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Shallow Ground Characterization Of Gedongsongo Geothermal Field Based On Microtremor Data

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Abstract – The research has been conducted in the Gedongsongo manifestation area, Mount Ungaran Geothermal Field. This study aims to characterize shallow subsurface manifestations using microtremor data. Microtremor data were recorded in Candi Village, Bandungan Subdistrict and Jubelan Village, Sumowono Subdistrict, Semarang Regency. The microtremor recording can be done directly using a seismometer with three components. The microtremor measurement is done by simultaneous recording at two or more points, one of the measurement points is selected in an area that has a hard rock structure to avoid frequency amplification due to ground motion. The spectrum ratio recorded in other areas will be compared with the spectrum ratio recorded in hard rock, so as to obtain the site response to microtremors. Based on the Vp/Vs ratio values, most of the research field is composed of very stiff rock types. The distribution of Poisson's ratio values in the research field ranges from 0.20 - 0.50 and in the steaming ground area the Poisson's ratio values range from 0.10 - 0.47. Based on the Poisson's ratio values, it shows that the research field is partly a water prospect area in the form of hot springs, while partly an area composed of dry rocks filled with steam or gas.

Keywords – Microtremor, Gedongsongo, Geothermal Manifestation, Vp/Vs ratio, Poisson's ratio

I. INTRODUCTION

The Gedongsongo Geothermal Field is located on the southern slope of the Mount Ungaran Depression Complex. Geothermal activity in Gedonsongo is indicated by the presence of fumaroles, hot springs, and alteration rocks. The alteration minerals formed can represent the temperature of the reservoir rock at that time, which ranged from 70°C to 200°C and in acidic conditions [1]. Geothermal exploration is initiated by conducting research on the manifestation surface. Geological investigations are carried out by direct observation and measurement of geothermal symptoms on active and fossilized surfaces, distribution relationships and rock units, rock outcrop profiles, and geological structures in the form of faults [2]. Microtremors are ground vibrations caused by natural or artificial events, such as wind, ocean waves, and vehicle vibrations that can describe surface geological conditions [3]. Microtremor measurement data can be processed using the HVSR (Horizontal to Vertical Spectral Ratio) method. According to [4], the HVSR method is a method of comparing the spectrum of the horizontal component to the vertical component of microtremor waves.

Refernce [5] stated that in geophysical studies, the ratio of compression wave velocity to shear wave velocity of sedimentary rocks is used to determine the Poisson's ratio value. Poisson's ratio is an important parameter in rock mechanics to identify subsurface lithology and represent rock deformation due to pressure. Reference [6] have conducted research using the microtremor method in the Sangubanyu geothermal manifestation area located between Batang Regency and Kendal Regency, stating that the microtremor method can be used to determine the subsurface structure of the geothermal manifestation area. Reference [7] have also conducted research using the microtremor method regarding the subsurface characterization of the

Diwak-Derekan Geothermal Field manifestation area which states that the manifestation area is located in a weak zone. Discovering the subsurface characteristics is a very important step in geothermal exploration. Therefore, a study was conducted using the microtremor method in the manifestation area of the Gedongsongo Geothermal Field, Ungaran, Central Java. This research mapped the characteristics of the subsurface layer of the research field. The purpose of this work is to map the distribution of seismic wave parameters to determine the subsurface lithology of the Gedong Songo geothermal field, Ungaran.

II. METHOD

2.1. Geology of Research Area

Mount Ungaran is part of an active volcanic belt on Java Island formed by the subduction of the Indo-Australian Ocean Plate under the Eurasian Continental Plate which has very active seismicity [8]. Physiographically, Mount Ungaran is located between the Kendeng Zone and the North Serayu Mountains [9]. Mount Ungaran is located on the back side of the main arc and strikes in the NW-SE direction. This orientation is influenced by the direction of the regional horizontal maximum force [10]. The geomorphology of Mount Ungaran can be classified into six clusters (as shown in Figure 2.2.), namely domes and lava flows of Old Ungaran, pyroclastic flows of Old Ungaran, lava flows of Young Ungaran, pyroclastic flows of Young Ungaran, central cone of Young Ungaran, and volcaniclastic deposits. Domes and cones are found around the summit and foot of Mount Ungaran.

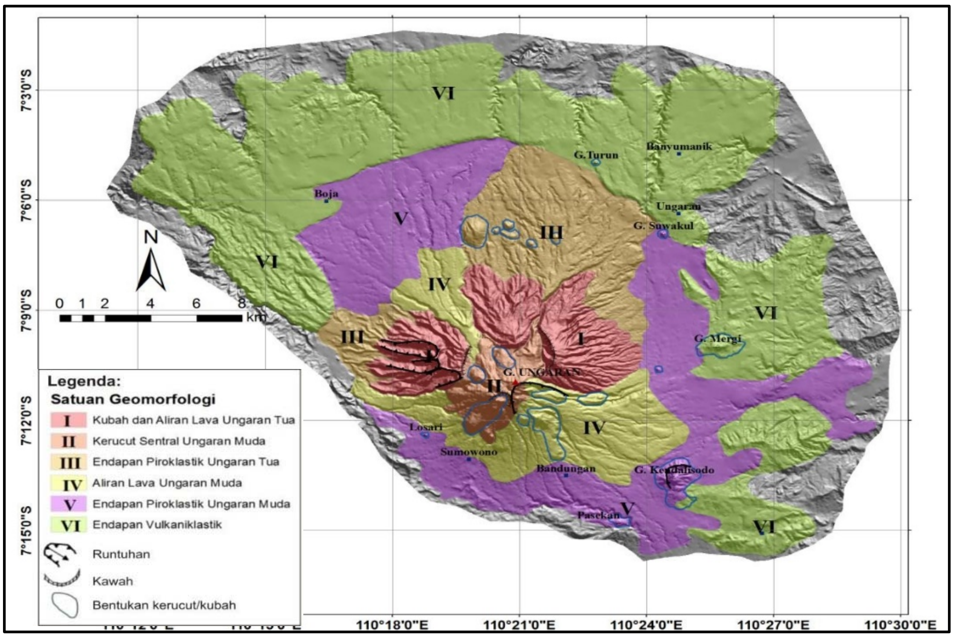

Fig.1 Geomorphological conditions of Mount Ungaran [10]

The most common structures found on Mount Ungaran and its surroundings are descending faults and braces. The descending faults include the Ringin fault, Corong fault, Gading fault, Kalibanger fault, Berokan fault, Losari fault, Gongso fault, Tarukan fault, and Panjang fault. The fault line that has geothermal manifestations is the Panjang descending fault line. The fault was formed due to the collapse of Mount Ungaran Muda, resulting in the formation of a steep fault scarp that leads to the south. On this fault line there are manifestations of steaming ground, hydrothermal alteration, fumaroles, hot springs and hot water pools. The alignment pattern in this area is based on the alignment pattern of the river channel and morphological shape that is northwest-southeast and north-south [11].

2.2. Gedongsongo Geothermal System

The geothermal system center in the Gedongsongo Geothermal Field is sourced around the Gedongsongo fumarole and to the east of the fumarole. A north-south trending fault zone is a probability. Intensive fault zones and brittleness make the rock permeable and porous. Extensive fault zones and brittleness can increase the permeability of the rock, causing geothermal fluids to rise to the surface as geothermal manifestations. The geothermal system consists of pyroclastic flows that act as reservoirs, altered lahars and altered pyroclastic flows that act as cap rocks, andesitic magma that acts as a heat source, and recharge areas located in Lanjan, Berokan, and Banyukuning [12].

2.3. Microtremor

Microtremors are seismic vibrations caused by natural factors such as ocean waves, wind, atmospheric pressure, traffic, heavy machinery vibrations, and so on [13]. Microtremors are also defined as ground vibrations with displacement amplitudes of about 0.1-1 micron and velocity amplitudes of 0.001-0.01 cm/s that can be detected by seismographs. Microtremor waves are caused by the phenomenon of multiple reflection of shear waves whose particle movement direction is perpendicular to the direction of wave movement [14]. Short-period microtremors are vibrations in shallow subsurface structures with a depth of several tens of meters, while long-period microtremors are vibrations in deeper soil structures that reach depths in hard rock with shear wave speeds of 3 km/s [15]. In the present study, Rayleigh wave dispersion curves obtained from the experimental setup were inversed using Dinver software which provides a set of dispersion curve models compatible with the observed dispersion. The inversion software uses a directed search method called the Neighborhood algorithm [16]. For dispersion curve inversion, the physical parameters of compressional wave velocity and shear wave velocity associated with Poisson's ratio can constrain the parameter space with complex boundaries [17]. In geothermal manifestation zones, Poisson's ratio values range from 0.25-0.30 for normal saturated rocks. In vaporous conditions, the Vp/Vs ratio value is below $\sqrt{3}$, hence the Poisson's ratio value is below 0.25. When the Vp/Vs ratio value is $\sqrt{2}$, the Poisson's ratio is zero. For a Vp/Vs value of $\sqrt{3}$, the Poisson's ratio is 0.25 and this value applies to rocks in the earth's crust and upper mantle. Zones with water prospects and high porosity have Vp/Vs ratio values above $\sqrt{3}$ and Poisson's ratio values above 0.25 [18]. The following graph of the relationship between Vp/Vs ratio and Poisson's ratio in geothermal systems is shown in Figure 2.

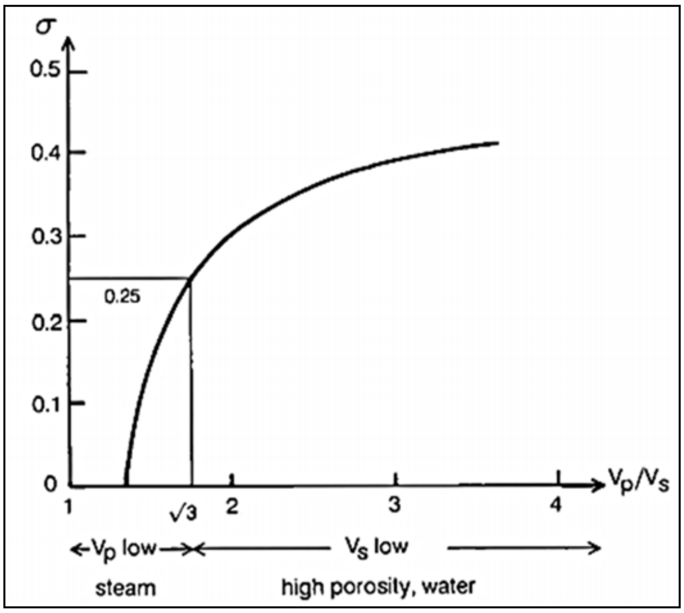

Fig.2 Relationship graph of Vp/Vs ratio with Poisson's ratio in geothermal systems (Hersir and Bjornsson, 1991)

Microtremor recording can be done directly using a seismometer with three components to record the horizontal NS (North-South), horizontal EW (East-West), and vertical (Up-Down) components. Microtremor measurements can be made by simultaneous recording at two or more points. One of them must be done in an area that has a hard rock structure to avoid frequency amplification due to ground motion. The ratio of spectra recorded in other areas will be compared with the ratio of spectra recorded in hard rock, so as to obtain the site response to microtremors [19]. Microtremor data recording can provide information on natural frequency values, amplification factors, and vibration characteristics of each soil type and subsurface structure. Research data collection was carried out as many as 51 measurement points from 10 tracks located in the Gedong Temple 2 to Gedong Temple 4 area in the Gedongsongo Geothermal Field located in Candi Village, Bandungan Subdistrict and Jubelan Village, Sumowono Subdistrict, Semarang Regency.

The research procedure was carried out through the stages of literature study, making research survey design, microtremor data acquisition, microtremor data processing with the HVSR method, interpretation of research data, and at the final stage making a research report. Data acquisition was conducted using DI-720 data loggers GL-240 data logger, and GL-840 data logger. The data acquisition process began with checking the equipment and setting all components in the same gain. The research procedure was carried out through the stages of literature study, making research survey design, microtremor data acquisition, microtremor data processing with the HVSR method, interpretation of research data, and at the final stage making a research report. Data acquisition was conducted using 2 DI-720 data loggers, 1 GL-240 data logger, and 1 GL-840 data logger. The data acquisition process began with checking the equipment and setting all components in the same gain. Microtremor data processing is carried out using several software. microtremor data recorded using the DI-720 data logger is first opened using WinDaq software to convert the existence of microtremor data into .txt form. microtremor data processing using Geopsy v2.9.1 software and Dinver Geopsypack-2.10.0 software applying the Neighborhood algorithm. Furthermore, we correlated the relationship between the Vp/Vs ratio value and the Poisson's ratio value based on the graph designed by [19]. Finally, analyzing the Vp/Vs ratio values with Poisson's ratio values to determine the level of rock porosity and water prospects in the form of hot springs in the research field.

III. Results And Discussion

The microtremor data acquisition results are in the form of position data and microtremor signals in a function of time consisting of three components, namely the horizontal X (E-W) component, the horizontal Y (N-S) component, and the vertical component. The dominant frequency value distribution in the research field has contrasting values. Most of the research field has a low frequency value distribution between 0.13 Hz to 3.19 Hz and only at some points has a high dominant frequency between 5.53 Hz to 8.99 Hz. The geothermal manifestation zone in the research field has a low amplification value. In the steaming ground zone, the amplification value ranges from 0.2 to 4, while in the fumarole zone the amplification value ranges from 2 to 4. The amplification value in the geothermal manifestation zone has a low to moderate value because the subsurface structure is composed of softer soil and rock layers, so the difference in shear wave velocity between layers is not too significant. Figure 3 shows the 2D amplification contours using Surfer software.

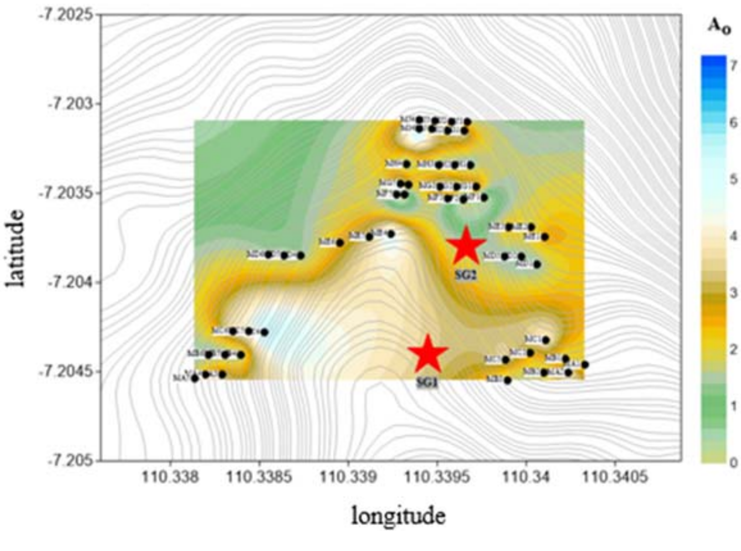

Fig.3 Amplification contours and distribution of measurement points shown with black dots.

The Vp/Vs ratio value can indicate the porosity level of the rock, the intensity of rock cracking, and the content of clay. The higher the Vp/Vs ratio value, the greater the porosity of the rock. Vp/Vs ratio values above $\sqrt{3}$ indicate rock conditions that are easier to crack, while Vp/Vs ratio values below $\sqrt{3}$ indicate rock conditions that are hard and more difficult to break. Based on the measurement results, the Vp/Vs ratio value in the research field ranges from 1.63 to 22.49. Figure 4. presents the Vp/Vs contours on the surface of the research field. The Vp/Vs value on the surface of the research field ranges from 1.63 to 18.59.

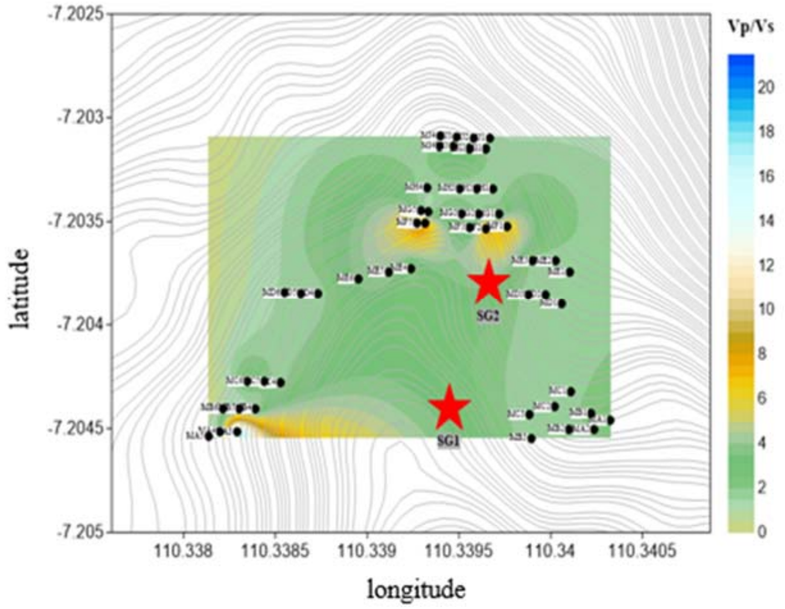

Fig.4 Analyzed Vp/Vs contours of 51 study points

Analysis of the Vp/Vs seismic parameters was complemented by the construction of a vertical profile across the steaming ground area showing the geothermal manifestation in the up flow section (as shown in Figure 5). In this trajectory, the highest Vp/Vs ratio value is 4.06 and the lowest value is 1.63. Based on the profile results, the Vp/Vs ratio value in the steaming ground area traversed by the track ranges from 1.65 to 2. Most of the layers consist of very stiff soil and rock types. However, the bedrock at point ME4 shows the presence of stiff soil and rock types, while the bedrock at point ME6 shows the presence of stiff soil and rock types and terracottaized rocks that have medium stiffness. In the layer of point ME5 shows the presence of rigid soil and rock types, teralterated rocks that have medium stiffness, and soft and saturated soil and rock.

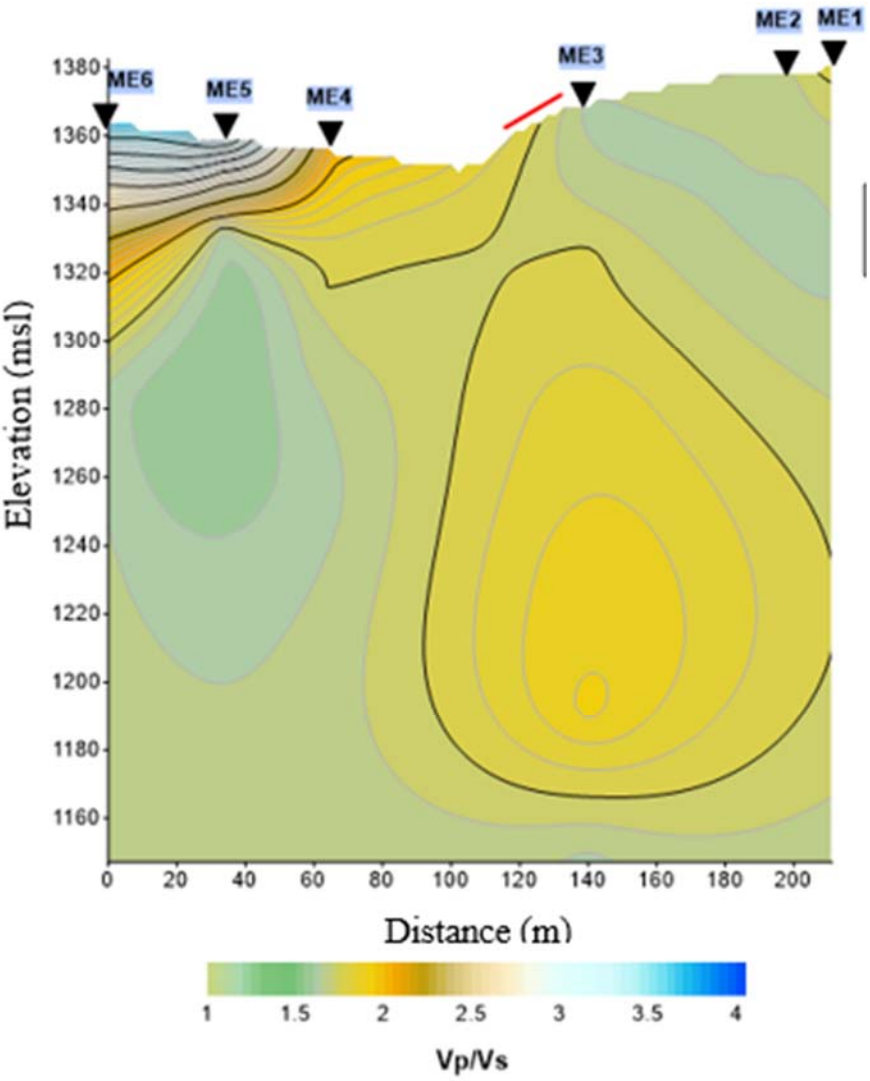

Fig.5 Vp/Vs profile that connects points through the steaming ground manifestation.

The red line shows the location of the steaming ground directly above the anomaly.

Poisson's ratio values can indicate a high degree of water saturation. The value is influenced by the lithology and porosity of the subsurface. In geothermal manifestation areas, the Poisson's ratio value will increase because there is water in the area. Poisson's ratio values above 0.25 indicate water prospect areas, while Poisson's ratio values below 0.25 indicate dry rock conditions filled with steam or gas. In normal saturated rock, the Poisson's ratio value ranges from 0.25 to 0.30.

Based on the measurement results, the Poisson's ratio value in the research field ranges from 0.20 to 0.50. This value indicates that the research field has water prospect areas in the form of hot springs. These results are in accordance with in areas where there are geothermal manifestations, the Poisson ratio value will show a high degree of water saturation because there is water in the geothermal manifestation area, so the Poisson ratio value will increase. Figure 6 presents the Poisson's ratio contours on the surface of the research field. The value of Poisson's ratio at the surface of the research field ranges from 0.22 to 0.46.

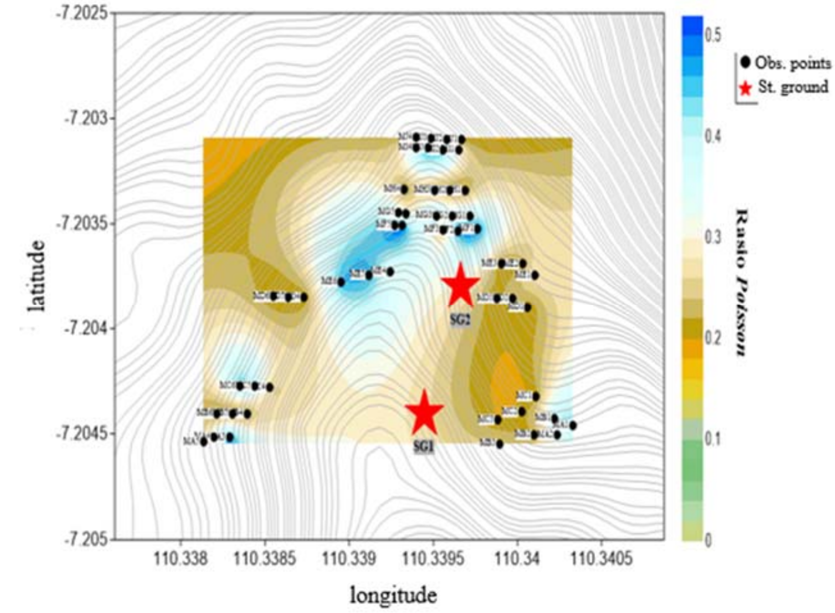

Fig.6 Poisson ratio contour on horizontal view.

The highest Poisson ratio value was 0.47 and the lowest value was 0.20. In Figure 7, the Poisson's ratio profile is presented. Based on the profile results, the Poisson's ratio value in the steaming ground area traversed in this trajectory ranges from 0.215 to 0.315. The largest water prospects at points ME4, ME5, and ME6, while at points ME1 and ME2 indicate the presence of dry rock filled with steam or gas.

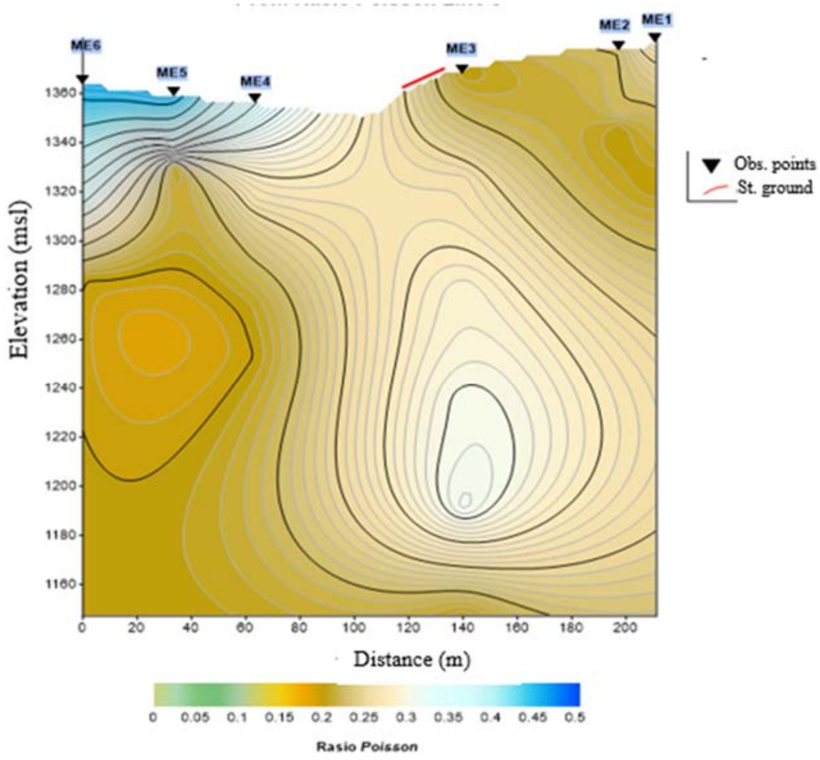

Fig.6 Poisson ratio profile created by connecting points passing through the steaming ground.

IV. Conclusion

In general, the distribution of Vp/Vs ratio values in the research field ranges from 1.63 to 22.49. In the steaming ground area, the Vp/Vs ratio values range from 1.5 to 4.5, while on the surface of the fumarole area, the Vp/Vs ratio values range from 1.5 to 2.5. Based on the Vp/Vs ratio values, most of the research field is composed of very stiff soil and rock types. A small part is composed of rigid soil and rock types, teralterated rocks that have medium stiffness, loose and soft rocks, and soft and saturated rocks. The distribution of Poisson's ratio values in the research field ranges from 0.20 to 0.50. Whereas in the steaming ground area the Poisson's ratio values range from 0.10 to 0.47, while on the surface of the fumarole area the Poisson's ratio values range from 0.22 to 0.3. Based on the Poisson's ratio values, it shows that the research field is partly a water prospect area in the form of hot springs, while partly an area composed of dry rocks containing steam or gas.

REFERENCES

[1] S. Indarto, D. S. Widarto, E. G. Zulkarnain, and I. Setiawan. “Studi batuan vulkanik dan batuan ubahan pada lapangan panas bumi gedongsongo kompleks gunung api ungaran jawa tengah”. vol 16 (1), 2006 pp 30-43.

[2] U. Harmoko, G. Yuliyanto, S. Widada, A.R. Ekasara. “Subsurface structure investigation of sangubanyu geothermal field,” vol 1217, 2019 pp 1-6.

[3] K. Tokimatsu. “Geotechnical site characterization using surface waves.” vol 3, 1995 pp 1333-1368.

[4] Y. Nakamura. “Clear identification of fundamental idea of nakamura’s technique and it’s application.” vol.2656, 2000 pp. 1-8.

[5] J.E. Johnston and N.I. Christensen, “Compressional to shear velocity ratios in sedimentary rocks.” 2000 vol 30 (7), 1993 pp.751-754.

[6] D.S. Sudjono, U. Harmoko, G. Yuliyanto. “Delineation of geothermal manifestation in sangubanyu area based on microtremor hvsr method.” vol.125 14012, 2019 pp. 1-5.

[7] V. Arintalofa, U. Harmoko, G. Yuliyanto. “Subsurface characterization of diwak-derekan geothermal field by hvsr analysis method based on mictrotremor data.” vol 2296 020057 2020, pp. 1-9.

[8] W.B. Hamilton, “Tectonics of the indonesian region.” USA: U.S. Government Printing Office, 1979.

[9] R.W. van Bemmelen, “The geology of indonesia.” Netherland, 1949.

[10] J. Marin, A. Harijoko, S. Pramumijoyo, and H. Humaida, “Studi geomorfologi gunung api dan petrogenesa batuan untuk memahami evolusi vulkanotektonik pada gunung ungaran,” 2015 pp. 447-458.Jakarta.

[11] Y.E. Sugiharto, “The geothermal study of ungaran, Indonesia.” 1305-1309. Houston, 2009 Texas.

[12] O. Novotny. “Seismic surface waves.” 2009 Salvador, Bahia

[13] Marjiyono., Ratdomopurbo., Suharna., M.H. Jazuli, dan R. Setianegara, “Geologi Bawah Permukaan Dataran Klaten Berdasarkan Interpretasi Data Mikrotremor.” vol 15 (1), 2019, pp.3-9.

[14] M. Mirzaoglu and U. Dykmen. “Application of Microtremors to Seismic Microzoning Procedurenal.” vol 6 (3), 2003 143-156.

[15] F. Panzera, S.D. Amico, P. Galea, G. Lombardo, M.R. Gallipoli, and S. Pace “Geophysical Measurements for Site Response Investigation: Preliminary Results on The Island of Malta.” vol 54 (2), 2013. pp.111-128

[16] M. Wathelet, “An improved neighborhood algorithm: parameter conditions and dynamic scaling.” vol. 34 2008, pp. 1-5.

[17] G.P., Hersir, and A. Bjornsson, “Geophysical Exploration for Geothermal Resources. Reykjavík, Iceland: Geothermal Training Programme,” 1991 The United Nations University.

[18] N. Haerudin, F. Alami and Rustadi. “Mikroseismik, mikrotremor, dan microearthquake dalam ilmu kebumian.” 2019 Bandar Lampung: Pusaka Media.

[19] T.H. Silitonga, E.E. Siahaan and A. Suroso. “A Poisson’s Ratio Distribution from Wadati Diagram as Indicator of Fracturing of Lahendong Geothermal Field, North Sulawesi, Indonesia.” Proceeding of World Geothermal Congress, 2005 pp. 1-5.G.

Eason, B. Noble, and I.N. Sneddon, "On certain integrals of Lipschitz-Hankel type involving products of Bessel functions," Phil. Trans. Roy. Soc. London, vol. A247, pp. 529-551, April 1955. (*references*)