Analysis of potential earthquake energy in the sianok segment

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Abstract. Earthquakes are natural disasters that often occur and can harm the people in West Sumatera-Indonesia. One that makes West Sumatra prone to earthquakes is due to the existence of the Sianok segment. In this segment, there was an earthquake on March 3, 2007 with a magnitude of 6.4 MW. Therefore the writer wants to calculate the amount of potential energy in this segment and the stress local conditions that exist in this segment. The data used is secondary data sourced from the earthquake catalog of the National Earthquake Information Center U.S. Geology Survey (NEIC / USGS) with an observation period of 1992 - 2016. Earthquake data used in this paper is M > 3.5 and h ≤ 70 Km. The processing of potential energy data uses the least square statistical and the local stress analysis is seen based on the a-value and b-value processed using the maximum likelihood calculation. The results of statistical calculations performed on the Sianok segment, the potential energy size for the Sianok segment is as much as 5.3763 x 10^{20} ergs since the March 2007 earthquake and the amount of the a-value and b-value in the Sianok segment is 4.51 and 0.808 ± 0.1.

1. Introduction

West Sumatra is one of the provinces in Indonesia that has high earthquake activity [1]. West Sumatra is dominated by a thrust mechanism. The west coast of West Sumatra stretches the subduction zone which is parallel to the coastline of Sumatra [2], Sumatra Fault System located on the mainland of Sumatra, and Mentawai Fault System [3]. The history of seismicity in West Sumatra that has happened on the Angkola segment in 1892, the Sumpur segment in 1977, the Sianok segment in 1926 and 2007, the Sumani segment 1943, the Suliti segment in 1943 and recurred in 2004, and the Siulak segment in 1909 and 1995 [3]. Earthquakes originating from the Subduction Zone in 2007 and 2009 and the Mentawai Fault Zone issued an earthquake in West Sumatra in 2007 and 2010. One segment in West Sumatra that often experienced earthquakes was the Sianok segment.

The Sianok segment is one of active segment West Sumatra. The history of seismicity in the Sianok segment has recorded a major earthquake in 1822 with magnitude Ms ~ 7 [2]. One of the characteristics of an earthquake is an earthquake that has repetitive properties. This large earthquake was occurred with a magnitude Ms 6.8 on August 4, 1926 [3]. A recent major earthquake that took place in the Sianok segment was on March 6, 2007 with a magnitude of Mw 6.4. As many as 67 people died in this earthquake, 826 people were injured, and 34,719 houses were damaged due to this earthquake [4]. Based on the recurring nature of the earthquake, the Sianok segment after the 2007 large earthquake will still experience energy accumulation and still allow a large earthquake to occur again in the future.

Earthquakes that occur are the release of accumulated deformation energy in rocks which causes the release of elastic rock energy or better known as Elastic Rebound theory that has experienced a period
or cycle of accumulation [5]. Stresses and strains result in deformations in rocks which result in the creation of energy collisions in rocks to the maximum extent so that they are released into earthquakes. Energy that has been released will experience accumulation of energy again because of its repetitive nature.

Earthquake energy can be grouped into three stages or cycles based on their repetition properties [5]. The first inter-seismic is that energy accumulates. The second co-seismic is the release of energy. the third post-seismic remaining earthquake energy is released slowly in a certain period of time until the initial balance stage returns. Based on the recurring nature of the earthquake, earthquake energy in an area can be distinguished into save energy (inter-seismic), loose energy (co-seismic) [6]. Based on these two energies we can find out how much potential energy in a segment. Potential energy is energy stored under the earth's crust, which at any time can be released in the form of earthquakes.

The earthquake energy generated depends on the conditions of local tectonic stress and seismic activity [7]. Based on seismotectonic parameters a-value and b-value can explain the situation. b-value has a clear relationship to stress in a rock volume where in his experiments Scholz observed a decrease in b-value associated with increased stress in rocks. A low value of b in a fault area can describe in this area high stress with a value of b around 0.4 - 0.9. High stress values will result in very large accumulated energy so that it has large energy potential [9]. a-value is a value that indicates the level of seismicity. A-value <6 is categorized as low [8]. The higher a-value means the area has a high seismic activity level, and vice versa. Areas that have a high seismic level mean that the area of earthquake energy does not accumulate so that it is easily released in the form of earthquakes and the local stress conditions are quite low [9].

2. Data and Methods

Processing of earthquake potential energy is processed using the least square method statistical approach. Determination of potential energy is calculated by looking at the amount of off-annual energy, annual energy expectation, total annual energy and then analysis with local stress conditions and seismicity based on a-value and b-value.

The data processing starts equalizing the type of earthquake magnitude to the surface magnitude (Ms). The magnitude is converted to energy using equation 1[6].

$$\log E = 11.8 + 1.5M_s$$

Annual off-energy calculations using the least square method statistical principle. In the least square calculation, this research uses two models, namely linear and exponential. The model that will be used to represent the value of annual energy is the model with the smallest error. Equations 2 and 3 for exponential models [10].

$$E_1 = \frac{n\sum(x_i y_i) - (\sum x_i)(\sum y_i)}{n\sum x_i^2 - (\sum x_i)^2}$$

$$\log E_1 = \frac{\bar{\sum y_i}}{n} - \log A \left(\frac{\sum x_i}{n}\right)$$

Where n is a lot of data, A is the regression coefficient, Y is the annual cumulative energy, X is the data sequence in the year, E1 is the annual off energy. The annual energy expectation is calculated by dividing the last largest earthquake that has ever occurred in a segment with its return period. Total energy is the amount of annual off energy and annual energy expectation. Potential energy calculations can be calculated using equation 5[8].

$$E_s = E_{tot} \times Z$$

$$E_p = E_{tot} - E_{gb}$$

Where Es is the loose energy should be, Z is many years after the earthquake is large, Egb is the amount of energy after the earthquake is large, and Ep is potential energy.
The seismotectonic parameters of a-value and b-value were obtained based on the frequency-magnitude distribution proposed by Ishimoto-Lida in 1939 and Gutenberg-Richter in 1944 [8]. This relationship can be expressed in equation 6.

\[
\log N(M) = a - bM
\]

Where \( N(M) \) is the cumulative number of earthquakes with magnitude, \( a \) and \( b \) are constants, and \( M \) is the magnitude of the earthquake. Based on equation 6 determining the constants \( b \) and constants \( a \) can be calculated using the maximum likelihood method like equations 7 and 8 [8].

\[
b = \log e \frac{m}{m_0}
\]

\[
a = \log N(m \geq m_0) + \log(b \log 10) + m_0b
\]

where \( \bar{m} \) is the average magnitude of the earthquake data and \( m_0 \) is the minimum magnitude. Calculation of a-value and b-value is helped by using the ZMAP application ver. 6.0.

The data used in this study are earthquake data sourced from the NEIC/USGS earthquake catalog with observation periods from 1992 to 2018. The earthquake data selected has a magnitude bigger 3.5 SR with the depth less than 70 km. The research area of the Sianok segment are at 0.7°LS - 0°LU and 100°BT - 100°78’BT).

3. Result and Discussions
Catalog of earthquakes in the Sianok-West Sumatra segment in the period 1992 - 2016. Catalog data of seismic activity in the Sianok-West Sumatra segment shown in the earthquake seismicity map in Figure 1.

![Seismicity of Sianok Segment Period 1992-2016 (data source: USGS).](image1)

Figure 1 shows the distribution of earthquakes originating from the Sianok segment. A total of 40 earthquake events have occurred in the observation period. Calculation of potential earthquake energy in the Sianok segment is based on the last largest earthquake that has occurred in the Sianok segment, namely on March 6, 2007 with a magnitude of 6.4 MW. Table 1 is the result of calculating potential energy in the Sianok segment.

| Category of Energy | Energy       |
|--------------------|-------------|
| loose energy       | 7.5772 x 10^{15} erg/year |
| Expectations energy| 4.9004 x 10^{19} erg/year |
| total annual energy | 4.9011 x 10^{19} erg/year |
| loose energy should be | 5.2913 x 10^{20} erg |
| energy after a big earthquake | 1.4964 x 10^{18} erg |
| potential energy   | 5.3763 x 10^{20} erg |
The results of the Sianok segment potential energy based on Table 1 show the accumulation of earthquake potential energy obtained at $5.37635 \times 10^{20}$ erg or equivalent to earthquake with a magnitude of 6. The catalog of earthquake events recorded in the Sianok segment between 1992 - 2015 released an annual earthquake energy of $7.57724 \times 10^{15}$ erg/year where this value is equivalent to an earthquake magnitude of 2.7. The last largest earthquake ever to occur in the Sianok segment was on March 6, 2007 with a magnitude of 6.4 Mw which was equivalent to earthquake energy of $1.86217 \times 10^{21}$ erg. The results of the calculation of the average period of the earthquake repetition with a magnitude of 6, 38 years it was found that the Sianok segment annually stores $4.90044 \times 10^{19}$ erg/year of energy.

The total energy per year in the Sianok segment is $4.90119 \times 10^{19}$ erg/year. 11 years since the last largest earthquake in 2007 to 2018 the Sianok segment should have collected an energy of $5.39131 \times 10^{20}$ erg which this energy should have been released. The earthquake catalog after the large earthquake from 2007 to 2018 shows that the Sianok segment has released earthquake energy of $1.49648 \times 10^{18}$ erg. The difference between these two values is the amount of potential energy.

Based on table 1, the potential energy obtained has a large value. In line with the theory explained that a large earthquake can be repeated so that this large one is likely to be released in the form of a large earthquake. The Sumatra fault zone, Subduction Zone, south of Nias Island and Mentawai Island had the potential to cause large and destructive earthquakes [11]. The potential energy obtained has the potential to be released in the form of large and destructive earthquakes.

The potential energy obtained in the Sianok-West Sumatra segment is likely to continue to experience greater energy accumulation every year. Based on the results of the 2007 Natawidjaja study, the segments in the SFZ experienced earthquake accumulation averages equal to 7.2 Mw - 7.4 every 100 years and 7.4 Mw - 7.7 Mw every 200 years [3]. Based on this, if the potential energy obtained is calculated for 100 years from the last large earthquake, the authors obtain a value for Sianok of $9.04423 \times 10^{21}$ erg which is equivalent to an earthquake of 6.8 Mw. Based on this, the potential energy in the Sianok-West Sumatra segment is likely to be greater than the calculation that the author gets.

The history of seismicity in the Sianok segment that experienced earthquake recurrence. Starting from the large earthquake in 1822 with a magnitude of about 7 Ms [2], a large earthquake resumed in the Sianok-West Sumatra segment on August 4, 1926 with a magnitude of 6.8 Ms [3], and recently a large earthquake occurred in the segment this was on March 6, 2007 with a magnitude of 6.4 Mw. When viewed within 100 years of the seismic period in the Sianok segment, the earthquake in 1926 was a repetition of the great earthquake of 1822. Based on this, the author assumes that the earthquake in March 2007 was the 100th anniversary of the earthquake's repetition period in 1926. If this is true, then the 2007 earthquake was 19 years faster than 100 years of the period of earthquake recurrence. This resulted in the Sianok segment from 2007 to the next 100 years still experiencing energy accumulation. The potential energy obtained is $9.89583 \times 10^{20}$ erg or the equivalent of an earthquake with a magnitude of 6.1 Ms will continue to grow. When viewed for the 100-year period from 2007 the West Sumatra-Sianok segment will experience an energy accumulation of $9.04423 \times 10^{21}$ erg which is equivalent to the 6.8 Mw earthquake. Based on this, the authors get results that in the West Sumatra-Sianok segment will experience an average seismic energy accumulation of ± 6.8 Mw every 100 years and ± 7 Mw every 200 years.

Based on the results of the a-value and b-value in the Sianok-West Sumatra segment based on the earthquake data in Sianok segment shown in Figure 2.
Based on the frequency-magnitude curve in Figure 4, the analysis of the value of a-value b-value, and the magnitude of completeness in the Sianok segment is obtained. The area in the Sianok segment is an a-value of 4.51 which indicates that this area has a low seismic level. The b-value in the Sianok-West Sumatra segment was 0.808 which indicates that this region has high stress conditions. The value obtained based on the results of the frequency curve analysis of magnitude is the magnitude of completeness which is equal to 3.6 which indicates that the frequency of earthquake events with a large magnitude of 3.6 will decrease.

The value of the a-value and b-value in the Sianok-West Sumatra segment can describe local stress conditions and high or low seismicity. The Sianok segment itself is in an area that has high local stress which is seen from a low b-value. High stress results in the Sianok segment to gather energy. The value of a-value can also affect energy accumulation. The lower a-value can indicate that the area has a low seismic level. Areas with low seismicity means the area is experiencing energy accumulation [6]. Based on the results of the West Sumatra-Sianok segment, a low a-value was obtained. This indicates that the Sianok segment experienced a slight earthquake event. Although earthquakes are rare, the Sianok segment is an active segment [3]. Active segments that rarely experience the release of energy to gather more energy than release it.

Based on the state of the potential energy value, a-value, and b-value there is a relationship of the three values. The results obtained that the potential energy value is associated with a state of stress and low seismic level. This is consistent with what is explained in theory that these two conditions will create a segment to experience energy accumulation. Based on this, the Sianok segment in West Sumatra should be suspected of having a large and destructive earthquake.

4. Conclusion
Based on the calculation of the results of statistical analysis conducted in the Sianok-West Sumatra segment, the potential energy for the Sianok-West Sumatra segment is $5.3763 \times 10^{20}$ erg since the March 2007 earthquake. Stress conditions and the seismic level of the sianok segment based on values a and b indicate that in this segment has a low category.
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