The First Study of 3-D Seismic Velocities Tomography Inversion to Delineate Reservoir Steam Zone at “FR” Geothermal Field West Java

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Abstract. Understanding reservoir conditions is one of the important aspects in fluid production monitoring activities in geothermal systems. The objective of this study to delineate the reservoir element especially the steam phase. It is the first study to requires mapping the existence and geometry of steam phase as an initial step to monitor reservoir conditions at “FR” Geothermal Field using the tomography travel time method. This study used seismogram data measured for 95 days and recorded by 11 seismometers. Arrivals time picking results get 213 microearthquake events with a minimum recorded by 3 recording seismometers. Hypocenter relocation is done by two methods in combination. The first use Joint Hypocenter Determination (JHD) and second use Double Difference relocation method. Then the travel time tomography inversion is using simulps12 software. The results of the hypocenter relocation distribution show one cluster around the main production well those are PPX well may be related to weak zones and reveal majority structure with NW-SE orientation. While in terms of hypocenter depth distributed clusters around the trajectory of production wells B and C from elevations +1 to 0 Km. The tomogram results show that the delineate steam zone at an elevation of +1 to 0 Km with strongly low perturbation $V_p$, low $V_S$ and low $V_p/V_S$ with around 1.6 to 1.7 value. Integration with MT data show the steam zone has located at reservoir boundary zone with resistivity value of 30 to 60 Ohm meter. Integration with PPX temperature profiling shows the steam zone has convection heat transfers.

1. Introduction

“FR” Geothermal Field have vapour dominated system and lies on volcanic highlands formed by Sunda Arc [1,2]. This Geothermal Field has been produced since 2014 with the existence of PLTP unit 1. PLTP unit 1 has production 60 Mw energy capacity. “FR” Geothermal Field is being formulated to increase the energy by developing Steam production. So that, the energy and supply of fluids especially steam zone still sustainable, it requires mapping the existence and geometry of steam phase as an initial step to monitor reservoir conditions at “FR” Geothermal Field. The condition of the reservoir that has been operation is inseparable from the extraction activity that is associated with the microearthquake events. The microearthquake methods that occur due to changes in stress and strains in rocks. The technology used for imaging steam phase reservoir conditions is 3-D $V_p$, $V_S$ and $V_p/V_S$ ratio Tomography inversions [3].
2. Geological Setting
Based on Figure 1, “FR” Geothermal Field covers on volcanic highlands formed by Sunda Arc. Main geological unit at “FR” from Patuha and Kendeng volcanism production [4]. Patuha Mount production (Qv) is the youngest lithologic rock consisting of andecitic lava and andesite lahar pyroxene. The product from Mount Kendeng (QI) is overlain by product from Mount Patuha(Qv) which consists of tuff breccia and intercalated lava with laharic of andesitic breccia. Then, lithology in the South and south-eastern of field is covered with undivided pyroclastic deposits (Qtv) which consist of lapilli tuff, tuff breccia and andesite breccia. Tertiary sedimentary and volcanic rock was found as surface outcrop in the south of field [2].

![Geological map at “FR” Geothermal Field and yellow rectangle line is research field.](image)

3. Method
In this study, microearthquake data was starts from waveform data with 11 seismometers to continuous recording for 95 days starts form January until April 2018 at “FR” Geothermal Field West Java. First, picking first arrival time data to detected microearthquake events. There are 215 events. Then, determined initial hypocenter using Geiger Algorithm by Hypo71 software. Initial 1-D velocity model is applied from Palgunadi [5]. Later on, improve the accuration microearthquake hypocenter and update velocity model using coupled velocity hypocenter on Velest [6]. In combination, output from Velest used as input to second relocation, there is double difference method for clustering microearthquake events. Output from double difference is used as input for tomographic inversion by using simulps12.

4. Results and Discussion
Distribution of hypocenter relocation can be seen at Figure 2. Microearthquake events distribution form clusters within the scope of seismometers recorded. Hypocenters distributions shows that fluid
injection and production activities in the reservoir zone can create microearthquake events. The majority microearthquake events are distributed around structures NW-SE orientation. Four of structures marked by circle yellow dash line are interpreted as main structures of secondary permeability reservoir at “FR” Geothermal Field. Many of microearthquake events are located around “PPX” trajectory as production wells and marked by circle blue dash line. This trajectory well is perpendicular with main structure NW-SE orientation.

Figure 2. Map of distributions of the relocated microearthquake events in this study, seismometer station and well trajectory.

Tomography inversion results just vertical section interest to be interpreted. Vertical section line with NW-SE orientation, that is adjusted with structure orientation and line section of magnetotelluric method. Based on previous study at Geyser Geothermal Field about seismic velocities method to determined fluid saturation, steam zone can be characterized by $V_p$ perturbation value are very attenuated because steam is a compressible fluid, has low $V_s$ perturbation and showed the extensive low $V_p/V_s$ ratio because depletion of pore liquid water change to steam [7,8]. Previous research has been done using double difference tomography inversion in “H” reservoir Geothermal Field produce that $V_p$ value are strongly attenuated in the steam zone. $V_p$ and $V_s$ also decrease because change fluid saturated from water to steam caused steam extraction without or less support from brine, so that produce low $V_p/V_s$ ratio [9].

Figure 3 show the result of tomography inversion in vertical section for NW-SE orientation. $V_p$ and $V_s$ structures values were based on perturbation percent. Blue indicate high anomaly and red indicate
low anomaly structures for $V_p$, $V_S$ and $V_p/V_S$ ratio. Based on Figure 3, steam zone shows with strongly low $V_p$, low $V_S$ and low $V_p/V_S$ ratio in range 1.6 to 1.7 which are located at elevation of +1.0 to 0.0 km.

![Figure 3](image-url)  
**Figure 3.** $V_p$, $V_S$ and $V_p/V_S$ ratio structures vertical section. Blue and red color indicate high and low anomaly.

The section vertical tomogram then to be integrated interpretation with magnetotelluric line and PPX temperature profiling well which can be seen in the Figure 4. Steam zone to be interpreted has low $V_p/V_S$ ratio around 1.6 to 1.7 for tomogram and has 30 until 60 Ohm meter for resistivity MT method. Tomogram and magnetotelluric section show the dome structure consistently. Dome structure is formed by high temperature and pressure and it indicates an upflow zone. According to results the MT zone of clay is observed at around +2 to +1 elevation. Zone of clay has high $V_p/V_S$ ratio anomaly. Profiling temperature well use is PPX well [2]. PPX well is a well that is very close to the tomogram line compared to the other wells. Meanwhile, PPX well is interpreted as a production well that has one fluid phase which are almost dominated by steam [2]. Result integrated that steam zone in tomogram has convection heat transfer in PPX profiling temperature well.
5. Conclusions
Hypocenter relocation results show the microearthquake events tend to distribute around the production and injection well. The majority of hypocentre result distribution also follow NW-SE structures orientation trend. While, the steam zone is delineated at +1 to 0 km elevation. The integrated of tomography inversion result with MT method and PPX temperature profiling well show that phase of steam zone has located at reservoir boundary zone and has convection heat transfer.

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