Focal mechanism of the August 18th 2012 Mw6.3 Palu-Koro earthquake and its implication of seismic hazard

Khairina, Fadiyah; Chen, Weiwen; Wei, Shengji; Suardi, Iman

2017

Khairina, F., Chen, W., Wei, S., & Suardi, I. (2017). Focal mechanism of the August 18th 2012 Mw6.3 Palu-Koro earthquake and its implication of seismic hazard. AIP Conference Proceedings, 1857, 050003-. doi:10.1063/1.4987081

<https://hdl.handle.net/10356/89081>

<https://doi.org/10.1063/1.4987081>

© 2017 The Author(s) (Published by AIP). This paper was published in AIP Conference Proceedings and is made available as an electronic reprint (preprint) with permission of the author(s) (published by AIP). The published version is available at: [<http://dx.doi.org/10.1063/1.4987081>]. One print or electronic copy may be made for personal use only. Systematic or multiple reproduction, distribution to multiple locations via electronic or other means, duplication of any material in this paper for a fee or for commercial purposes, or modification of the content of the paper is prohibited and is subject to penalties under law.

Downloaded on 26 Apr 2023 13:14:22 SGT

Focal Mechanism of the August 18th 2012 Mw6.3 Palu-Koro Earthquake and Its Implication of Seismic Hazard

Fadiah Khairina^{1,a)}, Weiwen Chen^{2,b)}, Shengji WEI^{2,c)} dan Iman Suardi^{1,d)}

¹*Sekolah Tinggi Meteorologi Klimatologi dan Geofisika (STMKG), Jakarta, Indonesia*

²*Earth Observatory of Singapore, Nanyang Technological University, Singapore*

^{a)}*fadifadifadi@gmail.com*

^{b)}*weiwen@ntu.edu.sg*

^{c)}*shjwei@ntu.edu.sg*

^{d)}*imansuardi@yahoo.com*

Abstract. The Palu-Koro fault is a left-lateral strike-slip fault in Sulawesi within the active triple junction generated by the ongoing fast convergence of the Pacific-Philippine plate, the Indo-Australian plate and the Sunda plate. There are densely populated areas that are susceptible to earthquakes occur along the fault, and the August 18th 2012, M_w 6.3 earthquake is one of such events. To better understand this earthquake and the seismic hazard in the region, we estimated source parameters of this earthquake using the Cut and Paste (CAP) inversion method with regional broadband waveform data. Our results show that the best solution of this event is 339° , 71° , -16° and 11 km for strike, dip, rake and centroid depth, respectively. Inversions using stations within different distance ranges, i.e. $0-5^\circ$, $0-10^\circ$ and $0-20^\circ$, reveal consistent solutions, suggesting the robustness of our result, which is also in agreement with that from the other agencies, i.e. USGS and Global CMT. We further verify the centroid depth by modeling the depth phases recorded at the teleseismic distance, which also confirm the depth of 11km. Finally we analyzed the Coulomb stress caused by this earthquake and historical events to investigate the interaction between the earthquakes in the region. Our analysis also shows that the unclamping effect from the 1996 Mw7.9 megathrust in the Minahassa Trench promoted the occurrence of the 2012 Mw6.3 event. High slip-rate across the fault and Coulomb stress analysis suggest that more attention should be paid to the segments along the Palu-Koro fault that did not rupture in the previous earthquake circle.

Keywords : focal mechanism, unclamping effect, CAP method, Palu-Koro fault

INTRODUCTION

The August 18th 2012 earthquake occurred in Palu, Central Sulawesi, Indonesia, at about 16:41:53 (local time). According to the reports of Indonesian Meteorology, Climatology and Geophysics Agency (BMKG), the earthquake distance was about 27 km from Parigi Mountong at 120°E and 1.26°S with M_w 6.3 at the depth of 12.5 km (figure 1), this moderate earthquake is the biggest earthquake that recorded in this region. The earthquake caused damage in three districts, ie Lindu, Kulawi and Gumbawa district. Based on the data from Kodam VII / Wirabuwana, 942 homes were damaged and five peoples died in this event. Based on the earthquake's epicenter in the figure 1, shows that the earthquake was caused by the Palu-Koro fault in the Central Sulawesi strike-slip left-lateral fault system. This fault was generated by the activity of the Pacific-Philippine plate, the Indo-Australian plate and the Sunda plate. The Sula block is rotating around a pole at an average speed about $4^\circ/\text{year}$ located at the end of the northern arm of Sulawesi, results 40 mm/year north-south motion along the Palu-Koro fault [1],[2].

The unclamping effects from the Minahasa earthquake (1996-1997) increase the sismicity in the palu-koro fault [3] (figure 2) and the August 18th 2012, M_w 6.3 earthquake is one of the event that triggered by it. We can see in

Figure 1, only four earthquakes were recorded for 30 years before the Minahasa earthquakes, and 10 earthquakes recorded for 19 years after the Minahasa earthquakes.

In order to mitigate the earthquake disaster, it is necessary to study the characteristics of the seismicity in the region. The purpose of this research is to improve the understanding of the source mechanisms of the earthquake in the region and the results are expected to provide important information for the reconstruction after the earthquake.

Fault plane solution can be obtained by several methods, such as geological survey, geodetic observation and inversion or rupture directivity analysis based on seismological data, as has been done by [4] using local waveform inversion, [5] using teleseismic waveform inversion, [6] using joint inversion on local and teleseismic waveform and [7] using joint inversion on geodetic (InSAR) and seismological data. Many algorithms and software have been developed to define source mechanism, one of them is waveform inversion using "Cut and Paste" (CAP) method which first introduced by [8]. Main idea of this method is by separating the body wave and surface wave and then do the inversion on it separately with grid search method. Furthermore, [9] developed the method by removing the normalization so the inversion can be done to the actual amplitude of the data. Normalization is omitted to add constrain which derived from maximum and minimum amplitude.

This earthquake recorded both on the BMKG regional network and the global network. We estimated source mechanism of this earthquake by using cut and paste method for regional and teleseismic data [10], [9].

FIGURE 1. The Palu-Koro earthquakes distribution with a magnitude more than 5 M_w that occurred a) before (1966-1996) and b) after Minahasa earthquakes (1997-2016). (IRIS modified, 2016)

DATA AND METHOD

This earthquake was recorded on the regional and global network. To better understand this event, we used CAP method for regional and teleseismic data. The basic principles of this method is by parting the waveform into body wave and surface wave to invert it independently and using distance range scaling to avoid the domination of the

FIGURE 2. The 18th August 2012 Palu-Koro earthquake (red beach ball) and the stations (orange triangle). a) Distribution of the regional stations (0-20°) and b) distribution of the teleseismic stations (30-90°)

nearest station. Using radial and vertical component for *Pnl* and radial, vertical and tangential component for surface wave for regional inversion and P and SH wave for teleseismic inversion. We didn't use the surface wave for the teleseismic inversion because the surface wave is sensitive to the lateral heterogeneity that make the inversion unstable [11], [12]. The assumption in the waveform inversion are double-couple source mechanism. Synthetic seismogram computed by the equation:

$$S_i(t) = M_o \sum_{j=1}^3 A_{ij}(\phi - \theta, \delta, \lambda) G_j(h, D, t)$$

where, $j=1, 2, 3$ is vertical, radial and tangential components, respectively. $i=1,2,3$ is vertical strike slip, vertical dip slip, and 45° dip slip, respectively. M_o is the seismic moment tensor, G_{ij} is the Green's function; h and D are the depth and distance respectively, A_{ij} are the coefficient of radiation; Φ, θ, δ and λ are station azimuth, strike, dip and rake, respectively [9]. Then the inversion was solved by using grid search method to get the best earthquake parameter model (strike, dip, slip and centroid depth). Before the inversion the data was filter with a long period filtering data, because at the higher frequency the inversion is getting difficult to do. We use the frequency-wave number to get the regional synthetic data [12] and tel3 code to get teleseismic synthetic data from [13]. For the velocity model, we used the PREM (Preliminary Reference Earth Model) by [5].

RESULTS AND DISCUSSION

The earthquake parameter solution (table 1) from the regional waveform inversion is $338-340^\circ$, $82-84^\circ$ and $-13-(-6)^\circ$ for strike, dip and slip respectively, for the nodal plane 1, and $69.4-71.1^\circ$, $77.1-84.1^\circ$ and $171.9-173.8^\circ$ for strike, dip and slip respectively for the nodal plane 2. The best focal depth was at the depth of 12 km with a moment

FIGURE 3. Tectonic setting in the Sulawesi region. Red focal mechanism : inversion results from CAP method, blue focal mechanism : GCMT inversion result for the August 18th 2012 earthquake. Black circle in the black rectangular are the main shock and aftershock of the October 10th 1998 earthquake with a magnitude more than 5 (1999-2016) (Vigny modified, 2002).

magnitude 3.6-3.7 (figure 4 and figure 5). the best depth obtained with the grid search method in the range of 5-20 km with a range of 1 km. Figure 4 a), b), c), d) shows the mismatch plotting against the depth, the smallest error is at a depth of 12 km. It can be seen also that the result of the source mechanism was almost consistent at different depths. The best depth from the teleseismic method was also consistent with the other result ie, 11 km. We believe that our result is reliable because the result from different distance range are consistent and the waveform fits between the synthetic and the observation waveforms can match well (figure 4 and figure 5) and also the size of the amplitude is almost the same. This focal mechanism solution also consistent with other agencies (table 1).

TABLE 1. Earthquake parameters from this method and other agency

	Origin time (UTC)	Lintang/ Bujur (°)	Momen magnitudo (<i>M_w</i>)	Centroid depth (km)	Bidang sesar I (strike/Dip/ Rake) (°)	Bidang sesar I (strike/Dip/ Rake) (°)
BMKG	09:41:53	-1,26/120,13	6,2	10	-	-
USGS	09:41:52	-1,315/ 120,096	6,3	12	70/86/-174	339/84/-4
Global CMT	9:41:56.2	-1,26/ 120,00	6,3	12.5	70/85/-173	339/83/-5
<i>Metode CAP</i>						
0-5°			6.37	12	69.4/77.1/-173.8	338/84/-13
0-10°			6.36	12	71.1/82.1/-171.9	340/82/-8
0-20°			6.36	12	70.8/84.1/-172.0	340/82/-6

Using regional and teleseismic broadband seismic records we get robust point source mechanism solution of the August 18h 2012 Palu-Koro earthquake, which is $338\text{--}340^\circ$, $82\text{--}84^\circ$ and $-13\text{--}(-6)^\circ$ for the nodal plane 1, and $69.4\text{--}71.1^\circ$, $77.1\text{--}84.1^\circ$ and $171.9\text{--}173.8^\circ$ for the nodal plane 2 for strike, dip and slip respectively. Our point source parameters solution are consistent with different distance range and with other agencies ie, USGS and GCMT. the centroid depth of 12 km is also consistent with the teleseismic method. The fault plane with strike of 171° .

- Walpersdorf, A., Rangin, C. and Vigny, C., 1998a. GPS compared to long-term geologic motion of the north arm of Sulawesi. *Earth Planet. Sci. Lett.*, 159, 47±55.
- Stevens, C., McCa rey, R., Bock, Y., Genrich, J., Endang, Subarya, C., Puntodewo, S.S.O., Fauzi and Vigny, C., 1999. Rapid rotations about a vertical axis in a collisional setting revealed by the Palu fault, Sulawesi, Indonesia. *Geophys. Res. Lett.*, 26, 2677±2680.
- Bellier, O., Sbrrier, M., Beaudouin, T., Villeneuve, M., Braucher, R., Bourles, D., Siame, L., Putranto, E., and Pramoto, I., 2001, High Slip Rate for a Low Seismicity along the Palu Koro Active Fault in Central Sulawesi (Indonesia). *Blackwell Science Ltd, Terra Nova*.13.463– 470.

4. Chester, F.M., and Chester, J.S., 2000, Stress and deformation along wavy frictional faults, *J. Geophys. Res.*, 105(B10), 23421–23430, doi:10.1029/2000JB900241.
5. Dziewonski, A.M., and Anderson. D.L., 1981, Preliminary reference Earth model. *Phys. Earth Plan. Int.* 25:297-356.
6. Vigny, c., Perfettini, H., Walpersdorf, A., Lemoine, A., Simons, W., Loon, W., Ambrosius, B., Stevens, C., McCaffrey, R., Morgan, P., Bock, Y., Subarya, C., Manurung, P., Kahar, J., Abidin, H.Z., and Abud, S.H., 2002, Migration of seismicity and earthquake interactions monitored by GPS in SE Asian triple junction: Sulawesi, Indonesi, *Journal of Geophysical Research*, Vol : 107, No : B10, 2231, doi:10.1029/2001JB000377,2002
7. Zhan, Z., Helmberger, D., Simons, M., Kanamori, H., Wu, W., Cubas, N., Duputel, Z., Chu, R., Tsai, V., Avouac, J., Hudnut, K.W. , Ni, S., Hetland, E., and Culaciati F., 2012, Anomalous Steep Dips of Earthquakes in the 2011 Tohoku-Oki Source Region and Possible Explanations, *Earth Planet. Sci. Lett.*, 353, 121–133.
8. Wei, S., Ni, S., Zha, X., Wang, Z., and Helmberger, D., 2011, Source Model of 11th July 2004 Zhongba Earthquake Revealed from The Joint Inversion of InSAR and Seismological Data, *The seismological society of China and Springer-Verlag Berlin Heidelberg*.
9. Dequan, H., Xingzhou, W., Libo, H., Hao, Q., and Bing, Z., 2012, Focal Mechanism Solution of the 2011 M_z 4.8 Anqing Earthquake Determined from the CAP Method,
10. Suardi, I., 2013, Analysis of Source Rupture Process of the September 2, 2009 Tasikmalaya Earthquake by using The Joint Inversion Method of Near Field and Teleseismic Data, *Disertasi*, Program Doktor, Institut Teknologi Bandung, Bandung.
11. Zhao, L.S., and Helmberger, D.V., 1994, Source Estimation from Broadband Regional Seismograms, *Bull. Seismol. Soc. Am.* 84, no. 1, 91.
12. Zhu, L., and Helmberger, D.V., 1996, Advancement in Source Estimation Techniques Using Broadband Regional Seismograms, *Bull. Seismol. Soc. Am.* 86, no. 5, 1634.
13. Zhu, L., and Rivera, L. A., 2002, A Note on the Dynamic and Static Displacements From a Point Source in Multilayered Media, *Geophys. J. Int.* 148, no. 3, 619–627.