Seismicity around Cirata Dam, West Java, Indonesia based on BMKG local seismic network

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Abstract. The addition of seismic stations to the seismic network of BMKG in 2019 has successfully located some local earthquakes. In the early 2020 occurred significant earthquakes around Cirata Dam, West Java. During a period of January-March 2020, there have been 5 earthquakes with magnitude ranging from 1.8-3.7. Those earthquakes caused ground shaking up to III MMI intensity scale around the epicenters area. The relocation of the hypocenter using the Teleseismic-OD method is applied in this study so that the data can be interpreted to show the fault geometry in this area. The relocated epicenters distribute in the east side of the dam elongated in SSW-NNE direction. Vertical distribution of relocated hypocenters show that the earthquake occurred at 1.1 km down to 14.5 km depth. Hypocenter depths are getting deeper to the north direction, this suggest dip orientation of the fault plane. The reconstructed dip orientation is consistent with nodal plane resulted from moment tensor inversion results, that shown fault planes oriented in N 229° – 272° E direction and dip 49°–50° to the north direction.

1. Introduction

Due to the subduction of the Indo-Australian plate beneath the Eurasian plate along Java Island, it caused stress transfer to the island and produced some active faults. In the West Java area, there are Cimandiri Fault [1], Lembang Fault [2], and Baribis Fault [3]. The latest GPS study indicate an active Kendeng-Baribis fault that extent from Central Java to the south of Jakarta [4]. Beside of those faults, we suspected other active faults in West Java. One of them is Cirata Fault. The fault should also be considered as hazard source in West Java area. Figure 1 showing the area of this study and active faults in West Java. Moreover, the Cirata Dam was built above this hazard zone. Cirata Dam is the main infrastructure for power plants, fisheries, irrigation as well as tourism object.

In the early 2020, between January-March there were five earthquakes occurred around Cirata dam area. Those earthquakes were significant events because they caused earth shocking up to III MMI (Modified Mercalli Intensity scale) around the epicenter area. The denser seismic station network of BMKG has provided more proper data to be used for this study. This study is intent to reconstruct fault geometry in this area. Strike and dip orientation of a fault are very important parameters as an input for further seismology studies such as surface rupture estimation, deterministic or probabilistic seismic hazard analysis. This study will also contribute to complete active fault database in Indonesia, especially West Java.
Figure 1 Earthquake hazard zone related to active fault distribution in West Java modified from the previous paper [5]. Research area located in the Bogor-Puncak-Cianjur earthquake zone (red square).

2. Data and Methods
This study used preliminary hypocenter data of the BMKG earthquake catalog. The preliminary hypocenter data were determined using the LOCSAT program [6] and global velocity model IASPEI91 [7], which are integrated in Seiscomp-3 seismic processing program. We then relocated hypocenters using Teletomo-DD [8] using the 3D velocity model for Indonesia region and the 1D velocity model for outside Indonesia [9–11]. Relocation processes were held simultaneously for all seismic events in Indonesia[12].

Moment tensor inversion was applied to selected events using the SCMTV program that included in the Seiscomp-3 seismic processing package. Stable inversion for the complete moment tensor algorithm [13] was used for moment tensor inversion. Green’s function was calculated using GEMINI [14] based on the PREM velocity model [15].

3. Results and Discussions
Epicenters of both preliminary and relocated ones distributed around the east side of the dam (Figure 3). Uncertainty of relocated epicenters location varied from 519.4 – 1033 meters for East-West and 280.0 – 437 meters for North-South direction (Table 1). Those results show a majority of those parameters is less than 1.0 km such as shown in Table 1. Relocated hypocenters show a significant shift in vertical distribution (Figure 4). The depth of preliminary hypocenters was ranging from 10 to 17 km. After relocated, hypocenters shifted to shallower crust between 1.1 – 14.5 km depth, with uncertainty ranging from 462.6 – 956.9 meters. Hypocenter parameters are show in Table 1. Relocated hypocenter depth of the two events (M3.5 and M3.7), are also shallower than depth determined by moment tensor inversion (Figure 4). This distinction caused by different velocity model that is used for hypocenters relocation and moment tensor inversion.

Moment tensor inversion were conducted for the two events: M3.5 and M3.7. The results are focal balls that indicate thrust oblique and strike-slip oblique mechanism. Those focal balls show that fault planes are elongated to south west and west direction and dip angle varied from 49° to 75° (Table 2). The centroid depth of those events are 8 km and 4 km and the resulted magnitude moment are Mw3.3 and Mw3.5. An example of the moment tensor inversion result of the January 14th, 2020 event is shown
in Figure 2. The plot of depth vs fitting of observed and synthetic seismogram was best fit at 8 km depth and Mw 3.3.

**Table 1** Comparison of hypocenter depth for preliminary, relocated and moment tensor inversion (CMT). EX, EY and EZ are uncertainty of relocated hypocenters for East-West, North-South, and vertical direction.

| Event Date | Origin Time (UTC) | Lon  | Lat  | Error (m) EX | Error (m) EY | Error (m) EZ | Depth (km) PDE | Depth (km) Reloc | Depth (km) CMT | Mag |
|------------|-------------------|------|------|--------------|--------------|--------------|----------------|----------------|----------------|-----|
| 14-Jan-20  | 20:16:07          | 107.33 | -6.76 | 1033.0       | 713.8        | 462.6        | 10             | 2.2            | 10             | 3.5 |
| 11-Mar-20  | 14:51:49          | 107.34 | -6.69 | 417.7        | 280.8        | 727.2        | 11             | 5.3            | -              | 2.3 |
| 11-Mar-20  | 15:50:14          | 107.36 | -6.69 | 488.6        | 511.2        | 665.4        | 17             | 14.5           | -              | 1.8 |
| 16-Mar-20  | 2:09:17           | 107.35 | -6.73 | 519.4        | 437.0        | 956.9        | 10             | 3.3            | -              | 2.4 |
| 20-Mar-20  | 14:41:31          | 107.35 | -6.74 | 630.5        | 607.5        | 656.4        | 10             | 1.1            | 4              | 3.7 |

**Table 2** Moment tensor inversion results of selected earthquakes M3.5 and M3.7

| Event Date | OT(UTC)   | Lon  | Lat  | Depth (km) | Mw  | Strike, Dip, Rake of NP1 | Strike, Dip, Rake of NP2 |
|------------|-----------|------|------|------------|-----|-------------------------|-------------------------|
| 14-Jan-20  | 20:16:07  | 107.33 | -6.76 | 10         | 3.3 | 142, 52, 125             | 272, 49, 52             |
| 20-Mar-20  | 14:41:31  | 107.35 | -6.74 | 4          | 3.6 | 126, 75, 138             | 229, 50, 20             |

**Figure 2** Moment tensor inversion result of the 14 January 2020 event. The plot of depth vs seismogram fitting shows the best result at 8 km depth and Mw3.3.
**Figure 3** Seismic events distribution around Cirata Dam. Red dots are preliminary results. Yellows dots are relocated epicenters. Beach balls show focal mechanism of M3.7 and M3.5 events. The white line from A to B is section line in Figure 4. Topographic were drawn using DEMNAS 0.27 ArcSecond[16].
Epicenters distributed in line from PasirCabe, Cipeundeuy, to Plered along with SSW – NNE direction (Figure 3). The fault plane solution from CMT inversion consists of a couple of planes that elongated to WSW – ENE direction. Therefore, the lineament of epicenters distribution does not represent strike direction of the fault because they are perpendicular to the fault strike. The mechanism of the Cirata Fault was different from the fault mechanism of the Cimandiri Fault as well as the Lembang Fault. The Cimandiri Fault around the Cianjur segment and the LembangFault showing a left lateral movement[17] while the Cirata Fault shows thrust oblique mechanism.

Previous research showed that there were three microearthquake zones around the Cirata Dam with depth shallower than 10 km. The distribution of those microearthquakes indicated three fault zones, those are the Citarum-Cisomang Fault, the Saguling Fault, and the PasirCabe Fault. Those faults have the potential to generate an earthquake up to M 7.0[18]. This study shows that relocated hypocenters below PasirCabe are shallower than hypocenters below Citarum-Cisomang Fault. On the other hand, PasirCabe could be the up-dip part while Citarum-Cisomang could be the down-dip part of the same fault plane. We then interpolated a fault plane along distributed hypocenters (Figure 4). The result is a dashed black line that is going deeper to the NNE direction. We also extrapolated the fault line from two focal balls (Figure 4) represented by dashed red lines. The extrapolated line are agree with the fault plane interpolated from hypocenters. Except they are different in-depth, yet the both showing a similar trend and they are represented the plane of Cirata Fault. Based on the cross-section in Figure 4 the length of the interpolated line is around 16 km. This length represents the width of the fault. By using the empirical relation of earthquake and fault size [17] the width of the fault is proportional to Mw6.6 earthquake. Magnitude estimation from this study is smaller than M 7 that approximated by the previous study. Even though a Mw 6.6 earthquake with shallow depth can also cause significant damaging.

Figure 4 Vertical section of seismicity. Black circles are preliminary hypocenters. Black dots are relocated hypocenters. Beach balls showing focal mechanism of M3.7 and M3.5 events. Black dashed line is reconstructed fault plane interpolated from relocated hypocenters. Red dashed lines are fault plane extrapolated from focal mechanism. Topographic section (blue line) were drawn using DEMNAS 0.27 ArcSecond[16] exaggerated 5 times for its vertical scale.
4. Conclusions
Vertical relocated hypocenter distribution clearly shows a trend related to the structural geology of the region. This trend shows an inclined fault plane to the north direction. The interpretation is also supported by the reconstruction of the fault plane extrapolated from the focal mechanism. Seismic events occurred at the up-dip part, down-dip part, and in between along the fault plane. The seismicity of this region probably caused by a single fault that is the Cirata Fault rather than three fault zones. Although this study has limitation on hypocenters data along strike direction, this study complements previous studies where the direction of the fault plane has not been resolved.

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