Identification of Fracture Density and Orientation at "R" Geothermal Field Using Shear Wave Splitting Microearthquake Method

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Abstract. Identification of permeable zones is an important aspect in the development and monitoring of geothermal fields. Permeable zones are generally associated with subsurface stress conditions and the presence of structures such as fractures in the reservoir. One of the geophysical methods to detect the presence of permeable zones is the shear wave splitting (SWS) microearthquake method. The microearthquake data recorded by seismograms in the period of January - April 2018. The SWS phenomenon occurs when an S wave propagates through an anisotropy medium. The rotation correlation technique is used to determine the SWS parameters; direction of polarization (ϕ) and delay time (dt) of the S wave. The results of this study indicate that the center area of study has high fracture density. The fractures maybe associated with the presence of wells where the largest steam is produced in the field and the appearance of more complex geological structures. The dominant direction of fracture orientation is relatively following the trend of local structures NW-SE and NE-SW.

1. Introduction

The "R" geothermal field is located in West Java, a part of the Sunda Land and adjacent to the convergent boundary plate between the Eurasian Plate and the Indo-Australia Plate [1]. The "R" geothermal is vapor-dominated system [2]. Now, the field is being projected to increase production by developing new PLTP unit. In this study, fractures at the geothermal field reservoir will be discussed. Stress conditions, fracture distribution and orientation become permeable zones for fluid migration in geothermal reservoirs. Study on fracture distribution and orientation and its relationship to stress conditions in the reservoir provides information on reservoir conditions, which can be used as a reference in optimizing the productivity of geothermal fields [3].

Identification of these fractures can be done by using microearthquake data. Microearthquakes may arise from volcanic activity, hydrothermal activity, and reservoir fluid extraction and reinjection activities on geothermal fields. Microearthquake distribution can indicate the presence of structures such as fractures that can be good porosity and permeability for the reservoir.

Furthermore, in determining the orientation and fracture density, the shear wave splitting (SWS) method can be used. The SWS phenomenon occurs when an S wave propagates through an anisotropy medium. The S wave will be divided into two polarizations (ϕ) with different velocity, namely S fast which is parallel and S slow which is perpendicular to the fracture orientation. Delay time (dt) between S fast and S slow is directly related to the number of cracks/fracture per unit volume (crack/fracture
density) in the medium [4]. While orientation of fracture obtained from rotation correlation between 2 horizontal seismogram components. The purpose of this study is to obtain the density and orientation of fractures in the reservoir.

2. Geological Setting
In Java, there are four different structure trends (Figure 1a); N-S (Sunda trend), NE-SW (Meratus trend), E-W (Java trend), and NW-SE (Sumatera trend). Based on the geological mapping report, the general structural trends found in this field are NE-SW and NW-SE, which are Meratus and Sumatra trends [2]. These structures are the result of regional tectonic and local volcanic activities.

![Figure 1. Location of “R” geothermal field. (a). Structure map of Java [5], (b). Focus area of study.](image)

3. Data and Method
Data used in this study is 185 from 215 events of microearthquake, as the arrival time \( S_{\text{fast}} \) and \( S_{\text{slow}} \) are read clearly. This method used to mapping the density distribution and orientation of reservoir fractures on the "R" geothermal field. The rotation correlation algorithm [6] is used to determine the Shear Wave Splitting (SWS) parameters; delay time (\( dt \)) and polarization direction (\( \phi \)). This method utilizes two horizontal components of seismogram (EW and NS) to be rotated from an angle of 0° to 180° with increment of 1°. At each corner, the two horizontal components are carried out by a cross correlation based on the delay time at a certain time window. Polarization direction and delay time are obtained based on the maximum cross correlation coefficient (CCC).

3.1. Rotation of Seismogram
Seismograms record in three directions components; vertical (Z), north-south (NS), and east-west (EW), then coordinate transformation into radial-transversal is necessary. The coordinate transformation uses the following equation:

\[
\begin{bmatrix}
R \\
T
\end{bmatrix} =
\begin{bmatrix}
\cos \phi & \sin \phi \\
-\sin \phi & \cos \phi
\end{bmatrix}
\begin{bmatrix}
N \\
E
\end{bmatrix}
\]

(1)

where R and T are radial and transverse components, and \( \phi \) is the angle formed between the radial component and the North axis of the earth. N is a horizontal component of NS, and E is a horizontal component of EW.

3.2. Cross Correlation
The cross correlation technique is commonly used in signal processing to increase the similarity between two waves, namely two horizontal seismogram components (NS and EW). The assumption underlying the cross correlation method for these two horizontal components is wave similarity [7]. Cross correlation in the time domain is defined as follows:
\( c(\tau) = \int u_1(t)u_2(t + \tau) dt \)

with \( u_1(t) \) and \( u_2(t) \) are two waves of the horizontal component of seismogram in time domain. From the time lag \( (\tau) \) the maximum amplitude or peak maximum \( (c(\tau)) \), the difference in travel time is obtained.

4. Results and Discussion

4.1. Delay Time
The value of the delay time is obtained from difference between arrival time of \( S_{fast} \) and \( S_{slow} \) wave of each event detected at each station. Large delay time can be caused by a high level of anisotropy, but the presence of anisotropy or structure cannot be known. Waves originating from the microearthquake source propagate and pass through an anisotropic medium, before being recorded at the station. The highest delay time values are found in stations B262, B14E, and B269 which are shown in red. The delay time with a medium value is green, namely at stations B157, B240, B4AE, and 6V21. While the lowest values at stations B13C, B207, B243, and 6V18 are shown by blue contours (Figure 2a). In general, the high delay time value is in the middle area. While in West and East area, the value of the time delay tends to decrease.

4.2. Raypath
The raypath value is the average distance from one hypocenter microearthquake to the station that records the event in straight path. The raypath value ranges from 1.6 to 2.7 km. The high value is shown by red, while the low value is blue. The lowest raypath value is recorded at B14E and B262 stations in the middle area of the study. This is also supported by the large number of microearthquakes that cluster in the area, so that the raypath is short as shown in Figure 2b. Whereas in the West and East areas, the raypath value tends to increase. This raypath value is used to compare and normalize the delay times from different sources per station. The fracture density recorded by each station can be known by normalizing the value of the delay time with the length of the raypath.

![Figure 2](image_url)

Figure 2. Contour map of (a). Delay time. (b). Raypath overlayed with epicenter.
4.3. Fracture Density

The value of the fracture density is obtained from the delay time (ms) divided by raypath (km). The value is interpolated to produce a contour map as shown in Figure 3. The range of fracture density values ranged from 3.9 - 29.8 ms/km. The large fracture density is in the middle of the study area. Whereas in the West and East area, the fracture density value tends to decrease. The magnitude of the density in the middle area of the study also shows large anisotropy. This is supported by the presence of production activities which are characterized by the presence of several wells with the largest steam production in the field. In addition, there are also more structures in the area than other regions. Conversely, areas with low density values indicate a small anisotropic value. This is supported by the lack of structure and the absence of production activities in the area. In the area around station B269 and 6V21 the value of fracture density is medium to high, presumably around the area there is a structure such as subsurface fracture which becomes a pathway for migrating geothermal fluids. This is supported by the presence of surface manifestations in Cibunggaok and Ciwidey Crater.

![Figure 3. Contour map of fracture density distribution and overlayed with epicenter.](image)

4.4. $S_{fast}$ Polarization Direction

Based on shear wave splitting analysis, the dominant strike direction of the fracture indicated by the $S_{fast}$ polarization of each station plotted into the Rosette diagram. In the Figure 4, it can be seen the polarization direction recorded at each station varies. However, there are two dominant directions of polarization, namely the direction of NW-SE and NE-SW which follows the direction of the local structure trend of the area. The orientation results are also in line with regional geological trends that influence the structure of the study area; the Meratus (NE-SW) and Sumatra (NW-SE) trends. The Rosette diagram showing the direction of polarization of each station is plotted into a map of the surface geological structure.
In general, the direction of polarization is consistent with the local strike direction around the area. This shows that the recorded $S_{fast}$ polarization direction is controlled by the structure near station as seen in stations B14E, B240, B243, B262, B4AE, and 6V21. In the area of the largest steam production zone; stations B14E and B262, there are several events that show the direction of polarization is not parallel to the local strike. This is likely due to the complexity of the subsurface structure due to the high activity of steam production in the area. The production activity may affects new and local fractures in this area.

![Figure 4. Contour map of polarization direction at each station and overlayed with geology structure.](image)

5. Conclusion
From this study, we can conclude that shear wave splitting method is able to map density and polarization direction of fracture. The results of the $S_{fast}$ polarization direction mapping at each station show the two dominant directions, NW-SE and NE-SW. Generally the direction of the dominant polarization is parallel to the regional structure on the surface. While the results of the fracture density distribution in the field ranged from 3.9 - 29.8 ms/km. Areas with high fracture density are in the middle of the study area, which shows zones with high levels of anisotropy or permeability. The fractures area most probably associated with the largest steam production and its impact of more complex structures than other regions. While in the West and East area, the fracture density value tends to decrease.

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