The most damaging Indian Ocean tsunami on December 26, 2004

B. ONTOWIRJO, A. MANO

The report summarizes few references dedicated to an initial estimate of the size of the rupture, the amount of energy released, the maximum displacement of the sea bottom and resulting initial water surface profile of tsunami source on December 26, 2004. How the wave train spreads and travels to the land end boundary of the Indian Ocean, and creating huge tsunami bore with so much energy to knock down buildings, trees, human lives, scrapping the land and creating a new landscape. Lesson learnt from remaining buildings, trees, morphologically changed coasts would lead us to the improvement of building code, effective measure of green belt and natural land sea barrier.

Keywords: subduction earthquake; tsunami run up; inundation distance


Schlüsselwörter: Subduktion; Erdbeben; Tsunami; Überflutung

1. Preface
The world condolences to the areas hit by December 26 Indian Ocean tsunami has overwhelmed the effort to understand and mitigate the event summarized in this report. The number of people believed being killed in December's tsunami disaster rose to 288,828. Among those missing and almost certainly dead stands at 114,521. Almost every family in Banda Aceh has lost at least one of their close or distance relatives. It is estimated that the potential hazard of a great earthquake on segments to the south remains. Therefore, it is important to know whether we have sufficient technology to assess the event. How we use the information collected from the field investigation and numerical simulation to recreate the event. How to identify the scales of future hazard and prepare a mitigation disaster hazard and landscape system to minimize the impact, providing evacuation access and shelter to public.

The size of the rupture that caused the earthquake is obtained from the length of the aftershock zone, the dimensions of historical earthquakes, and a study of the elastic waves generated by the earthquake. The aftershocks suggest that the earthquake rupture had a maximum length of 1200–1300 km parallel to the Sunda trench and a width of over 100 km perpendicular to the earthquake source. The amount of energy released by the earthquake was estimated 20 x 10^{17} Joules, or 475,000 kilotons (475 megatons) of TNT, or equivalent of 23,000 World War II atomic bombs.

The maximum displacement of the sea bottom above the earthquake source is somewhat less than the displacement on the earthquake fault at depth. In places, the block of crust beneath the sea floor and overlaying the causative fault is likely to have moved approximately 10 meters to the west-southwest and to have been uplifted by several meters. The most recent bathymetric survey around the earthquake rupture indicated that submarine landslides occurred along the uplifted displacement of the sea bottom.

The initial water-surface profile reflects a large, long uplifted area of the sea floor lying to the west (left) of Aceh Sumatra Island. The initial free surface, including the landslide generated uplifted free surface will then be released and propagated over transoceanic distances. When propagating wave reached the ocean coast, wave heights, run up distances, as well as the wave forces are estimated. The verification of the numerical model requires field data. Field data have been collected from most devastated areas around Banda Aceh, Lhok Nga, Meulaboh, and Simeulue, Nias islands. Field data from Thailand, Sri Lanka, India have also been well collected by other field investigation group, yet not included in this report.

Measured wave height at Lhok Nga Beach reached 25 to 31.9 m above the mean sea level, Banda Aceh 8 to 12.6 m, Calang 20 to 28.5 m, Meulaboh 12 to 17 m, Northern Simeulue Island 7 to 15 m. Converging waves heights are much higher in few places such as Lhok Nga and Calang due to the landscape geometry and bathymetry of the surrounding area.

The beach slope along the Northwest to Southwest coastline at the average about 1:40 with few exception around coastal hills. Run up distance at the average reached 2 km inland.
2. Introduction

The number of people believed killed in December's tsunami disaster rose to 288,828 as of February 18, 2005, more than seven weeks after the catastrophe, the number of people confirmed dead and buried in Indonesia to 120,644. Those missing and almost certainly dead remain unchanged at 114,921. Thailand's death toll stands at 5,395 confirmed dead. A further 3001 people are listed as missing, more than 1,000 of them foreigners. The toll in Sri Lanka, which was second hardest hit by the catastrophe, stood at 30,957. The number of people listed as missing was 5,637, but many were expected to be among those never formally identified, hurriedly buried and included in the confirmed death toll. In neighbouring India, the official death toll was 10,749, with 5,640 still reported missing and feared dead. Thousands of non-national from 25 countries from European, African continent, were also dead and missing. Sadly speaking, almost every family in Banda Aceh has lost at least one of their close or distance relatives.

Pre-recorded earthquake events since 1900 and prior to the December 26 earthquake showed that the largest earthquake along the subduction zone from southern Sumatra to the Andaman islands occurred in the year 2000 and had a magnitude of 7.9. A magnitude 8.4 earthquake occurred in 1797, a magnitude 8.5 in 1861 and a magnitude 8.7 in 1833. All three ruptured sections of the subduction zone to the south of the recent earthquake. Interestingly, the 1797 and 1833 quakes are estimated to have ruptured roughly the same area with only 36 years separating the events. Recorded tsunami wave heights were 1 m in 1797, in 9 m in 1861, 3 m in 1833 and 1 m in 2000 (Dunbar, 2004). Paleoseismic evidence shows that great earthquakes or earthquake couplets occur about every 230 years (Prasetya, 2005).

An initial estimate of the size of the rupture that caused the earthquake is obtained from the length of the aftershock zone, the dimensions of historical earthquakes, and a study of the elastic waves generated by the earthquake. The displacement of the sea bottom is somewhat less than the displacement on the earthquake fault at depth.

The main tsunami was produced by an instantaneous elevation and subsidence pattern on the sea floor caused by slip on the interface between the Indian plate and Burma microplate to the north and east. Tsunamis are unlike wind-generated waves, in that they are characterized as shallow-water waves, with long periods and wave lengths. A tsunami can have a wavelength in excess of 50 km and period approximately 15 to 30 minutes. Because of their long wavelengths, tsunamis behave as shallow-water waves. A wave becomes a shallow-water wave when the ratio between the water depth and its wavelength gets very small. Shallow-water wave move at a speed that is equal to the square root of the product of the acceleration of gravity (9.8 m/s²) and the water depth. Across the Indian Ocean, where the typical water depth is about 4,000 m, a tsunami travels at about 200 m/s, or over 700 km/hr. Because the rate at which a tsunami wave loses its energy is inversely related to its wavelength, tsunamis not only propagate at high speeds, they can also travel great, transoceanic distances with limited energy losses.

As a tsunami leaves the deep water of the open ocean and travels into the shallow water near the coast, it transforms. A tsunami travels at a speed that is related to the water depth, hence, as the water depth decreases, the tsunami slows. The tsunami's energy flux, which is dependent on both its wave speed and wave height, remains nearly constant. Consequently, as the tsunami's speed diminishes as it travels into shallower water, its height grows. Because of this so called shoaling effect, tsunami wave starting from only a few meter wave height in deep Indian Ocean water, may grow up to 10 to 20 m when the propagating wave reaches shorelines. When a tsunami finally reaches the coast, it may appear as a rapidly rising or falling tide, a series of breaking waves, or even a bore. They behave like a very fast moving tide that extends few kilometers inland. The associated extremely strong current generated by run up bore could easily knock down any obstacle and eroding the top soil. Because of complex interactions with the coast, tsunami waves can persist for many hours.

Numerical modeling tools have been developed to estimate wave run up, wave forces and the erosion rate associated with run up induced current. The verification of the numerical model requires field data. Field data have been collected from most devastated areas around Banda Aceh, Lhok Nga, Meulaboh, and Simeuleu, Nias Islands. Additional run up distance data are needed and will be collected during the second phase of field investigation.

3. Methodology

An initial estimate of the size of the rupture that caused the earthquake is obtained from the length of the aftershock zone, the dimensions of historical earthquakes, and a study of the elastic waves generated by the earthquake. The aftershocks suggest that the earthquake rupture had a maximum length of 1,200 to 1,300 km parallel to the Sunda trench and a width of over 100 km perpendicular to the earthquake source. Early estimates from the study of elastic waves show the majority of slip was concentrated in the southernmost 400 km of the rupture.

Analysis of seismograms from the December 26, 2004, Sumatra earthquake that generated the devastating tsunami shows that it was much bigger than previously thought. Measurements of seismic energy at vibration periods are much longer than previously studied. It showed that the earthquake was approximately three times larger than previously reported. Its revised moment magnitude, Mw = 9.3 instead of the previously reported 9.0, makes it the second largest ever recorded since the invention of the seismometer about 100 years ago. The additional energy release occurred by slow slip along the 1,200 km long fault delineated by aftershocks, making the rupture zone much larger than previously thought from analysis of shorter period waves (Ortiz, 2004) (Fig. 1).

The actual rupture duration on the fault (the time it took for the earthquake to take place on the fault and rupture the entire length) was approximately 3 to 4 minutes. The maximum displacement on the rupture surface between earth plates estimated from a preliminary study of the seismic body waves is 20 m. The

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**Fig. 1.** Map of the aftershock zone combined slow slip and fast slip area.