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HAZARD SEISMIC ZONATION ANALYSIS OF WEST SUMATRA REGION USING PROBABILISTIC HAZARD SEISMIC ANALYSIS (PHSA) METHOD

Mudzullah Rajif[1], Syafriani[2]

[1] *Physics Student, Faculty of Mathematics and Natural Sciences, Padang State University*
[2] *Teaching Staff of the Department of Physics, FMIPA Padang State University*

Corresponding author. E-mail: mudzullahrajif23@gmail.com[1] , syafri@fmipa.unp.ac.id[2]

ABSTRACT

Indonesia is one of the countries that is prone to high intensity seismicity, where Indonesia is located between three main plates, namely the Eurasian plate in the north, the Indo-Australian plate in the south and the Pacific plate in the northeast. As a result of the meeting of the three plates, Indonesia has a high level of seismicity both on land and at sea. One of the provinces with a high level of earthquake hazard is West Sumatra. Seismic hazards are useful in designing earthquake-resistant buildings and can describe the effects of earthquakes at a location which will help in anticipating community preparedness and earthquake disaster mitigation efforts. This type of research is descriptive, namely by collecting catalog data for the NEIC / USGS earthquake with the period 1969-2019 with M 5 SR Seismic hazard data processing uses the probabilistic seismic hazard analysis (PSHA) method. PSHA is based on earthquake parameters that produce the greatest ground motion. The magnitude of the intensity at a location due to an earthquake in the earthquake source area with a magnitude M and a distance of R can be used as an attenuation function. The attenuation function used in this study is Joyner-Boore (1997) and Young et al (1997). The results show that the largest seismic hazard occurs in the PGA with a maximum range of 1.28 g - 3.69 g in the Mentawai Islands region. The seismic hazard level is in the Bukit Barisan area with a maximum PGA value of 1.72 g - 2.12 g. The magnitude of the intensity at a location due to an earthquake in the earthquake source area with a magnitude M and a distance of R can be used as an attenuation function. The attenuation function used in this study is Joyner-Boore (1997) and Young et al (1997). The results show that the largest seismic hazard occurs in the PGA with a maximum range of 1.28 g - 3.69 g in the Mentawai Islands region. The seismic hazard level is in the Bukit Barisan area with a maximum PGA value of 1.72 g - 2.12 g. The magnitude of the intensity at a location due to an earthquake in the earthquake source area with a magnitude M and a distance of R can be used as an attenuation function. The attenuation function used in this study is Joyner-Boore (1997) and Young et al (1997). The results show that the largest seismic hazard occurs in the PGA with a maximum range of 1.28 g - 3.69 g in the Mentawai Islands region. The seismic hazard level is in the Bukit Barisan area with a maximum PGA value of 1.72 g - 2.12 g.

Keywords: Earthquake, PGA, PHSA, Hazard

I. INTRODUCTION

Indonesia is a country that is prone to high seismic intensity. Indonesia is located between three main plates, namely the Eurasian Plate, the Indo-Australian Plate, and the Pacific Plate. As a result of the meeting of the three plates, Indonesia has become one of the countries with a high level of seismicity both on land and at sea. One of the provinces with a high level of earthquake vulnerability is West Sumatra Province because it has an active fault segment consisting of the Sump Segment, Sianok Segment, Sumani Segment, Mentawai Segment and Difficult Segment [1].

Earthquakes occur due to the movement of rock layers on the earth's surface due to the release of energy in the earth's crust. This release of energy causes deformation of the tectonic plates in the earth's crust [2].

Earthquake vibrations can damage everything on the earth's surface such as buildings and other infrastructure so that it can cause casualties and property.

Every damage caused by an earthquake in a certain area is determined by earthquake parameters, one of which is by using the maximum ground acceleration (PGA) value. The acceleration value is an important parameter because it is the starting point in making earthquake-resistant building structures and other mitigation measures [3]. The stages for processing PSHA data, including [4]:

a. Identify all sources of earthquakes that can cause damage due to ground motion.

b. Characterization of earthquake magnitude distribution.

c. Characteristics of the distribution of the distance from the source to the location associated with a potential earthquake.

d. Predict the resulting distribution of ground motion intensity as a function of earthquake magnitude, distance, etc.

Combining all the uncertainties in terms of earthquake size, location, and ground motion intensity using the total probability theorem calculation.

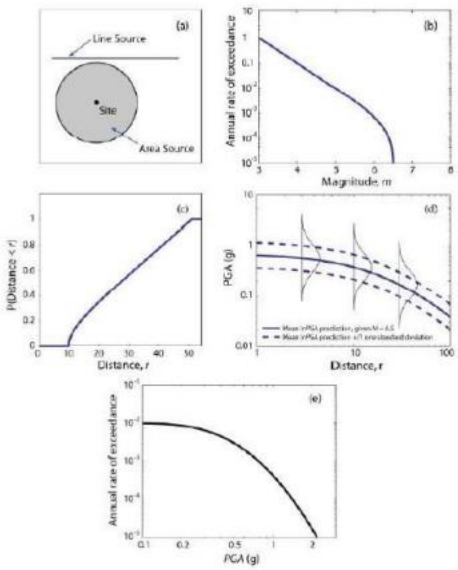

Figure 1. Stages of a probability seismic hazard analysis [4].

The basic formula of the total probability theory developed by McGuire in 1976 relates to the probability concept developed by [5], which is as follows:

$$P[I \geq i \backslash m, r] = \iint P\,[I \geq i; m, r] f_m f_r dmdr \quad (1)$$

where fm is a probability density function of magnitude, fr is a probability density function of the hypocenter distance, P[I≥i\m,r] is a random probability condition of intensity (I) that exceeds the value of (i) at a location due to earthquake magnitude (m) and the hypocenter distance (r).

The final result of this hazard analysis includes a map of the maximum acceleration in the bedrock at T = 0 seconds or usually also called PGA for the probability of exceeding 10% and 2% within 50 years. Earthquake risk is the possibility of an earthquake with a certain intensity being exceeded during the construction period. The value of earthquake risk is mathematically expressed in the following equation.

$$R_n = 1 - (1 - R_a)^N \quad (2)$$

Where Rn is earthquake risk, Ra is annual risk $\frac{1}{T}$, T is earthquake return period, and N = building mass. The attenuation functions that can be used in this study are:

1. Youngs, et al (1997)

Attenuation models for subduction zones can generally be divided into 2 (two) categories, namely earthquakes in the megathrust zone (interface) and in the Benioff zone (interslab). The equation form of the attenuation function Youngs et al. that is:

$$\ln(PGA) = 0.2418 + 1.414\ M\_w - 20552 \ln[r\_rup + 1.7818\text{^}0.554 M_w] + 0.00607\ H + 0.3846\ Z\_t \quad (3)$$

Where:

PGA : Peak Ground Acceleration (g)

Mw : Moment magnitude

rrup : Nearest distance to ruptere (Km)

H : Depth (Km)

Zt : Type of earthquake source (0 for interface and 1 for interslab).

2. Joyner and Boore (1997)

The equation for Joyner and Boore in 1997 was derived based on data from the earthquake in Wesren North America and the earthquake in the California area with an earthquake magnitude between 5.0 and 7.7 within 100 Km from the projected surface. The attenuation formula is as follows:

$$\ln(PGA) = b_1 + b_2(M_w - 6.0) + b_3(M_w - 6.0)^2 + b_4 \ln r + b_v \ln\left[\frac{V_s}{V}\right] \quad (4)$$

Where :

$$r = \sqrt{(r_{jb}^2 + h^2)} \quad (5)$$

rjb : Distance (Km)

Vs : Shear wave speed (m/sec)

b1 : [bISS/bIRS/bIALL]

bISS : for earthquakes with strike slip mechanism (-0.313)

bIRS : for earthquakes with reverse slipe mechanism (-0.177)

bIALL : for earthquakes with unknown mechanism (-0.242)[6].

II. METHOD

The type of research is descriptive research using secondary data in the form of earthquake data obtained from the USGS for the 1969-2019 period. The data obtained is then transferred to the Excel 2010 program with the data formats in the form of latitude, longitude, depth, magnitude, and time of the earthquake. Processing in this study was carried out in several stages as follows.

The first step is to convert the magnitude scale. In this study, it has different magnitude scales such as mb and ms so it must be converted into moment magnitude (Mw).

The second stage is to identify the source of the earthquake. The identification of the source of the earthquake was obtained from earthquake data in the national earthquake epicenter book obtained from the BMKG and the earthquake catalog. The earthquake source consists of several classifications, the geometry of the earthquake source in the form of strike direction, dip angle, and depth is needed in the study, and the mechanism of the earthquake source is also needed for identification.

The third stage is the characteristics of the earthquake source. The megathrust and beniof earthquake sources use the GR model by giving an appropriate weighting for each model. The input data are seismic parameters for each earthquake source, including the values of a and b in the Gutenberg-Richter distribution model which are then converted into values of and , where the value of = ax Ln10, = bx Ln10.

The next step is to find the ab value parameter obtained using matlab software and zmap software. After obtaining the ab value parameter, you can immediately process seismic hazard data using the PSHA USGS 2007 software.

III. RESULTS AND DISCUSSION

This study uses earthquake catalog data available on the National Earthquake Information Center US Geology Survey (NEIC/USGS) website for the period 1969 – 2019 with regional coordinates of 3.50 latitude – 1.20 longitude and 98.10 east longitude – 102.10 east longitude. Earthquake data has a magnitude of M 5 SR. The results obtained from this study are data processing using auxiliary software, namely PSHA-USGS 2007.

1. Earthquake Hazard Map in the West Sumatra region using the Probabilistic Seismic Hazard Analysis (PSHA) method.

The final result of data processing using the PSHA method is a contour map of the maximum soil acceleration (PGA) value in the bedrock of West Sumatra. With this PSHA method, three contour maps of PGA values can be produced with period T = 0s, period T = 0.2s, and T = 1s with a probability of exceeding 10% in 50 years or an earthquake return period of 50 years at the age of the building. acceleration in bedrock at T = 0 seconds with a 10% probability of being exceeded in a 50 year earthquake return period. This means that there is a 10% chance that the maximum PGA value of the area will be greater than what is on the map for 50 years.

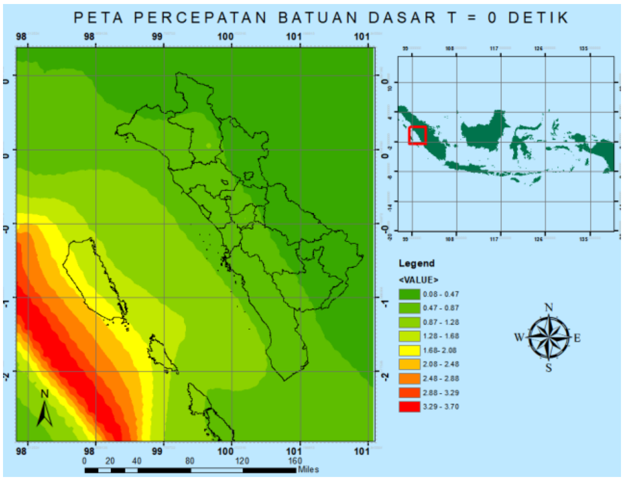

Figure 2. Hazard map for West Sumatra based on T = 0 seconds.

Based on Figure 2. the maximum PGA value, the area with seismic hazard is divided into 9 contour color degradations with each region having a different PGA area. Figure 3. Acceleration map in bedrock at T = 0.2 seconds with a probability of exceeding 10% in 50 years. In this map it can be seen that the seismic hazard in some areas is increasing.

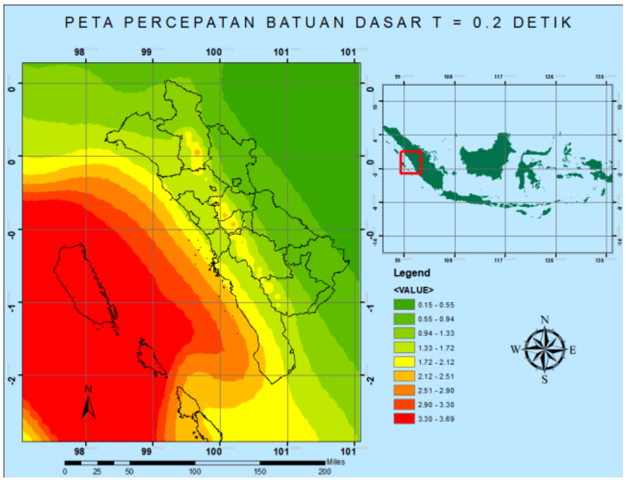

Figure 3. Hazard map for West Sumatra based on T = 0.2 seconds.

Based on Figure 3. there is a maximum PGA value that is different from Figure 2. where in Figure 3 there is a maximum PGA value with a moderate range of value located in the Bukit Barisan area. Figure 4. Contour map of acceleration in bedrock at T = 1 second with a probability of exceeding 10% in 50 years. On this map it can be seen that the seismic hazard in some areas is almost the same as the acceleration in the bedrock at T = 1 second.

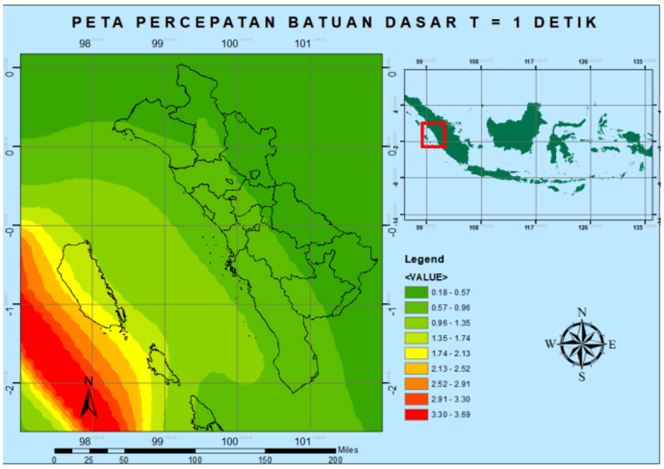

Figure 4. Hazard map for West Sumatra region based on T = 1 second.

Based on Figure 4. the maximum PGA value, the area with its seismic hazard has many similarities with Figure 2. where the acceleration values are different.

The results of data processing for each earthquake source obtained variations in the value of seismic hazard with the characteristics of each earthquake source represented by the maximum ground acceleration value in bedrock with a probability of exceeding 10% with a return period of 50 years. The seismic hazard level seen on the contour map of the period T = 0 seconds and T = 1 second has many similarities, while T = 0.2 seconds there is a difference where the range of Bukit Barisan has its maximum PGA, which is in the range of 1.72 g - 2.12 g. Areas with a high hazard level with a maximum PGA value are in the Mentawai Islands region with a maximum PGA value of 1.28 g – 3.69 g. Areas with moderate hazard levels are in the Bukit Barisan area with a maximum PGA value of 1.72 g – 2.12 g. The area with low hazard level is behind the Bukit Barisan with the maximum PGA value < 0.94 g. Areas that have a high level of seismic hazard are seen in the Mentawai Islands region. The West Sumatra region is traversed by three faults including the subduction zone, the Mentawai fault and the Sumatran fault which until now have shown their activity. According to [7] the West Sumatra region is traversed by 5 segments of the Sumatran fault, of which these 5 segments have a history of seismicity in the category of destructive earthquakes. The five segments include the Sianok Segment, the Sumani Segment, the Difficult Segment, the Sump Segment, and the Mentawai Segment. Mentawai Fault and Sumatran Fault which until now have shown their activity. According to [7] the West Sumatra region is traversed by 5 segments of the Sumatran fault, of which these 5 segments have a history of seismicity in the category of destructive earthquakes. The five segments include the Sianok Segment, the Sumani Segment, the Difficult Segment, the Sump Segment, and the Mentawai Segment. Mentawai Fault and Sumatran Fault which until now have shown their activity. According to [7] the West Sumatra region is traversed by 5 segments of the Sumatran fault, of which these 5 segments have a history of seismicity in the category of destructive earthquakes. The five segments include the Sianok Segment, the Sumani Segment, the Difficult Segment, the Sump Segment, and the Mentawai Segment.

2. Earthquake hazard level in West Sumatra region using the Probabilistic Seismic Hazard Analysis (PSHA) method

Based on Figure 2. we can make a table of acceleration values in bedrock at T = 0 seconds and the probability of exceeding 10% within 50 years (earthquake return period 50 years). From Figure 2. a table can be made and it can be seen in table 1.

Table 1. Acceleration of bedrock at T = 0 seconds

No	Region	PGA Max (g)	PGA Min (g)
1.	Agam District	0.87 g	0.47 g
2.	Dharmasraya Regency	0.47 g	0.08 g
3.	Mentawai Islands Regency	2.08 g	1.28 g
4.	Bukittingi City	0.87 g	0.47 g
5.	Padang city	0.87 g	0.47 g
6.	Padang Panjang City	0.87 g	0.47 g
7.	Pariaman City	0.87 g	0.47 g
8.	Payakumbuh City	0.47 g	0.08 g
9.	City of Sawahlunto	0.87 g	0.08 g
10.	Solok City	0.87 g	0.47 g
11.	District of Fifty Cities	0.87 g	0.08 g
12.	Padang Pariaman Regency	0.87 g	0.47 g
13.	Pasaman District	1.28 g	0.08 g
14.	West Pasaman District	0.87 g	0.08 g
15.	South Coast District	0.87 g	0.47 g
16.	Sijunjung District	0.47 g	0.08 g

17.	Solok District	0.87 g	0.08 g
18.	South Solok Regency	0.87 g	0.08 g
19.	Tanah Datar District	0.87 g	0.08 g

Based on the results of the analysis in Table 1. the probability of obtaining a maximum PGA value of 2.08 g is found in the Mentawai Islands Regency. As for the City of Sawahlunto, Kab. Fifty Cities, Kab. West Pasaman, Kab. Solok, Kab. South Solok and Kab. Tanah Datar 0.08 g – 0.87 g, Kab. Pasaman of 0.08 g – 1.08 g, Kab. Agam, Bukittinggi City, Padang City, Padang Panjang City, Pariaman City, Solok City, Kab. Padang Pariaman, and Kab. South Coast of 0.47 g – 0.87 g. Small maximum PGA of 0.08 g – 0.47 g, namely Kab. Dharmasraya and Kab. Sijunjung, and Payakumbuh City.

Based on Figure 3. we can make a table of acceleration values in bedrock at T = 0.2 seconds and the probability of exceeding 10% within 50 years (earthquake return period 50 years). From Figure 3. a table can be made and it can be seen in table 2.

Table 2. Acceleration of bedrock at T = 0.2 seconds

No	Region	PGA Max (g)	PGA Min (g)
1.	Agam District	2.12 g	0.94 g
2.	Dharmasraya Regency	0.94 g	0.55 g
3.	Mentawai Islands Regency	3.69 g	1.72 g
4.	Bukittingi City	1.72 g	1.33 g
5.	Padang city	2.12 g	1.33 g
6.	Padang Panjang City	2.12 g	1.72 g
7.	Pariaman City	1.72 g	1.33 g
8.	Payakumbuh City	0.94 g	0.55 g
9.	City of Sawahlunto	1.33 g	0.94 g
10.	Solok City	2.12 g	1.72 g
11.	District of Fifty Cities	1.33 g	0.55 g
12.	Padang Pariaman Regency	1.72 g	1.33 g
13.	Pasaman District	2.12 g	0.94 g

14.	West Pasaman District	1.72 g	0.94 g
15.	South Coast District	2.51 g	1.33 g
16.	Sijunjung District	1.33 g	0.55 g
17.	Solok District	2.12 g	0.94 g
18.	South Solok Regency	2.12 g	0.94 g
19.	Tanah Datar District	2.12 g	0.94 g

Based on the results of the analysis in Table 2. probability is obtained that the maximum PGA value of 3.69 g is found in the Mentawai Islands Regency. As for the District. Fifty Cities and Districts. Sijunjung 0.55 g – 1.33 g, Sawahlunto City 0.94 g - 1.33 g, Kab. West Pasaman of 0.94 g – 1.72 g, Kab. Pasaman, Kab. Solok, Kab. South Solok, and Kab. Tanah Datar, Kab. Agam 0.94 g – 2.12 g, Kab. Padang Pariaman, Pariaman City, Bukittinggi City 1.33 g – 1.72 g, Padang City 1.33 g – 2.12 g, Kab. Pesisir Selatan is 1.33 g – 2.51 g, and Solok City, Padang Panjang City is 1.72 g – 2.12 g. Small maximum PGA of 0.55 g – 0.94 g, namely Kab. Dharmasraya and Payakumbuh City.

Based on Figure 4. we can make a table of acceleration values in bedrock at T = 1 second and the probability of exceeding 10% within 50 years (earthquake return period 50 years). From Figure 4. a table can be made and it can be seen in table 3.

Table 3. Acceleration of bedrock at T = 1 second

No	Region	PGA Max (g)	PGA Min (g)
1.	Agam District	0.96 g	0.18 g
2.	Dharmasraya Regency	0.57 g	0.18g
3.	Mentawai Islands Regency	2.13 g	0.57 g
4.	Bukittingi City	0.96 g	0.57 g
5.	Padang city	0.96 g	0.57 g
6.	Padang Panjang City	0.96 g	0.57 g
7.	Pariaman City	0.96 g	0.57 g
8.	Payakumbuh City	0.57 g	0.18 g
9.	City of Sawahlunto	0.96 g	0.18 g
10.	Solok City	0.96 g	0.57 g

11.	District of Fifty Cities	0.57 g	0.18 g
12.	Padang Pariaman Regency	0.96 g	0.57 g
13.	Pasaman District	0.96 g	0.18 g
14.	West Pasaman District	0.96 g	0.18 g
15.	South Coast District	0.96 g	0.57g
16.	Sijunjung District	0.57 g	0.18 g
17.	Solok District	0.96 g	0.18 g
18.	South Solok Regency	0.96 g	0.18 g
19.	Tanah Datar District	0.96 g	0.18 g

Based on the results of the analysis in Table 3. probability is obtained that the maximum PGA value of 2.13 g is found in the Mentawai Islands Regency. As for the District. Agam, Sawahlunto City, Kab. West Pasaman, Kab. Pasaman, Kab. Solok, Kab. South Solok, Kab. Tanah Datar 0.18 g – 0.96 g, Bukittingi City, Padang City, Padang Panjang City, Pariaman City, Solok City, Kab. Padang Pariaman, Kab. South Coast of 0.57 g – 0.96 g. Small maximum PGA of 0.18 g – 0.57 g, namely Kab. Dharmasraya, Kab. Sijunjung, Kab. Fifty Cities, and Payakumbuh City.

The Mentawai Islands region has a large maximum magnitude, is in a subduction zone and is traversed by the Mentawai fault and has a history of seismicity that can be categorized as a destructive earthquake, making this area a high seismic hazard. High seismic hazard can also be seen from the high seismic activity that occurs in the area. According to [8] where the b-value reflects local stress activity, where the change in the low b-value can be concluded that it has a high stress level in the area. The Mentawai Islands region also has a maximum PGA value of 1.28 g – 3.69 g.

Areas that have a moderate level of hazard along the Bukit Barisan. The Bukit Barisan is traversed by four segments including the Sianok, Sumani, Difficult, and Sumpur segments. The Sianok segment has a maximum magnitude of 7.4, a segment length of 90 Km and a sliprate of 14.0 mm/yr. The Sumani segment has a maximum magnitude of 7.1, a segment length of 60 Km and a sliprate of 14.0 mm/yr. The difficult segment has a maximum magnitude of 7.4, a segment length of 95 Km and a sliprate of 14.0 mm/yr. The Sump segment has a maximum magnitude of 6.9, a segment length of 35 Km and a sliprate of 14.0 mm/yr. This area has a moderate hazard level because the maximum PGA is in the range of 1.72 g - 2.12 g. Even though the intensity generated is the same, the perceived earthquake will be different.

Areas that have a low level of seismic hazard are areas behind the Bukit Barisan, including the Dharmasraya Regency, Sijunjung Regency and Fifty Kota Regency. The three areas include areas that are far from the source of the earthquake location. This area has a low hazard level because the maximum PGA value is lower than 0.94 g.

Of the three PGA values at 0, 0.5, and 1 second, the highest PGA value is found in the Mentawai Islands region. This is because the Mentawai Islands area is in a subduction zone and is traversed by the Mentawai fault and has a history of seismicity that can be categorized as a destructive earthquake, making this area a high seismic hazard. High seismic hazard can also be seen from the high seismic activity that occurs in the area. This is also stated by [9] stating that the area that has a high PGA value is in the Mentawai Islands region. The high PGA value is due to a shallow earthquake with a large magnitude near that point. There was an earthquake on October 25, 2010 in the southwest of the Mentawai Islands with a magnitude of 7.8 on the Richter scale at a depth of 20 km.

IV. CONCLUSION

1. Seismic hazard map for West Sumatra, an area that has a high seismic hazard level is in the Mentawai Islands region. This region has a maximum PGA value at T = 0 seconds and T = 1 second at 1.28 g - 2.13 g and at T = 0.2 seconds at 3.30 g – 3.69 g. This seismic hazard map also shows an area with a low seismic hazard level, namely behind the Bukit Barisan because this area is far from the location of the earthquake source.
2. The region has a maximum PGA value less than 0.94 g. 2. Areas that have a high level of seismic hazard are in the Mentawai Islands region. The probability of earthquake hazard in this area is dominated by subduction zone earthquake sources. Areas that have a moderate level of hazard are in the Bukit Barisan area. Meanwhile, areas that have a low level of seismic hazard are areas behind the Bukit Barisan including Dharmasraya Regency, Sijunjung Regency, and Lima Puluh Kota Regency.

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