RAPID SOURCE PARAMETER DETERMINATION AND EARTHQUAKE SOURCE PROCESS IN INDONESIA REGION

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ABSTRACT

We proposed a magnitude determination method for the regional network of the Meteorological and Geophysical Agency (MGA), Badan Meteorologi dan Geofisika (BMG). This method was developed from the empirical formula from Richter's magnitude by using least square method. We use accelerogram from regional accelerometer network of BMG for one month range. The magnitude formula of BMG is as follows:

$$M_{BMG} = \log_{10} A_D + 2.15 \log_{10} R - 1.88$$

where A_D is the maximum displacement amplitude (μm), and R is hypocentral distance (km), respectively. The comparisons in magnitudes among this formula, Tsuboi's formula (1954), and M_W from Global CMT indicate that this formula could be improved after seismic records are accumulated in BMG.

Also we determined the moment tensor for the earthquakes by using program written by Kikuchi for calculating Green's function and inversion program coded by Yagi. To understand the state of tectonic stress field of area around epicenters, we investigated the tectonic feature by analyzing the focal mechanism obtained by moment tensor inversion.

Keywords: Accelerometer, Magnitude formula, Moment tensor inversion.

INTRODUCTION

When the great earthquake of Aceh occurred in December 26, 2004, more than 200,000 lives in total have been taken as victims, and it is clear that early warning of earthquake and tsunami information is important. However, it is too difficult to perform short-term prediction of earthquake, so early warning information is an important to mitigate tsunami disaster. A new system of tsunami early warning is carried out as soon as possible. The government of Republic Indonesia through the Meteorological and Geophysical Agency/MGA (BMG) in cooperation with the donor countries has been building the new system of Tsunami Early Warning System (TEWS) oriented to reduce the loss of lives caused by tsunami attack. Therefore rapid and accurate determination of earthquake source parameters is of an urgent necessity. The purpose of this study is to rapidly determine source parameter and moment tensor inversion related to tsunami early warning system. The rapid source parameter determination is focused on determining the earthquake magnitude.

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DATA

In this study, the accelerogram was converted into displacement record with SAC transfer command to measure maximum displacement. A third-order Butterworth filter of 0.1Hz cut-off frequency was used as the high-pass filter. Therefore we used a peak displacement which is used as maximum displacement amplitude.

Table 1. Earthquake event list from the Global CMT (4 March 2007 – 25 April 2007).

No.	Event	yyyymmdd	Location	M_W Global CMT	Depth (km)
1	event1	20070309	-6.34S, 130.23E	5.6	149.3
2	event2	20070313	-8.08S, 117.94E	5.6	24.1
3	event3	20070315	-0.73S, 127.60E	5.4	12.0
4	event4	20070315	4.19N, 127.04E	5.2	18.5
5	event5	20070317	1.30N, 126.37E	6.2	40.7
6	event6	20070326	0.98N, 126.05E	5.5	29.0
7	event7	20070331	1.55N, 122.63E	5.6	21.9
8	event8	20070407	2.72N, 95.47E	6.1	12.0

We retrieved earthquake event list from the CMT global catalog with the same time range to use M_W as reference magnitude. We got only 8 events from this continuous waveform data due to many bad waveforms (Table 1). Also we retrieved teleseismic body-wave (*P* waves) data recorded at the Data Management Center of the Incorporated Research Institution for Seismology (IRIS-DMC) stations through the internet.

THEORY AND METHODOLOGY

Magnitude Determination of BMG

In this individual study, we propose a magnitude determination method of BMG for the regional network. The empirical formulas from Richter's magnitude are the relationships among moment magnitude, M_W, the maximum displacement amplitude, A_D (m), and hypocentral distance, R (km), respectively (Richter, 1935). It can be approximately expressed as

$$\alpha_D M_W = \log_{10} A_D + \log_{10} R + \beta_D R + \gamma_D \tag{1}$$

$$\alpha_D M_W = \log_{10} A_D + \beta_D \log_{10} R + \gamma_D \tag{2}$$

where D is an index for displacement, α_D is coefficient correction for magnitude, β_D is coefficient correction for distance, and γ_D is a constant coefficient, respectively. We denote equation (1) and (2) as **type1** and **type2** empirical formulas, respectively. We assume the coefficient for $\mathbf{log}_{10}A_D$ is 1.0, since former researchers (ex., Utsu, 1982; Katsumata, 1996) indicated that the value of 1.0 is suitable to produce comparable magnitude to M_W on average. We determine the coefficients by using the least-square method.

Moment Tensor Inversion

In general, vertical component of observed seismic waveform at the station j due to ordinary earthquake can be expressed by

$$u_j(t) = \sum_{q=1}^{5} M_q \int G_{jq}(t-\tau, x_c, y_c, z_c) T(t) d\tau + e_o + e_m \tag{3}$$

where M_q is moment tensor at centroid of source (x_c, y_c, z_c), *T(t)* is source time function, and e_m is modeling error. The observation equation of (3) can be rewritten in vector form:

$$\mathbf{d}_j = \mathbf{G}(T(t), x_{c,} y_c, z_c)_j \mathbf{m} + \mathbf{e}_j \tag{4}$$

where **d** and **e** are *N*-dimensional data and error vectors, respectively, a is a *5*-dimensional model parameter vector, **G** is a *N x 5* coefficient matrix. The solution of the above matrix equation is obtained by using least square approach, if the observation waveform (**d**) and convolution Green's function with source time function (**G**) are known. We determined the depth of hypocenter and the duration and shape of source time function by grid search method since these are needed for moment tensor inversion.

The teleseismic body waves were windowed for 60 seconds, starting 10 seconds before *P* arrival time, and then converted into displacement with a sampling time of 0.25 seconds. To remove effects of detailed source process and detailed 3D structure, we apply the low pass filtering in the moment tensor inversion. Frequency range was selected by a try and error.

RESULTS AND DISCUSSION

Magnitude Determination of BMG

We used 8 earthquake events with data range from 4 March 2007 – 25 April 2007. After selecting and converting waveforms, we determined the coefficients using the least square method prepared by Dr. Kamigaichi (2007, personal communication).

For the calculated magnitude of **type2**, we assumed correction for magnitude α_D, as 1. We obtained the correction for distance, β_D, as 2.15, and a constant coefficient, γ_D, as -1.88, respectively. Therefore we can construct the magnitude formula for **type2** as follows:

$$M_W = \log_{10} A_D + 2.15 \log_{10} R - 1.88 \tag{5}$$

We compared the both results with the empirical equation from Tsuboi's formula (1954). The empirical equation from Tsuboi is as follows

$$M = \log_{10} A + 1.73 \log_{10} \Delta - 0.83 \tag{6}$$

where Δ is an epicentral distance (km) and *A* is the maximum displacement amplitude (μm) observed at each station within 2,000 kilometers from an epicenter. *A* is given by $A = \sqrt{A_{NS}^2 + A_{EW}^2}$, in which A_{NS} and A_{EW} are half the maximum peak-to-peak amplitudes of the whole trace of the two horizontal components. We found that the **type2** of magnitude formula is almost similar to Tsuboi's formula, meanwhile the **type1** is not (Figure 1). This is due to the similarity of the equation. The **type1** is polynomial equation; meanwhile **type2** and Tsuboi's formula are the linear equation. The Tsuboi's formula is applied to determine magnitude for large earthquakes and for those shallower than 60 kilometers. In this study, we used earthquake events with the depth less than 60 kilometers except event1 with the depth is 149.3 kilometers.

According to these above reasons, we choose the **type2** of empirical formula as a magnitude determination of BMG. We can express as

$$M_{BMG} = \log_{10} A_D + 2.15 \log_{10} R - 1.88 \tag{7}$$

where A_D is the maximum displacement amplitude (μm), and R is hypocentral distance (km), respectively.

From Figure 2, we found that the magnitude determination of BMG for all events is systematically consistent with the results from Global CMT.

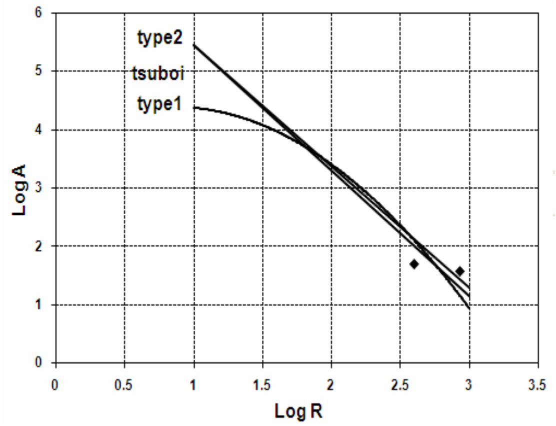

Figure 1. Example of comparison of maximum amplitudes for three types of magnitude calculation plotted against hypocentral distances (km) for each event (event1/20070309).

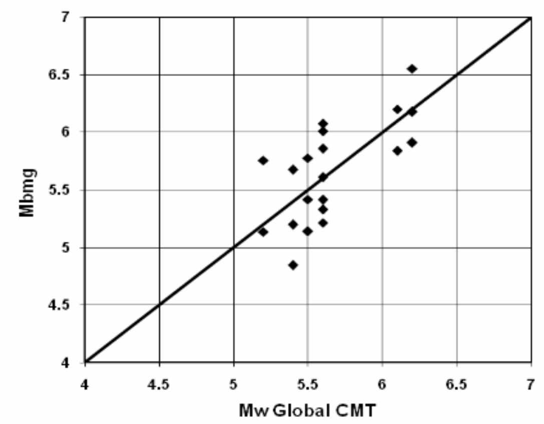

Figure 2. Comparison between the moment magnitude from Global CMT and the calculated magnitude of BMG (type2).

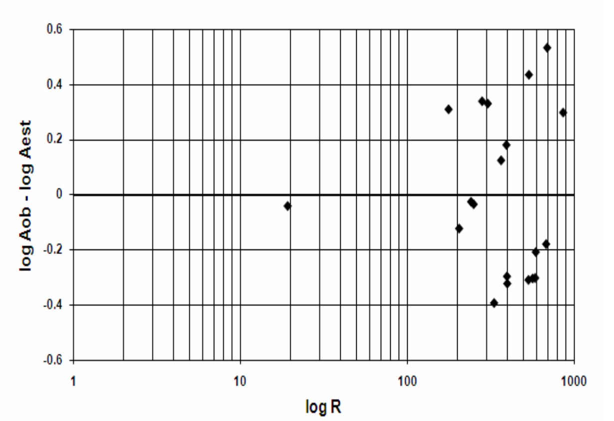

Figure 3. Difference between observed maximum amplitudes and estimated ones plotted against hypocentral (km) distances for all the events.

Figure 3 shows the difference between observed maximum amplitudes and estimated ones plotted against hypocentral distances for all the events. From this graph, we found that the magnitude determination of BMG is sufficient and reliable for the hypocentral distance less than 1,000 kilometers. The difference value is in the range from -0.4 to 0.6. The calculated magnitude distribution is concentrated less than 50 kilometers in depth with the excluded one is about 150 kilometers. Since we can expect the shallow earthquakes less than 150 kilometers, the magnitude determination of BMG will be reliable.

Moment Tensor Inversion

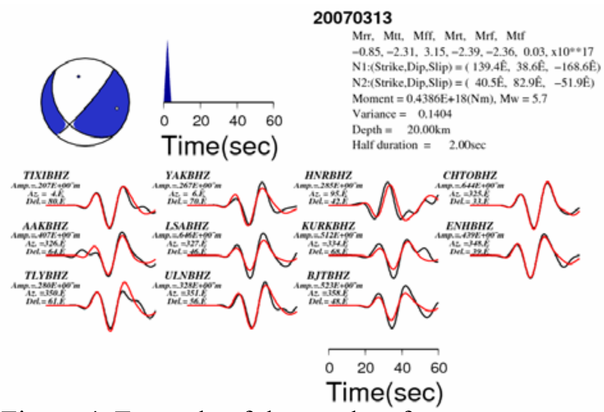

Figure 4. Example of the results of moment tensor inversion.

To understand the detailed source process of the earthquakes, we used moment tensor solution. We only retrieved vertical component from the IRIS-DMC broadband seismometer network. Out of 8 earthquake events used to determine magnitude of BMG, only 5 events are available to be retrieved from the IRIS-DMC data server. The program written by Koketsu and M. Kikuchi for calculating Green's function and inversion program coded by Y. Yagi were used to obtain the moment tensor. We used the grid search method of moment tensor inversion to constrain the

hypocentral depth. By varying the depth with minimum variance, we obtained a well constrained depth which is known as the centroid depth.
The results of moment tensor inversion of 5 earthquake events are shown in Figure 4 (for example). The observed waveforms and theoretical waveforms are systematically almost identical. It means that we can use these results for further studying the characteristic of seismotectonic of the region.

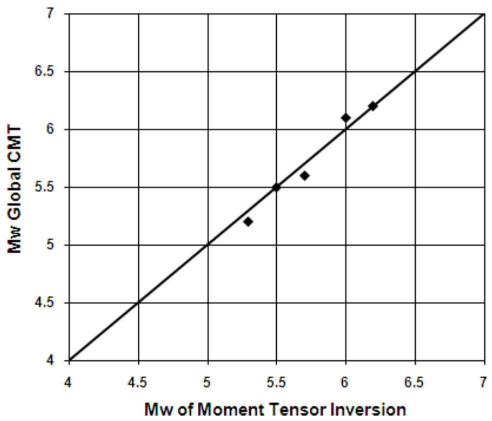

Figure 5. Comparison between the moment magnitude from Global CMT and the moment magnitude obtained from moment tensor inversion.

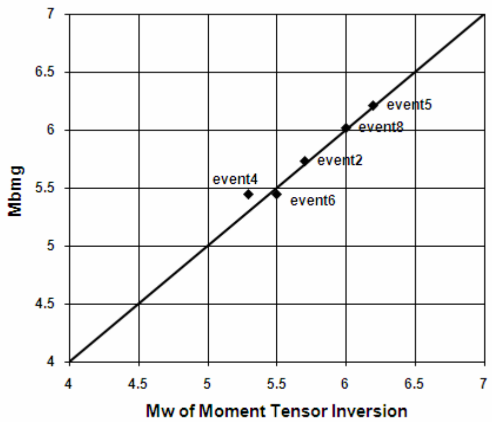

Figure 6. Comparison between the magnitude determination of BMG and the moment magnitude obtained from moment tensor inversion.

Figure 5, in general, it can be said that results of moment magnitude obtained from moment tensor inversion are systematically almost consistent with the results from Global CMT.
In this study, the consistency of both results depends on source time duration of moment tensor inversion. For event4, we found that the source time duration is short and about 3 seconds. The magnitude determination of BMG of event4 becomes overestimated (see Figure 6). However event6 has the longer source time duration than event4 in which the source time duration is about 12 seconds. The magnitude determination of BMG of event6 becomes underestimated. Therefore we revealed that for the rapid earthquake the magnitude determination of BMG became overestimated while for the slow earthquake the magnitude determination of BMG became underestimated, respectively.

CONCLUSIONS

By using least square method, a small number of event data from a few stations were used to calculate the coefficients of empirical formula. The obtained formula of magnitude determination of BMG is shown below:

$$M_{BMG} = \log_{10} A_D + 2.15 \log_{10} R - 1.88$$

where A_D is the maximum displacement amplitude (μm), and R is hypocentral distance (km), respectively.
By analyzing the consistency with the other magnitude determination, the formula for magnitude determination of BMG is still sufficient and reliable for shallow earthquakes less than 150 kilometers and the hypocentral distance less than 1,000 kilometers.
The seismic moments and moment magnitude estimated by moment tensor inversion are generally consistent with those of Global CMT solutions. To calculate moment tensor, we used teleseismic body waves; meanwhile the Global CMT used long period waves. Therefore there are the differences in the centroid depths between our moment tensor inversion and the Global CMT solutions.

The magnitude determination of BMG is systematically consistent with the results obtained by our moment tensor inversion. For the rapid earthquakes with short source duration time, the magnitude determined by using the formula for BMG will become overestimated. On the other hand the slow earthquakes with long source duration time, the magnitude determined by using the formula for BMG will become underestimated.

RECOMMENDATION

The magnitude determination of BMG cannot estimate magnitude for the hypocentral distance more than 1,000 kilometers yet. This is due to the limitation of number data used to construct it. Also the estimation of consistency with moment magnitude from moment tensor inversion is slightly not fixable.

According to above reasons, we recommend the following suggestions:

i. The formula of the magnitude determination of BMG could be improved after seismic records are accumulated in BMG. Collecting and storing data should be well managed. The long time collected data is of an urgent necessity in order to make reliable coefficients of this formula.
ii. The dense distribution of accelerometer station should be realized in order to obtain high quality of data.
iii. Intensive study of magnitude determination of tsunami earthquakes will give advantage to improve the reliability of this formula.

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