The 17 July 2006 Tsunami Earthquake in West Java, Indonesia

Jim Mori,[1] Walter D. Mooney,[2] Afnimar,[3] Sandy Kurniawan,[4] Aan Ibnu Anaya,[3] and Sri Widiyantoro[3]

A tsunami earthquake ($M_w = 7.7$) occurred south of Java on 17 July 2006. The event produced relatively low levels of high-frequency radiation, and local felt reports indicated only weak shaking in Java. There was no ground motion damage from the earthquake, but there was extensive damage and loss of life from the tsunami along 250 km of the southern coasts of West Java and Central Java. An inspection of the area a few days after the earthquake showed extensive damage to wooden and unreinforced masonry buildings that were located within several hundred meters of the coast. Since there was no tsunami warning system in place, efforts to escape the large waves depended on how people reacted to the earthquake shaking, which was only weakly felt in the coastal areas. This experience emphasizes the need for adequate tsunami warning systems for the Indian Ocean region.

INTRODUCTION

Following the disastrous tsunamis of 26 December 2004 and 28 March 2005 in Indonesia, yet another earthquake caused a tsunami with a large number of deaths and vast property damage. The 17 July 2006 West Java earthquake ($M_w = 7.7$) was located offshore near the trench of the Sunda subduction zone south of Java. The thrust earthquake produced a large tsunami along the southern coast of Java that resulted in more than 600 deaths and more than 75,000 people displaced. This event was a "tsunami earthquake," meaning that the levels of high-frequency seismic radiation were relatively low for the size of the event. The earthquake was only weakly felt in regions where large tsunami run-ups occurred, and this was one likely cause for the large number of casualties.

Several other notable earthquakes in the Java region have resulted in damaging tsunamis over the years. The $M_w = 7.8$ earthquake of 2 June 1994 produced a tsunami that had a maximum run-up height of 13 m and killed more than 200 people. That earthquake occurred south of Java about 600 km east-southeast of the 17 July 2006 Java earthquake, and it was similarly thrust faulting on the shallow plate boundary. On 20 August 1977, a magnitude 8.3 normal-fault earthquake occurred within the Australia plate about 1,200 km east-southeast of the 17 July 2006 Java earthquake, producing a tsunami that had a maximum run-up height of 15 m and killed almost 200 people. The 26 May 2006 earthquake, which had devastating effects in Central Java, was a moderate ($M_w = 6.3$) event that occurred at shallow depth within the crust of the overriding Sunda plate, but it did not cause a tsunami because the faulting took place was on land.

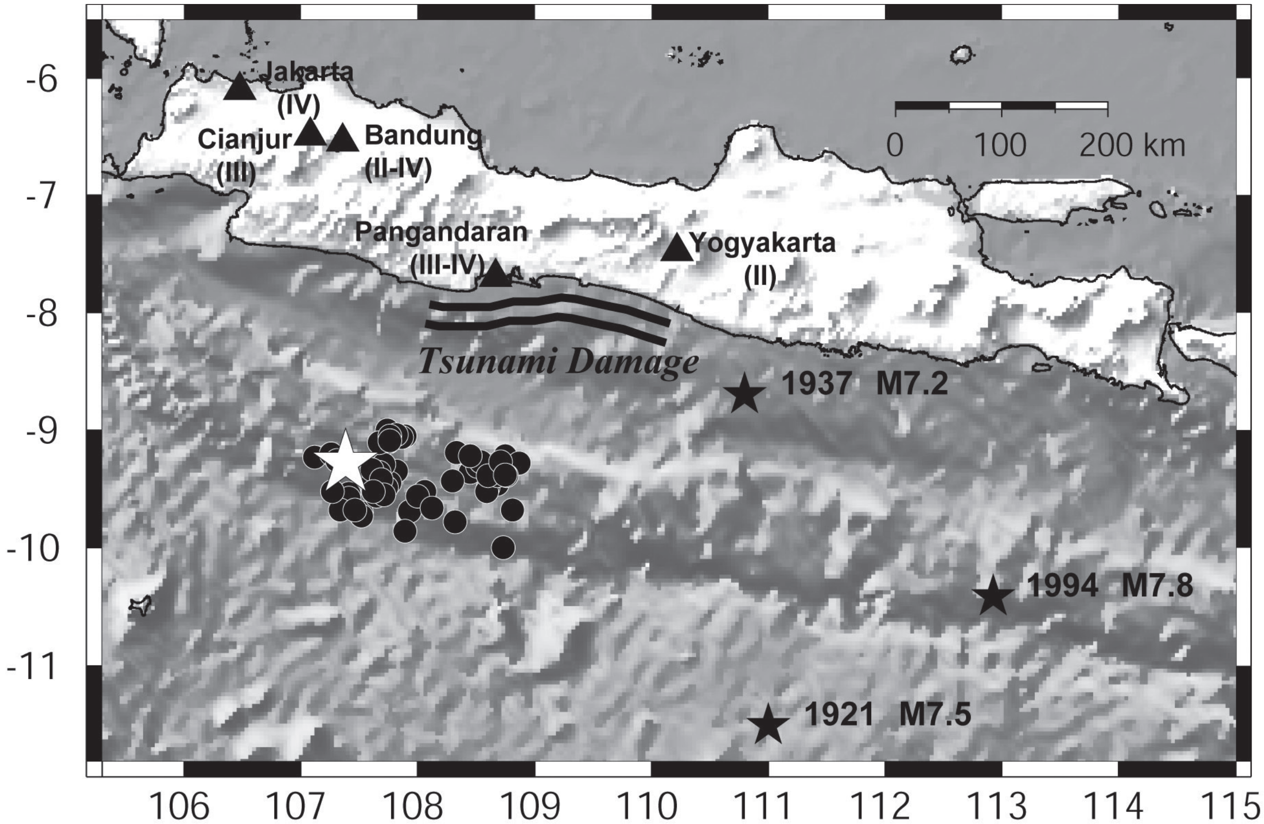
17 JULY 2006 TSUNAMI EARTHQUAKE

The 17 July 2006 earthquake occurred about 220 km off the southern coast of Java with a hypocentral depth of about 10 km (USGS, http://earthquake.usgs.gov). The mainshock and aftershock epicenters shown in figure 1 indicate primary unilateral rupture for about 150 km to the east. In the larger surrounding region there is fairly high subduction zone seismicity with large shallow events in 1921 ($M = 7.5$), 1937 ($M = 7.2$), and 1994 ($M_w = 7.8$), although there are no records of large earthquakes close to the rupture area of the recent event (figure 1).

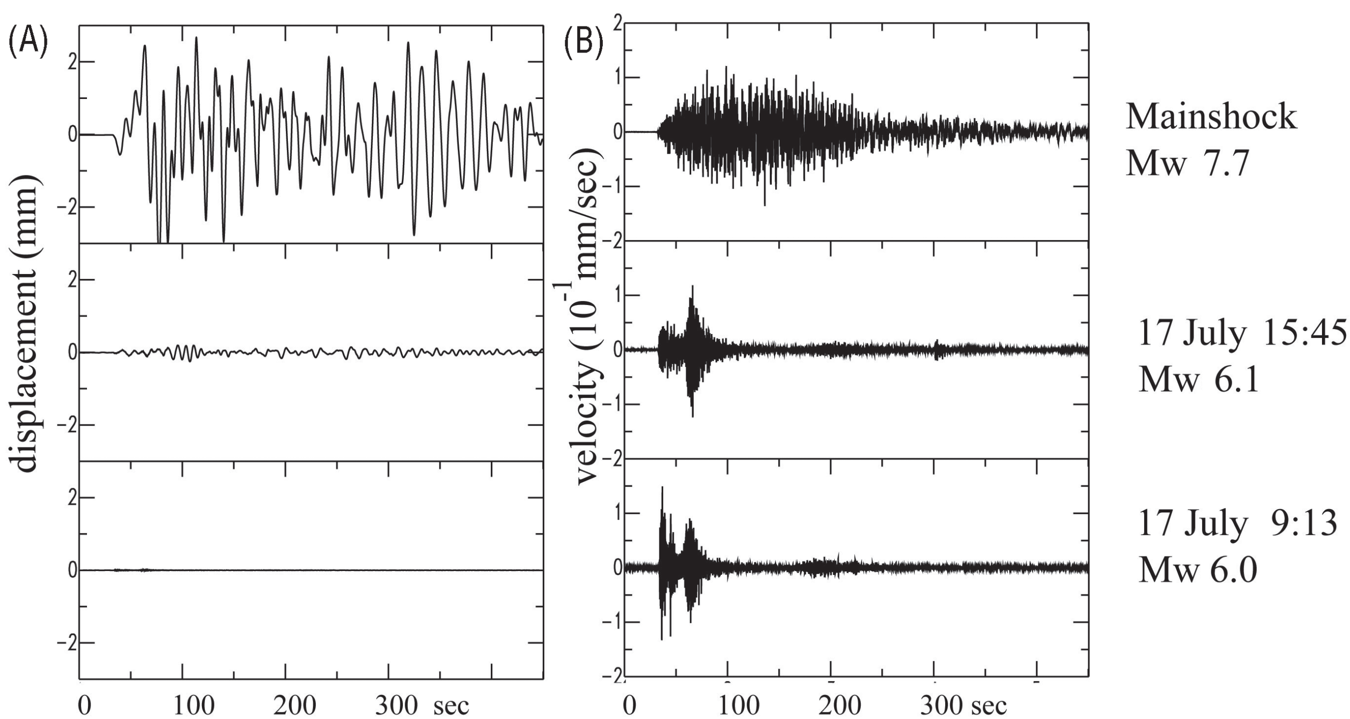
Different types of magnitude determinations for this event reflect different aspects of the size of the earthquake. Locally, the Indonesia Meteorological and Geophysical Agency (BMG) reported a magnitude $m_b = 6.8$ determined from short-period instruments. USGS quickly announced that the magnitudes for this event were $m_b = 6.1$ from 1- to 2-sec teleseismic P waves and $M_w = 7.2$. determined from 5- to 100-sec teleseismic body waves. Later, a moment magnitude of $M_w = 7.7$ was determined by a Harvard University seismological group using 150-sec surface waves. The large increase of the magnitude estimates as a function of period shows that there was a proportionately large amount of long-period energy generated by the mainshock, compared to "ordinary" earthquakes. There were numerous felt aftershocks that appeared to have characteristics of ordinary earthquakes.

This difference in frequency character can be seen in the seismograms of figure 2, which compares the mainshock with two aftershocks recorded at Christmas Island, about 200 km to the southwest. Figure 2(A) contains displacement seismograms showing that the $M = 7.7$ mainshock had much larger

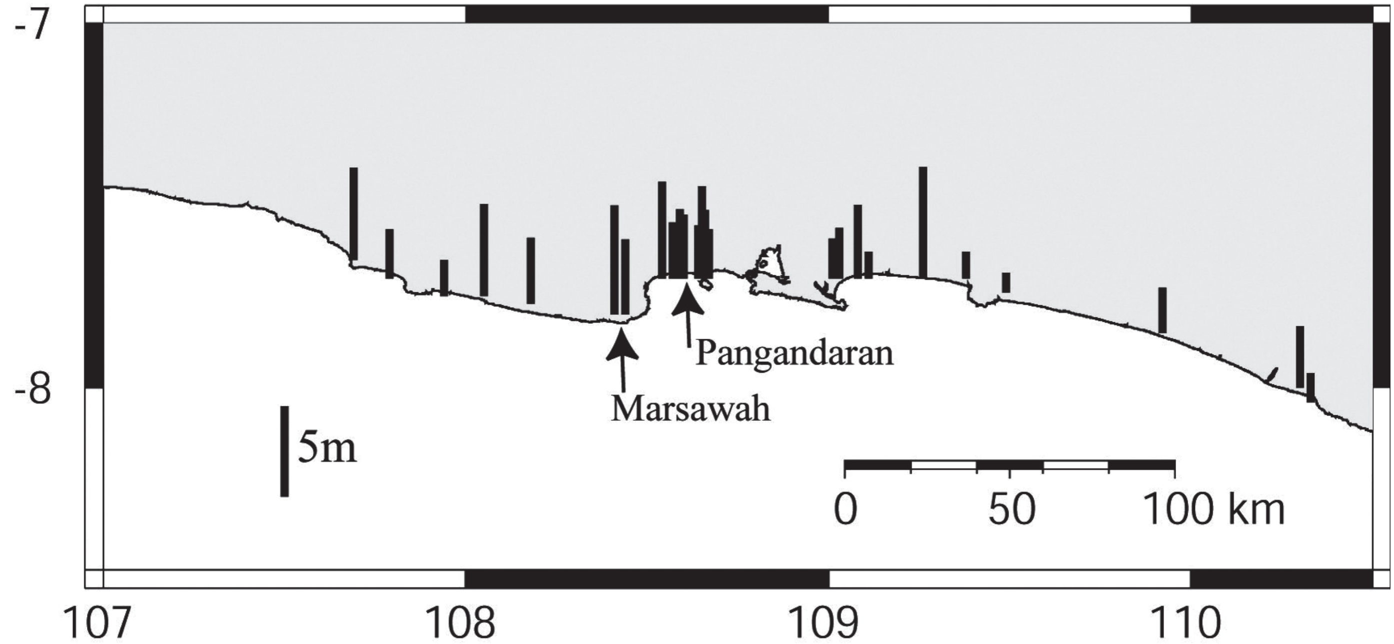
1. Disaster Prevention Research Institute, Kyoto University
2. U.S. Geological Survey, Menlo Park, CA
3. Faculty of Earth Sciences and Mineral Technologies Bandung Institute of Technology
4. Dept. of Geological Sciences, University of Texas, Austin



▲ **Figure 1.** Locations of mainshock (white star) and aftershocks (black circles) from USGS for the 17 July 2006 West Java earthquake. Roman numerals under place names show felt intensities.



▲ **Figure 2.** Waveforms of (A) displacement and (B) velocity high-passed filtered at 1 Hz for the mainshock and two larger aftershocks recorded at Christmas Island, about 200 km to the southwest.



▲ **Figure 3.** Tsunami run-up heights measured by Kongko *et al.* (2006) and the Indonesia Ministry of Marine Affairs and Fisheries *et al.* (2006).

low-frequency amplitudes than the $M = 6$ aftershocks. Figure 2(B) contains velocity seismograms high-pass filtered at 1 Hz to show the high-frequency content. The much smaller (in terms of seismic moment) aftershocks have about the same, or slightly larger, peak amplitudes for the higher frequencies, although the duration is much longer for the mainshock.

The coastal areas of West Java and Central Java are about 220 km from the source area of the earthquake. For a typical $M_w = 7.7$ earthquake, shaking is usually clearly felt at this distance; however, this was not the case for the 17 July 2006 event. The earthquake was only weakly felt in Pangandaran and other coastal areas where there were many tsunami casualties. Some people in the region did not sense the shaking at all, as shown by an informal questioning of 67 people. Of these, 59 people felt the earthquake only weakly (MM III–IV) and eight did not feel the earthquake at all. The 26 May 2006 $M = 6.3$ earthquake in Central Java, about 200 km to the east, was felt more strongly by almost everyone in Pangandaran. Other reports (USGS, http://earthquake.usgs.gov) indicate MM III at Cianjur, MM II–IV at Bandung, and MM II at Yogyakarta (figure 1). Although shaking from the earthquake was not felt very strongly along the southern coast of Java where the tsunami eventually hit, it was felt in the cities farther away, where tall buildings swayed and felt reports indicated MM IV shaking in Jakarta.

The smaller magnitudes estimated from short-period data and felt reports of low levels of shaking indicate that this is a so-called "tsunami earthquake," as discussed by Kanamori (1972), Fukao (1979), and Polet and Kanamori (2000). These shallow subduction zone earthquakes have lower levels of high-frequency radiation compared to similar-size ordinary earthquakes. Past examples of this type of event include the 1896 Sanriku, 1946 Aleutian, 1963 Kuriles, 1975 Nemuro, 1992 Nicaragua, 1994 Java, and 1996 Peru earthquakes (Polet and Kanamori 2000).

A tsunami magnitude Mt (Abe 1981) can be calculated from amplitudes measured on distant tide gauges using the following equation:

$$Mt = \log H + \log D + 5.8,$$

where H is the tsunami height and D is the distance. By using nine recorded tsunami amplitudes from distances of 1,000 to 4,000 km, as reported by the Australian Bureau of Meteorology and the Pacific Tsunami Warning Center, a relatively large value of $Mt = 8.1$ is determined. This is further evidence of the large tsunamigenic strength of this earthquake.

THE TSUNAMI

A large tsunami occurred over more than 250 km of the south Java coast from Garut prefecture in the west to Yogyakarta prefecture in the east. In the heavily damaged area of Pangandaran, the estimated run-up heights from eyewitness accounts is 4 to 6 m. Along the southwest shore of Pangandaran National Park, which is a small spit that extends about a kilometer to the south, the tsunami was relatively small. From observations of markers consisting of lines of sands and leaves, the tsunami did not appear very high—about 1 to 2 m. Measurements of run-up heights (Indonesia Ministry of Marine Affairs and Fisheries *et al.* 2006 and Kongko *et al.* 2006) show variable inundations ranging from 1 to 8 m across the region (figure 3). A tide gauge at Christmas Island, located about 200 km southwest of the epicenter, recorded a tsunami height of 83 cm.

Eyewitness accounts consistently mentioned two large waves with the second wave larger and about 10 to 20 minutes after the first. Also, Fritz *et al.* (2006) reported one area near Nusa Kambangan that had an usually high 21-m runup. A tide gauge at Christmas Island, located about 200 km southwest of the epicenter, recorded a tsunami height of 83 cm.

TSUNAMI DAMAGE

Three days after the earthquake, we were in the region of the tsunami to inspect the damage. We visited several sites along the south coast of Java from Pangandaran west to Marsawah village. The largest loss of life was in the resort area of Pangandaran, where more than 200 people were killed. Numerous wooden-structure cafes and shops within 20 m of the waterfront were all washed away by the tsunami. If the tsunami had occurred one or two days earlier on the weekend, there probably would have been many more deaths on the crowded beaches. There was severe damage to almost all structures within several hundred meters of the waterfront, where the construction was predominantly one- and two-story buildings of unreinforced clay-brick masonry. Some of the larger hotels appeared to have better construction and suffered less structural damage. Damage consisted of collapsed walls, walls with large holes (especially where windows and doorway once existed), and large piles of debris consisting of building material and small boats (figures 4A and B). Damage extended several hundred meters from the shore. At two other villages, Batu Hiu and Batu Karas, located 13 and 18 km west of Pangandaran, respectively, there was similar tsunami damage to buildings.

The most severe damage we saw was in Marsawah village, Bulakbenda, located about 22 km southwest of Pangandaran. Within about 150 m of the coast, all of the buildings were completely washed away; there were no walls standing and only the floors and foundations remained (figure 5). The buildings were one- and two-story residences of clay-brick masonry construction. Further inland, at distances of 300 to 500 m, many of the buildings were also completely destroyed. Eyewitness accounts report that the tsunami had heights of 6 to 8 m. It was reported that waves broke about 200 to 300 m inland from the shore and came down vertically on top of the houses in this region.

In addition to the direct damage caused by the tsunami, there have been about 75,000 residents displaced either because their houses were destroyed or they are afraid of returning to their homes, according to the National Disaster Management Coordinating Board of Indonesia. Aftershocks and smaller earthquakes in the area continue to send residents scrambling for higher ground in fear of another tsunami. Health officials are worried about the spread of disease among the several thousand displaced people and are giving injections to protect people from measles, tetanus, cholera, and other sicknesses. The beach resort of Pangandaran, which was hardest hit by the tsunami, was temporarily closed to the public on 20 July 2006 due to possible looting and the need to clean up debris.

TSUNAMI WARNINGS

Because the tsunami warning system had not yet been completed for this region, saving lives from the large waves has depended on the local knowledge of what to do when a large offshore earthquake occurs. Both the National Oceanic and Atmospheric Administration (NOAA) Pacific Tsunami Warning Center in Hawaii and the Japanese Meteorological Agency issued a tsunami “watch” (not a warning) within 30 minutes. However, the bulletin reported an M = 7.2 earthquake, and there was no effective way for this information to be disseminated to the public. There were many people who felt the earthquake and consequently moved away from the shore, although the low levels of felt shaking meant that most people did not feel a sense of urgency to move to higher ground. Probably a more dramatic sign that caused people to move away from the beach was the observation that the water receded significantly from the shore, exposing an additional 5 to 10 m of beach.

The low level of shaking from this earthquake points out the importance of monitoring the low-frequency energy of earthquakes with the tsunami warning systems that are being developed in Indonesia and other regions of the world. Although this type of tsunami earthquake is not common, its occurrence can cause great loss of life. The initial magnitude estimated for this earthquake based on peak amplitudes of first-arriving high-frequency seismic data would not have been adequate to issue appropriate tsunami warnings.

CURRENT EFFORTS FOR IMPROVING WARNINGS

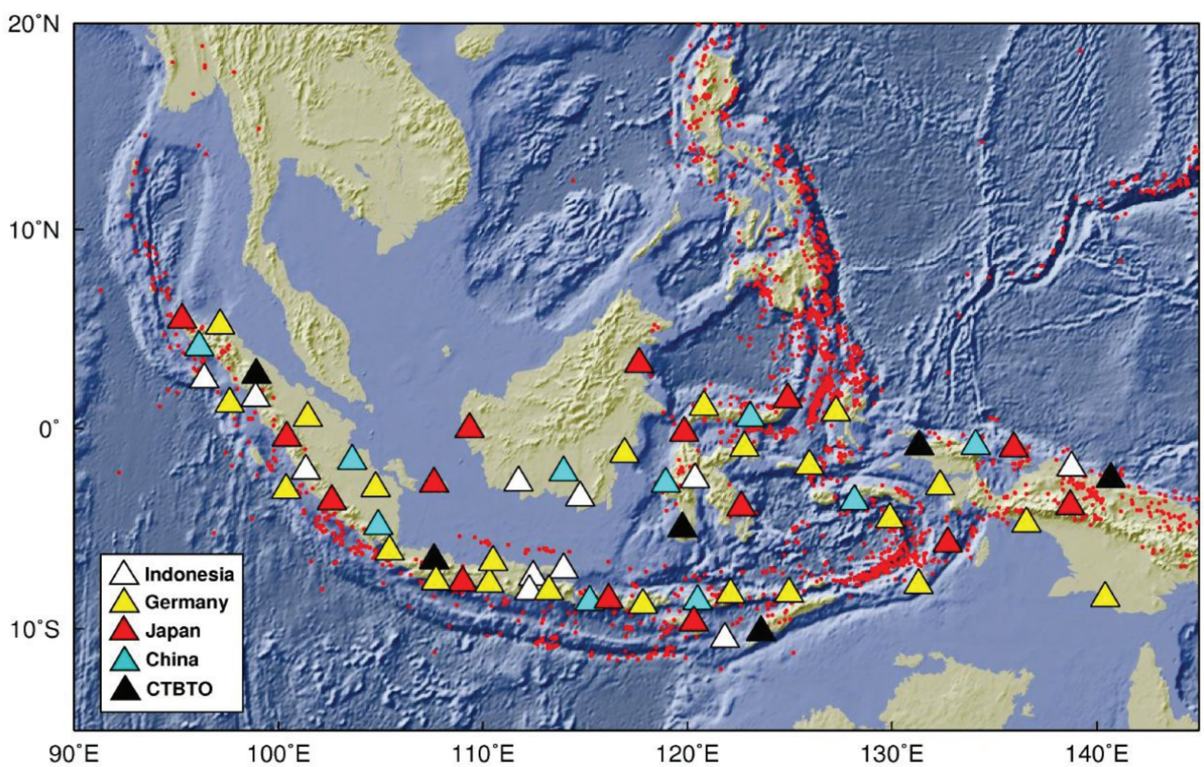
Since the 26 December 2004 tsunami, international partners have been working to strengthen seismic monitoring in Indonesia. While plans are continually evolving, Germany, Japan, and China intend to install 20, 15, and 10 broadband instruments respectively by 2007. BMG hopes to have a total of 106 broadband stations by the end of 2007, with 14 new stations installed by the end of 2006 (figure 6). There are also plans supported by the German government and the U.S. Agency for International Development and NOAA to install deep-ocean buoys off the coast of Indonesia in order to identify tsunamis while they are still at sea. Across the region, the Indian Ocean Tsunami Warning System is providing technical support in areas of hazard detection, warning formulation, and information dissemination. In related efforts, the United Nations Education, Scientific and Cultural Organization (UNESCO) announced in June 2006 that a temporary warning system was operational and that alerts could be relayed to Indian Ocean nations from existing tsunami monitoring centers in Hawaii and Japan. Also, the U.S. Geological Survey (USGS), along with the International Tsunami Information Centre have been providing basic seismological training to BMG employees. Such technical training programs continue to be a high priority.

The level of preparedness varies among other Indian Ocean nations. Thailand, which was also hit by the 26 December 2004 tsunami, has constructed 62 siren towers along the beaches in six provinces, each capable of alerting people as far inland as 2 km.

▲ **Figure 4(A).** Tsunami damage to unreinforced masonry buildings and debris in Pangandaran.

▲ **Figure 4(B).** Damage to buildings near Pangandaran. Note the damaged roof on the building on the left, which indicates the height of the tsunami.

▲ **Figure 5.** Severe damage in Marsawah village, where no walls were left standing within about 150 m of the shore.



▲ **Figure 6.** Planned international real-time broadband network for Indonesia. The nine white triangles represent existing broadband stations operated by Indonesia. The other triangles are stations to be installed between 2005 and 2007.

The alerts are issued by the National Disaster Warning Center, a government branch created after the devastating effects of the 26 December 2004 tsunami. Sri Lanka has coordinated with UNESCO's regional efforts and developed a system for spreading warnings from the capital by using churches and temples to sound the alarm. Malaysia has an ongoing program to improve its seismic monitoring and tsunami alert system.

CONCLUSIONS

The 17 July 2006 earthquake ($M_w = 7.7$) that occurred near the trench of the Sunda arc was a tsunami earthquake with a relatively low level of high-frequency radiation, as reflected in the short-period magnitude estimates and the local felt reports. There was no shaking damage from the earthquake and the event was only slightly felt in coastal areas, but the large tsunami killed more than 600 people and caused extensive property damage. Because there was no tsunami warning system in place for the southern coast of Java, people escaping the tsunami needed to respond to weak earthquake shaking and observations of the initial outward flow of the sea. This experience emphasizes the need for seismic monitoring at low frequencies as well as the implementation of a robust public warning system.

ACKNOWLEGMENTS

We received support from the Kyoto University Centers of Excellence Program (KAGI21). WDM received support from the U.S. Agency for International Development. We thank members of the faculty of the Department of Earth Sciences and Mineral Technologies, Bandung Institute of Technology, for their support.

REFERENCES

Abe, K. (1981). Physical size of tsunamigenic earthquakes of the northwestern Pacific. *Physics of the Earth and Planetary Interiors* **27**, 194–205.

Fritz, H., J. Goff, C. Harbitz, B. McAdoo, A. Moore, H. Latief, N. Kalligeris, W. Kodjo, B. Uslu, V. Titov, C. Synolakis (2006). Survey of the July 17, 2006 Central Javan tsunami reveals 21m runup heights. 2006 American Geophysical Union fall meeting (abstract).

Fukao, Y. (1979). Tsunami earthquakes and subduction processes near deep-sea trenches. *Journal of Geophysical Research* **84**, 2,303–2,314.

Indonesia Ministry of Marine Affairs and Fisheries, Japan Port and Airport Research Institute, Japan Society of Civil Engineers (2006). http://www.pari.go.jp/information/news/h18d/3/abstjoint%20survey.pdf

Kanamori, H. (1972). Mechanism of tsunami earthquakes. *Physics of the Earth and Planetary Interiors* **6**, 346–359.

Kongko, W., Suranto, Chaeroni, Aprijanto, Zikra, Sujantoko (2006). Rapid survey on tsunami Java 17 July 2006.

Polet, J., and H. Kanamori (2000). Shallow subduction zone earthquakes and their tsunamigenic potential. *Geophysical Journal International* **142**, 684–702.

Disaster Prevention Research Institute
Kyoto University
Gokasho, Uji, Kyoto 611-0011 Japan
mori@eqh.dpri.kyoto-u.ac.jp
(J.M.)