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Earthquake Recurrence Interval Based on Seismic Moment

Muhammad Fawzy Ismullah Massinai[1], Arif Wijaya[2], Jamaluddin[3], Muhammad Altin Massinai[4], Emi Prasetyawati Umar[5], Minarti[6]

[1] *Geophysics Department, Hasanuddin University, Makassar, Indonesia. E-mail: fawzy@sci.unhas.ac.id*

[2] *Mine Engineering Department, Universitas Muhammadiyah Mataram, Indonesia. E-mail: arif.wijaya@ummat.ac.id*

[3] *Department of Geology, STT- MIGAS Balikpapan, Indonesia. E-mail: jamaluddin@sttmigas.ac.id*

[4] *Geophysics Department, Hasanuddin University, Makassar, Indonesia. E-mail: altin@science.unhas.ac.id*

[5] *Mining Engineering Department, Faculty of Industrial Technology, Universitas Muslim Indonesia, Indonesia. E-mail: emiprasetyawati.umar@umi.ac.id*

[6] *Department of Physics, Faculty of Science and Technology, Universitas Islam Negeri Alauddin, Makassar, Indonesia. E-mail: minarti.minarti@uin-alauddin.ac.id*

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ABSTRACT

Indonesia is a country with high earthquake potential. This potential has been realized by its stakeholders and other parties. Various methods from many researchers from the fields of geophysics, geology, seismology, geodesy, geotechnical engineering, and others have been discussed to arrange earthquake mitigation. However, the discussions are unable to fit all earthquake mitigations across the country because they are still limited to specific characteristics of each fault among thousands of faults in Indonesia. Seismic moment is a parameter that provides information on the energy released when an earthquake occurs. This parameter, in any given scale, can provide information about the earthquake recurrence interval. The earthquake recurrence interval referred to here means that during a certain time period, the area under study has the possibility of experiencing an identical earthquake or with a lower magnitude. This study tries to offer and test the method of calculating earthquake recurrence interval based on seismic moments. The method tested in several case studies of earthquakes in East Kalimantan has acceptable results. The method in this research has advantages value and can be alternative method in earthquake disaster mitigation.

Introduction

Indonesia is a country with high earthquake potential [1], [2]. This is caused by tectonic settings which are characterized by the existence of many faults that potentially trigger earthquakes both on land and sea. This potential has been realized by many of its stakeholders and other parties. Knowing the condition, the Indonesian government has implemented standard operating procedures to minimize the number of victims of earthquake disasters, which are commonly called earthquake disaster mitigation.

Various methods of many researchers from the fields of geophysics, geology, seismology, geodesy, geotechnical engineering, and others have been discussed to arrange earthquake mitigation such as hypocenter determination and focal mechanism [3], [4], peak ground acceleration [5], GPS slip rate [6]. However, the discussions are unable to fit all earthquake mitigations across the country because they are still limited to specific characteristics [7] of each fault among thousands of faults in Indonesia. This is indicated by the assurance of the emergence of new information or insight after analysis of each new earthquake that occurred. Seismic moment is a parameter that provides energy information that is released by every earthquake event. This information is obtained from several parameters, namely the modulus of shear or rigidity, displacement, and slip caused by the earthquake. Slips have a length unit. Faulting as the cause of the earthquake has a slip rate per year. These two slip parameters, on any scale, can provide information about the earthquake recurrence interval.

The earthquake recurrence interval referred to here does not mean the ability to guess that an identical earthquake will occur after specific periods. However, it gives a meaning that the area under study has the possibility of an identical earthquake with a similar or lower magnitude within a specific period. This study tries to offer and test the method for calculating earthquake recurrence interval based on seismic moments. This study's results can be used as additional thoughts to the stakeholders and other parties involved in the preparation of earthquake disaster mitigation, especially in Indonesia.

Method

Subsurface complexity causes an earthquake to be unpredictable. Up to today, scientists are still unable to predict the occurrence of earthquakes, or even giving a short range of time when the earthquakes are probable to happen. Earthquake recurrence interval in a long-time span can be calculated if the assumption of the earth is simplified and then calculated using some mathematical models that have been formulated by previous experts.

The size of an earthquake can be measured based on the seismic moment (M_0), using the following formula [8], [9]

$$M_0 = \mu(LD)S \tag{1}$$

with,
M_0 : Seismic moment (dyne.cm)
μ : modulus of shear or rigidity (dyne/cm^2)
L : segment length (cm)
D : seismogenic depth (cm)
S : Slip (cm)
M_0 can be derived from moment magnitude with the following equation [10], [11]

$$M_w = \frac{2}{3}\log M_0 - 10.73 \tag{2}$$

with,
M_W : moment magnitude

If the calculation of an earthquake uses other types of magnitude such as body magnitude and local magnitude, magnitude is converted first to moment magnitude before it is converted to seismic moment. Some equations that can be used to convert magnitude are as follows [10], [12], [13]:

$$M_S = 1.27(M_L - 1) - 0.016{M_L}^2 \quad (3)$$
$$m_B = 0.63M_S + 2.5 \quad (4)$$
$$m_B = 1.5m_b - 2.2 \quad (5)$$
$$M_W = 0.85m_B + 1.03; 3.5 \leq m_b \leq 6.2 \quad (6)$$

with,
M_L : Local magnitude
M_S : Surface magnitude
m_B : Body magnitude
m_b : Body magnitude of ISC
In general, every earthquake with a high magnitude has a certain M_W, the parameter is changed into M_0 to get the value of the slip caused by a large earthquake in a particular segment, with a segment length and depth of the earthquake assumed to be known. The earthquake recurrence interval (T) in units of years can be calculated by dividing the accumulated slip (S) caused by an earthquake by the average slip rate per year (s) in that segment, i.e. [14]

$$T = \frac{S}{s} \quad (7)$$

The calculation of earthquake recurrence interval in each segment uses the equation discussed above.

Result and Discussion

The method described in the previous section was tested in case studies of selected earthquakes in East Kalimantan. Location selection caused by some earthquake event (next wrote just event) which is shocked people because Kalimantan well known as stable areas. Another reason is a political reason about capital reported will locate in East Kalimantan.

Kalimantan has three faults that are considered to potentially cause earthquakes, are Tarakan Fault, Mangkalihat Fault, and Meratus Fault [15], [16]. They have a length of more than 100 km and the potential to trigger events with M7.0. Tarakan strike-slip fault can be identified in the northern part of the Kalimantan which stretches from the mainland to continuously offshore. Mangkalihat Fault is a strike-slip fault, identified on the east coast of the Kalimantan. The reverse fault zone is recognized in the southern part of the Kalimantan, Meratus Fault, in the NE-SW [15]. The three faults can be seen in Table 1 and Figure 1.

Table 1. Data and parameter for fault in Kalimantan [15].

ID	Name	Slip rate (mm/yr)	Top (km)	Bottom (km)	Length (km)	M_{max}
1	Tarakan	0.3	3	18	100	7.0
2	Mangkalihat	0.5	3	18	111	7.0
3	Meratus	0.3	3	18	105	7.0

The selected event data is an earthquake that occurred in the range of 2010 to 2019 for the East Kalimantan region. The data was obtained from BMKG and GFZ databases with time on GMT. After the data is collected, magnitude conversion is carried out. All magnitudes are converted to moment magnitude. The data can be seen in Figure 1 and Table 2.

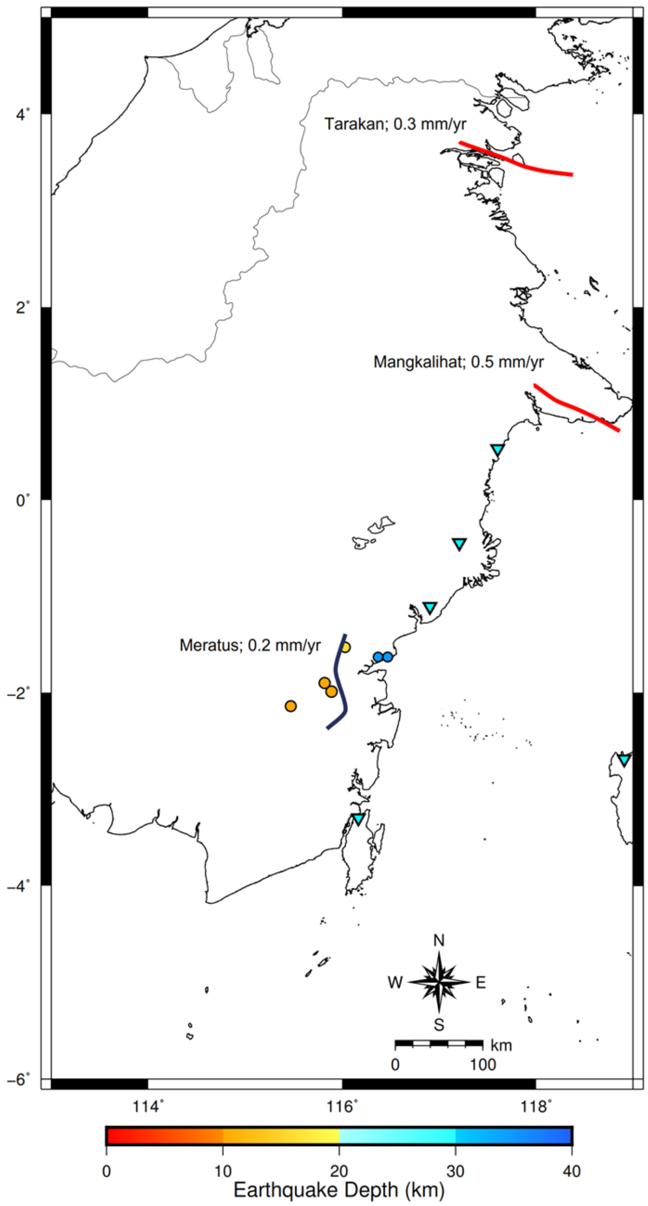

Figure 1. Circle dot is epicenter. Red line is confirmed fault and blue line is inferred fault. Blue inverted triangle is stations. This figure was drawn using GMT software [17].

Figure 1 shows events to be used located or close to the Meratus Fault. The event is thought to have occurred due to the fault activity. Based on this assumption, the next calculation will use the Meratus Fault parameter. Event data to be used is event data with the largest magnitude M_W5.0 which occurred on May 26, 2013. The shear or rigidity modulus used is 3 ×

10^{11} dyne/cm^2 for continental rock rigidity [8]. In the next calculation uses depth 3 (top), 5, 10 (event depth M_W5.0), 15 and 18 km (bottom). Calculation results can be seen in Table 3.

Table 2. Data used in this research.

ID	Time (yyyy-mm-ddThh:mm:ss)	Lat (°)	Long (°)	Depth (km)	Mag	Type	M_W
1	2010-06-01T12:51:11	-1.63	116.47	35	3.9	m_B	4.49
2	2012-09-22T03:06:29	-1.63	116.37	35	3.7	m_B	4.37
3	2013-05-26T12:25:12	-1.99	115.89	10	5.0	M_W	5.00
4	2014-01-22T06:00:17	-2.14	115.47	10	3.6	M_L	4.80
5	2015-08-29T10:07:22	-1.53	116.03	16.2	4.2	m_B	4.66
6	2018-05-02T19:21:48	-1.9	115.82	10	4.5	m_B	4.83

Table 3. Calculation result for M_W5.0 May 26 2013 event.

M_W	Log (M_0)	M_0 (dyne.cm)	L (cm)	D (cm)	μ (dyne/cm^2)	S (cm)	s (cm/yr)	T (year)
5.0	23.595	3.935×10^{23}	105×10^5	3×10^5	3×10^{11}	0.416	0.02	20.82276
5.0	23.595	3.935×10^{23}	105×10^5	5×10^5	3×10^{11}	0.250	0.02	12.49365
5.0	23.595	3.935×10^{23}	105×10^5	10×10^5	3×10^{11}	0.125	0.02	6.24683
5.0	23.595	3.935×10^{23}	105×10^5	15×10^5	3×10^{11}	0.083	0.02	4.16455
5.0	23.595	3.935×10^{23}	105×10^5	18×10^5	3×10^{11}	0.069	0.02	3.47046

Table 3. shows the results of calculations using the equations and data described earlier. By looking at the event data on May 26, 2013 (Depth 10×10^5 cm), we can find that the earthquake recurrence interval is 6.24683 years. Identical events or with magnitudes smaller than this event occurred on May 2, 2018 (Table 1). These two events have had hypocenter coordinates that almost coincide with each other. These two events were around 5 years or less than the recurrence interval of the research results, which was 6.24683 years (Table 3) so that the calculation results could be accepted. There is a difference of 1.2683 years from calculations and the earthquake event histories show that there is still much information that needs to be considered in future calculations.

Earthquake recurrence interval calculation for other events displays the different results. This result can be seen in Table 4.

Table 4. Calculation result for others event.

M_W	Log (M_0)	M_0 (dyne.cm)	L (cm)	D (cm)	μ (dyne/cm^2)	S (cm)	s (cm/yr)	T (year)
4.49	22.825	6.68344×10^{22}	10.5×10^6	35×10^5	3×10^{11}	0.00606	0.02	0.303104
4.37	22.655	4.51856×10^{22}	10.5×10^6	35×10^5	3×10^{11}	0.00409	0.02	0.204923
4.80	23.292	1.95960×10^{23}	10.5×10^6	10×10^5	3×10^{11}	0.06221	0.02	3.110560
4.66	23.080	1.20226×10^{23}	10.5×10^6	16.2×10^5	3×10^{11}	0.02356	0.02	1.177998
4.83	23.335	2.16272×10^{23}	10.5×10^6	10×10^5	3×10^{11}	0.06866	0.02	3.432887

New information got based on the summary result for all events (Table 5). Seen if the magnitude event is higher so recurrence interval took longer time. This condition corresponded to M_W. This may relate to the size of the event because M_W is for the event with high magnitude only. The result of recurrence interval calculation shows different with after the event, specifically for recurrence interval below 1 year.

Table 5. Summary result for all event.

ID	Time (yyyy-mm-ddThh:mm:ss)	Lat (º)	Long (º)	Depth (km)	M_W	T (year)
1	2010-06-01T12:51:11	-1.63	116.47	35	4.49	0.303104
2	2012-09-22T03:06:29	-1.63	116.37	35	4.37	0.204923
3	2013-05-26T12:25:12	-1.99	115.89	10	5.00	6.246830
4	2014-01-22T06:00:17	-2.14	115.47	10	4.80	3.110560
5	2015-08-29T10:07:22	-1.53	116.03	16.2	4.66	1.177998
6	2018-05-02T19:21:48	-1.9	115.82	10	4.83	3.432887

This result is compared with others research in Indonesia. Most of them start from frequency-magnitude distribution to get probabilities of earthquake occurrences. Such as in Sumatera, M_w6.1 – 6.4 has recurrences 30 – 50 years [18]. Or in Mentawai, an island near from west coast of Sumatera, M5.0 has 0.463 years and increases to M8.0 has 150.503 years [19]. The latest result is similar to our tested result which is the higher magnitude has longer time. However, that method used more than one event information and only used on high magnitude. Our proposed method can use one event only and can be used on lower magnitude too.

Other research has a different method to calculate recurrence intervals such as in California, Canada, Central Asia, Greece and Japan using the earthquake spatial distribution [7]. The recurrence interval on the central Longmen Shan fault zone is 3900±400 years, calculated by GPS and InSAR data to construct a moment rate [6], or by radiocarbon dating is obtained 3830±930 years [20] and 2300-3300 years [21]. Earthquake entropy was used to calculate the recurrence interval at Canterbury (New Zealand)[22]. All of the research is done strictly based on history [23]. Our research shows that the proposed method has simpler calculations than another method.

However, the method that we used in this research has uncertainties. This can improve by accommodating other subsurface parameters in the calculation, such as hypocenter [24], coseismic [6] or earthquake mechanism [25].

Conclusion

The method of calculating earthquake recurrence interval proposed and tested in this study has acceptable results. This method has simpler calculations and has advantage value than other method. However, further research is still needed to accommodate other subsurface parameters in the calculation. The method used in this study can become a new insight in the preparation of future earthquake disaster mitigation.

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