

The July 17, 2006 West Java Earthquake and Tsunami

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Synopsis

A tsunami earthquake ($M_w = 7.7$) occurred south of Java on July 17, 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 south coasts of Western 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 the reaction of people to the earthquake shaking, which was only weakly felt in the coastal areas. This experience emphasizes the need for adequate tsunami warning systems for regions around the Indian Ocean.

Keywords: Tsunami, Earthquake, Tsunami earthquake, Java

1. Introduction

Following the disastrous tsunamis of December 26, 2004 and March 28, 2005 in Indonesia, yet another earthquake caused a tsunami with a large number of deaths and large property damage. The July 17, 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 with over 600 deaths and displacing over 75,000 people. 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 runups occurred and this was one likely cause for the high

casualties.

There have been several other notable earthquakes in the Java region with damaging tsunamis over the recent years. The $M_w = 7.8$ earthquake of June 2, 1994 produced a tsunami that had a maximum run-up height of 13 meters and killed over 200 people. That earthquake occurred south of Java about 600 km east-southeast of the July 17 Java earthquake, and was a similar thrust faulting event on the shallow plate boundary. On August 20, 1977, a magnitude 8.3 normal-fault earthquake occurred within the Australia plate about 1,200 km east-southeast of the July 17 Java earthquake, producing a tsunami that had a maximum run-up height of 15 meters and killed almost 200 people. The May 26, 2006 earthquake, which had devastating effects in central Java (over 5700 people killed), was

a moderate ($M_w = 6.3$) event that occurred at shallow depth within the crust of the overriding Sunda plate, but did not cause a tsunami since the faulting was on land.

2. July 17, 2006 Tsunami Earthquake

The July 17 earthquake occurred about 220 km off the southern coast of Java with a hypocentral depth of about 10 km (USGS). 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 rate of 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 Harvard University using 150 sec surface waves. The large increase of the magnitude estimates as a function of period shows that there was proportionately less amounts of short-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. On the left are displacement seismograms showing that the $M=7.7$ mainshock had much larger low-frequency amplitudes than the $M=6$ aftershocks. On the right are 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 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 July 17 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 8 people did not feel the earthquake at all. The May 26, 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) indicate MMIII at Cianjur, MMII-IV at Bandung, and MMII 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 further away, where tall buildings swayed and felt reports indicated MM IV shaking in Jakarta.

The smaller magnitudes estimated from short-period data and low levels of felt reports 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 M_t (Abe, 1981) can be calculated from wave amplitudes measured on distant tide gauges using the following equation:

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

where H is the tsunami height and D is the distance. Using 9 recorded tsunami amplitudes from distances of 1000 to 4000 km, as reported by the Australian Bureau of Meteorology and the Pacific Tsunami Warning Center, a relatively large value of $M_t=8.1$ is determined. This is further evidence of the large tsunamigenic strength of this earthquake.

3. 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 the 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, 2006, and Kongko et al., 2006) show variable inundations ranging from 1 to 8 meters across the region (Figure 3). Also, Fritz et al. (2006) reported one area near Nusa Kambangan that had an unusually 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.

Eyewitness accounts consistently mentioned two large waves with the second wave larger and about 10 to 20 minutes after the first. Many people reported the water receded from the shore about ten meters before the first tsunami waves arrived. An initial 'down' motion for the tsunami is consistent with a shallow offshore thrust mechanism.

4. Tsunami Damage

We were in the region of the tsunami occurrence to inspect the damage three days after the earthquake. We visited several sites along the south coast of Java from Pangandaran and west to Marsawah village. The largest loss of life was in the resort area of Pangandaran, where over 200 people were killed. 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. Within 20 meters of the waterfront were numerous wooden structure cafes and shops that were all washed away by the tsunami. Within several hundred meters there was severe damage to almost all structures, where the construction was predominantly one and two story buildings of unreinforced clay brick masonry construction. 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 existed, and large piles of debris consisting of building material and small boats (Figures 4a and 4b). Damage extended several hundred meters inland from the shore. At 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 meters of the coast, all of the buildings were completely washed away, there were no walls standing and only the floor 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 meters, many of the buildings were also completely destroyed. Eyewitness accounts report that the tsunamis had heights of 6 to 8 m. It was reported that waves broke about 200 to 300m 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 were 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 the fear that another tsunami might strike. Health officials are worried about the spread of disease among the thousands of displaced people, and are giving injections to protect people from measles, tetanus, cholera, and other illnesses. The beach resort of Pangandaran, which was hardest hit by the tsunami, was temporarily closed to the public on July 20 due to possible looting and the need to clean up debris.

5. Tsunami Warnings

Since the tsunami warning system has not yet been completed for this region, saving lives from the large waves depended on the local knowledge of what to do when a large offshore earthquake occurs. Both the NOAA Pacific Tsunami Warning Center

(PTWC) in Hawaii and the Japanese Meteorological Agency (JMA) issued a tsunami 'watch' (not a warning) within 30 minutes. However, the bulletin reported a $M=7.2$ earthquake, and there was no effective way for this information to be disseminated to the public. There were many people that did feel 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 some people to leave the waterfront, was the observation that the water receded significantly from the shore, exposing an additional 5 to 10 m of beach. The tsunami arrived in Pangadaran about an hour after the earthquake occurred, so there was ample for people to leave the beach area had there been a warning system and proper information.

The low level of shaking from this earthquake points out the importance in monitoring the low-frequency energy of earthquakes, for 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, their occurrences can cause large 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.

6. Current Efforts for Improving Warnings

Since the December 2004 tsunami, international partners have been working in Indonesia to strengthen the seismic monitoring. 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 (Fig. 6). There are also plans supported by the German government and the U.S. Agency for International Development (USAID) 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 (IOTWS) 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 (ITIC) 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 2004 tsunami, has constructed 62 siren towers along the beaches in six provinces, each capable of alerting people as far inland as 2 km. The alerts are issued by the National Disaster Warning Center, a newly instated government branch, created after the devastating effects of the 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 their seismic monitoring and tsunami alert system.

7. Conclusions

The July 17, 2006 earthquake ($M_w = 7.7$) that occurred near the trench of the Sunda arc was a tsunami earthquake with 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 over 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-frequency as well as implementation of a robust public warning system.

8. Acknowledgements

We received support from the Kyoto University

Centers of Excellence Program (KAGI21). WDM received support from USAID. We thank members of the Faculty of Earth Sciences and Mineral Technologies Bandung Institute of Technology for their support..

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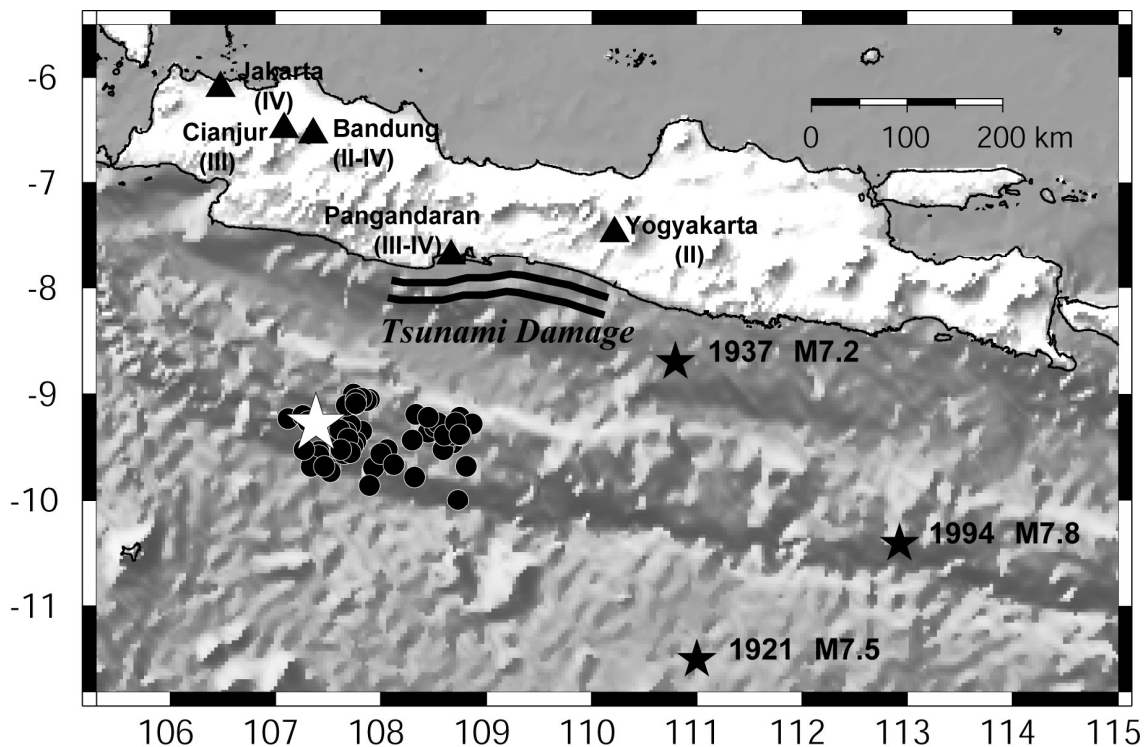


Fig. 1 Locations of mainshock (white star) and aftershocks (black circles) from USGS for the July 17, 2006 West Java earthquake. Roman numerals under place names show felt intensities.

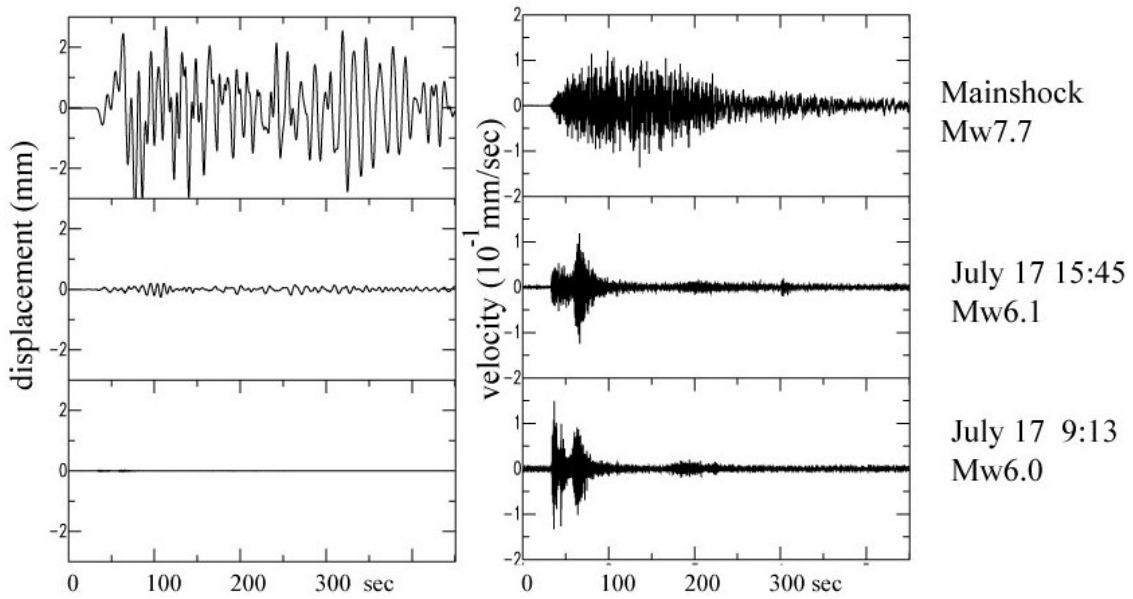


Fig. 2 Waveforms of displacement (left) and velocity high-passed filtered at 1 Hz (right) for the mainshock and two larger aftershocks recorded at Christmas Island, about 200 km to the southwest.

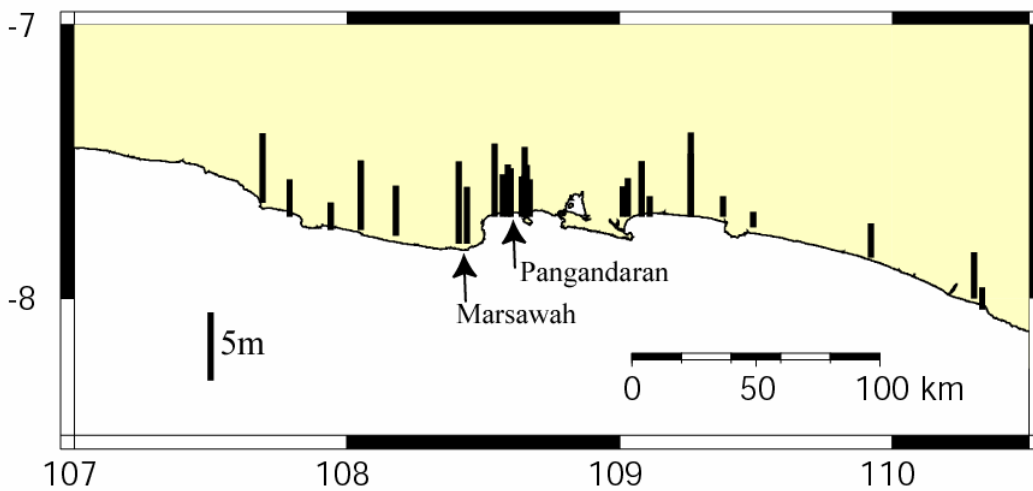


Figure 3. Tsunami run-up heights measured by Kongko et al.(2006) and the Indonesia Ministry of Marine Affairs and Fisheries et al. (2006).



Fig. 4a Tsunami damage to unreinforced masonry buildings and debris in Pangandaran.



Fig. 4b Damage to buildings near Pangandaran. Note the damaged roof for the building on the left, indicating the height of the tsunami.



Fig. 5 Severe damage in Marsawah village where no walls were left standing for buildings within about 150 m of the shore.

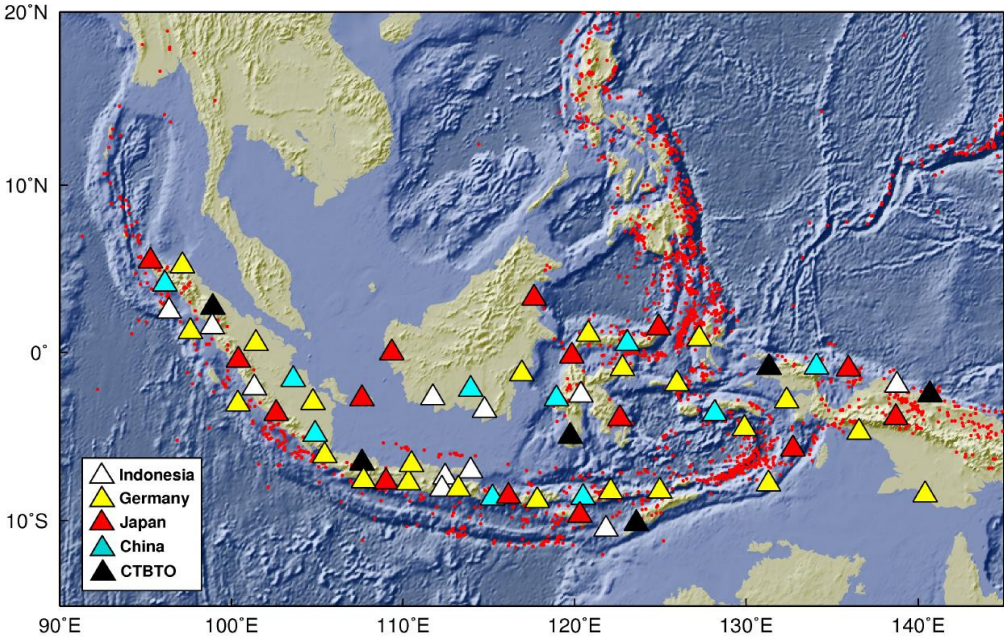


Fig. 6 Planned international real-time broadband network for Indonesia. The nine white triangles represent existing broadband stations operated by Indonesia. The other triangles are stations to be installed between 2005 and 2007.

2006年7月17日西ジャワ地震と津波

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要 旨

2006年7月17日にインドネシアジャワ島南部で発生した津波地震は、パンガンダランでの現地調査の結果、地震の揺れは小さかったが、政府や住民の意識の低さが多大な被害をもたらしたことがわかった。津波警報システムの重要性を考える。

キーワード：津波、地震、津波地震、ジャワ島