Application of P-Wave Moment Magnitude ($M_{wp}$) and Rupture Time Duration ($T_{dur}$) to Analyze A Potential Tsunami Earthquake in Sumatra

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Abstract. Tsunami warning is one of many important reports to save lives and reduce the damage for local peoples. A moment magnitude of P-wave ($M_{wp}$) and the rupture time duration ($T_{dur}$) can be used as the quickly parameters to disseminate the tsunami warning. In this paper, we analyze the seismic waveform from global network to get $M_{wp}$ and $T_{dur}$ of South-West Coast of Sumatera earthquake. $M_{wp}$ was calculated using automatic and manual phase picking of P phase. The results of this study show a well-analyzed relationship between P wave from automatic and manual picking, $M_{wp}$ and time duration, respectively. The result also give an encouraging studies for the early warning system that will be set up in the future in the region.

Keywords: $M_{wp}$, Rupture, P wave, $T_{dur}$

1. Introduction

Tsunami is one of nature disaster that cause damage in land by generating massive erosion and loss of life in coastal areas. Based on that, a quick and robust tsunami early warning need to be announced earlier before run-up touch the coastline [1, 2, 3]. By fast calculating of seismic waveform, we can spread a quickly report for earthquake parameters which can generate the tsunami [3]. Specific parameters are important to give a decision about tsunami warning for an earthquake that quickly occurred in the subduction zone [4, 5]. The warning give more time to do a mitigation and evacuation. That time is known as the golden time to reduce and minimalize the damage and victims. These parameters is influenced by window length of seismic waveform that started from origin time of earthquake depend on station distance, arrival time of seismic phase and waveform quality They are calculated to get specific parameters like P-wave Magnitude ($M_{wp}$) and rupture duration time.

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Tsuboi et al [9] analyzed the first arriving of P-waves phase to estimate earthquake size accurately and promptly and derived the P-wave moment magnitude. Mwp. Whitmore et al. [10] make a linear comparison between Mwp with Mw to get a correction about Mwp value. Tsuboi et al. [9]make the Mwp by calculating the P-waves phase from far-field stations, but Mwp also can be applied for local and regional even[11,12,13].

Mwp is useful as the initial estimator of seismic moment from large earthquake that can be inferred from the earliest-arriving seismic phase in the far field. Mwp has been implemented and currently constitutes the procedure in use at both the Pacific Tsunami Warning Center (PTWC) and the West Coast/Alaska Tsunami Warning Center (WC/ATWC) for the purpose of estimating earthquake sources for tsunami-genic potential. In other hand, Lomax and Michelini [14] suggested if tsunami early warning can be reported in 3 – 10 mins after origin time with calculating the earthquake rupture duration time (Tdur). Rupture duration has a correlation with rupture length which the most influential parameter and can describe how big the magnitude of an earthquake that caused the tsunami.

In addition, the duration of the rupture, Mwp can be used for tsunami early parameters because of its methods used faster and more stable [9, 10, 13, 14] where the earthquake used was the tele earthquake (300-900). Both parameters use the P-wave phase so that it does not require time long and contains comprehensive information about earthquake event size and source character [16, 17, 18, 19, 20]. In this paper, we present Mwp and Tdur values determined for one big earthquake with Mw 7.7 that occurred in the subduction zone of South-West Coast of Sumatera. This area is very seismically active and mostly many earthquake is generated by thusting system in subduction system. From the result, we get a good linear regression between our Mwp and Tdur [9, 10].

2. Data and Method
We used seismic waveform from tele stations that downloaded from IRIS in Fig (1). The stations distance (dist > 45°) is used to avoid the effect of the lateral heterogenity.

Figure 1. Seismic Stations Location (Blue inverse Triangle) and earthquake epicenter (Red Stars). This is the waveform recording from all stations in distance (45 ° - 80°) in Fig (2).
Figure 2. Seismic waveforms were started in 500 – 700 s after the main earthquake occurred and the body-wave phase P (red circle) and S (blue circle).

Mwp is a magnitude that obtained based on recording analysis of P wave. To produce Mwp, we must obtained the moment magnitude. It takes several steps to produce moment magnitude. Seismogram vertical component in velocity must be convert to displacement by integration. Then, the time domain is transformed to frequency domain with operation Fast Fourier Transform (FFT) so it can be known a corner frequency to determine the upper and lower frequency limit. In the processing, Bandpass butterworth filter is used. Seismic Moment (M₀) is calculated by using Tsuboi et al. [9] with Eq. 1.

\[ M₀ = \left[ \max \left( \int U_z(x, t) \, dt \right) \right] \frac{4\pi \rho a^2 r}{\alpha} \]  

(1)

Then, the displacement signal as a source time function and the integration of the seismic moment derived from maximum amplitude of the P wave is formulated by equation (1). \( U_z(x, t) \) is value of the shift in the vertical component of the P wave for a far earthquake (farfield) at the station \( x_r \).

\[ r = \cos \theta - 1 \sin \theta \sin \theta \sin \phi \cos \phi \]  

(2)

\( \theta \) and \( \phi \) as epicenter latitude and longitude coordinates, \( \theta \) and \( \phi \) as station latitude and longitude coordinates. The actual P velocity wave (apparent P velocity, APV3) is expressed as \( \alpha \). Kanjo et al. [21] changed the method relationship of distance and velocity from the P wave based on the earth model table of IASP91 in equation (2).

\[ \alpha = 0.16 \Delta + 7.5 \text{ km/s} \]  

(3)

Calculation of the moment magnitude using the Kanamori [22] method is mathematically formulated in Eq. 4 as follows:

\[ M_v = \frac{1}{1.5} \left( \log M_0 - 9.1 \right) \]  

(4)
Mwp can be obtained in equation (5) by Tsuboi (1995):

\[ M_{wp} = M_w + 0.2 \]  

Adding a value of 0.2 in calculation of the moment magnitude of P wave (Mwp) to correct the radiation pattern of the propagation P wave to the value of Mwp. Tdur is the overall duration signal or set of dominant P waves from a high frequency seismogram. Tdur is one of the additional parameters in issuing tsunami early warnings. Lomax and Michelini [14] have found that the rupture length parameter of an earthquake is the most dominant parameter linear to rupture duration.

3. Result and Discussion
We investigated the rupture duration of each stations with several ways. First, we investigated the noise artifact and the amplitude spectra with spectrogram visualization in Fig (3).

![Figure 3](image_url) 

Figure 3. Spectrogram on Z component in ULN station and all stations show a good SNR and amplitude spectra.
From looking and investigating the waveform, we gave a bandpass filter (0.1 – 9 Hz) with assuming the P wave very clear. Then, we enveloped to see the amplitude spectra and from that we get the time duration of earthquake by using seismic analysis code [23]. The example processing is showed in Fig. 4 and 5, we compare the close and far stations distance.

**Figure 4.** A multiple plot of PET station which show real recording, waveform with bandpass 0.1 – 10 Hz, the envelope and time duration.

The comparison results in Fig (4) on LBTB station have same pattern of PET station in (Fig (5). The different result is addressed on enveloping graph of amplitude spectra and the window length of earthquake time duration which has bigger value than PET station.

**Figure 5.** An another multiple plot of LBTB station which show real recording, waveform with bandpass 0.1 – 10 Hz, the envelope and time duration.
After calculating the Mwp and Tdur, we compared all result to see the correlation factor. The correlation is analyzed by linear regression to get pearson values which shown in Fig (6) and Tabel 1.

Figure 6. The comparison of all result and regression linear show a relationship between automatic and manual picking of P wave. In Fig 6 (a), the heat matrix correlation show a good and bad values, in Fig 6 (b) and (c), both graph and histogram show the comparison result of linear regression between Mwp and Distance, Mwp and Tdur, Tdur in automatic picking and manual picking, and Pp arrival time with automatic and manual, all relationship perform a well-analyzed result.
Table 1. Result comparison of p-wave time, mwp and mo for all stations.

| Stations | Distance (°) | P arrival time | Pp Auto | Pp Manual | T.dur Auto | T.dur Manual | Sensitivity | Mw moment (m_w) |
|----------|--------------|----------------|---------|-----------|------------|--------------|-------------|------------------|
| LBTB     | 75.2722      | 699.3          | 867.81  | 870       | 168.51     | 170.70       | 7.60E+09    | 7.46             |
| ABKT     | 58.2227      | 590.58         | 719.72  | 730       | 129.14     | 139.42       | 1.72E+09    | 7.48             |
| CASY     | 61.9895      | 616.42         | 753.01  | 770       | 136.59     | 153.58       | 1.02E+09    | 7.51             |
| FURI     | 63.9425      | 629.41         | 770.18  | 765       | 140.77     | 135.59       | 9.56E+08    | 7.71             |
| GNI      | 68.2565      | 657.12         | 807.77  | 850       | 150.65     | 192.88       | 1.06E+09    | 7.48             |
| GUMO     | 46.7459      | 505.51         | 619.55  | 640       | 114.04     | 134.49       | 8.67E+08    | 7.65             |
| PET      | 74.6567      | 695.74         | 862.61  | 810       | 166.87     | 114.26       | 1.06E+09    | 7.51             |
| SBA      | 80.4926      | 728.3          | 911.5   | 890       | 183.2      | 161.70       | 8.38E+09    | 7.52             |
| KMBO     | 64.1654      | 630.87         | 772.13  | 765       | 141.26     | 134.13       | 1.03E+09    | 7.59             |
| ANTO     | 76.6444      | 707.23         | 879.55  | 860       | 172.32     | 152.77       | 9.72E+08    | 7.46             |
| KIV      | 71.2980      | 675.85         | 833.98  | 820       | 158.14     | 144.15       | 1.31E+09    | 7.57             |
| PMG      | 45.6840      | 497.16         | 609.27  | 610       | 112.11     | 112.84       | 1.03E+09    | 7.51             |
| YAK      | 69.7372      | 666.33         | 820.56  | 775       | 154.23     | 108.67       | 1.07E+09    | 7.54             |
| TLY      | 55.9473      | 574.47         | 709.23  | 700       | 134.76     | 125.53       | 1.60E+09    | 7.58             |
| BRVK     | 63.0087      | 623.23         | 761.98  | 760       | 138.75     | 136.77       | 1.03E+09    | 7.47             |
| ULN      | 52.3371      | 548.14         | 673.96  | 660       | 125.82     | 111.86       | 1.06E+09    | 7.35             |
| WMQ      | 49.6137      | 527.66         | 647.41  | 640       | 119.75     | 112.34       | 9.19E+08    | 7.55             |
| KURK     | 58.3377      | 591.38         | 720.74  | 715       | 129.36     | 123.62       | 1.63E+09    | 7.59             |
| ARU      | 69.9802      | 667.82         | 822.66  | 810       | 154.84     | 142.18       | 1.72E+09    | 7.61             |
| ERM      | 59.8222      | 601.67         | 733.88  | 740       | 132.21     | 138.33       | 1.69E+09    | 7.68             |

From Fig (6) and Table 1, we perform a well-analyzed relationship between earthquake magnitude moment of P-Wave with time duration. The results of linear regression imply if the Mwp and Tdur can be used as the quickly parameters to report a tsunami warning and both can calculated from automatic and manual pick for P-wave arrival time. As we mentioned before, the tsunami warning issue is the one of important case to reduce and need to combine with seismic hazard assessment to give a vulnerability for potential earthquake that generate a tsunami. The probability and deterministic analysis of seismic hazard can be used to explain the vulnerability effect of tsunami event [24], explain the seismic system in active faults [25, 26, 27], and also the ground motion prediction equation to disseminate a reliable report of shake map of tsunami earthquake [28, 29, 30] in the future.

4. Conclusion

We perform a well-analyzed results to show an important relationship between Magnitude moment of P-Wave and time duration for quickly report of potential tsunami earthquake. The result of linear regression between Mwp and time duration is very reliable with physical waveform properties and both can be used as the specific parameters to disseminate a quickly report of potential tsunami. Furthermore, seismic hazard analysis and ground motion prediction equation can be used to explain the vulnerability level of the area which close to the source of potential tsunami earthquake in the future.

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