House Seismic Vulnerability and Mitigation Strategies: Case of Yogyakarta City

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Abstract

The increasing vulnerability of urban areas in Indonesia to earthquake disaster is one of the daunting problems for sustainable development. This paper summarises an assessment of earthquake vulnerability of houses in Yogyakarta City as one of high earthquake hazard areas in Indonesia, reveals the principal reasons why the identified vulnerability happened, and highlights some mitigation strategies. The house data were collected just before the Yogyakarta earthquake May 27, 2006 through field survey on 402 houses. In addition, in depth interview with their owners or occupants and a focus group discussion with several experts were held to complement the earlier data collection. The overall houses were categorized into 5 types: mud bricks/MD, bricks (BR), reinforced bricks (RBR), reinforced concrete (RC), and others (OT). The results have revealed that 84.8% houses in Yogyakarta were non-engineered houses and very vulnerable to earthquake and most of them were BR and RBR. Such vulnerability has occurred because of (1) lack of knowledge by builder, (2) lack of awareness, and (3) the absence of political commitment. The prominent mitigation strategies are (1) a wider political commitment of the government and legislature board, (2) a greater awareness of earthquake-related matters by all stakeholders to the building processes, and (3) the necessary knowledge and competencies by designers and builders to deliver earthquake-resistant construction end-products. These findings have opened the precious window that the seismic performance improvement of houses in major Indonesian cities is indispensable.

Keywords: *earthquake vulnerability, houses, non-engineered houses*

1 Introduction

An earthquake is a sudden, rapid shaking of the Earth caused by the breaking and shifting of rock beneath the Earth's surface. The National Earthquake Information Center (NEIC USA) locates about 50 earthquakes each day or about 20,000 a year (USGS, 2004a). The infamous Indian Ocean Indonesian Aceh's Earthquake on 26th December 2004 (located off the West Coast of Northern Sumatra, Indonesia) was the 5th largest earthquake recorded in the world since 1900 (USGS, 2006). At the present time, scientists cannot predict precisely when and where an earthquake will occur (BSSC, 1995). Although earthquakes cannot be prevented, modern science and engineering provide tools that can be used to reduce their effects, based on the fact that much of the damage caused by earthquakes is predictable and preventable (USGS, 2004b). Broadly speaking, predicting earthquakes may be difficult, but preparing for disaster is not.

Several thousand earthquakes have occurred throughout the world, and populations have witnessed massive deaths and series of costly and damaging outcomes. The Asian Disaster Preparedness Center (cited by BAPPENAS, 2006 and Ellul et al, 2004) comments that, certainly over the past ten years, such massive death tolls have not been necessary from a technical and scientific point of view. These disasters include: the 1999 Turkish earthquake, with a death toll of 17,127 people; the 2001 Indian earthquake, with 20,005 deaths; the infamous Indian Ocean Indonesian earthquake and tsunami in 2004, with more than 225,000 deaths across 12 nations (165,708 deaths in Indonesia alone); the 2005 Pakistani earthquake with 73,338 deaths, and again, in 2006, Indonesian Yogyakarta's earthquake with 5,716 deaths.

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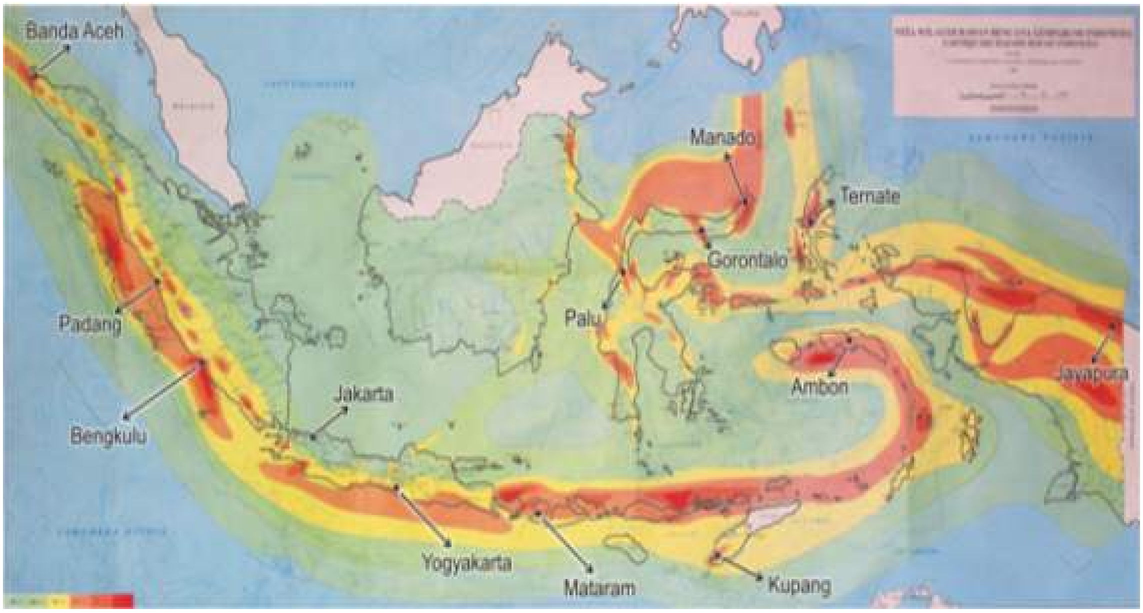

Figure 1. Earthquake hazard map of Indonesia (GRDC, 2001)

Tectonically, the Indonesian archipelago is one of the most active areas in the world, commonly called as 'The Ring of Fire'. It has a typical four junction plate convergence (Australian plate in the South, Eurasian plate in the Northwest, Philippine plate in the North, and Pacific plate in the East) leading to the complicated geological and tectonic mechanisms of the region. According to the seismic prone region of Indonesia, in 2001 the Geological Research and Development Centre (GRDC), Indonesia, arranged 'The Earthquake Hazard Susceptible Map of Indonesia', which was compiled on the basis of the highest intensity figure or the highest level of destruction resulting from earthquake events. The magnitudes of the intensity and the level of destruction depend largely on a number of factors, e.g. distance from the earthquake source and the geology of the area. The closer the distance to the source, the higher the intensity figure and the more severe the destruction (see Figure 1).

Places on the map which have a similar degree of intensity or a similar level of destruction are represented by an isoseismic line; this map, therefore, indicates or defines places or regions of an equal level of destruction. The intensity scale used in the map is the Modified Mercalli Intensity (MMI), with a range of intensity from I (lowest intensity) to XII (highest intensity). The seismic zone maps are revised from time to time, as further data and understanding are gained of the geology, the seismotectonics, and the seismic activity in the country. This 2001 seismic zone map is not the final word on the seismic hazard of the country.

As shown in Figure 1, there were 12 national capital cities in 2001 that had a high level of earthquake hazard, in which it was possible for the ground to shake on a scale of more than 6 MMI. In Figure 1, the zones are indicated by the colour red. The cities are Yogyakarta, Mataram, Banda Aceh, Manado, Gorontalo, Bengkulu, Kupang, Padang, Ternate, Palu, Ambon, and Jayapura. Among the 12 cities, the most densely populated city is Yogyakarta (BPS, 2003). It is also indicated that there are high concentrations of buildings and infrastructure at Yogyakarta City. In other word, based on the picture, Yogyakarta poses the greatest risk to its population in the event of a strong earthquake because of high population density and a high level of earthquake hazard. In fact, the Yogyakarta earthquake in May, 27, 2006 which tragically caused a further 5,716 unacceptable deaths and destroyed 156,662 residential houses and other constructions proved a great disaster occurred in a densely populated area, which had earthquake-vulnerable constructions.

Despite the inherent and known hazards of vulnerable construction, vulnerable dwellings continue to proliferate within low income and low-to-medium income populations due to increasing pressures for more affordable basic housing and community infrastructure in Indonesia. Such houses are typically low-storey, constructed from un-reinforced concrete or structural masonry (Boen, 2006 and Sarwidi, 2001). Ideally, the proportion of vulnerable constructions to earthquake ground shaking in major cities in Indonesia shall be identified and quantified in order to trigger concrete action to reduce the risk.

This paper highlights the house earthquake vulnerability of Yogyakarta City as one of earthquake prone areas in Indonesia, reveals the principal reasons why the identified vulnerability happened, and mentions some mitigation strategies in order to reduce those vulnerability.

2 Research Methodology

The research methodology involved a triangulated quantitative-qualitative approach by conducting multiple analysis. Data of house typologies were gathered just before the Yogyakarta earthquake May, 27, 2006 through field survey on 402 houses distributed along 12 districts. During the field survey, research team investigated and asked some structural-element-related questions of each house to their occupants or owners. Photo documentations were used to complement the investigation data. Then, a focus group among practitioners and construction experts (5 people) was held to collate, analyse, and categorise the overall house data into 5 types of houses referring the typical of structural fragility of houses developed in Taiwan (Lee et al, 2002). The categorised houses fall within the most vulnerable houses to the least vulnerable ones. The following data collection was a series of in-depth interviews with respondents (three construction experts, two community leaders, and three building-related government staffs) during the reconstruction process to address why the identified vulnerable houses proliferated over time in Yogyakarta and then claimed thousands of such houses collapsed during the strong earthquake in 2006. The appropriateness of each respondent was determined by their role, responsibilities and activities within their own organization and the level of experience in the specific subject. These allowed detailed discussion of individual experiences and a more enhanced understanding of events, issues, concerns, and problems to be reached.

Quantitative data of the building stocks were simply categorised into 5 types of houses via a focus group meeting, while qualitative data gathered from the interview was processed using NVivo software to code prominent patterns in the views and opinions of the respondents. Using these methods, trends in the quantitative and qualitative data could be established and integrated to highlight the rudiments central to answering the questions posed by the objectives.

3 Typical House Vulnerability of Yogyakarta City

The variability of house typology in Indonesia is countless. People often arrange several houses in the same group depending on their specific own objectives. Architect and civil engineer would indeed have different point of view when classifying them. In term of earthquake vulnerability, most civil engineers agree to divide houses depend on their structural elements. Uncertainties are inherent in any such vulnerability methodology. They arise in part from incomplete scientific knowledge concerning earthquakes and their effect upon buildings and in part from the approximations and simplifications necessary for comprehensive analyses.

At the present time, there is not available a publication of typical and quantifiable vulnerability of houses in Indonesia which is formally published by Indonesian government bodies. Therefore, in this research, the process of conducting seismic performance studies on a large number of existing housings in Yogyakarta City with a view toward determining their level of seismic vulnerability refers to the research publication in Taiwan by Lee et al (2002). Subject to several limitations, it should be highlighted that this research is designed to demonstrate the existing methodology rather than to achieve precise results.

Overall houses collected were categorized into five types in regard to earthquake vulnerable level as developed by Lee et al (2002). All building types have high correlation of PGA and damage ratio. The order is as follows: “Mud Bricks/MB or Pure Clay”, “Bricks/BR”, “Reinforced Bricks/RBR” and “Reinforced Construction/RC”. Table 1 describes several characteristics in relation to each type of houses where buildings constructed by. “Mud Bricks/Pure Clay” are the weakest structure as they begin to have damage at about 150gal; however, “RC” buildings with the most excellent resistance structure and start to be damaged at about 280gal.

Table 1. Characteristics of house typology used in this research which are taken and modified from Lee et al (2002)

No	Types of houses		Descriptions	
	Code	**Structural elements**		
1	MB	Un-reinforced bricks with mud mortars	This includes: (1) un-reinforced brick houses with mud mortar, (2) un-reinforced brick aged houses without a proper maintenance. This type of houses is not designed and built by competent engineer, called as non-engineered houses	Photo documentations on several angles of each sample house were collected when categorising this type of house
2	BR	Un-reinforced bricks with cement mortar	This includes: (1) one-floor un-reinforced brick houses with cement mortar (2) aged brick houses with a strengthening in some parts. This type of houses is not designed and built by competent engineer, called as non-engineered houses	
3	RBR	Reinforced bricks	This includes: (1) one-three floor brick houses partly reinforced, i.e. tie-beam, practical columns, and/or ring balk without lintel band, (2) aged brick houses with a fully strengthening. This type of houses is not designed and built by competent engineer, called as non-engineered houses	
4	RC	Reinforced concrete	This includes: fully reinforced concrete/brick houses which are designed and built by competent engineer, called as engineered houses	
5	OT	Others	Non-engineered houses made of timber or other lightweight materials	

Through field survey, the process of conducting seismic performance studies on a large number of existing housings in Yogyakarta City began at January 5 2006 and had to cease at May, 26, 2006 because the strong earthquake occurred next day at May, 27, 2006. Sample of houses was collected along 12 districts (kecamatan), and there were 2 districts left out because the Yogyakarta situation was chaos as the tragic disaster. Within 12 districts, there were 402 sample houses. Judgement of experts through a focus group discussion was held to classify the overall data collected into 5 types of houses mentioned earlier. The result of focus group describing the type of overall 402 houses is depicted in Table 2.

The weakest houses i.e. MB were only 1%, while the strongest one i.e. RC is 6.47%. The type of RBR constitutes the first majority of house typology in the area, up to 44.8%. In total, the result shows that 93.5% of Yogyakarta City housing stocks were non-engineered structures, i.e. MB, BR, RBR, and OT (see Figure 2).

The first three house types are then able to be grouped into non-engineered houses made of heavy material in regard to their characteristics and earlier assumptions. The percentage of such houses (MB, BR, and RBR) was 84.8%, of which 1% were the very old houses without reinforcement and proper maintenance and the remainder seemed to be ‘the new culture (i.e. one or half-brick thick masonry’ buildings)’. This figure indicates that the majority of house stocks in Yogyakarta City are very vulnerable to earthquake ground shaking.

Table 2. House typologies collected in Yogyakarta City

No	Districts	House typologies *					Number of house data
		MB	**BR**	**RBR**	**RC**	**OT**	
1	Gedong Tengen	0	20	20	0	1	41
2	Gondomanan	0	19	12	1	1	33
3	Kraton	0	17	10	0	3	30
4	Wirobrajan	0	12	19	3	1	35
5	Danurejan	2	17	9	1	11	40
6	Mergsangsan	0	8	4	0	1	13
7	Pakualaman	1	18	18	0	3	40
8	Umbulharjo	1	1	38	0	0	40
9	Jetis	0	11	17	6	6	40
10	Mantrijeron	0	11	2	1	0	14
11	Ngampilan	0	13	14	6	5	38
12	Tegalrejo	0	10	17	8	3	38
13	Gondokusuman	Within the two districts, data were not gained because a strong earthquake happened in Yogyakarta City at May 27 2006 and the situation was chaos					0
14	Kotagede						0
	Total	**4**	**157**	**180**	**26**	**35**	**402**
	Percentage	**1%**	**39%**	**44.8%**	**6.47%**	**8.7%**	**100%**

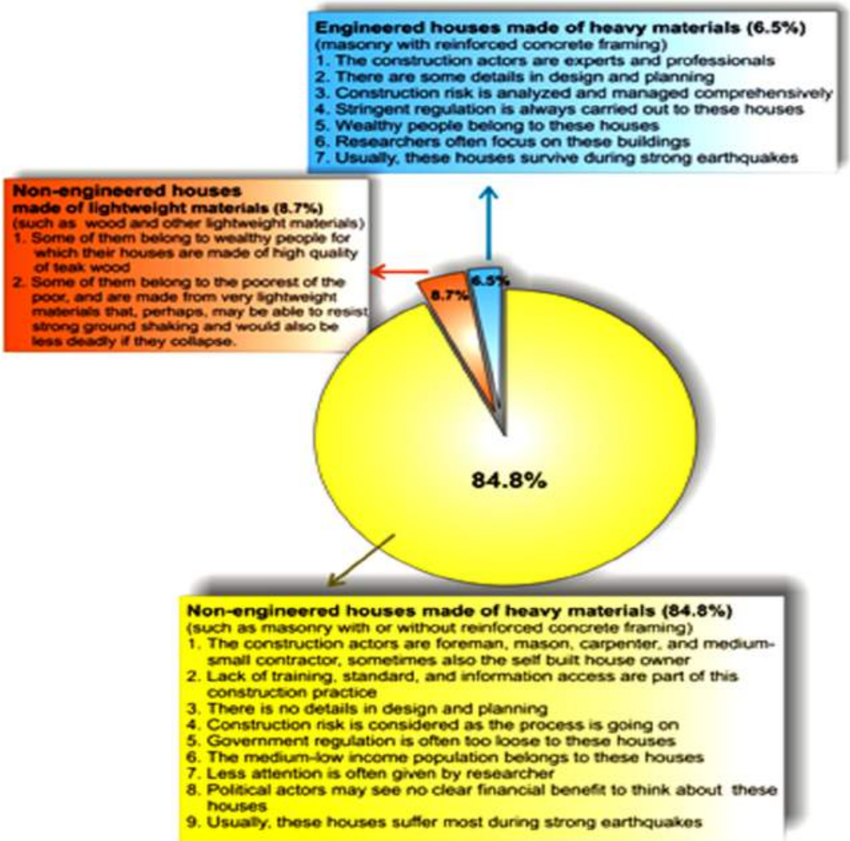

Figure 2. A characteristic comparison between non-engineered and engineered houses (Winarno and Sarwidi, 2009)

The percentage of non-engineered houses built with lightweight materials such as teakwood in traditional and historic houses, or other lightweight materials elsewhere, was 8.7%. Some of them belong to the poorest of the poor and are made from very lightweight materials that, perhaps, may be able to resist strong ground shaking and would also be less deadly if they collapse. The remaining 6.5% are the engineered houses, which definitely belong to wealthy people and are earthquake resistance.

The tremendous percentage of vulnerable houses made of heavy materials in Yogyakarta City (up to 84.8%) has a correlation with the collapsed and/or damaged houses following the catastrophic earthquakes in Yogyakarta City at May, 27, 2006. This event claimed 6.095 houses severely damaged or destroyed, 8.408 moderate damaged, and 15.384 slight damaged (PKY, 2006).

The large percentage of vulnerable houses in Yogyakarta City and the number of destroyed and/or damaged houses following the tragic events suggest to find the principal reasons why such vulnerability took place. The ground shaking when earthquakes strike will not become a disaster if communities understand the root problems and have such measures to reduce the risk beforehand.

4 Principal Reasons Why Such Vulnerable Houses Took Place

The data identified three key factors of influence in respect of why vulnerability on houses in Yogyakarta City persists over time as the result of earlier investigation and the disastrous event in 2006. These were lack of knowledge by builder, lack of awareness of among all community members and stakeholders, and the absence of political commitment.

Respondents suggested that a prominent reason for the existing vulnerability of houses in Yogyakarta City was that those tradespersons and builders involved in constructing residential dwellings simply do not know how to build an earthquake resistant structure. The quality of workmanship was largely dependent upon the inherent practices of individuals who relied upon custom and tradition for their input rather than reference to building standards and specifications. The lack of technical knowledge matched by appropriate abilities was highlighted as a major shortcoming.

It was also clear that difficulties emerged from the lack of awareness among all community members and stakeholders. People and stakeholders who are living and working in hazard prone area do not have adequate general information on earthquake likelihood, degree of severity and location. Scientific information on local geological conditions and seismic history clearly exists and yet its availability was lacking and its inclusion into local planning absent. This meant that community and regulatory awareness was at a low level and ignored when planning residential building development.

A lack of awareness of the specific and wider roles of government bodies and legislature board was also highlighted. Regulation and control of building activity was seen to be weak such that compliance with earthquake-related building codes is not well monitored and enforced. If people understood that one of the government's main duties is to maintain public safety, people would probably show no surprise that physical vulnerability is intrinsically linked with government political commitment. In reality, people's understanding of government functions is very low and weak, and also is far from the desired goal. Certainly, this commitment should be in the forefront. The skill improvement of builders, who are primary technical actors in real non-engineered construction, is easily achieved under the umbrella of good and smart government. It is hoped that government awareness of the degree of seismic risk is soon translated into concrete action rather than contemplation. All of these have meant that awareness, knowledge and understanding of seismic vulnerability of houses, and indeed all constructions, has really remained at a low level and the action to reduce it through design and enforcement during construction has not been widespread or effective.

5 Discussion

Earthquake events around the globe have reminded the world communities of the importance of understanding the facts of high seismic risk. Lessons learned from past earthquakes have indicated that vulnerable buildings, specifically residential housings, will suffer most during earthquakes. Most of the loss of life during earthquakes has occurred due to the collapse of these buildings. With increasing number of vulnerable housings into areas susceptible to earthquakes, vulnerability to earthquakes will intensify. It is deeply concerning that communities continue to experience excessive losses of precious human lives and valuable property, as well as serious injuries and major displacement, due to earthquake events. Yogyakata City for example has proved that the large proportion of the existing vulnerable houses is due to (1) lack of knowledge by builder, (2) lack of awareness of among all community members and stakeholders, and (3) the absence of political commitment.

In response to the above findings, it can be summarized many key areas where positive mitigation action might be taken to improve practice. The prominent actions are that:

- The government and legislature board must take wider political commitment to disaster reduction through the use of seismic building codes and their enforcement in order to reduce the number of vulnerable buildings in earthquake prone areas (also suggested by Petak (2002)).

- Greater awareness of earthquake-related matters must be ensured by all stakeholders to the building processes, and from a broader perspective there must be greater owner, occupier and widespread public awareness; Also, there must be frequent, timely and reliable information on earthquake risk available to building stakeholders through effective communication mechanisms;

- Designers and builders must have the necessary knowledge and competences to deliver earthquake-resistant construction end-products;

The findings revealed that the role of government is becoming increasing critical to the matter of earthquake response. Also, that the role of the builder in non-engineered construction was seen to be vitally important. Seismic risk is a real fact for those who live in earthquake-prone areas and the occurrence of a seismic event is not always predictable or avoidable. People have no option but to live as harmoniously as one can with the risk (also mentioned by Covenry and Dutson, 2006). In this sense, a good awareness of those risks together with a better understanding of earthquake phenomena and characteristics is of the highest importance, underlying those initiatives which seek to reduce apparent risk (also suggested by Winarno (2007)).

6 Conclusion

Seismic risk is simply a real fact for Yogyakarta people, and indeed for many Indonesian people. Since 84.8% of housing stocks in Yogyakarta were vulnerable to earthquake and the true depressing tragedy of earthquake in 2006, the research findings suggest to take urgent action due to lack of knowledge by builder, lack of awareness of among all community members and stakeholders, and the absence of political commitment. It is not a wise solution to force Yogyakarta's populations to leave their beloved but hostile areas; therefore the people should be able to live harmoniously with the seismic risk. One of the strategic solutions to live harmoniously with seismic risk and to bridge the above gap is to enhance their 'seismic knowledge and awareness' and carry out vulnerability reduction actions aimed at reducing losses through the implementation of seismic codes on existing and new non-engineered buildings.

A better combination of technical and non-technical measures is a substantial contribution towards the successful house vulnerability reduction through voluntary initiatives or through stringent regulation enforcement. Government political commitment should be first, followed by other stakeholders. This needs wider recognition that building a culture of disaster prevention should become everybody's duty of care on a daily basis to ensure sustainability. It is important to achieve change among non-engineered construction actors by introducing a new concept of seismic resistance, in which they should be equipped with a better fit between the steady flow of dissemination and communication of local seismic risk and the importance of seismic features and their continuous individual skill improvement.

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