A Tale of Two Earthquakes

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Abstract

On 27/05/2006 a 6.2 M_W earthquake near Yogyakarta resulted in 5,782 deaths and massive damage, but no tsunami. On 17/07/2006 a 7.7 M_W earthquake in the Sunda Trench, 240 km south of the south Java coast generated a tsunami along 200 km of the coast. The death toll was 668. There are huge challenges in reconstruction, given the limited resources. The events have interesting lessons for disaster reduction, in particular, how to seismically retrofit housing in an affordable and culturally acceptable way. It would seem that a building modified to stand after a major earthquake will also stand after a tsunami of height 3 metres or more.

Introduction

The two earthquakes resulting in fatalities in Java in 2006 fell in shadow of the Indian Ocean tsunami of 26/12/2004 (M_W = 9.2) with over 230,000 fatalities and the Nias earthquake of 28/3/2005 (M_W = 8.7), with 1,700 fatalities. But for the former events those of 2006 would have loomed larger in global perception. The Yogyakarta earthquake was as deadly as the Great Hanshin (Kobe) earthquake of 17/01/1995.

On the other hand, arising from the experience of the earlier events, Indonesia and the worldwide providers of aid were more prepared to deal with the disasters in an appropriate manner, even though the aid committed afterwards was far less than for the Indian Ocean tsunami.

Some single storey dwellings and shops are timber frame, offering little resistance to tsunamis, and some stability during earthquakes. The main hazard there is perhaps collapse of the tiled roofs. The majority of small buildings are masonry. The brick walls are typically a single skin made with lime mortar, plastered or rendered on both sides, with tiled roofs on timber battens and rafters or trusses. These offer little resistance to either tsunamis or earthquakes, unless there is some form of reinforced concrete framing around the brickwork. The damage to buildings with reinforced concrete frames was mostly minor.

No cases were encountered of masonry buildings constructed without framing with retrofitting for earthquake of tsunami resistance. This is the current and future challenge.

The South Java Tsunami 17/07/2006

The tsunami on 17th July 2007 originated at an earthquake 240 km south of Java. It affected 200 km of coast with 2m-6m height (run-up). There were 668 deaths, 65 reported missing and 54,256 displaced (WHO, 2006). A simulation of the tsunami was provided by Dr Hamsah Latief of the Jurusan Geofisika & Meteorologi, Institute of Technology, Bandung, within hours of the event (Figure 1)

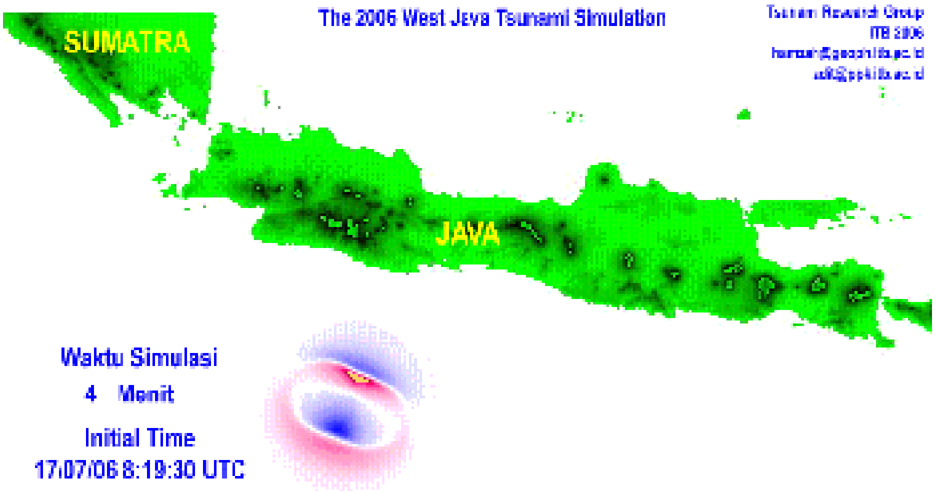

Figure 1: Tsunami generation 17/07/2006

Despite the magnitude of M_W 7.7 and the shallow depth (34 km) of the epicentre, the earthquake was only weakly felt in Java., and it was generally not noticed in regions experiencing the subsequent tsunami. It was one of a relatively rare tsunami-earthquakes, where most of the energy is at low frequencies.

The tsunami first arrived on the south coast of Java twenty minutes after the first shock. (There were many aftershocks of lesser magnitude.) There was no time to send an effective early warning. Nor are there as yet appropriate emergency evacuation procedures and refuges in place. About 10% of those caught in the waves perished. Parts of the coast consisted of paddy fields virtually at sea level behind a coastal dune. The tsunami penetrated inland up to 500m and many died moving inland into the paddy fields to escape the tsunami (Reeves et al, 2007).

Tsunami damage

As always with tsunamis, scour is a significant source of damage. Along many parts of the coast a low sand dune separates the sea from the paddy fields. The tsunami would scour the inland side of the dune and dump the sand on the paddy field, to add to the salt contamination.

Structural damage was in line with previous experience. Where the tsunami height was above one metre, timber framed buildings were swept away, leaving the floor slab on ground. Free standing masonry walls were knocked over. Single storey masonry buildings without structural framing generally collapsed when the tsunami height reached two metres.

The columns of RC frames ranged from 100mm x 100mm with four 3mm diameter wires for reinforcement to 200mm x 200mm with four plain bars of 10mm or 12 mm diameter. The RC framed house shown in Figure 2 probably had the former type of column. The height of the tsunami was estimated to be 3.8m. The front has been demolished and the masonry walls punched out. The house shown in Figure 3 probably had more substantial columns and the damage from the tsunami of a similar height is superficial.

Figure 2: An RC framed building damaged by a 3.8m tsunami (Reeves et al, 2007)

Figure 3: An RC framed building which survived a 3.8m tsunami with minor damage (Reeves et al, 2007)

Of course, the building shown in Figure 2 could have been struck by debris, the worst forms being floating cars or boats carried along at about 4-5 m/s for the given depth of water. In the absence of debris, rules have been developed for 'tsunami load' on inundated structures (Okada et al, 2005). The most significant is the lateral force due to run-up against the wall facing the oncoming tsunami. There are possibly impact and drag forces, but these are usually less. Run-up is assumed to be three times the height of the tsunami (Figure 4). The lateral pressure of the (stationary) fluid is hydrostatic. Buildings with transparency to water flow at ground level, or standing in isolation allowing flow around the building, will experience less run-up. A building properly design for seismic loading in Indonesia is likely to be adequate for tsunami loading.

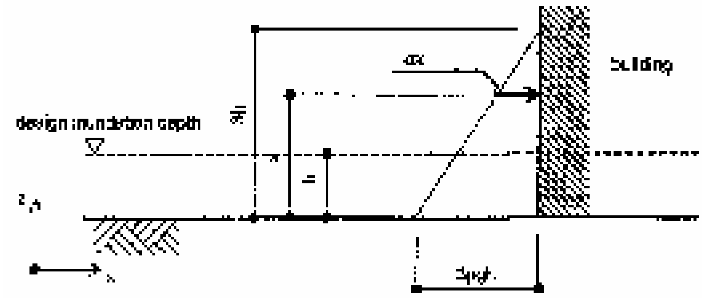

Figure 4: Lateral pressure, *qx*, due to tsunami of height h (Okada et al, 2005)

Indonesia and Japan Joint Survey

The magnitude and extent of the tsunami and the consequent damage was reported in a Joint Survey (2006) headed by Dr Shigeo Takahashi, Ports and Airports Research Institute, Japan, and Dr SubandonoDiposaptono, Ministry of Marine Affairs and Fisheries, Indonesia. Findings were similar to Reeves et al (2007). Se Figure 5. Observed tsunami heights are given in Figure 6.

Figure 5: Damage at Pangandaran; elevation ~2.5m, tsunami height 3.3-5.4m

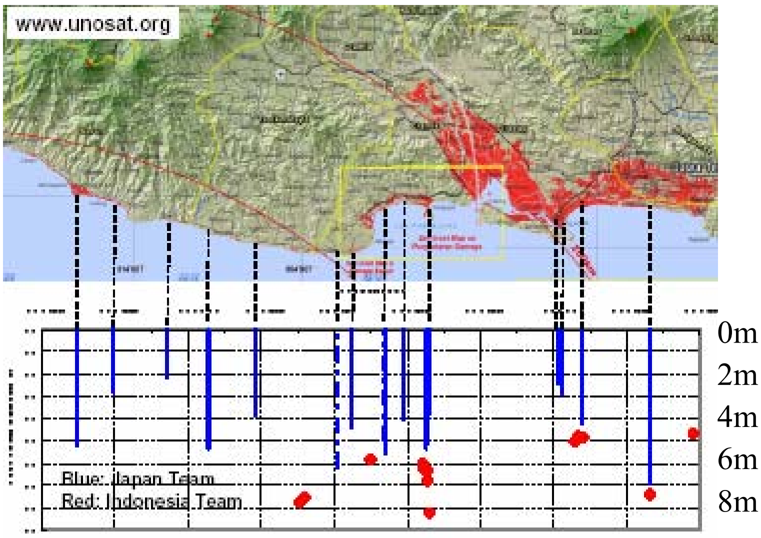

Figure 6: Observed tsunami heights

The report made the following recommendations:

1. Tsunami warning and education
2. Transmission of tsunami warning to the people in beaches
3. Evacuation facilities
4. Land use planning near beaches
5. Monument

Effective implementation of these recommendations is still in the future.

The Yogyakarta Earthquake 27/05/2006

The Yogyakarta earthquake of 27/05/2006 had its epicenter some 20 km SSW of the city centre (Figure 7).

Figure 7: Location of epicenter, Yogyakarta

Estimated losses are compared in Table 1 with the Kobe earthquake of 17/01/1995

Table 1: Losses, Yogyakarta versus Kobe

	Yogakarta	**Kobe (Great Hanshin)**
Moment magnitude, M_W	6.2	6.8
Killed	5,782	6,434
Injured	36,000+	34,900
Houses damaged	135,000	200,000
Homeless	1.5 million	240,000

Apart from volunteer work and in-kind aid, an estimated US$43.5 million was pledged in aid for the Yogyakarta earthquake victims. This is about US$15 per victim, compared with US$7,300 per victim world wide for the tsunami and earthquake of 26/12/2004.

The Great Hanshin earthquake of 17/01/1995 inflicted damage estimated at US$200 billion, or 2.5% of Japan's GDP.

Damage to buildings

As with most major earthquakes, the buildings with some degree of structural design generally survived. Most destruction occurred with masonry walls without any structural framing. Roofs with terra cotta tiles collapsed with the walls. Between them these elements accounted for many deaths.

Figure 8 depicts a severely damaged commercial building under restoration. There is evidence of poor detailing at joints, and the infill masonry is being replaced.


Figure 8: A severely damaged engineered building under restoration

Figure 9 depicts the fate of many houses of traditional construction. The foundation consists of a ring beam of reinforced concrete not deeply bedded, with additional beams under interior walls. The ring beam is filled in with hand compacted rock and gravel to provide a floor level above the natural surface. The masonry walls usually have rather thin bricks with rather thick beds of lime mortar. They are plastered. Rafters and battens supporting roof tiles sit on the walls.

Figure 9: A house cleared of rubble awaiting reconstruction

Reconstruction of domestic housing - design

After the earthquake temporary reconstruction used some bamboo, and corrugated iron and asbestos cement sheeting was used for roofing. These are unpopular materials: in spite of its robustness in earthquakes bamboo is considered a poor man's option, and it does not adapt easily to use with masonry. Further, government policy has been to cut down 'messy' bamboo forests.

The basic building materials of cement and concrete are expensive for Indonesians. Reinforcement comes as plain round bars in small diameters up to 12mm. It is salvaged from demolished structures. Masonry is commonly laid with lime mortar, which hardens more slowly and to a lower strength than Portland cement mortar.

Reconstruction has been relatively slow. In March 2007 a guide for building simple earthquake resistant houses was produced with funding by the Red Cross and the Red Crescent. See Figure 10. It consists of reinforced concrete frames with brickwork infill, seated on the traditional foundation of RC ring beams. Walls and timber roof trusses support timber joists and battens. See Figure 11

Figure 10

Figure 11

The booklet is intended for use by villagers rebuilding their own houses, where the highest level of skill, if it is to be found, is bricklaying. It includes instructions for mixing concrete and mortar (Figure 12) including slump tests, for setting out the foundations (Figure 13) and for the construction sequence (Figure 14).

The handbook also contained warnings on the dangers of asbestos cement, as well as instructions on how to handle it safely. Corrugated AC sheeting is one of the cheaper forms of cladding available in Indonesia.

Houses were being constructed using these concepts before the booklet was published. A handbook was developed by Prof Sarwidi of the Universitas Islam Indonesia (also located in Yogyakarta). This was first published in 2002 or earlier, and it been through five editions (Figure 15). It has more detail on earthquakes and general principles, and it is perhaps less accessible at the village level. A number of houses constructed using the principles in the booklet survived the earthquake while others around them collapsed.

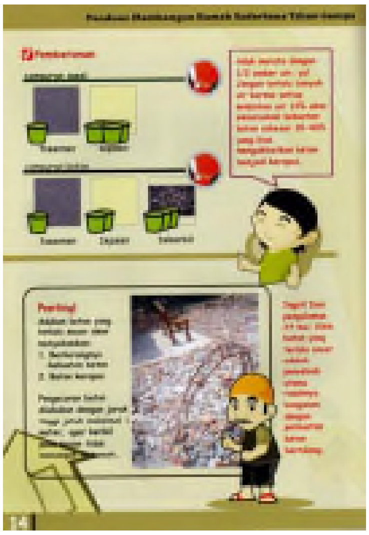

Figure 12

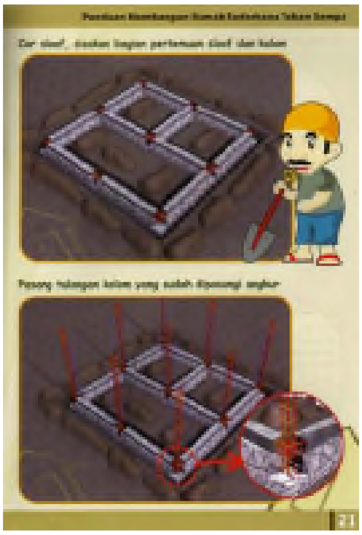

Figure 13

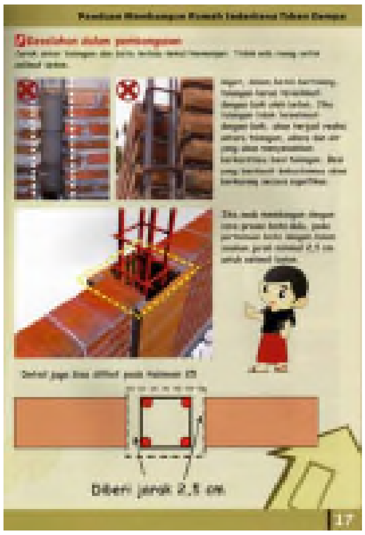

Figure 14

Figure 15 – Handbook of the Centre for Earthquake Effects, Dynamic Effects and Disaster Studies (CEEDEDS)

One problem tackled was reconstruction in final form rather than in a temporary intermediate form. The “Core House” concept was developed at UGM which would allow the construction of two rooms which could be later extended, using starter bars from the concrete frame to link the extension structurally (Figure 16). Examples of the basic Core House and the completed extended Core House are given in Figures 17 and 18.

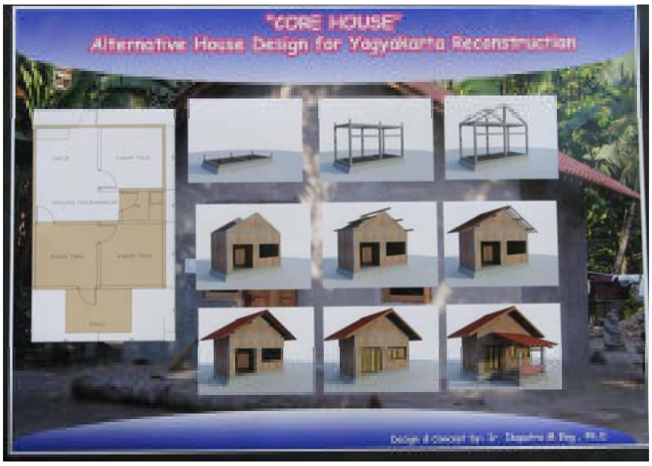

Figure 16 – Core House design

Figure 17 – Basic Core House

Figure 18 – Extended Core House

Reconstruction of domestic housing - Construction

An even greater challenge than finding affordable earthquake resistant designs that could be built with minimal expertise imported from outside the community, was the achievement of adequate standards of construction. Figure 19 shows a house in preparation for reconstruction with RC framework; Figure 20 shows a completed brickwork and framing prior to rendering. However, Figures 21 and 22 show very poorly compacted concrete in the columns, which could largely undo the earthquake resistance of the structures.

Figure 19

Figure 20

Ideally, the concrete should be compacted with a mechanical vibrator. Such an item is too expensive for the individual house builder, but a community should be able to share or rent one, and to have a short training course in its proper use.

Woven grass screens were used for walls in some cases (Figure 23). These allow quick construction and are less dangerous in earthquakes, but they lack durability and provide less privacy. The frame is bamboo, which is good for earthquake resistance provided that there is adequate bracing to keep the roof in place.

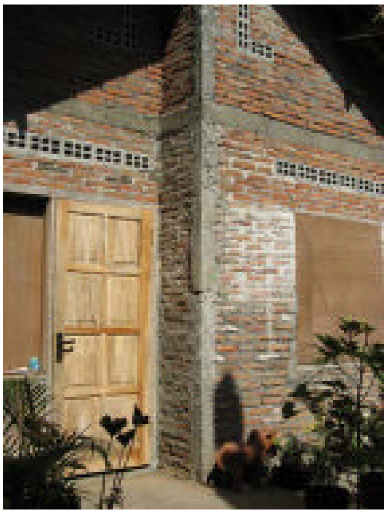

Figure 21: Typical RC framed brick construction

Figure 22: Rebar exposed in uncompacted column

Figure 23 – Bamboo framed house with grass mat walls

Commercial and craft industry buildings

Figure 24

Figure 25

Bamboo framework has been adopted much more readily for commercial buildings, many of which in pottery and other crafts, are open sided. The bamboo frames are converted to portal action by means of struts lashed into the corners. (Figures 24 and 25.) Rather than heavy tiles lighter roofing material, asbestos cement sheeting one side and thatching on the other, are used. The life of the binding rope is variously estimated, typically 30-40 years. The bamboo requires soaking for a month as part of the preparation. Chemicals can shorten this period.

Some frames used connections incorporating a single long bolt (Figure 26). These buildings recycled the roof tiles from the buildings which fell in the earthquake.

Figure 26 – Bamboo framed craft centre with long bolted connections

Rebuilding heritage

Restoration of cultural heritage and local industry is a key part of recovery from major disasters. The kingdom of Kotagede, a district near Yogyakarta, dates from the 16th century. The district is home to pottery silversmithing, and other crafts. The UGM's Center for Heritage Movement acquired Joglo House, a traditional community building which was badly damaged in the earthquake. This is being restored using traditional materials and forms compatible with earthquake resistance It will provide a focus for the heritage of the district. Apart from the earthquake damage, some of the timber is affected by termites. This adds to the difficulties of authentic restoration.

Reduction of vulnerability in undamaged regions

Of prime interest to the author is disaster risk reduction. This involves interaction with local communities to retrofit buildings currently at risk of collapse in an earthquake, so that they will survive such an event. Obviously it is harder to engage a community in such action than it is to initiate reconstruction after disaster strikes. Raising awareness of the risk to a level where retrofitting is initiated is the first major challenge.

The second challenge lies in the design of the retrofitting actions which are effective both in raising earthquake resistance to an acceptable level and in achieving the result at low cost. The designs for reconstruction are not readily adaptable to designs for retrofitting. How does one insert a concrete column with embedded brick ties into an existing brick wall?

This is the next major challenge for those committed to reducing the impact of earthquakes and other natural disasters on these communities.

Conclusions and observations

1. There is much good reconstruction in place, with community engagement, but the elapsed time between the earthquake and the completion of reconstruction is long, with much still to be done.
2. Viable methods of reconstruction using methods appropriate to the skills of local communities were developed, mainly in academic centres of engineering and architecture.
3. The difficult task of engaging local communities in reconstruction, itself a key factor in restoration of a normally functioning society, was assisted by those preparing the technical aspects of reconstruction having a close cultural relationship with the affected communities.
4. A shortcoming in the reconstruction was the lack of expertise in executing the construction methods described in the well documented structural guide. This might have been overcome by some basic training and community investment in equipment needed to mix and place good concrete, perform difficult fastenings, etc..
5. The Yogyakarta earthquake has resulted in a practical reconstruction method for housing based upon sound structural principles. The bigger challenge for disaster risk reduction is firstly, to devise a method of retrofitting houses to make them secure against collapse in future earthquakes (anywhere in Indonesia), and secondly, to find ways of engaging communities in the risk reduction process.

References

Jon Hinwood (2005). Disaster Design for Tsunamis- Coastal Engineering Considerations**,** *Structural Engineering International***, 15, 3**, 189-193, August

Indonesia and Japan Joint Survey on 2006 Java Tsunami. Tentative report version-1.0 (27/07/2006)

Okada T, Sugano T, Ishikawa T, Ohgi T, Takei S and Hamabe C. (2005) *Structural design method of buildings for tsunami resistance (proposed)I*. English translation of paper submitted to Building Letter, Building Technology Research Institute, The Building Center of Japan.

S. Reese, W. J. Cousins, W. L. Power, N. G. Palmer, I. G. Tejakusuma, and S. Nugrahadi. (2007). Tsunami vulnerability of buildings and people in South Java – field observations after the July 2006 Java tsunami. Nat. Hazards Earth Syst. Sci., 7, 573–589, 2007. www.nat-hazards-earth-syst-sci.net/7/573/2007/

WHO: Java Tsunami – Situation Report # 11, 3 August, (2006). http://www.searo.who.int/en/Section23/Section1108/Section2077 11956.htm