An Integrated Method 3D Velocity Model and Fuzzy Clustering for Fracture Characterization

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Abstract. Enhanced Geothermal system assessment conducted to have a better understanding of characteristics of fracture caused by a fluid injection in the geothermal reservoir. Fluid injection may cause microseismic occur. These events allow us to map and characterize fractures in the geothermal system. Fractures play important role at the geothermal system due to its ability to increase permeability for fluid movement within the reservoir. In this study, we combined tomographic inversion method and fuzzy clustering to identify fracture characteristics at the EIF Geothermal Field. Tomography helped in delineating fluid-filled fractures with high permeability area which shown by lower velocity Vs anomaly than Vp and higher Vp/Vs ratio. Fuzzy clustering allowed us to map microseismic movement and estimate suitable locations for the future well injections or productions.

1. Introduction

Microseismic occurs due to several parameters, such as pore-pressure increases, temperature and/or volumetric changes due to fluid withdrawal or injection, and chemical alteration of fracture surfaces. Fracture characterization in the geothermal system is conducted by monitoring microseismic events. These events correlate with the migratory of fracture network and indicate connectivity within fracture [1,2]. In this study, we implement the combination of tomographic inversion and fuzzy clustering methods to have a better understanding of fracture characteristics at the EIF Geothermal Field. SimulPS12 code [3] utilizes travel time tomography and classifies microseismic events regarding Vp, Vs and Vp/Vs characteristics. The previous study of tomographic inversion around geothermal field in Indonesia region showed a prominent anomaly in seismic and attenuation structure around geothermal field [4, 5, 6].

We use microseismic data from a period of October 2012 until Mei 2013 which are recorded at least by four station observations. Catalog data contains of 1,116 micro-seismic events and 11,433 P- and 11,433 S- wave phases and is monitored by 35 stations observation. First, we relocate hypocenter catalog data and update velocity model simultaneously by using coupled hypocenter – velocity method from VELEST program code [7]. The relocated hypocenter and updated 1D velocity model are applied as input for tomographic inversion by applying SimulPS12 program code [3] resulting three-
dimensional seismic velocity model and a precise hypocenter from the codes. These results can determine fracture characterization and also predict potential high permeability zone.

Second, we clustered hypocenter and three-dimensional velocity structures of Vp, Vs and Vp/Vs using fuzzy clustering method. The movement of cluster center over time can represent the fracture propagation. We used a time window of three months since October 2012 – May 2013.

2. **Methodology**

2.1. **Coupled hypocenter – velocity method**

Minimum 1D velocity model and hypocenter location utilized as the input parameters in tomographic inversion SimulPS12. These two factors were obtained by coupled hypocenter – velocity method from VELEST program code. The relocated hypocenter, updated 1D velocity model, and stations correction were calculated simultaneously until minimum RMS misfit of the solution reached. The minimum RMS misfit, which lied between 0.02 – 0.2 s, showed the most reliable solution.

2.2. **Inversion of Tomographic**

Three-dimensional velocity structure obtained from SimulPS12 program code. This program calculated hypocenter, updated three-dimensional velocity model (Vp and Vp/Vs ratio) and station correction simultaneously. Initial velocity model obtained from VELEST inversion program. Damping parameters were determined from trade – off curve between variance of both data and model. The most applicable damping were chosen by the minimum value of those variances. We used damping parameter of 10 for both Vp and Vp/Vs. Grid velocity model with a dimension of 2 x 2 x 1 Km applied to get three-dimensional velocity structures of Vp and Vp/Vs ratio with good resolutions.

2.3. **Fuzzy clustering**

Fuzzy clustering is one of the statistical analysis technique. Data was classified into several groups consist of similar characteristic using fuzzy logic. Fuzzy logic ‘membership’ degree pointed out the similarity of data for each clusters. The degrees of similarity lied between 0 to 1 which indicated the lowest and the highest similarity of data within each clusters. In this process, microseismic events were clustered as a function of time window from October 2012 – May 2013. To obtain optimum partition data, we validated the number of clusters using validity index of Xie and Beni [8]. The optimum partition data determined by using two clusters.

3. **Results**

Figure 1 depicts tomogram section of Vp, Vs and Vp/Vs ratio at elevation of 0 to 1 Km BSL. The area within black dashed line had good resolution. The observation at the elevation of 1 Km showed lower Vp and Vs anomaly with higher Vp/Vs ratio. These features were interpreted as fluid-filled fracture zones. Tomogram images at elevation of 0 to 1 Km could not show significant anomaly at red dashed line area because hypocenter at this area concentrated at the depth between -6 to -10 Km. We presumed that microseismic events at this area might not correlate with geothermal activities. Hence, we clustered microseismic event only at black dashed line area.
Figure 1. Depth section of tomogram Vp, Vs, and Vp/Vs ratio at elevation of 0 to 1 Km BSL. Black dash line indicated area with good resolution, fault(black line), station(blue triangle) and mountain(black triangle). Red color indicated low anomaly meanwhile blue indicated high anomaly.

To estimate microseismic movement, we clustered microseismic event over time with the time window of three months from Oct 2012 until May 2013. The cluster center represented a connected fracture network. The result of fuzzy clustering which depicted in Figure 2 were located at the center of microseismic distribution and presumed as the center of connected fracture network. Then, the microseismic movement represented by the cluster center over time. The cluster center showed movement with orientation of NW from Oct 2012 to May 2013.

Figure 2. Cluster center movement with time, star symbol is cluster center at microseismic event in October – December 2012, square symbol is cluster center at microseismic event in April – May 2013.
4. Conclusions
The combination method of fuzzy clustering and tomographic inversion could map microseismic movement and characterize fracture at EIF geothermal field. The three-dimensional of velocity structure delineates an area with high permeability shown by low Vp and Vs anomalies with high Vp/Vs ratio. This anomaly were interpreted as fluid-filled fractures. The movement of microseismic event fuzzy cluster centers movement as a function of time. Cluster center position located at the center of microseismic distribution may correlate as center of fracture network. The cluster center showed movement with the orientation of NW from October 2012 to May 2013. After overlaying fuzzy cluster center and three dimensional velocity, the cluster center located around high permeability zone and this location considered as the best location for the next injection or production wells for enhancing the geothermal system.

5. Acknowledgements
The author would like to acknowledge Star Energy Geothermal Limited for micro-seismic waveform data used in this research, GDP Lab, Faculty of Mining and Petroleum Engineering ITB for supporting this study and LPDP Scholarship.

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