Fault Plane Estimation Through Hypocentres Distribution of the July-August 2018 Lombok Earthquakes Relocated by using Double Difference Method

M S Rosid¹, R Widyarta¹, T Karima¹, S K Wijaya², and S Rohadi³
¹ Geophysics, FMIPA Universitas Indonesia, Depok 16424 Indonesia.
² Physics Departement, FMIPA Universitas Indonesia, Depok 16424 Indonesia.
³ Research and Development Center, Meteorological, Climatological, and Geophysical Agency (BMKG), Jl. Angkasa 1 No. 2, Kemayoran, Jakarta, Indonesia.
Email: syamsu.rosid@ui.ac.id

Abstract. Indonesia is actually located in collisions between three large plates of Eurasia, Indo-Australia, and Pacific. It causes earthquakes to occur frequently in several regions, one of which occurs sequentially the 5 big shocks in Lombok in period of July-August 2018. There is a Flores thrust fault in the North of the Lombok Island region. The objective of study is determining whether the earthquakes sequence is related to the fault. The study is done through the analysis of relocated 321 of 489 hypocentres of the earthquakes acquired from 13 BMKG stations in July-October 2018. The hypocentres are relocated by using the double-difference method. The events are focused only with magnitude > 3.5 M. The relocation result is validated by the RMS residual histograms with the average value close to 0. The results show that the seismic activity mostly spread in the northern part of the Island of Lombok. The distribution of the epicenter points tends to form a pattern oriented from West to East in the northern region of the island which is thought to be the zone of the faults. The events most likely have not generated and not laid along the Flores Fault.

1. Introduction
Bali, Lombok and the Islands of Nusa Tenggara are one of the regions in Indonesia that have a high level of vulnerability to earthquakes. One source of the earthquake that has been identified is an earthquake originating from a subduction zone in the South of Indonesia [1]. This zone originates from collisions between the Indo-Australian plate (South) and Eurasia (North). Other causes of earthquakes can also come from the movement of fault structures in the earth. Such events that occur in this region are earthquakes in the Lombok region, Nusa Tenggara in July-August 2018. From the data of the National Disaster Management Agency (BNPB) there are ± 555 people died and material losses worth ± 5.04 trillion rupiahs. The earthquake is indicated to occur due to the movement of the thrust fault in the northern part of the island arc [2].

To analyze and prove the seismicity caused by tectonic activities as in the Lombok case, it is necessary to determine the exact location of the hypocenter point. One technique to relocate earthquake hypocenter points is the double-difference method. The data used in this method is wave travel time data between pairs of earthquake events with observer stations. The principle of this method assumes that if the distance between two paired earthquakes is relatively small compared to the distance between each earthquake and the paired observer station, then the raypath and the second waveform are
considered almost the same [3]. Thus the velocity model error can be minimized without using station correction [4]. The purpose of this study is relocating the hypocenter point of the Lombok 2018 earthquake using the double difference method and to find out the estimated of the fault structure from the hypocenter distribution pattern. This study, therefore, can be used as a parameter for subsequent earthquake mitigation analysis.

2. Data and Methodology

The hypocenter relocation method used in this study is the double difference. The method runs to minimize the residual travel time of calculations and observations. The data used in the study are 1086 earthquakes obtained from BMKG catalog from July 1, 2018 till Sept 15, 2018 with magnitude 3.5 - 9 M and depth 1-150 km. The study area in Lombok, Nusa Tenggara located in -6.62 S – 9.83 S and 113.12 E - 122.6 E. The study results is validated by looking at the value of residual histogram where the difference between travel time calculation and observation is small.

Double difference method assumes if there are two adjacent earthquake events, with smaller distances between events compared to the distance between the two events to the recording station, it is considered raypath these two events tend to be the same [5]. Travel time difference between two events recorded at the station is a function of distance between earthquakes. The difference in travel time of observation and calculation of two events is called residual time, which is written in the form:

\[ d_t^{ij} = (t_k^i - t_k^j)^{\text{obs}} - (t_k^i - t_k^j)^{\text{cat}} \]  

(1)

The equation above is the double difference equation, which \( t_k^i \) is the first term of observation travel time for two event \((i,j)\) in \(k\) station and the second term is for the calculation travel time. The processing of this method is run by HypoDD software.

3. Results and Discussion

The results of the earthquake hypocenter relocation indicate a change in the location of the coordinates of both the latitude, longitude and depth. The new hypocenters are different from the hypocenter coordinates before relocated. The changes of locations are clearly seen in the epicenter map. The results indicate that the distribution of relocated epicenter is probably closer to the geological interpretation of the study area.

Figure 1 shows the distribution of epicenter point of the earthquake which is divided based on depth parameters. Red points indicate shallow depth events (<60 km), yellow indicate moderate depth (60-300 km) and green indicate deep depth events (> 300 km). It can be seen that if the epicenter point is seen approaching the area that is suspected to be the fault line, the epicenter point forms an East-West oriented pattern (yellow circle in Figure 1b). Then if we look further at the vertical sections (see Appendix 1), it can be seen that before the data is relocated, the distribution of hypocenter spreads at a depth of 10 km, which is an effect of recording data that is less than perfect or commonly known as fixed depth. After relocation, the distribution of the hypocenter becomes more diffuse and can be more interpreted. It can be seen if the hypocenter distribution (of mainshock and aftershock) that had been clustered at a depth of 10 km began to spread and form a pattern or trend (yellow circle) which is assumed to be shaped like a structure that slopes towards the south (Figure 3).

Figure 2 shows a graph of comparison histogram between residual values before and after the relocation process. The residual value is the difference in travel time between the travel time of observation and the travel time of calculation. In the graph, the residual value of the relocated event is mostly displayed close to 0 (more toward the middle). It really different from the residual value of events before the relocation process where there is still a lot of data with high residual. The residual value close to 0 can be interpreted that the difference time of observation and calculation is not much different, which means that the relocation results are good [6].
Figure 1. Epicenter distribution from the July-September 2018 Lombok earthquake data (a) before and (b) after relocation. The events are dominated by shallow earthquake and tends to spread in east-west orientation.

Figure 2. The histogram of residual value before and after the relocation process.

From the series of figure in the appendix and Figure 3, appear that most of the events occur around the line of BB', CC', and DD'. Along the line AA' and EE' only quiet seismicity. The hypocenter trend here indicates a thrust fault with the dip to southwards. This is clearly visible on the section of CC' and DD'. From a hypocenter spread, the alleged fault was at a depth of several km to 50s km. This fault
plane seems next to the north Island of Lombok and in the south of Thrust Flores Fault and tends to align with the Flores Fault.

Figure 3. The vertical section at the BB’ line shows the hypocenter distribution (a) before relocation and (b) after being relocated.

4. Conclusion
The results of the relocation Lombok earthquake data that are taken from July 1 to October 15, 2018, show the seismic activity occurring in the study area mostly spread in the northern part of the Island of Lombok. Mostly the shallow epicenter points are gather to form a pattern oriented from West to East which is thought to be the zone of the presence of fault plane. The active faults most likely in the northern region of the island as a local fault rather than a tectonic fault.

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Appendix

The section of hypocenter distribution map before-after relocation along line of AA’, BB’, CC’, DD’ and EE’ of Figure 3.