Cimandiri Fault Identification Using Earthquake Tomography Double-Difference Method

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Abstract. Cimandiri Fault is one of major faults in West Java, which has a considerable potential hazard to the surrounding populated area. Therefore, it’s important to have a better understanding about the fault in order to improve disaster mitigation effort in Indonesia. This study is done to identify the Cimandiri Fault based on tomography earthquake data. The recorded data of 290 events were acquired from 15 BMKG seismograph stations located in the vicinity of study area. All events have a total of 2,895 phases consisted of 2,072 P-wave phases and 823 S-wave phases. The method used in this study to produce images beneath the surface of Western Java is double-difference travel time seismic tomography. Inversions were performed using the TomoDD algorithm to image seismic velocity models with horizontal variations from Banten Province and West Java. The final results of this study show the existence of Cimandiri Fault located in the southern part of West Java and extends with direction of North East-South West through Pelabuhan Ratu until it reaches the ocean in the south of Banten.

1. Introduction
Western Java is one of the regions in Indonesia that is still experiencing active deformation due to the tectonic plate activity that occur beneath the surface of Indonesia [1]. These tectonic activities produce three active faults, and one of them is Cimandiri, which is located in highly populated areas such as Pelabuhan Ratu, Sukabumi, and Bandung Area, as shown in Figure 1 [2, 3]. Febriani in 2016 [3] have done a study regarding earthquake activities around Cimandiri Fault zone and indicated that the area is dominated by M > 3 earthquakes at shallow depth and might be associated with the activity of Cimandiri Fault zone.
Cimandiri Fault has taken major roles in shaping the current geological condition in West Java region throughout the histories, though its activities may inflict great damage to the population in the area. Therefore, it’s important to have a better understanding about the presence of the fault in order to anticipate the negative effect of the activated fault.

2. Data and Method

The data used in this study are the recording data of Meteorological, Climatological, and Geophysical Agency of Indonesia (BMKG) seismograph network with a total of 15 stations which are divided into 3 stations located in Banten, 4 stations located in Lampung, and 8 stations located in West Java (Figure 2). This study uses data records for 15 months starting from December 1, 2017 to February 21, 2019.

Data processing in this study uses arrival time picking results catalog of P waves and S waves from waveform data signal recording from BMKG. The total data used is 290 events (Figure 2) data that are located in between 05°57’ S - 07°41’ S and 105°20’ E – 107°20’ E. The phase recorded were a total of 2.895 phases in the form of 2.072 P phases and 823 S phases.

The method used in this study to image the velocity structure beneath West Java and Banten area is seismic double-difference tomography. This method has been used in several studies to image the structure beneath some area such as Hayward Fault in California [4], and the velocity structures in Central Java [5].

Figure 1. The location of Cimandiri Fault zone and regional geology of the study area. (1) quaternary volcanics, (2) alluvial plain, (3) Bogor zone, (4) dome and ridge in Bandung zone, (5) Bandung-Cimandiri zone, (6) southern mountains, and (7) trace of Cimandiri Fault [3].
This study used the TomoDD algorithm by Zhang and Thurber in the inversion process [4]. TomoDD algorithm used absolute data in the form of travel time catalog data for every events. Inversion process in TomoDD algorithm combines absolute data with differential data. The differential data pairs events with certain criteria as a part of double-difference calculation, so the travel time can be more accurately corrected. This method can provide events location and velocity structure with higher accuracy than other tomography method that only uses absolute data [6].

3. Results and Discussion

After the relocation process, there are 270 of 290 events successfully relocated, with 20 events relocated outside the grid area. In TomoDD, the events which are relocated outside the grid after the inversion are not included in further inversion process. These results give a justification that there are improvements in the data quality, that can be seen in the residual value. Before relocation process, the travel time residual value is between -4.4 to 4.3 seconds. After the relocation, the residual value has been reduced to between -1 to 1.3 seconds. Comparison of travel time residual graphs before and after relocation are shown in Figure 3.

The relocation results showed that there are some hypocenter points grouped in the South of Banten (Figure 4), precisely at Pelabuhan Ratu and has South West to North East direction. These relocated hypocenter points might indicates earthquake hypocenter caused by Cimandiri Fault activity which has same location and direction.
Figure 3. Travel time residual graphs (A) before relocation and (B) after relocation.

Figure 4. Map showing earthquake events epicenter (A) before relocation and (B) after relocation. Blue dots indicates shallow earthquake events with $Z < 60$ km and red dots indicates intermediate earthquake with $60$ km $< Z < 300$ km.

Horizontal cross-section tomogram shows the $V_S$ value (in percent perturbation) for depths of 0 km, 20 km, and 40 km from mean sea level (Figure 5). At the depth of 20 km, there is a density contrast in $V_S$ tomogram. These result can be associated with the existence of fault in this area, that is suspected to be Cimandiri Fault. The result of earthquake relocation in this area also support this argument by showing the hypocenter position grouped in the Southern region of Banten and heading North East with a trend resembling Cimandiri Fault.

The area with low $V_S$ value in the $V_S$ tomogram for 20 km depth indicates the part that falls on a fault. On the contrary, the area with high $V_S$ value indicates the part that rises on a fault. This condition is in accordance with Haryanto et al. [7] that there are regional normal faults along the Cimandiri Fault line caused by reduced compression tectonics on the Island of Java in the Early Quarter.

At the depth of 0 km and 40 km we cannot see the difference in $V_s$ value that can indicates the existence of Cimandiri Fault. This results matched the condition in Java region where the average crustal thickness only ranges from 37 km to 39 km while more than that are estimated to be Moho [8].
Figure 5. Horizontal cross-section $V_S$ tomogram for three depth variation with relocated earthquake hypocenter (red dots). Black line showing the rough trend of Cimandiri fault according to relocation result and velocity contrast.

This identification result of Cimandiri Fault shows similarities with studies conducted in this study area, for example, the study conducted by Febriani et al. [9] using CSAMT method to obtain the image of the western part of Cimandiri Fault. The study showed the presence of conductive and resistive zone which characterizes the western part of Cimandiri Fault in the same area as the study we have done.

Compared to other studies using TomoDD method in different areas, the detail of cross-section image (Figure 5) needs more improvement. Zhang and Thurber [4] tested the TomoDD method along Hayward...
Fault and gained velocity structure which is sharper compared to standard tomography. Allam et al. [10] also managed to obtain a sharp velocity contrast in the San Jacinto fault zone, California. Those results can be obtained because both studies used a lot of events that are more concentrated. With that being said, deeper understanding about the structure of Cimandiri Fault can be attained with more detailed events data in the study area.

4. Conclusion
The data acquired for seismic tomography study is located in West Java and Banten region and have succeeded to produce velocity maps with depth variations in the study area. The results produced in this study are able to image the velocity anomaly which resembles Cimandiri Fault only in the depth of 20 km from mean sea level. The strike of the fault is North East – South West. For future work, the tomography inversion process shall be conducted in a more detailed depth with interval about ±5 km to ±10 km to produce more precise depiction of Cimandiri fault.

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