Characterization of Tsunamigenic Earthquake in Java Region Based on Seismic Wave Calculation

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Abstract. This study is to characterize the source mechanism of tsunamigenic earthquake based on seismic wave calculation. The source parameter used are the ratio (Θ) between the radiated seismic energy (E) and seismic moment (M_o), moment magnitude (M_W), rupture duration (To) and focal mechanism. These determine the types of tsunamigenic earthquake and tsunami earthquake. We calculate the formula using the teleseismic wave signal processing with the initial phase of P wave with bandpass filter 0.001 Hz to 5 Hz. The amount of station is 84 broadband seismometer with far distance of 30° to 90°. The 2 June 1994 Banyuwangi earthquake with M_W=7.8 and the 17 July 2006 Pangandaran earthquake with M_W=7.7 include the criteria as a tsunami earthquake which distributed about ratio Θ=-6.1, long rupture duration To>100 s and high tsunami H>7 m. The 2 September 2009 Tasikmalaya earthquake with M_W=7.2, Θ=-5.1 and To=27 s which characterized as a small tsunamigenic earthquake.

Keywords: Characterization, earthquake, tsunami, seismic energy, moment seismic.
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INTRODUCTION

The earthquake around java was influenced by the Sunda subduction system lengthwise from Andaman into Timor region [1]. It also generates tsunami with the moderate magnitude and shallow depth. The aim of study is to characterize the tsunamigenic earthquake in this area which has high tsunami more than 7 m as the 2 June 1994, Banyuwangi, East Java earthquake and the 17 July 2006, Pangandaran, West Java earthquake. We also calculate the 2 September 2009, Tasikmalaya, West Java earthquake based on Indonesian tsunami warning issuance even though no tsunami run-up level [2]. Therefore we can estimate hazard vulnerability caused by earthquake generating tsunami disaster.

THEORY AND PROCEDURE

The basic theory and procedure present the source parameters of earthquake as ratio (θ) between the radiated seismic energy (E) and seismic moment (M_o), moment magnitude (M_W), rupture duration (To) and W phase. Seismic moment describes the magnitude of changes in physical and mechanical rock due to tectonic earthquake source [3]. Moment magnitude is the scale of seismic moment. Those calculated from P phases of body waves recorded from teleseismic station as far as more than 30°. We change velocity seismogram into displacement from 783 vertical component broadband sensors of Incorporated Research Institutions for Seismology (IRIS) stations. We calculate the formula following [4] using the teleseismic wave signal processing with the initial phase of P wave with Butterworth bandpass filter 0.001 Hz to 5 Hz. The equation of seismic moment (M_o') and moment magnitude (M_W) derived from [3,5,6]:

$$Mo = |\ max\ (\int u_z(\ u_z(x_r,\ t)\ dt\ )\ |\ 4\pi\rho\alpha 3r \quad (1)$$

$$Mw = (\ log\ Mo\ -9.1\ )\ /\ 1.5 \quad (2)$$

Where $u_z(x_r, t)$ displacement signal, ρ=3.4 x 10^3 kg.m^{-3} material density, α=7.9 x 10^3 m.s^{-1} P wave velocity, r distance from source to station.

The procedure started from cutting the raw velocity signal of IRIS stations from the onset time of P phase to the end of pP phase. The P phase propagates directly from the source the receiver. The pP phase reflected before its arrival. It is to eliminate the other effects of propagation. We use Tau-P program with IASP91 velocity model [7] and refer to Table Jeffery Bullens [8]. For signal processing program used Seismic Analysis Code (SAC) [9].

The procedure follow [4] as shown in **Figure 1** for the ENH (Enshi, Hibei, China) station as far as 39.35° from the epicenter of 2006 Pangandaran, West Java earthquake with M_W=7.7. We use raw velocity signal from vertical component of broadband. Its instrument response removed by the transfer function. The Butterworth bandpass filter between 0.01 to 5.0 Hz which defined by frequency spectrum and the earthquake size of preliminary magnitude. Cutting the waveform using Tau-P to obtained P- pP wave phases. Then we taper the signal to make it symmetric from

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end to the beginning point. The integral function of the velocity signal (v) change it to displacement which equivalent to moment rate (M_{or}). Then the twice integral and apply the formula [5] make moment rate become seismic moment (M_o) and moment magnitude (M_W).

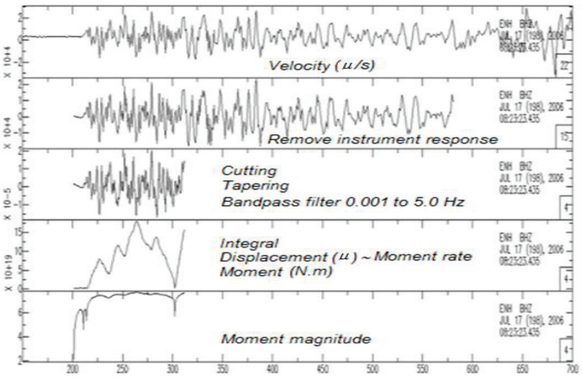

Figure 1. Procedure of seismic moment and magnitude.

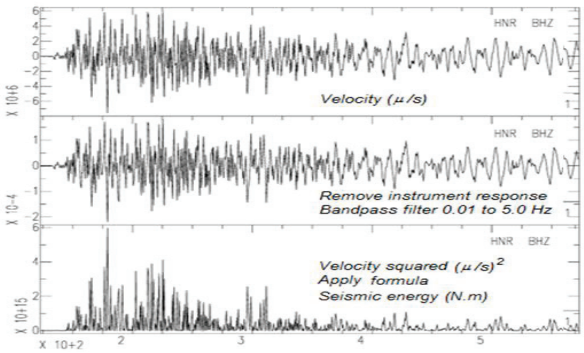

Figure 2. Procedure of seismic energy.

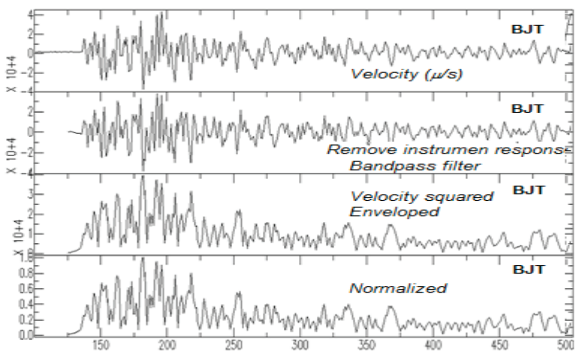

Figure 3. Procedure of rupture duration.

Radiated seismic energy is also the size of earthquake which proportional to the flux energy of seismic waves frequency propagating from source into surface through earth interior. The formula determined from [3]:

$$Es_P = 4\pi \{<F^P>^2 / <F^P>^{2}\} * (R_P^{/} F^{gP})^2 * \varepsilon^{gP} \quad (3)$$

Where Es_P energy of P-S phase, $<F^P>^{2}=4/15$ radiation pattern of P phase, $<Fg^P>=1$ radiation pattern of group of P phase, $(1+q)=16.6$, $\rho=2.6 \times 10^3$ kg.m^{-3} density, $\alpha=5 \times 10^3$ m.s^{-1} velocity of P wave, r distance from source to station. Then substitute the constant parameters, then the equation (3) become more simple [4]:

$$Es = 2.2 \times 10^{15} * r^2 \int v^2 (t)\, dt \quad (4)$$

The procedure as shown in **Figure 2** is same as the seismic moment except no signal conversion. The velocity signal being squared and applied the equation (4). The energy value is averaging of those energy calculation in each stations thus we get seismic energy with Newton meter dimension same as seismic moment.

Therefore we follow [4,10] to make the ratio (Θ) of seismic energy and seismic moment to identify the types of the earthquake generating tsunami.

$$\Theta = \log_{10} (E / M_o) \quad (5)$$

The previous researchers [4,10] calculated all types of earthquake included interplate, intraplate, downdip, deep, tsunami earthquake, strike-slip crustal, reverse-faulting crustal and normal-faulting crustal. The type of tsunami earthquake has the less ratio $\Theta < -5.5$.

Rupture duration (To) is the time for earthquake as long as fault area from the beginning until the end process of breaking. We measure the area of wave velocity as the polynomial distribution following [4].

$$To^3 \propto M_o, \Theta \quad (6)$$

$$To = (1-w)\, T^{90} + w\, T^{20} \quad (7)$$

Where $w = [(T^{80} + T^{50})/2\text{-}20]/40$. The procedure is shown in **Figure 3**. The velocity signal after process of cutting, removing instrument response, filtering, then squaring the velocity signal. We make signal enveloped, normalized and applied with the equation (6) and (7). The all signal stations then stacked to obtain single signal of rupture duration.

To determine the focal mechanism, moment magnitude, hypocenter and half duration used the inversion method of W phase. It supports tsunami early warning confirmation. The P-S phase propagation is straight and flat as the whispering gallery. It detected by the great earthquake and teleseismic within the minimum distance of 10° [12,14]. The frequency is very low between 0.001 Hz until 0.01 Hz. W phase determination is faster than Global Centroid Moment Tensor (Global CMT) of Harvard University and fairly consistent. Hypocenter determination is to know the source position along the subduction zone. Hence we make the depth cross section.

RESULTS AND DISCUSSION

The earthquakes on the Sunda subduction zone in this area have the quite large of tsunami impact. See **Figure 4**. The 2 June 1994 East Java earthquake has hypocenter with shallow depth *D*=15 km and closed to the trench exactly around accretionary wedge. The focal mechanism of W phase show the thrust fault with longitude 113° E, latitude 11.23°S, strike 94°, dip 84°, and slip 91° which similar with Global CMT. It has moderate magnitude M_W=7.8, almost low source parameter of seismic moment M_o=2.69x10^{20} Nm, energy *E*=2.57x10^{14} Nm and ratio Θ=-6.0. Even though the size of earthquake is medium scale but generating tsunami height impact high as *H*=14 m [16]. This event occurred relatively no ground shaking with long rupture duration *To*=100.4 s, thus no warning of impending tsunami hazard [16]. These parameters are accordance with the previous research [4,13]. Hence this event categorized as tsunami earthquake.

The 17 July 2006, Pangandaran, West Java earthquake has shallow depth *D*=20 km which located around trench and accretionary wedge. The W phase focal mechanism is thrust fault with longitude 108° E, latitude 10.68° S, strike 108°, dip 78 and slip 93° similar with Global CMT. The earthquake size almost low as magnitude M_W=7.8, seismic moment M_O=4.36x10^{20} Nm, energy *E*=3.16x10^{14} Nm and ratio Θ=-6.1, but tsunami impact as *H*=8 m [17]. The both of tsunami events located in deep sea of Indian Ocean with a lot of water volume supporting tsunami deformation. The resident felt slight or no shaking [18]. The rupture duration is long *To*=136 s which due to seismic energy emitted from the source that quite low compared to seismic moment. These parameters are similar with the previous research and categorized as tsunami earthquake [17]. The slip distribution near the surface with shallow depth is a characteristic of tsunami earthquake [18].

The hypocenter of 2 September 2009 Tasikmalaya, West Java earthquake is fairly deep *D*=53 km in beneath subduction zone called as intraplate earthquake and characterized as tsunamigenic earthquake. The location is very near to the coastal area which not enough to make tsunami deformation because of narrow area of fore-arc basin with less sea water volume. The earthquake size is almost small with magnitude M_w=7.2, seismic moment M_o=6.02 x 10^{19} Nm, energy *E*=4.46 x 10^{14} Nm, ratio Θ=-5.1 and very short rupture duration *To*=27 s. Tsunami report survey conducted by Indonesian Meteorological Climatological Geophysical Agency (BMKG , personal comm.) said no found the run-up height reached shore. However tsunami warning issued at that time based on earthquake parameter information such as epicenter on ocean, magnitude *M*>7.0, depth *D*<70 km [19]. The focal mechanism of W phase as thrust fault with longitude 108° E, latitude 7.92° S, strike 118°, dip 83°, slip 92° is different with Global CMT as strike slip. It is due to the influence of local disturbances, amount number and distance of the station, filter frequency and parameters constant.

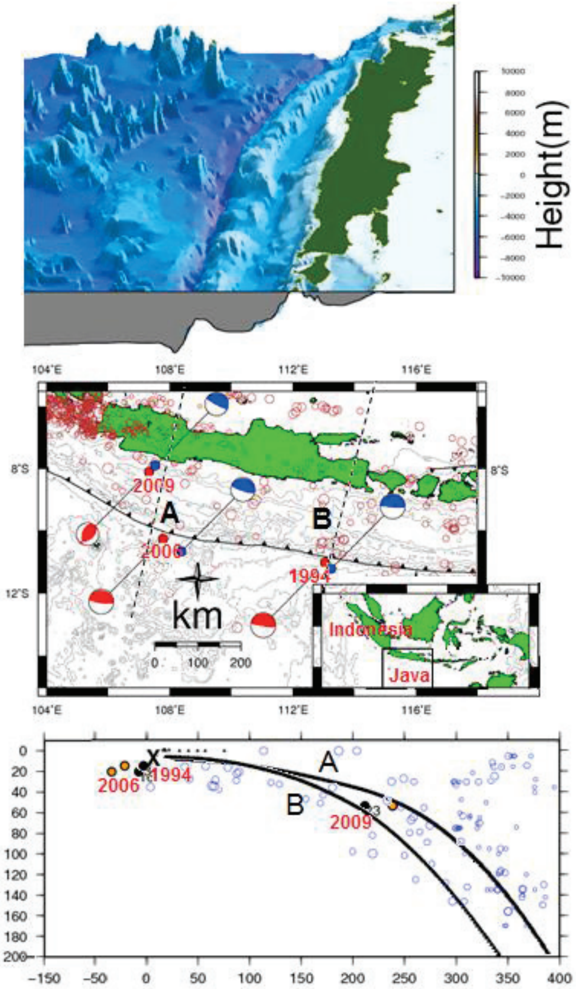

Figure 4. Focal mechanism of Global CMT (red nodal) and W phase (blue nodal). Line A and B are cross sections.

CONCLUSSION

We conclude that the 1994 East Java earthquake and the 2006 West Java earthquake categorized as tsunami earthquakes with characteristics of small size of earthquake, e.g. seismic moment M_o<4.36x10^{20} Nm, energy *E*<3.16x10^{14} Nm, ratio Θ<-6.0 and slow rupture duration *To*>100 s. These events caused tsunami impact as *H*>8 m supported the large area of Indian Ocean as tsunami deformation of sea water volume. It located near the trench or accretionary wedge, hence indicated as interplate earthquakes. The 2009 West Java earthquake has the criteria as a small tsunamigenic earthquake with of seismic moment, energy, ratio, rupture duration which due to small earthquake size as magnitude M_w=7.2. The fairly depth of hypocenter and strike-slip faulting do not support large tsunami arising due to the narrow fore-arc basin and less sea water volume around the area.

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