Overview

On May 27, 2006 at 5:54 AM local time, a moment magnitude 6.3 earthquake struck the island of Java, Indonesia near Yogyakarta. The affected area is a densely populated mix of urban and rural communities on the southern slope of Mt. Merapi, an active volcano. The epicentral location was first reported as off the coast in the Indian ocean (Fig. 1); it was later revised to 20 km SSE of Yogyakarta, at 7.962°S, 110.458°E, which is southeast of the village of Imogiri along the Oyo river in Bantul District (USGS, 2006). The depth reported by USGS was 10 km.

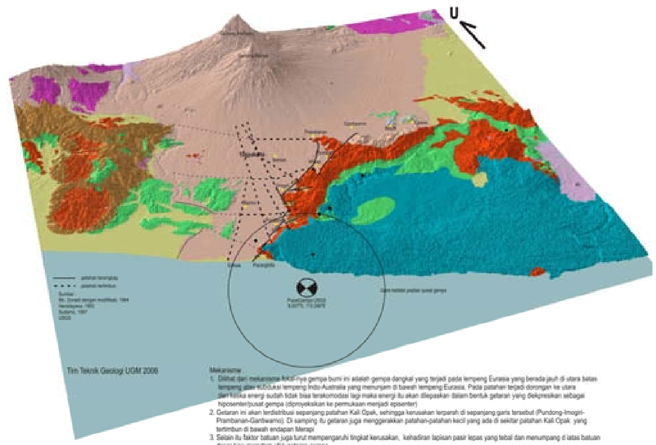

Figure 1. Epicentral region, UGM (2006)

The latest casualty figures stand at 5,176 killed and between 37,000 and 50,000 injured. An estimated 600,000 to one million people are currently without permanent shelter.

The total amount of damage and loss caused by this earthquake is estimated at US$3.1 billion (CGI, 2006), ranking it as the fourth most costly natural disaster in a developing country in the last 10 years. Houses were hit the hardest by the earthquake, accounting for over half of the total damage and loss. An estimated 154,000 houses were completely destroyed and 260,000 suffered some damage. These totals are higher than the combined total number of houses requiring reconstruction and repair in the areas of Indonesia affected by the December 26, 2004 tsunami and the March 28, 2005 Nias earthquake.

The most heavily affected areas are Bantul district in Yogyakarta Special Province (DIY), in which 47,000 houses were destroyed, and Klaten district in Central Java Province, in which 66,000 houses were destroyed. CGI, 2006 estimates 4.1 million cubic m of debris exist in the affected region (Figs 2 and 3).

Figure 2. Debris along main street through Imogiri, S7.92282°, E110.38374° IMG_6551

Figure 3. Debris in Gantiwarno (Klaten, Central Java). S7.76802 E110.54156 IMG 6916

<u>Housing Damage</u>

Houses were severely affected by this earthquake; estimated 7.4% of the housing stock in the six most affected districts was lost (CGI, 2006). In some villages, 70-90% of the houses were completely destroyed. Houses in the area affected by the earthquake can be divided into three general categories:

(1) Unreinforced masonry – older houses (pre-1990) consisting of unreinforced fired clay brick masonry walls with flexible, pitched or hipped timber truss or bamboo roofs with clay tiles,
(2) Confined or partially confined masonry – newer houses (post-1990) built of confined or partially confined brick, solid concrete block or stone masonry in cement mortar walls with flexible, pitched or hipped timber truss or bamboo roofs covered by clay tiles,
(3) Timber frame – timber frame houses were less common, and often still included some masonry wall.

Unreinforced Masonry. Unreinforced masonry houses were ubiquitous throughout the affected area and the most severely damaged (Fig. 4 and 5). No steel reinforced concrete foundation beams, columns, or ring beams were used in older houses.

Figure 4. Destroyed unreinforced masonry houses, Pleret (Bantul), S7.83686° E110.41552° IMG_6633

Figure 5. Unreinforced masonry house, damage category D3, Tlogo, Prambanan (Klaten), S7.75259° E110.49550° IMG_6852

Wood-fired clay bricks were laid in sand-clay mortar or weak cement-sand-lime mortar. In many cases, the mortar would crumble under finger pressure. The walls of the oldest masonry houses were approximately 25 cm wide, built with full brick bonding (English bond). The bricks used in the oldest houses tended to be longer (25cm x 11cm x 4cm) than their modern counterparts (22 cm x 11cm x 4 cm). Full brick wide bonding is not possible with the shorter bricks, so common practice transitioned to a 17 cm wide bond in which two bricks were laid in the plane of the wall and one brick turned on its side (Fig. 6 and 7).

Figure 6. Unreinforced masonry. Sumbermilo (Bantul) IMG_6771

Figure 7. Unreinforced masonry, Bebekan Mulyodadi, Bambang Lipuro (Bantul). S7.94160°, E110.32297° IMG_6806

Confined or Partially Confined Masonry. Many newly built confined masonry houses with reinforced concrete tie columns and bond beams at the plinth and roof levels performed well in this earthquake. Examples of good performance of confined fired brick, solid concrete block, and stone masonry were scattered throughout the heavily affected areas (Figs. 8 through 10). 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 8mm in diameter with stirrups ranging from 3 to 6mm in diameter. Stirrups were often spaced at 15 to 20 cm intervals.

Figure 8. Well designed and built confined brick masonry house, edge of heavily damaged Pleret (Bantul), S7.83686° E110.41552°, IMG_6636

Figure 9. Backside of well designed and built confined brick masonry house, Bebekan Mulyodadi, Bambang Lipuro (Bantul), S7.94160°, E110.32297°, IMG_6804

Figure 10. Partially confined stone masonry house with timber ring beam, Platar Somopuro, Jokonalan (Klaten), S7.75478, E110.53557, IMG_6897

Prior to the earthquake, three houses were built in Wonokromo, Pleret (Bantul) under the supervision and direction of Prof. Sarwidi of the Center for Earthquake Engineering, Dynamic Effect, and Disaster Studies (CEEDEDS) at Universitas Islam Indonesia. These confined masonry houses used connection detailing shown in the posters distributed by CEEDEDS (Figure 11). The houses performed very well in the earthquake, with only hairline cracks, and in one case minor some damage to masonry gable wall (Figure12).

Figure 11. Beam column connection detailing in posters distributed by CEEDEDS, UII, IMG_6618

Figure 12. Crack at masonry gable, CEEDEDS house, Jejeran-2, Wonokromo, Pleret (Bantul), S7.86676° E110.38764°, IMG_6696

Although good performance of confined masonry houses was evident, many confined or partially confined masonry houses collapsed or were severely damaged. The most common reasons are listed below.

(1) Insufficient connections between reinforced concrete tie columns and bond beams and between tie columns and masonry walls. This was the most dominant cause of failure for newly-built confined masonry houses in which tie columns and bond beams were present (Figs. 13 – 17).

Figure 13. Confined masonry house under construction, insufficient connections, Pleret (Bantul). S7.87574°, E110.40703°, IMG_6575

Figure 14. Zoom-in view of ring beam – column connection. IMG_6577

Figure 15. Zoom-in view of beam without connection, IMG_6579

Figure 16. Insufficient connection between column and beam, Segoroyoso, Pleret (Bantul) S7.88174° E100.40869°, IMG_6749

Figure 17. Insufficient connection between column and beam, Pleret (Bantul) S7.88174° E100.40869°, IMG_6746

(2) Tall, slender poorly confined masonry walls. Newer houses use running bond for the masonry wall, resulting in a half-brick wide wall (13 cm with plaster, 10-11 cm without) which is often over 3m tall. Gables add another 1 – 2m to the height. Damage and failure to masonry gable walls was widespread throughout the affected region and plagued both new and older houses with and without reinforced concrete ring beams (Fig. 18 and 19). In most cases, gable masonry was neither properly confined nor properly connected to the roof. Cross-bracing between gables was not common. Offset gables, a popular architectural style that accommodates a larger living room and terrace, were also damaged (Fig. 20 and 21).

Figure 18. Masonry gable wall overturning, Keputren, Pleret (Bantul) S7.86905° E110.40272°, IMG_6721

Figure 19. Masonry gable wall overturning (Bantul) S7.89468°, E110.37341°, IMG_6542

Figure 20. Minor damage to offset gable, Gantiwarno (Klaten), S7.75485° E110.53555°, IMG_6905

(3) Absence of plinth beams and ring beams. Many newer houses had reinforced concrete columns but no reinforced concrete ring beams (Fig. 22 and 23).

Figure 21. Collapse of offset gable, Kasongan, Kasihan (Bantul), S7.84512° E110.33534°, IMG_6824

Figure 22. Collapse of masonry wall (note absence of ring beam), Pleret (Bantul) IMG_6589

Figure 23. Collapse of masonry wall (note absence of ring beam), Kebutren, Pleret (Bantul) S7.86905° E110.40272°, IMG_6725

(4) Insufficient connections between walls or columns and roof. Column steel was often wrapped around a timber beam which functioned as a ring beam Fig. 24). Timber beams were generally 8cm by 12cm and made from coconut trees or hardwood from Java and Kalimantan. Bamboo is also common for roof structures. Some older houses were a mix of structural system, in which part of the roof load was carried by timber posts infilled with masonry. A typical timber truss is shown in Fig. 25.

Figure 24. Common connection between column and beam – column steel wrapped around timber, Jejeran-1, Wonokromo, Pleret (Bantul), S7.86480° E110.38821° IMG_6672.

Figure 25. Typical timber truss with steel plates reinforcing the joints, Kasongan, Kasihan (Bantul), S7.84512° E110.33534° IMG_6831.

(5) Use of reinforced concrete trusses. Reinforced concrete trusses were seen in a few of the houses, all of which had non-ductile failures at the beam-column connections (Fig. 26 and 27). These buildings were mixed use; the rear part was used for storage or living area, and the front for a shop. As a result, the front was typically an open frame (no shear wall).

Figure 26. House/shop with reinforced concrete truss, Bebekan Mulyodadi, Bambang Lipuro (Bantul) S7.93460° E110.32194°, IMG_6778

Figure 27. Reinforcement in beam for house/shop, Bebekan Mulyodadi, Bambang Lipuro (Bantul) S7.93460° E110.32194°, IMG_6781

(6) Foundation Issues. Foundations for both older and newer houses consisted of shallow strip footings built of random, angular mountain stone or brick masonry in mud or cement mortar. Only one foundation-related failure was found; masonry walls of a single story house shifted horizontally at the interface between the wall and the stone masonry foundation (Fig. 28).

Figure 28. Sliding along wall/foundation interface, Tegal Kebong Agung, Imogiri (Bantul) S7.93434° E110.36667°, CIMG1769

Transitional Housing

Tents were distributed in some areas, as were hammers, shovels and other tools to support debris clearing and recycling. Many families with destroyed houses have already rebuilt transitional one or two-room shelters on the foundation of their destroyed house (Fig. 29 and 30). Transitional shelters use a mix of recycled timber, bamboo, and window and door frames, and new plastic tarps, plywood and corrugated galvanized iron sheets. Also, many families were continuing to live in houses that were damaged beyond repair and vulnerable to collapse in aftershocks.

Figure 29. Transitional house in Pleret (Bantul), S7.83686° E110.41552°, IMG_6646

Figure 30. Transitional house in Pleret (Bantul) IMG_6727

Housing Reconstruction

The Indonesian Government has announced a plan to allocate Rp. 33 million (US$3,700) to rebuild each destroyed house. It is not clear if the funds will be given directly to homeowners, or channeled through government-hired contractors.

Yogyakarta is an intellectual and cultural center of Indonesia, home of many universities, historical sites, and small to medium-scale enterprises, such as handicraft producers. Yogyakarta is not a center of heavy industry; although fired bricks are produced locally, many building materials must be brought in by highway from other cities. A price survey done during the reconnaissance indicated that materials prices are already at a level consistent with current materials prices in tsunami-devastated Aceh. In Aceh, materials and labor for a 2-bedroom, 36m^2 reinforced concrete confined masonry house with septic tank and electrical wiring is in the range of Rp. 52-60 million (US$5,800 - 6,700).

References

The Consultative Group on Indonesia, 2006. Preliminary Damage and Loss Assessment, Yogyakarta and Central Java Natural Disaster. A Joint Report form BAPPENAS, the Provincial and Local Governments of D.I. Yogyakarta, the Provincial and Local Governments of Central Java, and International Partners, June 2006. The 15th Meeting of The Consultative Group on Indonesia, Jakarta.

UGM, 2006, USGS, 2006

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