Potential impact and return period analysis study of Sumatra paleo megathrust earthquake using scaling law relations of earthquake parameter (case study: Siberut-West Sumatra megathrust earthquake 1797, Mw 8.2 ~ 8.8)

Jaya Murjaya1*, Suaidi Ahadi1,2, Katsumi Hattori3, Aditya Setyo Rahman1, Petrus Demon Sili1, Dwikorita Karnawati1,4, Dedi Sugianto1, Sutiyono1, and Sulastri1

1Agency for Meteorology, Climatology and Geophysics, Jakarta, 10610, Indonesia
2Geophysical Station Padang Panjang, Indonesia
3Department of Earth Sciences, Chiba University, Japan
4Geological Engineering Department, Faculty of Engineering, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia

Abstract. The paleo-megathrust earthquake occurred in Siberut, West Sumatra in 1797 and it was estimated to have a magnitude (Mw) of about 8.2–8.8. This earthquake triggered a tsunami in the West Sumatra coast and its vicinity. The seismograph was not installed yet at that time, therefore it didn’t has earthquake parameter for advanced analysis. This study hoped to be able to see the earthquake potential impact if the earthquake occurred in this present era. Hereinafter using the scaling law relations of earthquake kinematic model in processing. The result is maximum intensity in Siberut and Tanahbala islands about VII-IX MMI, Painan, Padang, and Pariaman cities about V-VII MMI, and the northern part of West Sumatra region about VI-VII MMI. The PGA in Siberut and Tanahbala is about 60 % g, and Painan, Padang, and Pariaman are about 20 % g or more. Then the value of PGV in Siberut and Tanahbala is about 60 cm/s, in Painan about 10-20 cm/s, and in Padang and Pariaman city about 20-30 cm/s. Furthermore, an estimation of the return period of the earthquake if the source mechanism was modelled as a thrust and strike-slip faults for Mw 8.2-8.8 about 185 until 235 years and 336 until 616 years respectively.

1 Introduction

The paleo-earthquakes in 1797 were occurred in Siberut area western part of Sumatra Island. This earthquake was reported as a destructive earthquake and also triggered tsunami which stuck the coastal area and its vicinity. The seismograph instrument for recording the earthquake signal didn’t yet exist at that era therefore the earthquake parameters couldn’t be known exactly. In the earthquake catalogue, that earthquake was not discovered data on the epicentre location, focal depth, magnitude, and only a little information on a macro-seismic data including the tsunami impact was reported. The location of the earthquake source had been estimated around Siberut Island and its vicinity as shown in Figure 1. One of the neighboring with the Siberut paleo-megathrust earthquake in 1797 was the Bengkulu earthquake of 1833 with a magnitude estimated to reach M~ 9.0, the Mentawai earthquake 1861 M ~ 8.5, the Bengkulu earthquake of 2007 Mw 8.4, Padang earthquake 2009 Mw 7.8, and Pagai earthquake 2010 Mw 7.8. The magnitude estimation of the Siberut paleo-megathrust earthquake 1797 such as Subarya. C. et al (~ Mw 8.2) [1], Suleyman, et al (Mw ~8.7) [2], Dietrich, et al (M 8.7- 8.9) [3], Konca, A.O et al (~Mw 8.8) [4].

* Corresponding author: murjaya1@gmail.com

Fig. 1. Seismicity of large earthquakes during 1900-2019, and dotted line rectangular as an area estimation of the major
earthquakes (before 1900) along the Sumatra trench and its vicinity. The red circle showed of Mw ≥ 9.0, brown circle showed of 8.0 ≤ Mw < 9.0 and the yellow circle showed of 7.5 ≤ Mw < 8.0, with a base map from USGS and it has been modified.

In this paper, we used the magnitude range between Mw 8.2 – 8.8 as background study. Some scientists gave specific attention to the estimate of the return period of the Siberut earthquake (1797). Perhaps the earthquake 1797 was the major earthquake (M > 8) before the Bengkulu earthquakes (1833, 2007) and Aceh earthquake (2004), and the earthquake estimate was located at one of the seismic gaps in Sumatra Island. Then there did not occur yet the large earthquakes in this zone after the earthquake of 1797. We tried to estimate the return period (Tr) of the Siberut earthquake of 1797 using scaling law relations of earthquake parameters to determine its static stress drop and return period (Tr). This study is hoped to become one of the consideration factor to support risk mitigation planning of the earthquake hazards and long-term a landscape program in the future. The return period of the tectonic earthquake will be longer if it has a larger static stress drop and paradoxically the return period of an earthquake is shorter if it has a smaller static stress drop [5].

2 The tectonic setting and seismicity review

The tectonic setting of the Sumatra region including in western part of the Indonesian tectonic is characterized as a complex tectonics region. In the western part of the Sumatra Island is a convergence between Eurasian and Australian plates, characterized by oblique subduction. In the land of Sumatra Island there is a right lateral large Sumatran fault (LSF) along almost 1600 km from the north to the south (southeast). Mentawai islands (Figure 1) is one of the effects of oblique convergence plates between Eurasian and Australian plates [6-7], and the other effect is the large Sumatran fault. The slip rate value of convergence is estimated between 5-7 cm/year [8], and the slip rate of LSF varies. Newcomb et al [9] stated that large earthquakes have been occurred in Sumatra and its vicinity such as earthquakes in 1797, 1833, 1861, 2000, 2004, 2005, and 2007 and 2009. Based on the focal mechanism distribution of earthquakes there are has a dip about of 10° - 30° with a dominant dip about of 20° [10]. Handayani [11] refer to Suparka (1992) divided 3 earthquake distribution zones in the Sumatra region and its vicinity there are earthquake zone along the trench region (subduction zone), Mentawai fault, and LSF.

3 Data and methodology

The parameters data of the Siberut paleoearthquake event 1797 is not recorded exactly on all earthquake catalog sources, except the magnitude estimation that has been published in several papers. The magnitude of the Siberut paleoearthquake 1797 is estimated between 8.2-8.8 as like explained above[1-4]. Then we used the slip rate data of tectonic movement around the Sumatra trench [8, 12, 13].

For calculating of length and width of the fault we are using a scaling law relation for earthquake [14]. Then to estimate of an earthquake return period was approximated from seismic moment and moment rate function or relation of observe stress drop and stress accumulation rate. In this paper, the source mechanism is considered as thrust and strike-slip faults. Figure 2 shows of an illustration the earthquake return period model [15].

![Concept of the initial stress (σ1), critical stress (σ0), stress drops, and earthquake return period (Tr) relations (modified from Haskel [8]).](https://doi.org/10.1051/e3sconf/202346407003)

Fig. 2. Concept of the initial stress (σ1), critical stress (σ0), stress drops, and earthquake return period (Tr) relations (modified from Haskel [8]).

4 Result and discussion

4.1 Potential of earthquake shaking impact

The Siberut earthquake of 1797 has just limited macroseismic data and based on some publications which have been published, the earthquake magnitude is about 8.2 – 8.8. Generally, the effect of the earthquake is a shaking impact on the ground such as intensity/shakemap, peak ground acceleration (PGA), peak ground velocity (PGV), and peak ground displacement (PGD). This paper is just discusses a model of shakemap, PGA and PGV caused by a megathrust earthquake near Siberut island. Then the epicenter model is assumed as a point source located in the area of the earthquake 1797 near Siberut island. By using a magnitude (Mw) of 8.8 and focal depth (h) of 12 km, the result shown at Figure 3 (a), (b), and (c) respectively.

The ground shaking impact such as shakemap, PGA, and PGV is revealed in the MMI scale, percentage of g (% g) and cm/s respectively. Based on Figure 3a, the maximum intensity in Siberut and Tanahbala islands about VII-IX MMI, Painan, Padang, and Pariaman cities about V-VII MMI, and the northern part of West Sumatra region about VI-VII MMI. Figure 3b shows that PGA in Siberut and Tanahbala is about of 60 %g, and Painan, Padang, and Pariaman about 20 %g or more. Whereas in Figure 3c shows that PGV in Siberut and Tanahbala is about of 60 cm/s, Painan is about 10-20 cm/s, and Padang and Pariaman city and its vicinity about 20-30 cm/s.
Fig. 3a. Shakemap of the earthquake (M 8.8) effect model in Siberut island. The maximum intensity about of VII-IX MMI in Siberut and Tanahbala islands. In Padang, Painan and Pariaman cities about of V-VII MMI, and the northern part of West Sumatra region about of VI-VII MMI.

Fig. 3b. PGA map of the earthquake (M 8.8) effect model in Siberut island. The largest PGA is about of 60 % g in Siberut and Tanahbala islands. In Padang, Painan and Pariaman about 20 % g or more.

Fig. 3c. PGV map of the earthquake (M 8.8) effect model in Siberut island. The largest PGV is about 60 cm/s in Siberut and Tanahbala islands. in Painan about 10-20 cm/s and in Padang and Pariaman city about 20-30 cm/s.

4.2 Potential of tsunami triggering

Based on historical data of earthquakes and tsunamis in the Sumatra region almost of all shallow earthquakes event with a thrust fault and magnitude ≥ 8 triggered tsunamis including a strike-slip fault outer rise earthquake (M ~ 8.6) in Indian Ocean Ridge on April 11, 2012. Effect of this earthquake, the tsunami high recorded about 20-30 cm in Sabang, Banda Aceh. Based on the tsunami catalogue we found at least 3 tsunamis events triggered by thrust earthquake (M ≥ 8) in Sumatra along 2000-2007. There are the huge Aceh Tsunami(2004), Nias Tsunami (2005), and Bengkulu Tsunami (2007). Then Pagai tsunami was triggered by a “slow earthquake (trusting) M~7.8 on October 25, 2010. To refer to that historical tsunami event, the megathrust earthquake with scenario M 8.8 in Siberut island has very potential to trigger tsunami including the possibility tsunami by a submarine landslide. This case was discussed at the Mentawai Megathrust Direx event in Padang on February 17, 2014.

Figure 4 shows the simulation result of tsunami travel time caused by the Siberut Megathrust earthquake using scenario M 8.8. The Tsunami will arrive in Siberut Island about of less than 15 minutes and in Padang around 20-25 minutes.
Fig. 4. Travel time model of tsunami caused by Siberut Megathrust earthquake M 8.8. Tsunami will arrive in Padang around 20-25 minutes.

4.3 Estimation model of return period

We explained above that the Siberut earthquake of 1797 has a magnitude about of Mw 8.2 – 8.8 from the journal publication. Using scaling law relations of the earthquake, we calculated Mo, L, and A and estimated the static stress drop (Δσobs) (Table 1). The Δσ estimation was verified with plotting at Log Mo-Log S diagram by Kanamori and Anderson in Figure 5 [16] and they are still consistent for interplate earthquake.

Table 1. Show the relation between Mw, Mo, L, A, and Δσ based on scaling law relation of the earthquake.

<table>
<thead>
<tr>
<th>Mw (Scenario) (dyne-cm)</th>
<th>Mo</th>
<th>Type of Fault</th>
<th>L (km)</th>
<th>A (km²)</th>
<th>W app (km)</th>
<th>Δσ (10⁶ bars)</th>
<th>(Tr) (a years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.2</td>
<td>TF</td>
<td>202</td>
<td>11,117</td>
<td>55</td>
<td>3.48</td>
<td>185</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SF</td>
<td>330</td>
<td>9,120</td>
<td>28</td>
<td>6.34</td>
<td>336</td>
<td></td>
</tr>
<tr>
<td>8.4</td>
<td>TF</td>
<td>270</td>
<td>17,485</td>
<td>65</td>
<td>3.77</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SF</td>
<td>463</td>
<td>13,803</td>
<td>30</td>
<td>7.65</td>
<td>405</td>
<td></td>
</tr>
<tr>
<td>8.6</td>
<td>TF</td>
<td>361</td>
<td>27,415</td>
<td>76</td>
<td>4.07</td>
<td>215</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SF</td>
<td>651</td>
<td>20,92</td>
<td>32</td>
<td>9.54</td>
<td>505</td>
<td></td>
</tr>
<tr>
<td>8.8</td>
<td>TF</td>
<td>483</td>
<td>43,053</td>
<td>89</td>
<td>4.43</td>
<td>235</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SF</td>
<td>916</td>
<td>31,622</td>
<td>351</td>
<td>1.64</td>
<td>616</td>
<td></td>
</tr>
</tbody>
</table>

Mw = magnitude moment Mo = seismic moment Type of Fault = F M = Mechanism Focal L = length of fault W = width of fault Δσ = static stress drop (dyne/cm²) W app = rupture area

Fig. 5. Relation between Log S (Area) and Log Mo diagram [16] for evaluating Siberut paleoearthquake simulation with magnitude scenarios 8.2-8.8. The yellow and red colors for each circle, triangle, rectangular, and star, indicated Δσ estimation of strike slip and thrust fault model for all magnitudes between 8.2-8.8 respectively. The all Δσ estimation for Mw scenario 8.2-8.8 of Siberut paleoearthquake 1797 is a good fit in the graph.

Table 1 shows the relation between Mw, Mo, L, A, and Δσ based on scaling law relations of earthquake. Wojciech Debski [17] explains that to describe the stress release effects, seismology uses three basic parameters namely the static stress drop, the Coulomb stress transfer, and the dynamic stress drop. Furthermore, the Δσ result compared with some earthquakes has shown at figure 5. All result of the static stress drop value has a range around of 10 – 100 bars and it is consistently located in the fixed line except for magnitude scenario 8.8 (thrust fracture) is about 10 bars. Kanamori and Anderson demonstrated that the average stress drop is higher for intraplate than interplate earthquakes, and since intraplate events have generally longer repeat times than interplate events. Based on result in the Figure 5, the Δσ of the Siberut paleoearthquake has a trend located in a group of interplate earthquakes.

Then Figure 6 (a) and (b) is a result of Tr estimation using the scaling law for magnitude Mw 8.2-8.8 thrust and strike-slip fault scenarios.

In this paper, we try to calculate the return period estimation for the Siberut paleomegathrust earthquake 1797 which used scenarios of the magnitude moment between Mw 8.2 – 8.8. The source mechanism was assumed as thrust fault and strike-slip fault models. We consider that the strain energy is accumulated during the interseismic period (Figure 2) for hundreds of years without breaking of crust in this area and it will be released during a coseismic event after the critical stage of rock is passed over which is called a stress drop static.
The return period (Tr) of earthquake for magnitude scenarios about 8.2, 8.4, 8.6, and 8.8 is about of 185, 200, 215, and 235 years for the thrust model and 336, 405, 505, and 616 years for strike-slip model respectively. Natawidjaja [18] revealed that based on the paleo geodetic history from the Bulasat site, North Pagai island in the Mentawai region shows the megathrust cycles for the past 700 years and recurrence interval is just over 200 years. The other method to estimate the return period of the earthquake is by dividing the moment of an earthquake by the source time function or moment rate accumulation [19].

5 Conclusion

Regarding the result of this study of the Siberut paleoearthquake 1797 with consider that an earthquake has a magnitude between 8.2-8.8, and we calculated just a magnitude of 8.8 to predict the potential impact of the earthquake. Based on Figure 3a, the maximum intensity in Siberut and Tanahbala islands about VII-IX MMI, Painan, Padang, and Pariaman cities about of V-VII MMI, and the northern part of West Sumatra region about VI-VII MMI. Figure 3b shows that PGA in Siberut and Tanahbala is about of 60 % g, and Painan, Padang, and Pariaman are about of 20 % g or more. Whereas in Figure 3c shows that PGV in Siberut and Tanahbala is about of 60 cm/s, Painan about 10-20 cm/s, and Padang and Pariaman city and its vicinity about 20-30 cm/s. Furthermore, for the return period estimation with source mechanism scenarios like thrust and strike-slip fault. By using the slip rate 6-7 cm/y and scaling law relations of the earthquake, it was found the return period estimation about of 185, 200, 215, and 235 years for the thrust fault model and 336, 405, 505, and 616 years for strike-slip fault model respectively. Then for the simulation of tsunami travel time which caused the Siberut Megathrust earthquake using scenario M 8.8, it will arrive in Siberut island in less than 15 minutes and to Padang around 20-25 minutes. This result is hoped to become one of the consideration factors to support a risk mitigation planning of the earthquake hazards and long-term a landscape program in the future.

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References