

Overview

On September 12 and 13, 2007 two earthquakes struck off the island of Sumatra, Indonesia, causing damage in the provinces of Bengkulu, Jambi, West Sumatra and the Mentawai Islands.

According to USGS (2007) the events occurred on the boundary between the Australia and Sunda plates, as shown in Figure 1. The first event, $M_w=8.4$ at 6:10 PM local time on September 12, was centered approximately 130 km off the coast SW from Bengkulu city, at a depth of 30 km (USGS, 2007). The second event, M_w 7.9 at 6:49 am local time on September 13, was located 225 km northwest of the first event, on the northern end of the aftershock zone. Aftershocks are ongoing.

The affected areas include urban centers of Bengkulu and Padang, a string of coastal, rural communities along the main highway between Bengkulu and Padang, and the villages in the Mentawai Islands. The latest casualty figures stand at 25 killed and 100 injured (OCHA Situation Report No. 8). The Indonesian National Development Planning Agency (BAPPENAS) puts economic losses at IDR 1.5 trillion (US\$164 million).

Similar to other recent earthquakes in Indonesia, houses were hit the hardest by the September 12 and 13 events. On mainland Sumatra, 17,695 houses were destroyed, 21,035 houses severely damaged, and 49,496 mildly damaged (OCHA Situation Report No. 8).

The Indonesian Meteorological and Geophysics Agency (BMG) is in the process of installing a network of strong ground motion instruments throughout Sumatra. At the time of writing, it was not clear if strong ground motion recordings exist for the September 12 and 13 events.

This reconnaissance report was compiled after site visits to Bengkulu province, West Sumatra province, and the Mentawai Islands. The focus is on the performance of houses, other low-rise buildings such as schools, multi-story RC frame buildings, and liquefaction effects on houses.

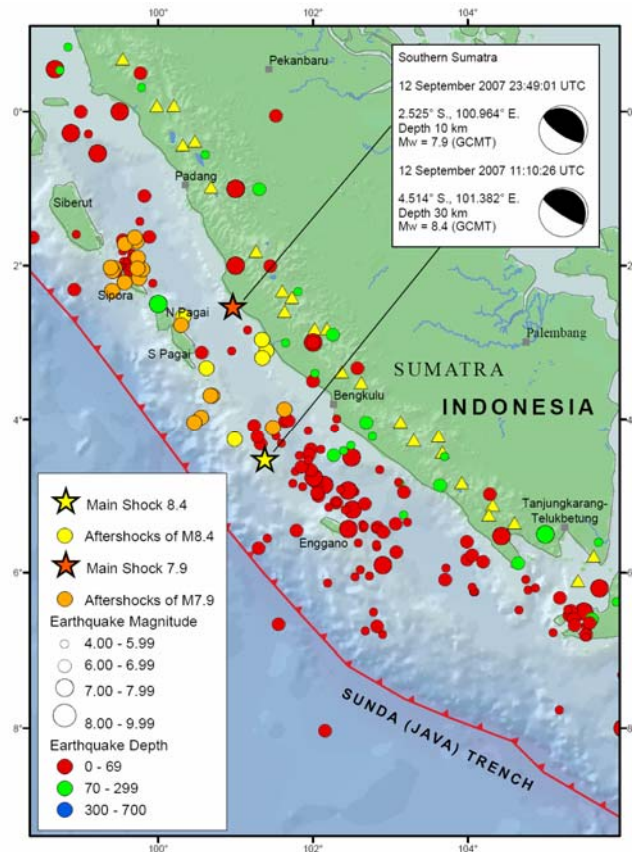


Figure 1. Location of main events and aftershocks, USGS (2007)

Housing Damage on Mainland Sumatra

Houses were significantly affected by the earthquakes. On mainland Sumatra, housing damage becomes more pervasive traveling along the coast either north from Bengkulu or south from Padang to Pasisir Selatan District.

Foundations are generally shallow strip footings made of rounded river stone masonry in cement mortar. Roofs consist of timber trusses supporting lightweight CGI sheets, asbestos sheets, or clay tiles. Hipped and pitched roofs are both common; in the Bengkulu area, timber gable walls are more common than masonry gables.

Wall systems for houses affected on mainland Sumatra include the following structural types:

- (1) Confined or Partially Confined Masonry – Full height fired clay brick masonry wall with varying degrees and types of confinement, ranging from unconfined (unreinforced) masonry walls, timber tie columns and bond beams, reinforced concrete tie columns with timber bond beam, and reinforced concrete tie columns and ring beams
- (2) Timber frame with masonry skirt around the lower third of the wall, and woven, plastered bamboo or timber above
- (3) Timber frame.

Confined or Partially Confined Masonry. This structural type is supported by a shallow river stone masonry strip footing, and may have a reinforced concrete foundation (plinth) beam. Two types and sizes of fired clay bricks were common – the traditional hand-molded and wood kiln-fired bricks, which are generally 9 cm wide by 19 cm long by 4 cm in height. Their quality and strength can vary considerably depending on the type of clay used, duration of firing, and placement in the kiln. Machine-mixed, molded and fired perforated bricks were more common in and around Bengkulu. These bricks are 9 by 19 by 9 cm in size. Regardless of the type of bricks, houses typically use running bond for the masonry wall, resulting in a half-brick wide wall (13 cm with plaster, 10-11 cm without).

For confined masonry houses, columns were typically cast after the masonry wall was built, flush with the wall, and thus the same width as a brick or block (10 or 11 cm). Smooth reinforcing steel was common, typically 6 or 8 mm in diameter with stirrups ranging from 3 to 6mm in diameter. Stirrups and ties were spaced at 15 to 35 cm intervals.

The most common reasons for damage or collapse of confined or partially confined masonry houses are the following:

- (1) Insufficient connections between confining elements. Figures 2, 3 and 4 illustrate the importance of connections between confining elements. Note that the reinforced concrete columns and beams, despite their insufficient and inconsistent section and use of small diameter bars and stirrups or ties at large spacing, remain largely intact, with failure occurring in the masonry wall and at the connection between tie column and bond beam.
- (2) Poor quality workmanship in the masonry wall. Figures 2 and 3 also illustrate the importance of good quality masonry; in this case, partial collapse was initiated in the walls.
- (3) Lack of sufficient stiffness in the in-plane direction of the front wall. A common architectural preference in Indonesia is to have many large openings at the front of the house. This lack of stiffness in the in-plane direction contributed to several partial collapses (Figs. 5, 6 and 7).
- (4) Insufficient connections between tie columns and masonry walls. Figure 8 shows the failure of a masonry panel without any connection to the column.
- (5) Tall, slender wall prone to out-of-plane failure. With plaster, the common wall is only 13 cm thick, and walls tend to be 3m in height. In the case shown in Figure 9, the wall was over 3.5m tall with a span over 5m without interior crosswalls or bracing.



- (6) Use of timber for bond beams. Common practice was to use reinforced concrete for tie columns and timber for the bond beams. This construction practice was not sufficient to prevent collapse of walls of some houses. See Figures 7 and 10.
- (7) Unreinforced masonry without confinement. Figure 10 shows a partially collapsed house with unreinforced brick masonry walls, some timber tie columns at door frames, and a timber bond beam which is hooked to the wall.

Several confined masonry houses located in a housing development in Bengkulu were damaged for similar reasons (Figures 11 through 16). This sloping subdivision of at least 60 houses was built by a developer, and the houses were subsequently purchased by owners. Although there were some variations in floor plans, most houses were identical, two bedroom with kitchen and indoor bathroom, single story, and approximately 40m².

Damage was common at the upper column-beam connection in the open frame supporting the gable wall above the covered terrace (Figures 11, 12 and 13). The gable wall and the side walls collapsed completely in several cases. The most significantly damaged structure was the only one that was not yet plastered (Figures 15 and 16); in Indonesia, cement-based plaster adds significant strength to the masonry wall. That some houses were more damaged than others is probably because of (1) variations in construction quality and workmanship, and (2) location on the hillslope.

These failures should be studied for the purpose of improving guidelines for new confined masonry construction. These causes of failures (particularly workmanship and poor connections) should be emphasized as key features in these guidelines.

Timber Frame with Masonry Skirt. Many timber frame houses with 40 cm to 1m of masonry around the base of the wall performed well in the earthquake. Like confined masonry, this type of house is supported by a shallow stone masonry strip footing, however, there is rarely any connection between the timber posts and the footing, or the timber posts and the masonry panel. The damage to these structures, considered “semi-permanent” in Indonesia, consisted of cracking of the masonry panel, failure of the masonry panel as a rigid block, and shifting and damage to the timber frame (Figures 17 and 18).



Figure 2. Confined masonry house with failure in masonry walls and connections between tie columns and bond beams, Kec. Airnapal (North Bengkulu)



Figure 3. Confined masonry house with failure in masonry walls and connections between tie columns and bond beams, Kec. Airnapal (North Bengkulu)



Figure 4. Collapsed confined masonry or RC frame with masonry infill house, note lack of sufficient connection (North Bengkulu)



Figure 5. Partially collapsed confined masonry house, (North Bengkulu)



Figure 6. Partially collapsed unreinforced masonry house with timber bond beam, (North Bengkulu).



Figure 7. Partially collapsed brick masonry house with RC tie columns and timber bond beams, note partial collapse of masonry gable wall, and lack of in-plane stiffness in front wall, Kec. Lais (North Bengkulu)
S3.53217° E102.03771°



Figure 8. Confined masonry house with failure of masonry wall not connected to column, Kec. Lais (North Bengkulu)



Figure 9. Confined masonry house with failure in masonry walls and connections between tie columns and bond beams, Kec. Airnapal (North Bengkulu)



Figure 10. Partially collapsed unreinforced masonry house with timber bond beam, Lempuing (Bengkulu), S3.82799° E102.28473°



Figure 11. Subdivision of confined masonry houses, damage to covered terrace, Bengkulu. S3.83218° E102.29287°



Figure 12. Subdivision of confined masonry houses, damage to covered terrace, Bengkulu. S3.83218° E102.29287°



Figure 13. Subdivision of confined masonry houses, damage to covered terrace, Bengkulu. S3.83218° E102.29287°



Figure 14. Subdivision of confined masonry houses, separation and beam-column joint, Bengkulu. S3.83218° E102.29287°



Figure 15. Subdivision of confined masonry houses, collapse of masonry wall exacerbated by insufficient connections, Bengkulu. S3.83218° E102.29287°



Figure 16. Subdivision of confined masonry houses, connection between beam and column, Bengkulu. S3.83218° E102.29287°



Figure 17. Timber frame with masonry skirt, Kec. Lais (North Bengkulu)



Figure 18. Timber frame with masonry skirt, superstructure has shifted off although the relatively heavy roof structure remains largely intact, and the masonry panel is partially collapsed, Kota Agung, Kec. Lais (North Bengkulu). S3.55841° E102.08951°

Housing in the Mentawai Islands

In many villages on the southernmost of the Mentawai Islands, North Pagai and South Pagai, between 25 and 90% of the houses were destroyed or uninhabitable. The Mentawai Islands are a predominantly rural, sparsely populated chain of four major and many small islands approximately 9 hours by boat from mainland Sumatra.

There are three primary structural housing types in the villages: (1) timber frame houses on stilts or shallow stub footings, (2) timber structures with a concrete block masonry skirt up to 1m, and (3) confined or unreinforced hollow or cellular block masonry structures with timber truss roofs. In all cases, roof cover is lightweight, consisting of CGI sheets, asbestos sheets or locally made thatch (rumbia). Concrete block structures were damaged more significantly and in greater numbers than the timber houses.

Timber. The following problems were observed for timber structures:

- (1) Timber posts rest directly on the ground, which caused the posts to sink in the ground at soft soil sites and sites inundated by tsunami; this foundation system to weathering of the timber due to the lack of isolation from water uptake from the ground (Figure 19)
- (2) Some houses with a stone or concrete stub foundation slid off the foundation
- (3) Superstructures lack bracing in the in-plane direction
- (4) Members are connected with nails only
- (5) Timber is not maintained or treated; newer houses with treated or painted timber performed better than those with older, weathered timber.

Timber Frame with Concrete Block Skirt. Concrete Block Skirt structures failed in similar manner to those on mainland Sumatra described previously.

Confined Concrete Block Masonry. Confined Concrete Block Masonry structures have similar problems to the confined masonry structures described in the mainland Sumatra section, including lack of sufficient connections between confining elements, and poor quality block masonry (Figure 20). Most concrete blocks are cellular. There was a wide variation in the strength of the blocks used, some of them crushing easily under hand pressure. Low strength is a result of low cement content, use of beach sand, and production by hand (without mechanical vibration).



Figure 19. Timber frame with posts resting directly on soft ground, Barimanua, Pulau Sipora, Mentawai Islands.



Figure 20. Confined concrete block masonry, partial collapse due to lack of sufficient connections between confining elements, Barimanua, Pulau Sipora, Mentawai Islands.

Liquefaction Effects on Houses

Effects of liquefaction, in the form of differential settlement and foundation cracking (Fig. 21), vertical cracks in masonry walls (Fig. 22), heave and cracking of interior floors (Figs 23 and 24), and reports of water and sand coming up through the cracks in the floors, were found in at least six houses in Lempuing, a village on the edge of Bengkulu city. This low elevation, high groundwater table site consists of clean, fine to medium sand near the surface. Floor slabs generally consist of thin (5 – 10 cm) unreinforced concrete.



Figure 21. Cracks in foundation and walls associated with settlement and tilt on liquefiable soils, Lempuing (Bengkulu), S3.82799° E102.28473°



Figure 22. Ground cracking and vertical cracks in walls (behind owners), Lempuing (Bengkulu), S3.82799° E102.28473°



Figure 23. Floor heave and cracking, Lempuing (Bengkulu), S3.82799° E102.28473°



Figure 24. Floor heave and cracking, Lempuing (Bengkulu), S3.82799° E102.28473°

Multi-Story RC Frame Buildings

In the urban areas of Bengkulu and Padang, RC frame with masonry infill is still the most common structural type for multi-story commercial buildings and hospitals, although a handful of steel frame structures are under construction in Padang. In the cities, many multi-story RC frame with masonry infill buildings had cracks, however, little structural damage was observed. In Padang, two buildings collapsed completely, both RC frame buildings with RC slab roof and floors. The Mitsubishi showroom was already under demolition at the time of the site visit, and the Hyundai shop is shown in Figure 25.



Figure 25. Hyundai Shop, Padang.

Major structural damage to RC frame buildings in Bengkulu was similarly limited, and observed at only two buildings, both “ruko” buildings, which are combination house (rumah) on upper floors and shop (toko) on ground floor. The ground floor is an open frame at the front, with a brick infill wall at the back and possibly a brick infill wall halfway back with a door. Both damaged rukos were located on sites that slope downward away from the road or parking area, and thus the ground floor is supported by a frame on spread footings bearing at different elevations. Do to safety concerns it was not possible to do a detailed inspection of settlement and deformation of the foundation elements.

The ground floor of the five-bay, two story ruko shown in Figures 26 through 28 dropped by approximately one meter due to failure at the column-slab interface (Fig. 28). The structure is tilting back by approximately 4 degrees, and the first floor columns leaning to the left at 3 degrees. Ribbed, 14mm diameter steel was used in the columns and beams, with ties of 6mm diameter spaced at 4 cm near the joint. Similar failure at the column – ground floor beam interface occurred at a three-story, two bay ruko (Figures 29 through 31). In this case, the failure was clearly exacerbated by slope failure towards the building. The columns were 32 cm by 32 cm and used up to 8 smooth, 15mm diameter longitudinal bars.

Non-structural damage, primarily in the form of cracks in masonry infill walls, was common in multistory commercial buildings (Figures 32 through 38), such as the Batang Arau Hotel, Bumi Minang Hotel, Pasar Raya, Plaza Andalas, Dr. MDJamil Medical Center, BPKP office, Governor’s office, BNI office, Bank Mandiri office, and Telkom office in Padang and at the Muhammad Yunus hospital in Bengkulu. Cracks and falling hazards existed at many frame structures in which the column was not located at the corner, and unreinforced masonry walls were used to extend the plan area (Figures 32 through 34).



Figure 26. Two-story ruko, Bengkulu. S3.80362° E102.27617°



Figure 28. Two-story ruko, top of column below the ground floor slab, Bengkulu. S3.80362° E102.27617°



Figure 30. Ground settlement and lateral spreading toward three-story ruko, Bengkulu. S3.80581° E102.27953°



Figure 27. Two-story ruko, 3° tilt in first floor column, Bengkulu. S3.80362° E102.27617°



Figure 29. Three-story ruko, Bengkulu. S3.80581° E102.27953°



Figure 31. Three-story ruko, failure at the top of the column below ground floor beam, Bengkulu. S3.80581° E102.27953°



Figure 32. University of Bengkulu, political science building, note failure of masonry wall extending out beyond main column, Bengkulu.



Figure 34. Telkom building, Padang.



Figure 35. Two-story mosque near Bumi Minang Hotel, damage from earthquake consisted of vertical crack along wall-column interface; wall has been partially demolished since earthquake. Note minor columns are not connected to ring beam. Padang.



Figure 33. Plaza Andalas, 4-story shopping mall, damage to masonry walls, Padang.



Figure 36. Bank Mandiri office, Padang.



Schools

UN OCHA reports that 260 educational facilities were destroyed, and 450 severely damaged. The SMAK-SNT Carolus school in Bengkulu consists of two separate two-story RC frame buildings, one of which was a new building constructed after the previous building collapsed in an earthquake in 2000. The other building was repaired after the 2000 earthquake. Only hairline cracks were found at the edges of masonry infill walls in the new building, however, the timber truss roof collapsed where it was joined to or impacted by the older building. The repaired building had new, hairline cracks in the same pattern as those that were plastered and painted after the last earthquake. The tops of the first floor columns were also cracked. It appeared that they had been previously repaired by a sealant or adhesive. Some masonry interior walls were partially collapsed.

Confined masonry interior and end walls collapsed at a rural single story school complex in Lais Subdistrict (Sekolah Dasar Negeri No. 04) (Fig 41 through 44), leaving the long walls standing and supported against out-of-plane failure primarily through column steel tied around the roof trusses. Without strong-motion recordings, it is difficult to say how much directionality contributed to the end and interior wall collapses. The ring beams were not capable of spanning these wide classrooms. Ring beams were approximately 15 cm by 11 cm in section, used four 8mm diameter longitudinal bars with 4-5mm diameter stirrups spaced at distances of 20 to 30 cm (Fig. 43). Similar to the problems observed for confined masonry houses, connections between tie columns and bond beams were insufficient (Figures 43 and 44). Coarse gravel to cobble-size aggregate was used in the concrete; concrete was broken easily by hand pressure.

A second school compound with significant damage in Lais Subdistrict consisted of two buildings. A single story confined masonry building collapsed. The plinth was built of rounded river stone masonry, without a plinth beam for the columns to tie into. Failure at these and the upper column-beam joints likely led to collapse. The columns themselves appeared to be largely intact. A newer single story building, rectangular in plan with a covered terrace on one side, experienced cracking and tilt of the columns on the terrace. Cracking from deformation in the out-of-plane direction (perpendicular to the long axis of the building) was observed.



Figure 37. SMAK SNT Carolus School, pre-2000 earthquake building on left, post-2000 earthquake building starting with verandah and going right, Bengkulu. S3.82846° E102.29587°



Figure 38. SMAK SNT Carolus School, pre-2000 earthquake building on right, post-2000 earthquake building on left, Bengkulu. S3.82846° E102.29587°



Figure 39. SMAK SNT Carolus School, pre-2000 earthquake building column on left, post-2000 earthquake building on right, Bengkulu. S3.82846° E102.29587°



Figure 40. SMAK SNT Carolus School, pre-2000 earthquake building, new cracks in same pattern as those plastered over after 2000 earthquake, Bengkulu. S3.82846° E102.29587°



Figure 41. Sekolah Dasar Negeri No. 04, end and interior masonry walls collapsed, Kec. Lais (Bengkulu). S3.52958° E102.04525°



Figure 42. Sekolah Dasar Negeri No. 04, note steel splice location, use of rounded cobbles in concrete, Kec. Lais (Bengkulu). S3.52958° E102.04525°



Figure 43. Sekolah Dasar Negeri No. 04, collapsed ring beam over end wall, note use of cobble size aggregate, Kec. Lais (Bengkulu). S3.52958° E102.04525°



Figure 44. Sekolah Dasar Negeri No. 04, column-beam and column-truss connection, Kec. Lais (Bengkulu). S3.52958° E102.04525°



Figure 45. Collapsed confined masonry building, Pal 30, Kec. Lais, (North Bengkulu). S3.53490° E102.05996°



Figure 46. Collapsed confined masonry building, note lack of plinth beam and connection between column and plinth, Pal 30, Kec. Lais, (North Bengkulu). S3.53490° E102.05996°



Figure 47. Rectangular plan school, note several columns out of plumb, Pal 30, Kec. Lais, (North Bengkulu). S3.53490° E102.05996°



Figure 48. Rectangular plan school, cracks due to out-of-plane deformation, Pal 30, Kec. Lais, (North Bengkulu). S3.53490° E102.05996°



Figure 49. Lateral spreading toward river, Sikakap (Sikakap, Mentawai Islands) photo courtesy SurfAid International



Figure 50. Temporary houses, Barimanua Village (Mentawai Islands).

Transitional Housing and Housing Reconstruction

The Indonesian government has promised Rp. 15 million (approx. US\$1,700) for each family with a destroyed house, IDR 10 million for severely damaged houses and IDR 5 million for mildly damaged houses. However, it is unlikely that this funding be disbursed to the families until 2008. Homeowners are staying in temporary shelters consisting of recycled timber, thatch, tents and tarps (Figure 50) and starting to rebuild using recycled materials and their own resources. The Indonesian Red Cross and some international aid agencies are providing some basic materials such as nails and tarps. In fear of a tsunami, some villages in the Mentawai Islands have asked to relocate to inland or higher ground.

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