house with current construction method. Although the experiment result is still preliminary, the information obtained here is useful for analyzing and upgrading the seismic capacity of the non-engineered RC frame with masonry wall house in developing countries.

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