Identification of Earthquakes That Generate Tsunamis in Java and Nusa Tenggara Using Rupture Duration Analysis

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Abstract. Java and Nusa Tenggara are the tectonically active of Sunda arc. This study discuss the rupture duration as a manifestation of the power of earthquake-generated tsunami. We use the teleseismic (30° - 90°) body waves with high-frequency energy Seismometer is from IRIS network as amount 206 broadband units. We applied the Butterworth high bandpass (1 – 2 Hz) filtered. The arrival and travel times started from wave phase of *P* - *PP* which based on Jeffrey Bullens table with TauP program. The results are that the June 2, 1994 Banyuwangi and the July 17, 2006 Pangandaran earthquakes identified as tsunami earthquakes with long rupture duration (To > 100 second), medium magnitude (7.6 < Mw < 7.9) and located near the trench. The others are 4 tsunamigenic earthquakes and 3 inland earthquakes with short rupture duration start from To > 50 second which depend on its magnitude. Those events are located far from the trench.

Keywords: High-frequency energy, tsunami earthquake, tsunamigenic earthquake, rupture duration.
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INTRODUCTION

Earthquakes-generated tsunami in Java and Nusa Tenggara region affected by the Sunda subduction system extends from the Andaman, Sumatra, Java, Nusa Tenggara and Timor-timur. This subduction formed some mountain folds and faults in the mainland Java and Nusa Tenggara [1]. Earthquakes on the Sunda subduction usually zone gave high tsunami impact. Since 1991-2007. There are 4 events, as the December 12, 1992 (M_w = 7.8) Flores, Nusa Tenggara earthquake, the June 2, 1994 (M_w = 7.8) Banyuwangi, East Java earthquake, the May 14, 1995 (M_w = 6.8) Timor, Nusa Tenggara earthquake, and the July 17, 2006 (M_w = 7.7) Pangandaran, West Java earthquake. This study aims to determine the characterization of earthquakes-generated tsunami in Java and Nusa Tenggara based on rupture duration parameter. Rupture duration can identify the types of tsunami that generated by earthquakes. Thus it is expected to mitigate earthquake and tsunami disaster in these areas in the future.

DATA

We collected by 6 events of earthquakes-generated tsunami from Pribadi, et al. [2]. For comparison, the authors compute the inland earthquakes with high intensity scale damage more than V MMI from The Indonesian Meteorological Climatological and Geophysical Agency (BMKG), www.bmkg.go.id. As shown in Table 1. This research has the incidence of magnitude M_w > 6.5, depth $D \leq 70$ km and located at the range of coordinate longitude 105˚ E - 127 ˚ E and latitude 14˚ S - 1˚ S. Tsunami height data is taken from the tsunami and earthquake catalog of the National Oceanic and Atmospheric Administration (NOAA), http://www.ngdc.noaa.gov. Earthquake parameter data is taken from the Global CMT, http://www.globalcmt.org/CMTsearch.html. The author used the results of the 1965-1995 hypocenter relocation of Engdahl et al. [3] to create a cross-sectional depth. Vertical component broadband sensors are used as much as 206 units of Incorporated Research Institutions for seismology (IRIS).

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TABLE 1. Earthquakes-generated tsunami in Java and Nusa Tenggara

No	Region	Event	Depth (km)	M_w
1	Timor	19910704	28.8	6.7
2	Flores	19921212	27.7	7.8
3	Banyuwangi	19940602	18.4	7.8
4	Timor	19950514	11.2	6.8
5	Pangandaran	20060717	34.0	7.7
6	Tasikmalaya	20090902	62.8	7.0
7	Yogyakarta	20060526	33.0	5.9
8	Bima	20091108	36.0	6.7
9	Ciamis, Java	20100626	34.0	6.3

THEORITICAL MOTIVATION

Rupture duration is the used time for an earthquake to rupture with a certain velocity field measuring fracture in a fault plane. Lomax et al. [4] introduced a parameter analysis of source rupture duration by the rapid phase of *P - PP* waves for the earthquake in whole world since 1992 - 2006 with magnitude M_w > 6.7. Hara [5] developed a similar method for 69 major earthquakes with the shallow depths since1995 - 2006. Zainal [6] practiced some computing applications of rupture duration of Kanjo and Okamoto [7] for a major earthquake around Malaysia since 2005 - 2008. Madlazim [8] used rupture duration analysis method based on Lomax et al. [4].

$$To^3 = \frac{Mo^2 W}{K^2 E}. \quad (1)$$

$$K = \frac{1}{15\pi\rho\alpha^5} + \frac{1}{10\pi\rho\beta^5}. \quad (2)$$

$$W = \frac{1}{x(1-x)^2}. \quad (3)$$

where, T_0 = rupture duration (s), α = *P* waves velocity ($5\text{x}10^3$ m. s^{-1}), β = *S* waves velocity ($\alpha/\sqrt{3}$), x = time function as 0.1 - 0.5, W = contant coefficient of trapezium box car, ρ = material density in source ($2{,}6\text{x}10^3$ kg.m^{-3}), E = seismic energy from wave phase of *P-PP* (N.m), K = constant material density of *P* and *S* waves.

In this study, rupture duration using wave phase of *P - PP* as the representative of power in the source. Signal used is a ground motion velocity seismogram from vertical broadband component. The stations distribution is started from 30 ˚ - 90 ˚. The purpose is to eliminate the effect of triplication, diffraction and mixing a wave phase to the other ones. Beside that is to eliminate the effect of interference by applying the high frequency (1 - 2 Hz) of the Butterworth bandpass filter. The filter is based on the transformation of signal Fast Fourier transform (FFT) into the frequency domain.

The cutting *P-PP* wave phase is determined by an automatic Tau-P applications with IASP91 velocity model and Table of Jeffery Bullens [11, 12]. Enveloping and normalization processes was done to get the maximum positive amplitude value. This study is slightly different from previous study [2] that followed the procedure of Lomax et al. [4]. In this study, authors applied the procedure of Hara [5] where the value of total rupture duration was derived from the median of the entire stations. Station that has a high noise and most different from the average value were excluded from the calculation. The example of rupture duration processing can be seen at station ENH (Enshi, Hubei, China) in Figure 1.

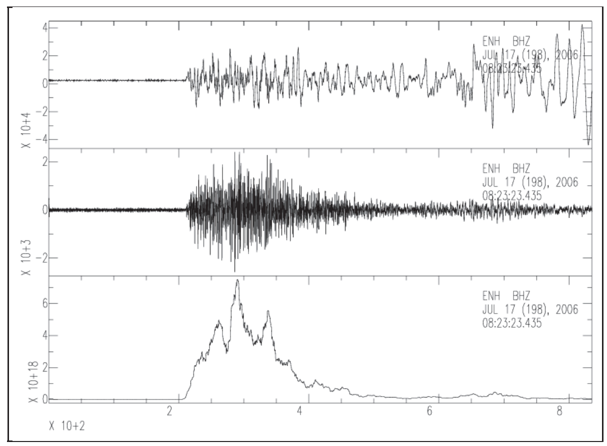

FIGURE 1. Procedure of rupture duration of ENH (Enshi, Hubei, China) station for the July 17, 2006, Pangandaran earthquake. From top to bottom: velocity signal, after applying the response removal tools and high frequency filter, enveloping and normalization.

RESULTS AND DISCUSSION

In this study, an earthquake generally has a duration of rupture (To > 50 s). This is due to the shallow depth of the earthquake. Bilek and Lay [13] explained that a depth of shallow earthquakes near the trench subduction, has a weak geological material because it is composed of young sedimentary rocks. This situation led to the attenuation of seismic energy due to the rocks friction. Therefore the energy release process takes much longer. This character is for the type of slow earthquake which has unfelt shaking by people around the coastal area. Tsunami earthquake have a characteristics of body wave magnitude (m_b) which is lower than the moment magnitude, shallow depth and close to the subduction trench. It became a problem because that the natural tsunami warning can not be applied in the field. Tsunami waves come suddenly without any prior warning earthquake of ground shaking.

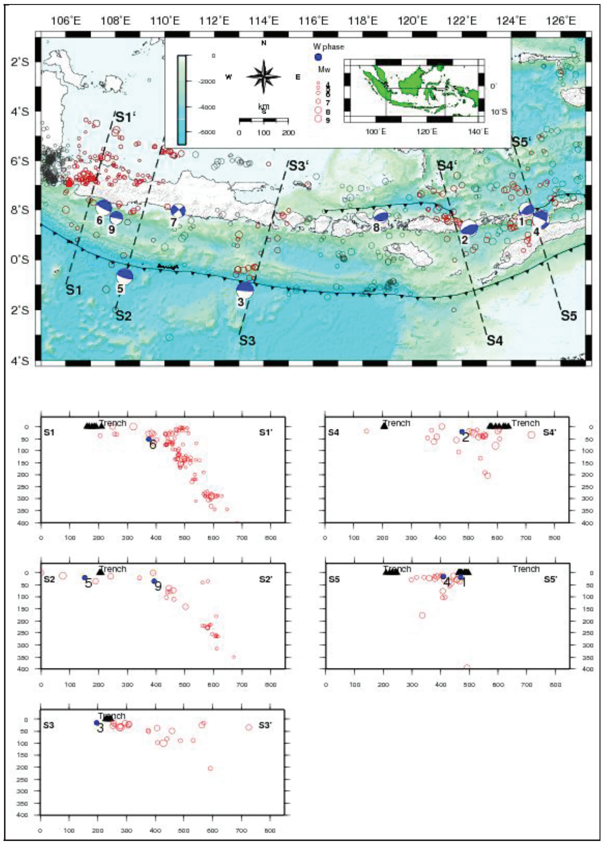

FIGURE 2. Cross sectional depth of Java and Nusa Tenggara. (Top) Seismicity distribution (black), seismicity projection (round red), with a focus on W-phase mechanism [2] and Global CMT (nodal blue). (Bottom) Cross-section with a depth of seismic line projected SS 1-5. Event number see Table 1.

The earthquakes-generated high tsunami which more concerned in this study are event number 2,3,4,5 as the December 12, 1992 Flores earthquake (*Th* = 26.2 m), the June 2, 1994 Banyuwangi earthquake(*Th* = 14 m), the May 14, 1995 Timor earthquake (*Th* = 4 m), and the July 17, 2006 Pangandaran earthquake (*Th* = 7.7 m).

The June 2, 1994 Banyuwangi earthquake (M_w = 7.8) and the July 17, 2006 (M_w = 7.7) Pangandaran earthquake are classified as tsunami earthquake with a maximum duration of rupture using median calculation as 102 s and 155 s. Ammon et al. [14] issued that the July 17, 2006, Pangandaran earthquake has slow rupture speed of 1.5 km.s^{-1}. This result fits with Lomax and Michelini [15]. More details, see Table 2.

Table 2. Comparison of This Study (*To*) with Previous Researchers.

No	Ch	Sta	SP1	SP2	Ma	Lo1	Lo2	Am
1	--	5	62	57	19	-	-	-
2	Ts	3	98	97	78	100	91	-
3	Ts	5	102	102	130	108	97	-
4	Ts	3	62	60	53	-	-	-
5	Ts	49	154	155	170	178	157	185
6	--	35	63	50	13	-	-	-
7	Eq	22	85	82	-	-	-	-
8	Eq	38	75	76	-	-	-	-
9	Eq	46	57	51	-	-	-	-

Remarks: Ts – earthquake generated tsunami, Eq – inland earthquake, -- no tsunami, SP1 & SP2 = mean & median of Pribadi et al. (2013b), Ma = Madlazim (2011), Lo1 = Lomax and Michelini (2008), Lo2 = Lomax et al. (2007) Am = Ammon et al. (2006).

The events which no tsunami but registered in NOAA tsunami catalog are event number 1 and 6 as the July 4, 1991 Timor earthquake and the September 2, 2009 Tasikmalaya earthquake. The absence of tsunami is because the magnitude is low (M_w = 6.7) and deep hypocenter (*D* = 62.8 km). The September 2, 2009 Tasikmalaya earthquake had no tsunami because far position of the epicenter into the subduction zone. The rupture duration of both events are fairly short as 57 s and 50 s.

Similarly earthquake rupture duration on land can produce fairly short duration (To ≤ 82 s). Those are event number 7, 8, 9 as the may 26, 2006 Yogyakarta earthquake, the November 8, 2009 Bima earthquake and the June 26, 2010 Ciamis earthquake.

To clarify the characterization of earthquake generating tsunami, then we made a cross-sectional depth. The results are as shown in Figure 2 that the June 2, 1994 Bayuwangi earthquake and the July 17, 2006 Pangandaran earthquake, are located at the beginning of the trench subduction area which have shallow depth and distance from the coast. Other whise the earthquake did not cause a tsunami, located far from the subduction zone and very near into the beach, so that the volume of sea water is less to produce tsunami waves.

The December 12, 1992 Flores earthquake and the May 14, 1995 Timor earthquake generated the tsunami wave that have height *Th* = 4 m. It is due to the location of the hypocenter between Nusa Tenggara subduction zone and coastal area [16, 17]. The December 12, 1992 Flores earthquake is not classified as a type of tsunami earthquake which has less ratio of energy and seismic moment Θ > -5.7 and fairly short rupture duration *To* < 86 s [2]. This earthquake caused landslide tsunami and killed 2,080 people.

SUMMARY

In general, the results of rupture duration signal analysis method using the median calculation the whole station is quite consistent with the previous researchers. Results of this study can be used as material characterization earthquake and tsunami generating earthquakes in Java and Nusa Tenggara. We classify the types of earthquakes in this area, as: tsunami earthquake, landslide earthquake-generated tsunami, and earthquakes-not generated tsunami. The earthquake-generated tsunami and landslide tsunami have long rupture duration due to the shallow depth of the earthquake and weak geological settings. Earthquakes do not cause tsunamis is located far from the subduction and near the beach.

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