The Correlation Between P-Wave Velocity Value With Pathways Of Geothermal Manifestation In The Area Ie Jue, Aceh Besar As Hazardous Side Study

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Abstract. Refraction seismic survey has been carried out in the manifestation area of Ie Jue, Seulawah Agam Volcano Region, Seulimuem, Aceh Besar Regency. This research aims to identify weak zones related to channel of geothermal outflow that would bring about a potential hazard for human activity and that goal is obtained by extracting information from P-wave velocity. The data acquisition was conducted for two seismic lines located near to the geothermal manifestation area of Ie Jue. Both of the seismic lines were set up by linking the 24 geophones to the Seismograph PASI 16S and placing them in three meters spacing of each other. The offsets either left or right were laid out at 35 meters from first and last geophones, so the total spread length of each seismic line is 139 meters. The data recorded by the tool then were processed by using ZONDST2D and finally, the 2D velocity profile was obtained. The results show that the 2D velocity profiles illuminate us to portray and interpret the features figured out. The most valuable information provided by the profile is the existence of such the weak zones of the first and second seismic lines at relatively near-surface depth. These weak zones were suspected as the fractured or low-velocity zones, where their velocity ranges approximately at 0.2 - 1.2 km/sec. These low-velocity layers are strongly predicted as the pathways or channels of the geothermal fluids that appears to the surface. The shallow weak zones are potentially to become the hazard grounds because they are regularly traversed by timber trucks from which the dynamic load will be pushing them down. As consequence, the ground surfaces could gradually become a land subsidence endangering human activity within the vicinity of the area.

1. Background
Aceh is one of the provinces in Indonesia that has geothermal potential which can be explored and developed for alternative energy. One of them is in Aceh Besar Regency which is in the Seulawah Agam volcano. The geothermal manifestation has two important sides. The first side is as an advantageous view, which indicate a potential resource of geothermal energy. However, the second view also has a potential hazard which are channels or pathways of geothermal fluid flow.
research focuses on the disadvantageous side. To intensify this concern, refraction seismic method was considered as one of the geophysical methods that can be used to find out more about the shallow structures that are associated with the geothermal manifestation such as outflow, fumaroles etc. The refraction seismic method utilizes the seismic wave propagation from which the subsurface model velocity value can be generated based on the processed seismic data. The value of subsurface model velocity distribution toward depth is then used as the result to interpret the subsurface information of a research interest.

This study focuses on identifying weak zones where the settlements use the manifestation path as their traffic to support their livelihood and those zones could potentially cause the hazard for them. The weak zones are a subsurface layer that is soft and not compact because of heating by manifestation fluid. The weak zones have the characteristics of smaller density and larger porosity values than stronger zones, so that this gives the possibility of potential hazard to be occur such as subsidence, considering that the area of Ie Jue itself is an active area traversed by timber trucks. The dynamic and regular pressure affected by timber trucks on the surface could cause the surface going down and it gradually can raise the occurrence of subsidence in the area, so that this is a research background was conducted.

2. Study Literature

2.1 Geological setting of the study area

This research area is located in geothermal manifestation area of Ie Jue, Lamteuba Village, Seulimum Sub-district, Aceh Besar Regency. Geothermal manifestation of Ie Jue is situated in Seulawah Agam Volcano area. Based on geological map in Figure 1, informed that the areas of Seulawah Agam Volcano are dominated by rocks of lava member (Qvlt) and volcanic rock (QTvt) and consist of andesite volcanic rock to dacite, breccia, pumice, tuff, agglomerate, and ash flow [1]. The Seulawah Agam volcano has some near subsurface manifestations, for example Ceumpaga crater, located in the Southside, Heutz Crater, located in the Northside, manifestation of hot spring in the Ie Su’um Krueng Raya area, and hot spring manifestation in Ie Jue Lamteuba. There are some manifestations in geothermal area Ie Jue, like warm ground, steaming ground, hot springs, fumarole, and mud puddle [3].
2.2. Weak zone

Weak zone is a layer of soil or rock that is soft and not compact. Weak zone can be identified by a variety of geophysical methods, one of which is by using seismic investigation. Refraction seismic and 2D resistivity survey are two geophysical methods that are considered suitable for obtaining information about the characteristics of rocks for the weak zone. According to [7], a zone classified as soft layer if it includes the following types of characteristics such as, zones that contain weaker material; tension fracture zones; weathered zones; shear zones and fault zones.

Based on geophysical research using seismic methods and examining of rock samples collected at field in rock mechanics laboratories at the Lulea University of Technology, [8] concluded that zones, where P wave velocity values of layer lower than 4000 m/s, can be grouped as weak zones. These weak zones are characterized by contrast of velocity between weak zones and surrounding rocks.

Weak zones have the characteristics of small density and large porosity values compared to their surrounding rocks.

In addition to measurements using the refraction seismic method, the 2D resistivity measurement is also one of the geophysical methods that can be used to identify weak zones. This method provides different resistivity values of each rock body or stratum. The difference in resistance of each contrast layer will affect how the electrical current flow through different layers in the soil or rock. According to the geophysical research using resistivity method, zones that have low resistivity values are identified as weak zones.

2.3. Seismic wave

Seismic wave can be distinguished based on the way of their propagation, where the earth media are strongly control their direction propagation. Based on that view, they are classified as body wave that propagate through the earth's interior and some are propagating through the earth's surface called surface wave [11]. The body wave are the wave that propagate in the elastic medium and the direction of its propagation throughout all parts of the earth. They have a higher frequency than surface wave.
Based on the motion of particles in the media and their direction of propagation, they can be distinguished into P and S wave.

Historically, in seismic survey it only P wave is used because it facilitates survey techniques in two ways. Firstly, the ease of data acquisition because it does not require a three-component detector (the detector records the motion of particles vertically). Secondly, a higher P wave velocity makes it always the first time to reach a detector (geophone), making it easier to recognize [4]. Some P wave velocity values in various rock types are summarized in Table 1.

### Table 1. P wave velocity [2].

| Materials               | Velocity (ms⁻¹) |
|-------------------------|-----------------|
| Topsoil                 | 0.2 – 0.6       |
| Weathered layered       | 0.3 – 0.9       |
| Alluvium                | 0.5 – 2.0       |
| Clay                    | 1.0 – 2.5       |
| Sandstone and shale     | 2.0 – 4.5       |
| Limestone               | 2.0 – 6.0       |
| Granite                 | 5.0 – 6.0       |
| Metamorphic rock        | 3.5 – 7.0       |
| Basalt                  | 5.4 – 6.4       |

The velocity of seismic wave propagation in subsurface rock layers is different each other, this difference is influenced by several physical properties of the rock layer. According to [10], there are several factors that influence the velocity of seismic wave propagation in subsurface rock layers, such as rock lithology, density, porosity, depth, pressure, and temperature.

### 2.4. Seismic method

For active seismic technique, it is divided into two methods, that are refraction and reflection seismic. Refraction seismic is used to investigate shallow subsurface of geological structure. While, reflection seismic is applied for imaging of deep geological structure. Refraction seismic method is considered as suitable method that used to identify the shallow subsurface features of geothermal area. It utilizes concept of seismic waves that refracted by boundary layers. The survey of refraction seismic aims to identify shallow subsurface of geological structure, to determine the depth of layer subsurface, and to specify rocks layer by analyzing seismic wave velocities that propagate in rocks layer [11].

The refraction seismic method utilizes the time taken by the wave to propagate on the rock from the position of the seismic source to the receiver at a certain distance. In this method, the waves that appear after the first signal (first break) are ignored, because the refraction seismic waves travel fastest compared to other waves except at relatively close to offset so that the first arrival of waves recorded at receiver plays the important role. The P wave velocity is greater than the S wave velocity by then the arrival time of the P wave is used in the refraction seismic method. Parameters of distance and time of wave propagation are associated with fast wave propagation in the medium. The magnitude of wave propagation velocity is controlled by a group of physical constants in the material known as elasticity parameters [6].
2.5. Method of seismic tomography

In this research, tomographic modeling method is being used. The tomographic method is a special technique that can be used to provide an inner profile of a solid object without cutting or slicing it. This is done by taking measurements outside the object from various directions (which are called making projections), then reconstructing them. In addition to this, the tomographic refraction method begins with making the initial model and then continuing forward refraction raytracing through modeling. The next stage is comparing the travel time of the calculation with travel time of the measurement and then trying or modifying the initial model to minimize the difference (misfit) between the travel time of the calculation and observation. By repeating these processes until the time of calculation and measurement reaches a minimum value (approaching zero), and obtaining misfit or Root-Mean Squares (RMS) error is at the lowest value, the velocity model presents a predicted subsurface features. The main goal of raytracing technique is to search the minimum travel time between source and receiver for each pair of recipient sources [5].

3. Method

This research was conducted in Lamteuba Village, Seulimuem Sub-district, Aceh Besar. The approaching methodology performed in this research was the refraction seismic method. Refraction seismic survey is used to verify the P-wave velocities of different strata from the subsurface geothermal manifestation by which the probably existed hazard of ground or surface can be analyzed. The data acquisition were conducted for two seismic lines. These two seismic lines oriented from the Southwest-Northeast, where the coordinate of the initial and final positions of the first line is 5°30′23.51″N / 95°37′40.57″E and 5°30′27.34″N / 95°37′42.80″E, where the second line is 5°30′23.22″N / 95°37′39.37″E and 5°30′25.16″N / 95°37′43.21″E. Both lines were intersected with each other intending to strengthen prediction of subsurface manifestations. These lines were positioned close to the surface manifestations (hot steam) which are located within radius of more and less 3 meters.

### Table 2. Research equipment.

| Tools dan materials                  | Quantity   |
|-------------------------------------|------------|
| Seismograph PASI 16S-24P            | 1 unit     |
| Power Supply 12 Volt                | 1 unit     |
| Battery connecting cable            | 1 unit     |
| Sledge-hammer 5 Kg                  | 1 unit     |
| Iron plate                          | 1 unit     |
| Geophone trigger 10Hz               | 1 unit     |
| Trigger connecting cable            | 1 set      |
| Geophone 10 Hz                      | 24 pieces  |
| Geophone connecting cable           | 2 set      |
| Global Positioning System (GPS)     | 1 unit     |
| Gauge                               | 2 unit     |
| Software ZONDST2D                   | 1 (sharedware) |
This research was conducted by utilizing PASI 16S-24P Seismograph equipment. All of the seismic lines were set with the same layout geometry such as three meters spacing of each. The left and right offsets were placed at 35 meters, so that the total spread length of each line is 139 meters. The data generated from the tool were then processed by using ZONDST2D to generate the profile of P-wave velocity describing the distribution of P-wave velocity in the subsurface. Based on the velocity profiles and their values, the correlation between the values of P-wave velocity and pathway or channel of geothermal manifestations for particular subsurface features would be analyzed. To meet the goal, the equipment used in this research include:

The procedure carried out in this study consists of 3 stages, include:

3.1. **Data acquisition**
The first stage was a preliminary survey. This preliminary survey aims to review several locations that are used as locations for research data acquisition, observe the geological surface conditions at the research locations and also for planning of layout data acquiring. After determining the field design, the next step is data acquisition. The travel time obtained is then used to modeling the wave velocity of the subsurface layer based on the depth of the layer at the research location.

3.2. **Refraction seismic data processing**
The subsurface model was obtained from the data generated during measurements in the field, so that data processing is needed to obtain the seismic wave velocity value and followed by analyzing then interpreting the velocity profile. Data processing and 2D modeling were carried out with four main stages including such as data input and geometry measurements, first break picking and band-pass filtering, review of wave propagation travel time and inversion process with refraction seismic tomography method (non-linear least square).

3.3. **Data interpretation**
This interpretation stage was done after obtaining a model 2D of data analysis, then comparing with the geological data of the actual location that has previously been studied and also with other (secondary) supporting data, such as previous study in this research area. The data interpretation was also performed by means of qualitative interpretations based on the seismic wave velocity models derived from the distribution of the subsurface layer of the research location. The value of seismic wave velocity found in the model 2D was then matched with the reference table of seismic wave velocity values as shown in Table 1, so that it can be identify the shallow subsurface weak zone structure in the geothermal manifestation.

4. **Result and discussion**

4.1. **Line 1**
The first seismic line was an expansion of path that crosses directly into the streamlet, so that end-shot 1 was very close to the streamlet. Determination of the first seismic line was based on the possibility of existed a weak zone that could be clearly seen due to the outflow of manifestation flows directly into the streamlet. The line marked by red color was positioned intersecting with the second line colored by yellow sketched out in figure 2. That is an intention to reinforce the prediction of existence a weak zone. The first line is a measurement trajectory that was located close enough to one of geothermal manifestations where its distance was relatively 3 meters to the outflow. The type of outflow is hot steam-water mixture.
The 2D velocity profile of the first line shows that there was a weak zone that could be identified. The weak zone was located at distances of around 15-50 meters as shown in the dashed red line in Figure 2. The weak zone has P wave velocity value that ranges from 0.2 km/s - 1.2 km/s and it was identified as topsoil or totally complete weathered soil. This estimation of weak zone based on the velocity interval referred to P wave velocity values lower than 4000 m/s (4 km/s) that was an approach value studied by [8]. The weak zone that was found from the first line was suggested as a fracture zone associated with the geothermal system in the Ie Jue geothermal field, Seulawah Agam, Seulimum, Aceh Besar, where the fracture zone was assumed as the path of the fluid exits to the surface.

4.2. line 2
The second line was an intersected line to the first line at the point where it was closed to streamlet flow. Determination of the second line was also based on the possibility identification of a weak zone intended to verify or validate to the first line result. The center point of the second line was placed close to the streamlet itself. Same as first line, the second line was also a measurement line that was close enough to the hot steam-water mixture which was ± 3 meters away. Based on the results of data processing from the second line, it indicates as a weak zone at a distant range of 10 - 65 meters as shown in the marked box of red line in Figure 3. This weak zone also has a P-wave velocity value ranging from 0.2 km/s - 1.2 km/s and it was similarly predicted as completely changed to surface soil. This could be caused by the influence of temperature that involves in geo-chemical process of weathering. When the temperature in a rock layer increases, the rocks or soils would experience an expansion that affects porosity enlargement and shrinks density [10]. The weak zone produced from the second line was strongly indicated as a weak zone associated to the the weak zone of the first line. This zone was also expected as the pathway of the manifestation.
Figure 3. The 2D velocity profile of the second line.

The predicted weak zones obtained from these two seismic lines were suggested as the manifestation pathways from which fluids of have reached to surface. The pathway would gradually to be weaken because of continuous heating from the boiling water and gas fluids, so that the porosity of the layer would be even larger. Enlargement of the porosity causes the layer under the surface not to be compact. This unconsolidated zone could potentially raise a hazard. As previously explained, the Le Jue area itself is an active area that has traversed by timber trucks. This routine traffic becomes the dynamic loads pressuring from the surface to few meters of subsurface where the outflow channels are situated. As consequence, these expected weak zones could potentially produce a decline of bearing capacity. Finally, the land surface results a subsidence in the vicinity of the area. Figure 4 shows the results of the interpretation of the weak zone profiles association from the first and second lines where the lines intersect of each other and quite close to the surface manifestation of A1.
5. Conclusion

The result of this research shown that for both measured lines there are a strong estimation of relationship between P-wave velocity values with shallow structure as a pathway of fluid flow originated from geothermal source. The near surface structure consists of weak zones. This assumption derived from a relatively low P-wave velocity value. For the first line, the position of weak zone laterally is at a distance of 15-50 meters and vertically at 35 meters depth, while for the second line its position horizontally and vertically is at 10 - 65 meters distance and 35 meters respectively. These structures of weak zone are strongly predicted as the low-velocity zones or low-velocity layers (LVZ) and being a dominantly weathered zones. They are predicted as the channels for fluids from which geothermal manifestation have emerged to the surface. The low P-wave velocity values (0.2 - 1.2 km/sec) may reliable evidence indicating the manifestation pathways of geothermal. These pathways are frequently passed by timber trucks and motorcycles from which producing a dynamic load that pressures the ground overlaying the weak zones. This daily traffics will possibly produce a subsidence endangering for human activity.

6. References

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