

Seismic Hazard characterization study using an earthquake source with *Probabilistic Seismic Hazard Analysis* (PSHA) method in the Northern of Sumatra

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Abstract Sumatra region is one of the earthquake-prone areas in Indonesia because it is lie on an active tectonic zone. In 2004 there is earthquake with a moment magnitude of 9.2 located on the coast with the distance 160 km in the west of Nanggroe Aceh Darussalam and triggering a tsunami. These events take a lot of casualties and material losses, especially in the Province of Nanggroe Aceh Darussalam and North Sumatra. To minimize the impact of the earthquake disaster, a fundamental assessment of the earthquake *hazard* in the region is needed. Stages of research include the study of literature, collection and processing of seismic data, seismic source characterization and analysis of earthquake *hazard* by probabilistic methods (PSHA) used earthquake catalog from 1907 through 2014. The earthquake *hazard* represented by the value of *Peak Ground Acceleration* (PGA) and *Spectral Acceleration* (SA) in the period of 0.2 and 1 second on bedrock that is presented in the form of a map with a return period of 2475 years and the earthquake *hazard* curves for the city of Medan and Banda Aceh.

1. Introduction

Indonesia has a complex and tectonic conditions because lie on three tectonic plates, including the Indo-Australia plate moves relative to the North, the Eurasian plate is relatively moved to the South and the Pacific plate moves relative to the West. Movements and meetings between the plates forming the collision and causing subduction zones contained in several regions in Indonesia [1]



Figure 1: Map of tectonic Indonesia [1]

With this tectonic system, Indonesia be a disaster-prone areas because of potential earthquakes particularly in the northern part of Sumatra. In 2004 there is earthquake with a moment magnitude of 9.2 scale, centered offshore at 160 km in West of Nanggroe Aceh Darussalam and triggered a tsunami [2]. These events take a lot of casualties and material losses, especially in the Province of Nanggroe Aceh Darussalam and North Sumatra. Associated with tectonic conditions in Sumatra that is so active



and causing earthquakes that have a damage in material or fatalities. Therefore it is necessary to carried out an assessment of the potential regional earthquake with earthquake *hazard* analysis which can be used as a basis of reference mitigation and planning earthquake-resistant buildings in the research area.

The purpose of the implementation of this research is to gain an earthquake *hazard* that may occur in the research area based on seismic source characterization by PSHA method. While The purpose of the study is:

1. Make a seismic hazard map (*seismic hazard*) which is described by the value of vibration acceleration in the bedrock at the 2475 year return period earthquake in research area using PSHA method.
2. Make *probabilistic curve hazard* in Banda Aceh and Medan in order to determine the contribution of the source of the earthquake *hazard* affecting.

2. Basic Theory

Sumatra subduction zone spread from the northern part of the Sunda Strait to the Andaman Sea. Sumatran subduction zone in the segments affected by the meeting of the Indo-Australian Plate and Plate Micro Burma as part of the Eurasian plate. The Eurasian plate subduction urges under the Indian Ocean to the northwest of Sumatra to the north of Java by varying the speed of movement. The second direction of the plate subduction path forming an acute angle thereby creating a fault zone on the island of Sumatra, which is dominated by horizontal fault.

Sumatra fault line or fault stretches along 1,900 km stretching from Aceh to the Sunda Strait (**Figure 2**). The fracture splitting into two parts of Sumatra island stretching. Sumatra fault is divided into segments amounted to 19 sections with a length of each segment ranges from 60 to 200 kilometers. The segments fault Sumatra is a segment of the Sunda, Segment Semangko, segment Kumering, segments, Manna, segment Musi, segment Ketaun, Segment Dikit, Segment Siulak, segment Sulii, segment Semani, segment Sianok, Segment Barumon, segment Angkola, segment Toru, segment Renun, Tripa segment, segment segment Seulimeum Aceh and [3].

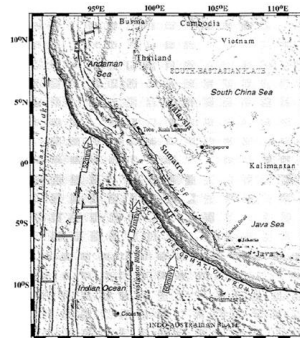


Figure 2 Map tectonic Sumatra Island [3]

3. Method

3.1. Data collection

This study use compile catalog of institutions domestically and internationally, such as the Badan Meteorologi Klimatologi dan Geofisika (BMKG), Engdahl van der hilst and Bulland (EHB) *Bulletin*, and *United States Geological Survey* (USGS) from 1907 to 2014 with a maximum depth 300 km by 700 km radius of the outermost point of the study area. In addition the data used *focal mechanism of the International seismological Center* (ISC).

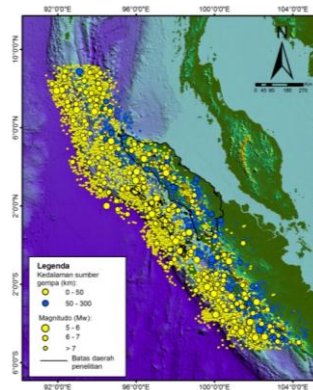


Figure 3. Map of seismicity around Sumatra from compiling catalogs

3.2. Earthquake Data Processing

Magnitude in the catalog that are used are not uniform, then the magnitude is converted to a moment magnitude (M_w) by using empirical correlation by [4]. To calculate the b -value and *rate recurrence* mainshock only the data that is used, so the earthquake followup (*foreshock* and *aftershock*) is removed using a program Zmap [5] with the criteria Gardner & Knopoff (1974). Analysis completeness of data [6] is used to remove the data *mainshock* incomplete. *Mainshock* at intervals of 5-6 M_w complete during the interval of the last 51 years, the magnitude of M_w 6-7 complete during the last 51 years and the magnitude of more than 7 M_w complete over 107 year.

3.3. Earthquake Source Modeling

In this study the seismic source model used is the subduction zone and *shallow crustal*. Characterization model is based on the seismotectonic conditions, regional geology and spatial data. For subduction zone, it is using three-dimensional models. Model subduction zone is divided into two mechanisms: *megathrust* with a depth of 0-50 km and *Benioff* at a depth of 50-300 km. For geometry modeling *megathrust* zones and using catalogs *Benioff* EHB *bulletin* for this catalog has been relocated. Do manufacture *cross section* as a basis for making seismic data to generate profiles hypocenter (Figure 4)

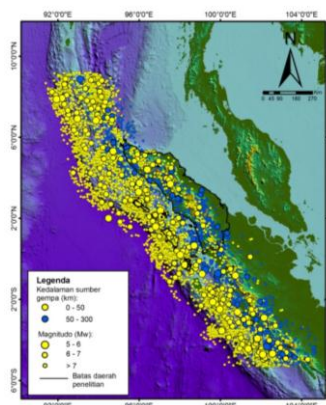


Figure 4. Cross section for geometry modeling of subduction

The hypocenter profile then *overlaid* with tomogram created from the data of the P wave velocity deviation (DVP) extracted from LLNL-G3Dv3 [7] to generated cross sections as shown in Figure 5. While the interpretation of the geometry of the subduction zone re shown in Figure 6. Referring to the research by [4] subduction zones used in the study were divided into three segments.

For *shallow* crustal *earthquake* source is divided into two: the source of the earthquake source seismic faults that are modeled in 3-dimensions and for a zone that contained the seismic activity but have not yet identified the source accommodated with *shallow* earthquake source *background* is modeled two-dimensional or *area source*.

For fault earthquake source models it is used data from the research results by [4] and then in the re-use map SRTM90m *trace*. Used as many as 14 segments of the fault in this study. Visualize the source of the earthquake fault is shown in **Figure 7**.

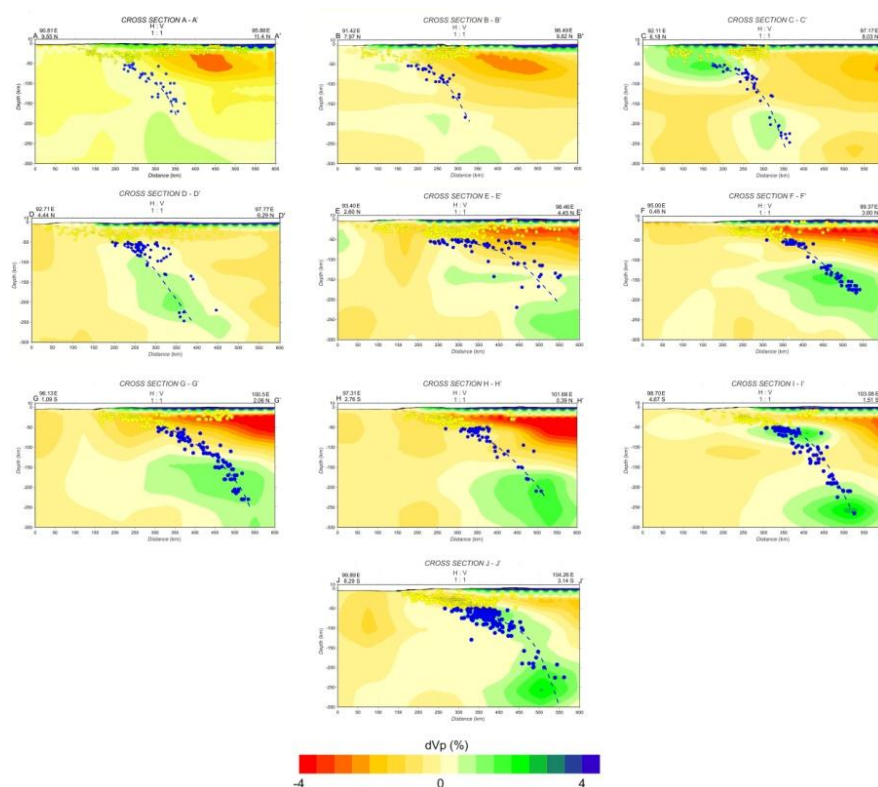


Figure 5 Hypocenter and tomogram Sectional profile extracted from LLNL-Earth3D [7]

Background shallow earthquake data with seismic source area is modeled after the *focal mechanism* of ISC is used as a weighting on the basis of the mechanism of the earthquake that will be used for the analysis of *seismic hazard*. The weighting value given to the mechanism of earthquake dominant in these areas. While the area is not accommodated *focal mechanism*, given the weighting of 0.4 for the *reverse-slip* mechanism, *strike-slip* to 0.4 and 0.2 for *normal-slip* mechanism.

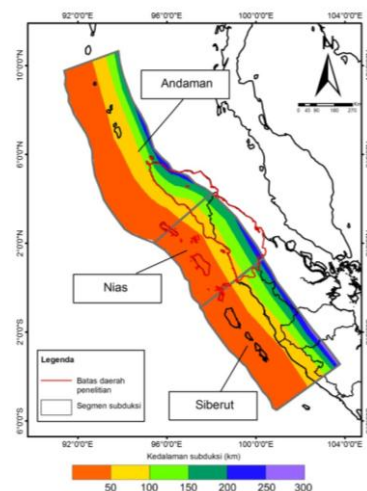


Figure 6. Results of the interpretation of the geometry of subduction

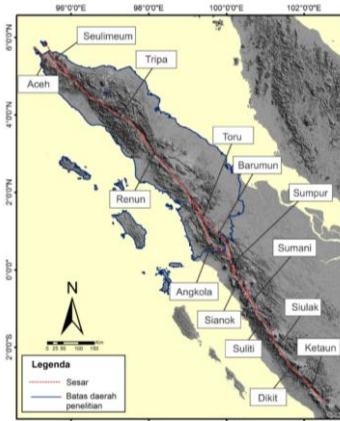


Figure 7. Map of the fault segment that is used in research

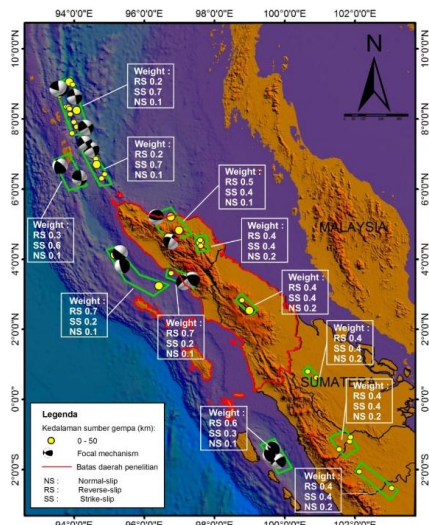


Figure 8. Model *shallow* earthquake source *background*

3.3. *b*-value and rate Earthquake

Analysis of seismic hazard parameters required *recurrence relationship* that is *b*-value and the *rate* of earthquake. Determination of these parameters obtained from seismic data clustering by source and type of mechanism is then used two methods, they are *Least Square* [8] and *Maximum likelihood* [9]. From both methods obtained the value of *a* and *b*-value which is used to search earthquake *rate* for each source.

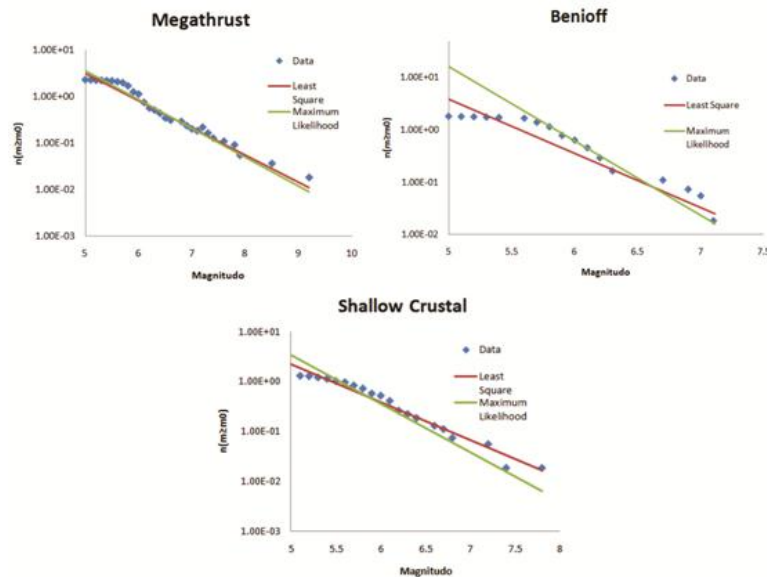


Figure 9. Curve *recurrence relationship* each seismic source

3.4. Maximum magnitude, Slip-rate and Attenuation Function

The maximum magnitude of the earthquake as well as *slip-rate* subduction earthquake sources *megathrust* and fault using the research results of [4]. The magnitude of the earthquake fault is determined by an empirical formula by [10] :

$$M_{max} = 5.08 + \log L \quad (1)$$

with:

M_{max} : maximum magnitude that can occur (M_w)

L : Long fault segment (km)

Table 1 Function Attenuation used

Source quake	Function attenuation
<i>megathrust</i>	Youngs et al (1997)
	Zhao et al (2006)
	Atkinson-Boore, <i>Worldwide</i> (2003)
<i>Benioff</i>	Atkinson-Boore, <i>Worldwide</i> (2003)
	Atkinson-Boore, <i>Cascadia</i> (2003)
	Youngs et al (1997)
<i>Fault & shallow background</i>	Campbell-Bozorgnia, <i>NGA</i> (2008)
	Boore-Atkinson, <i>NGA</i> (2008)
	Chiou -Youngs, <i>NGA</i> (2008)

Because there is no attenuation function is derived specifically for the Indonesian region then used the attenuation function is derived for other regions as well as *worldwide*. Selection is based on the attenuation function similarity of geological and tectonic conditions of the area where the attenuation function is made.

3.5. Logic Tree

The processing using *logic tree* in PSHA to solve uncertainty parameter values that used during the *seismic hazard* analysis. Using *logic tree* provide a more appropriate framework to in this method. So the *logic tree* models applied to four seismic source model that has been created. Examples *logic tree* used in this study looked at Figure 10.

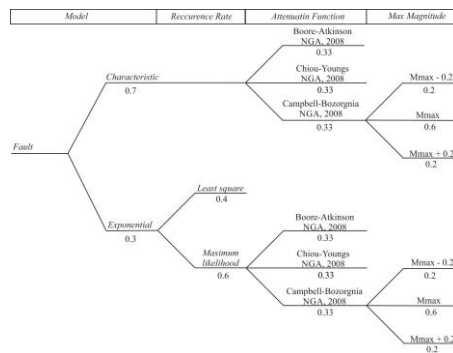


Figure 10. Logic tree to the earthquake source fault

3.6. Seismic Hazard Analysis

After obtained the parameters of the previous stage then *seismic hazard* analysis using EZ-Frisk program 7:52 to obtain parameters such as acceleration PGA and SA in the period spectra 0.2 and 1 second. Grid used is $0,1^\circ \times 0,1^\circ$ to a radius of about 50 km of the fault zone and $0,5^\circ \times 0,5^\circ$ outside the zone. The results of seismic acceleration at each grid was mapped using ArcGIS 9.3 program to obtain a map of seismic *hazard* in the northern part of Sumatra at 2475 year return period earthquake. *Hazard* analysis carried out on the layer of bedrock S_B to the value of the S wave velocity ($V_{s_{30}}$) at 750 m / s.

4. Results and discussion

The results of the analysis of *seismic hazard* in this study is the acceleration of earthquake *hazard* maps for the bedrock in northern Sumatra region covering the provinces of Nanggroe Aceh Darussalam and North Sumatra on condition PGA, SA 0.2 second and 1 second at 2475-year return period earthquake. The visualization can be seen in **Figure 11** to **Figure 13**. As well as *hazard* curves for Banda Aceh and Medan can be seen in **Figure 14** and **Figure 19**.

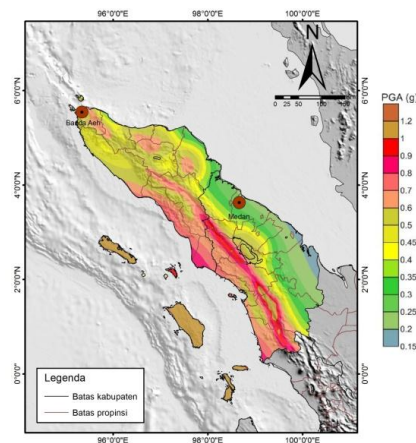


Figure 11. Map of PGA *hazard* conditions in the bedrock over a period of 2475 years of northern Sumatra region

PGA in the bedrock value for the period 2475 earthquake in northern Sumatra region ranged from 0.15 to 1.3g. High acceleration values found on islands and coastal areas in the southwest and around the fault segment. From the pattern contour, *megathrust* and faults are the dominant source of the earthquake in the region.

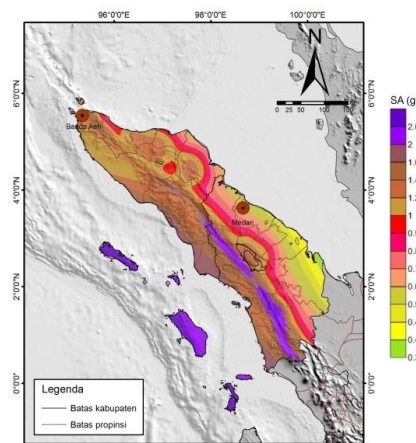


Figure 12. Map of *hazard* conditions SA 0.2 seconds in the bedrock over a period of 2475 years of northern Sumatra region

Value SA 0.2 seconds in bedrock for 2475 year return period earthquake in northern Sumatra region ranged from 0.35 to 2.8 g. Contour pattern looks the same as the map of the PGA, but the value of the acceleration in 0.2 seconds SA is much higher than the PGA.

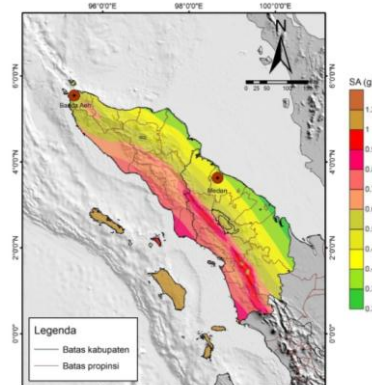


Figure 13. Map of *hazard* conditions SA 1 second in the bedrock over a period of 2475 years of northern Sumatra region.

Value SA 1 second on the bedrock for the 2475 year return period earthquake in northern Sumatra region ranging from 0.3 to 1.3g. In this period of acceleration values decreased significantly compared to the period of 0.2 seconds, especially in the southwest region.

SA 0.2 seconds has an estimated as the highest acceleration of bedrock has relatively low natural vibrating period of less than or equal to 0.2 seconds so the response at this *site* tend to be younger, especially in areas that close to the earthquake source. So the content of the frequency of earthquakes at close distance is still dominant with a high frequency that makes the response of the medium with a low natural frequency or short to a maximum.

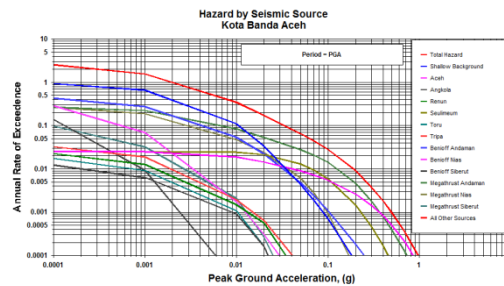


Figure 14. Curve *hazard* conditions in the bedrock PGA Banda Aceh

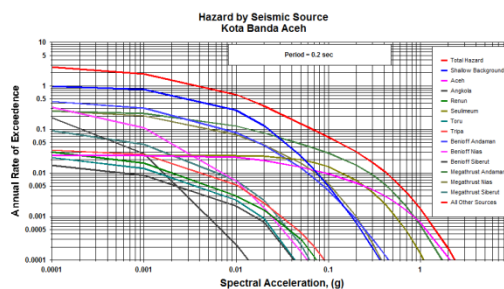


Figure 15. curve SA 0.2 seconds *hazard* conditions in the bedrock Banda Aceh

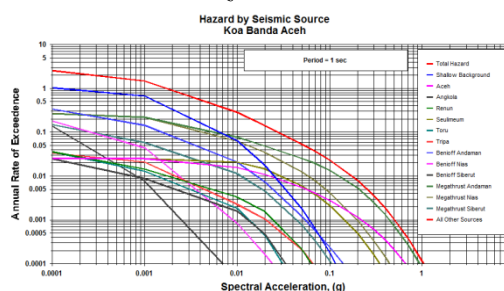


Figure 16. Curve *hazard* conditions SA 1 second on the bedrock of Banda Aceh

Based on the *hazard* curves for the city of Banda Aceh, the dominant source of the earthquake fault segment is *megathrust* in Aceh and Andaman segment. Both of these sources provide significant *hazard* than other seismic sources.

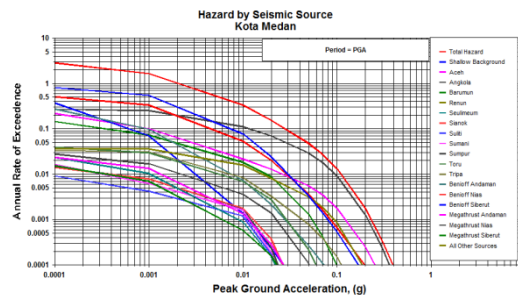


Figure 17 Curve *hazard* conditions in the bedrock PGA Medan

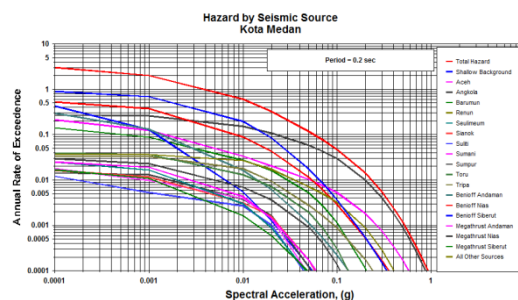


Figure 18 curve SA 0.2 seconds *hazard* conditions in the bedrock Medan

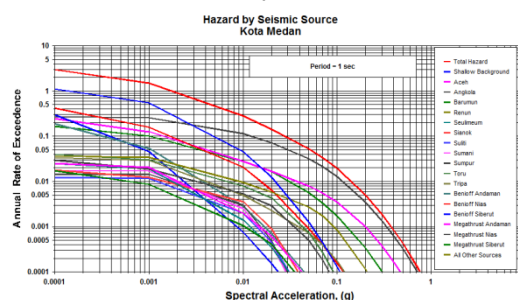


Figure 19 Curve *hazard* conditions SA 1 second on the bedrock of Medan

Based on the *hazard* curves for the city of Medan, the dominant source is *megathrust* earthquake in Nias segment. It is estimated that resources *megathrust* earthquake magnitude and the maximum length of the segment is relatively large so it still feels significant *hazard* at a considerable distance. This is also supported by the value of the *slip-rate* that makes a big earthquake return period to be faster.

5. Conclusion

Based on the results in the form of *hazard* maps by the tremor in the bedrocks, the value of PGA in northern Sumatra ranged from 0.15 to 1.3g, SA 0.2 seconds value ranges from 0.35 to 2.8 g and SA 1 sec ranging from 0.3 to 1.3g with the dominant source of the earthquake in the region and the *megathrust* fault.

Based on the *hazard* curve to Banda Aceh at 2475 year return period earthquake, equivalent to 0.0004 *annual rate of exceedence*, PGA value is from 0.68g, SA 0.2 seconds of 1.57g and 0.69g SA 1 second of the *megathrust* source. The dominant earthquake in Aceh and Andaman are the fault segments. As for the Banda Aceh and Medan the value of PGA is 0.29g, SA 0.2 seconds of 0.65g and 0.51g SA 1 second of the seismic source *megathrust* dominant segment of Nias.

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