Determination of Shear Wave Splitting Parameters in 2018 Lombok Earthquake Using Rotation Correlation Method: Preliminary Result

Annisa Trisnia Sasmi*, Andri Dian Nugraha, Muzli Muzli, Sri Widiyantoro, Zulfakriza Zulfakriza, Shengji Wei, David P Sahara, Nanang T Puspito, Awali Priyono, Haunan Affi, Pepen Supendi, Daryono Daryono, Ardianto Ardianto, Devy Kamil Syahbana, Yayan Mi'rojul Husni, Billy S Prabowo, Kadek Hendrawan Palgunadi, Achmad Fajar Narotama Sarjan

1 Geophysical Engineering, Faculty of Mining and Petroleum Engineering, Institut Teknologi Bandung, Bandung, Indonesia
2 Global Geophysics Research Group, Faculty of Mining and Petroleum Engineering, Institut Teknologi Bandung, Bandung, Indonesia
3 Earth Observatory of Singapore/Asian School of the Environment, Nanyang Technological University, Singapore
4 Meteorology, Climatology, and Geophysics Agency (BMKG), Jakarta, Indonesia
5 Faculty of Engineering, Maranatha Christian University, Bandung 40164, Indonesia
6 Center for Volcanology and Geological Hazard Mitigation (PVMBG), Bandung, Indonesia
7 Meteorology, Climatology, and Geophysics Agency (BMKG), Bandung, Indonesia
8 Laboratory of Volcanology and Geothermal, Faculty of Mining and Petroleum Engineering, Institut Teknologi Bandung, Bandung, Indonesia
9 Physical Science and Engineering, King Abdullah University of Science and Technology, Saudi Arabia

Corresponding author’s email: trisnia24@gmail.com

Abstract. Shear-wave splitting (SWS), or the propagation of two independent shear waves, can be used as an indicator of seismic anisotropy. In this study, we utilize this concept using aftershock data of the 2018 Lombok earthquake which had been acquired in period of August 4 – September 9, 2018. The goal of this research is to better understand the crack distribution related to the rupture zone of the 2018 Lombok earthquake. After applying instrument correction to the data, the waveform data were then windowed in each P and S arrival time. To determine the SWS parameters, we performed rotation in each horizontal seismogram component. The horizontal components were rotated from azimuth 0° to 180° with an increment of 1°. Cross-correlation coefficient (CCC) was determined for each rotation angle. The polarization direction and the SWS delay time were chosen from the parameters shown in the highest value of CCC.
Keywords: Shear Wave Splitting, 2018 Lombok Earthquake, Seismogram Rotation, Cross Correlation

1. Introduction

Lombok Island is one of the islands in Indonesia, which is located in the border area between the Sunda Arc and the Banda Arc. The seismicity condition of Lombok Island is controlled by two tectonic settings around the area, including: the megathrust trench in the south of Lombok Island [1,2], and the Flores Back Arc Thrust / FBT system in the north [1,2,3]. In addition, Lombok Island is flanked by the Lombok Strait Strike Slip Fault in the west, and the Sumbawa Strait Strike Slip Fault in the east [4]. Some researchers also suggest a submerging structure in the north of Lombok Island called Flores Oceanic Crust / FOC [4, 5, 6, 7, 8]. The implication of the complexity of this tectonic feature is the vulnerability of Lombok Island to earthquakes. Seismic activity on the island of Lombok also has been recorded since 1856 [9].

On July 29 2018, an earthquake measuring M 6.4 hit Lombok Island [10]. A series of significant earthquakes reoccurred on August 5 (M 7.0), August 9 (M 5.9) and August 19 (M 6.3 and M 6.9), with earthquake intensity on the VIII-IX MMI scale [11]. BMKG [10] reports that the hypocenter of these significant earthquakes is mostly located in the north of Lombok Island. This disaster caused 564 causalities, with the most victims were reported in the North Lombok Regency area [12].

A number of studies have been conducted to explain the mechanism of the 2018 Lombok earthquake. Based on the location of the hypocenter, the main earthquakes on August 5, August 9 and August 19, were shallow earthquakes with a depth of less than 35 km [7, 13]. The significant earthquakes that had occurred several times were thought to be the result of segmentation of the rupture that was formed before the emergence of the earthquakes with strong magnitudes [7, 14]. As a result of the 2018 series of earthquakes in Lombok, a deformation occurred in the north of Lombok Island [15], causing an uplift of 70 cm [16]. However, more detailed information regarding the rupture of these significant earthquakes (such as the orientation and distribution of the crack in the rupture zone, as well as the direction of slip movement) is still not well defined.

The presence and orientation of cracks in an area can be analyzed using the SWS concept. Splitting or polarization of shear waves occurs when shear waves propagate through an anisotropic medium, one of the causes is a fractured zone. This process produces orthogonal polarization of shear fast and slow waves which are separated based on the characteristics of the delay time. SWS using local station network data has been applied to study the faulting system in the 1995 Kobe earthquake [17]. Parameters that are also generated using the SWS method are shear wave anisotropy parameters in rocks (K). Seismic anisotropy is defined as the variation in seismic wave velocity with respect to direction [18]. The anisotropy properties are caused by 3 things: (i) laminations that occur in rocks, (ii) orientation of minerals, (iii) fractures and microcracks [19]. The SWS tomography study has been applied by [20] to determine the distribution of anisotropy (K) values in the active fault region.

In this study, to explore the explanation of the 2018 Lombok earthquake rupture, SWS was conducted by utilizing data from 16 local seismographic stations which had been installed in the Lombok Island region on August 4 to September 9 2018. This study is expected to provide detailed information about the crack orientation in the Lombok rupture zone and its spatial distribution.

2. Data and Method

To perform the Shear Wave Splitting (SWS) analysis, the earthquake waveforms used in this study were recorded via 16 temporal seismographic network from ITB and EOS / NTU. The seismographic network was installed on June 5 to September 9 2018 with the configuration as shown in Figure 1. The location of earthquake hypocenters had previously been determined [7].
Figure 1. The location of station distribution (inverted blue triangles) and earthquake hypocenters used in this study. The yellow stars show the location of the significant earthquakes from [7]: (August 9 [M 5.9], August 5 [M 7.0], and August 19 [M 6.3 and M 6.9]); The diamond symbol depicts the mainshock of July 29 [M 6.9] event. The color scale represents the earthquake focal depth.

The SWS technique is carried out to determine the propensity of the cracks distribution which were formed during the earthquake series. This process is applied to determine the delay time (dt) and polarization angle (φ) between the two pairs of S-phase wave, that is, $S_{fast}$ and $S_{slow}$. This process is applied to the local network data. There are several stages of routine data processing that have to be prepared before performing a SWS analysis, including the selection of waveform data, equalization of sampling frequency, and instrument correction. In the data selection process, we filter the data as following: the data must be recorded by a minimum of three seismometer stations; the data has a complete seismometer component (vertical, E-W, N-S); and has a high signal-to-noise ratio on S-phase waveform. The $S_{fast}$ and $S_{slow}$ dominant frequency were determined by using the Short Time Fourier Transform (STFT). The next process is determining the SWS parameters by applying the rotation-correlation method [21].

3. Result and Discussion
A total of 2,619 aftershocks events have been identified for the S phase for further SWS analysis. From these events, the number of S phases that met the criteria was 14,249. The number of phases read at each station can be seen in Figure 2. The windowing process using STFT had been applied to determine the dominant frequency of each $S_{fast}$ and $S_{slow}$ phase. This process was applied to determine the dominant frequency of the 0.4 s wavelength sample picking area. Then, the dominant frequency was used to set the length of the signal period. This period length then will be used to perform the cross-correlation between two signal, $S_{fast}$ and $S_{slow}$.
The determination of the polarization angle and SWS delay time was performed using cross-correlation between the two waveforms that have been rotated into radial and transversal directions (Figure 3). We vary the rotation angle between 0° and 180° with an increment of 1°. Meanwhile, the value of the delay time used in this study has a range from 0 to 0.2 s with an increment of 0.01 s. The reason for using this increment is that the sampling rate used in this study was 0.01 s. Based on these two parameters, a correlation contour will be formed as shown in Figure 4. The value of delay time and the angle of polarization can be found in the highest contour of every pair of $S_{fast}$ and $S_{slow}$. This process is still continuing to obtain all of the $dt$ and the polarization angle value of every S event.

**Figure 2.** Number of S phase distribution at each seismograph station

**Figure 2.** a). An example of cropped waveform (from LM09 station) before rotation; b). Waveform after rotation from station LOM-09; c). Hodogram before rotation; d). Hodogram after rotation.
Figure 3. Contour of rotation-correlation between a pair of S phase in LM09 station. The color scale bar depicts the cross-correlation coefficient (CCC). The highest coefficient value is depicted by the black diamond symbol, and shows that the polarization angle of the event pair is 38° with a delay time of 2.4 s.

4. Conclusions
A number of 14,249 S-phase events of 2,619 Lombok aftershock events had been determined to conduct SWS analysis. The windowing process of $S_{\text{fast}}$ and $S_{\text{slow}}$ had been implemented using STFT as a benchmark in rotation-correlation process. The rotation-correlation process was applied using a range of 1°-180° polarization angle, and the highest correlation value shows the delay time and polarization angle of a pair of S phase event. This process will be applied to all of the data in the future in order to investigate the anisotropy of the study area in detail.

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