Preliminary Results from a Field Experiment on Volcanic Tremor at Ijen Volcano Using an Array of Digital Seismographs

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Abstract: Spectral is a basic characteristic that needs to be understood from a volcanic event. This study aims to analyze the spectral and direction of orientation of the source of the volcanic tremor of Ijen volcano. Volcanic tremors are the volcanic events that usually appear before, during and after volcanic eruptions. In 2012 the Ijen volcano showed abnormal conditions, namely the recording of many volcanic tremors with a dissertation on changes in the condition of the lake. This study used secondary data, digital seismic recordings of the Ijen volcano in January-February 2012 (the conditions at Ijen were not normal). Spectral analysis was performed using the Fast Fourier Transform method. Analysis of the direction of source orientation is carried out using the convariance matrix method. The volcanic tremor spectral of Ijen volcano has the characteristics of two frequency peaks with one dominant frequency peak in the range of 1.3-1.5 Hz. The direction of the orientation of the epicenter is towards the Ijen crater and the hypocenter is towards the bottom of the Ijen crater, ranging from a depth of 400-1000 meters. The most appropriate source model to explain the source process of volcanic tremors of Ijen volcano is fluid fill crack.

1 INTRODUCTION

Indonesia is surrounded by 129 active volcanoes spread throughout Indonesia. Volcanic eruption disasters can disrupt the socio-economic life of communities around volcanoes, and can even be life threatening (Wildani, Maryanto, Gunawan, Triastuty, & Hendrasto, 2013). Ijen volcano is an active volcano in Indonesia, which is included in the Banyuwangi Regency, East Java. It is one of the volcanoes that is used as a tourist destination. The eruption can be dangerous for tourists or residents around it (Virgiawan, 2020). In 2012, the seismic activity of the Ijen volcano experienced a significant change in activity which made the authorities (PVMBG) raise the status of the Ijen volcano to standby, namely level 3 (on a scale of 1 to 4). Unusual volcanic earthquake activity and changes in the condition of the crater lake were recorded at this time. Volcanic tremor activity was recorded in large numbers and dominated the seismic activity of Ijen Volcano at that time. Volcanic tremor activity recorded at that time was followed by changes in crater lake conditions such as the appearance of gas bubbles and an increase in crater lake temperature (Caudron et al., 2012). Even though at that time there was no phreatic eruption, monitoring and understanding (from a research perspective) this volcanic tremor activity was important to do. Understanding this can be done by understanding everything related to this volcanic tremor such as the nature of the signal, the location of the source and the mechanism of the source.

The nature of a volcanic seismic signal (in this case a volcanic tremor) can be identified from its frequency characteristics. Determination of the frequency of seismic signals has become one of the main tools for investigating the nature of volcanic

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seismic signals (K. I. Konstantinou & Schlindwein, 2003). In determining the frequency of volcanic seismic tremor signals, special treatment is required that is not the same as determining the frequency of other volcanic seismic signals (Båth, 2012). This is because several volcanic tremor conditions were found which were not found in other seismic signals. among others, Volcanic tremors are recorded over a period of more than one minute or even up to several days so that there is an accumulation of large amounts of data. Second, there are temporal changes in amplitude and frequency that must be considered because they are related to source modeling and predictions of future eruptions. Third, the resulting spectrum may have some sharp peaks around narrow frequency bands, in which case high resolution is required to resolve individual frequencies. One method to overcome this is the direct segment method (Zobin, 2012). The long tremor time series is then cut into small parts that do not overlap and the spectrum is calculated for each part through the Fast Fourier Transform (FFT). The final spectral estimate is the average of all the individual spectra. This method has been used in volcanic tremor recordings from Mt. Etna, Italy (Nunnari, 2021; Sciotto, Cannata, Di Grazia, & Montalto, 2022; Zuccarello, Burton, Saccorotti, Bean, & Patanè, 2013) Hakone volcano, Japan (Mannen et al., 2021; Yukutake et al., 2017; Yukutake, Honda, Ukawa, & Kurita, 2022), Semeru Volcano, Indonesia (K. Konstantinou, Perwita, Maryanto, Budianto, & Hendrasto, 2013; Maryanto & Mulyana, 2008). And this method is still being used to analyze seismic signals of volcanic tremors from various volcanoes in the world.

The characteristics of the seismic signal spectra can also provide information on whether the signal is caused by a site, path, or source effect. This can be done by comparing the recorded spectra from many stations or from one 3-component station. The general method for examining possible site effects is to compare the volcanic tremor spectra recorded at the same station. Meanwhile, to examine the path effect is more difficult than the site effect because it requires knowledge of the geological structure in the area around the volcano. but if the stations are spread azimuth around the source it can be done by comparing the volcanic tremor spectra at different stations (Schlindwein, Wassermann, & Scherbaum, 1995).

A realistic visualization of vibrational sources should not only account for the temporal evolution of their properties, but should also extend spatially over several volumes beneath the volcano, representing possible channel geometries over a magma reservoir or hydrothermal fluid circulation through a crack system(K. I. Konstantinou & Schlindwein, 2003). The methods discussed so far can determine the origin of the tremor. One of the methods that can be used for limited digital recording data is the convariance matrix or polarization method. This method can provide the orientation of the location of the volcanic tremor source. The method has been applied to the Tungurahua volcano, Ecuador (Zobin, 2012).

In this paper we investigate the site, path, and source effect as well as the direction of the orientation of the source of the Ijen Volcanic tremor during unrest in 2012. We analyzed the spectral at 3 different stations and at two 3-component stations. We also analyze particle motion to determine the orientation of the source of the Ijen volcano volcanic tremor. we then combined the results of both analyzes to discuss the possible source mechanisms of triggering volcanic tremors.

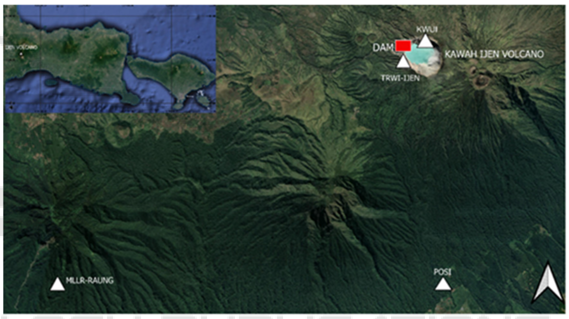

Figure 1: Kawah Ijen seismic network (KWUI, IJEN,POSI dan RAUNG : short-period sensors ; MLLR and TRWI :Broadband seismometer), the top left corner of the map shows the location of mountains in Indonesia, more precisely in the province of East Java which is marked with a white triangle.

2 METHODOLOGY

This study uses secondary data obtained from the Center for Volcanology and Geological Hazard Mitigation (CVGHM) Indonesia. The data used is seismic data from the Ijen volcano from January-February 2012. The data includes all records from six stations around the Ijen volcano, namely IJEN, KWUI, MLLR, POSI, RAUNG and TRWI stations. Figure 1 shows the Ijen volcanic activity monitoring network for all stations.

The data recorded by the six stations is a collection of seismic signals in the form of digital data. Data reading was carried out using Seisan software. This software reads data for 10 minutes in one reading window from several stations on Mount

Ijen as shown in Figure 2. The sampling time is 100 sample per second. So, in the event of 1 second, as many as 100 points are recorded in digital recording. The signal recordings in Figure 2 are volcanic tremors at IJEN, KWUI, MLLR, POSI, RUANG and TRWI stations respectively.

The recording at POSI and RAUNG stations was not good, so that the data selection only used four stations, namely IJEN, KWUI, MLLR, and TRWI. The volcanic tremor signal from the recording results is selected or selected based on the clear waveform at least at 3 seismic stations.

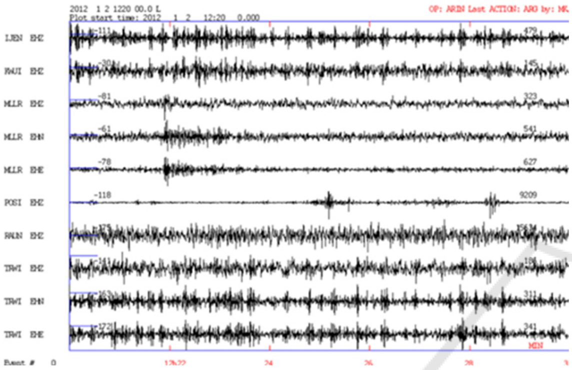

Figure 2: Record section of velocity waveforms of volcanic tremor recorded at all Ijen volcano monitoring station that occurred in 12.20-12.30 WIB on January 2, 2012 (from top to bottom: IJEN, KWUI, MLLR, POSI, RAUNG dan TRWI).

Spectral is determined by applying the Fast Fourier Transform (FFT) method. In this study using the help of Geopsy software. Before implementing FFT. data is filtered first using a band pass filter in the range between 0.05 Hz to 25 Hz. Then, data sampling is carried out for 1 minute on the signal with the maximum amplitude and finally the application of FFT to the sampled data.

The direction of the orientation of the epicenter of the volcanic tremor in this study was carried out by plotting the amplitudes of the North-South and West-East (NS-EW) components of the seismic recording of the volcanic tremor of Ijen volcano. Meanwhile, the direction of the hypocenter orientation in this study was carried out by plotting the amplitude of the radial and vertical components.

3 RESULT AND DISCUSSION

Figure 2 shows the recordings of volcanic tremors from all seismic stations scattered around the Ijen volcano at 12.10-12.20 WIB on January 1 2012. Volcanic tremors were very clearly recorded at Ijen, TRWI and KWUI stations, whose station positions are around the top of Mount Ijen. Volcanic tremors were also recorded at stations far from the Ijen crater, namely MLLR and RAUNG.

Figure 3 shows the spectra of volcanic tremor at all seismic stations scattered around Ijen volcano. The peak at 1.35 Hz in the spectrum was observed at all stations. The exact same spectrum peaks were seen at stations close to the Ijen crater, namely IJEN, TRWI and KWUI stations, which means that the volcanic tremor signal in this incident is a source effect. Meanwhile, at stations far from the Ijen crater, namely RAUNG, MLLR and POSI, they also show peaks of 1.35 HZ but are not the dominant frequency, this is thought to be due to the path and site effect. The effect of path and site is also seen in the component spectra (TRWI and MLLR). The 1.35 Hz peak is still recorded in the 3-component data, but the vertical component is not the maximum frequency peak.

The spectral volcanic tremor of the Ijen volcano shows that the volcanic tremor signal originates from a source effect, so in the next section we will discuss the most suitable source model to explain the appearance of the volcanic tremor of the Ijen volcano. Models of volcanic tremor sources have been developed to explain the occurrence of volcanic tremor from a volcano, among others 1) fluid flow induced oscillations (Julian, 1994) which has been used in several volcanoes, including Mt. Etna (Godano, Cardaci, & Privitera, 1996), Stromboli (Godano & Capuano, 1999), Vatnajokull (K. I. Konstantinou, 2002). 2) Excitation of fluid fill crack (Chouet, 1988, 2003) which has been used in Mt. aso (Sassa, 1935) , 3) hydotermal boiling (Leet, 1988) dan 4) Resonance of large magma budies (Bame & Fehler, 1986). All these models have their own characteristics both in terms of seismogram characteristics, spectral or geometric parameters. The approach by comparing the results of analysis from field data with the results of mathematical modeling is the most likely way to discuss the source model that best fits the Ijen volcanic tremor source model.

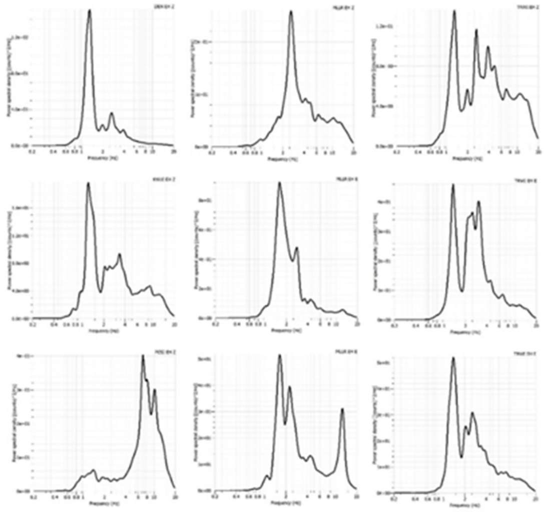

Figure 3: spectral of volcanic tremor of Ijen volcano which occurred at 12.20-12.30 WIB on 2 January 2012 at all stations (far left from top to bottom: IJEN, KWUI and POSI; middle from top to bottom: MLLR vertical, NS and EW components; most right from top to bottom: vertical component TRWI, NS and EW).

The spectral characteristics of the volcanic tremor of the Ijen volcano are one dominant frequency peak with a low value, namely at 1.12-1.3 Hz and there is another very small frequency peak with a value of around 2.3 Hz. These spectral characteristics are closer to or match the results from the fluid fill crack modeling. So, in this study we used the fluid fill crack model approach to explain the process of the source of volcanic tremor at Ijen volcano. The fluid fill crack model explains that volcanic tremors are caused by resonances that occur in fluid driven cracks caused by impulsive stress transients. Where the frequency value depends on the crack stiffness value of the crack. The greater the stiffness value of this crack, the frequency will be lower (K. I. Konstantinou & Schlindwein, 2003). This means that the low frequency of volcanic tremor of Ijen volcano indicates a large crack stiffness value. The crack stiffness is proportional to the length of the crack and inversely proportional to the thickness of the crack. Meanwhile, the duration of the signal depends on the viscosity of the fluid, the greater the viscosity value, the longer the duration of the signal. The duration of volcanic tremors was found to be less than days, but a few minutes or hours, proving that the fluid that is the source of volcanic tremors is not magma, but steam or gas. This condition is supported by monitoring at the Ijen crater that at the time of the 2012 crisis no magma was found flowing through the crater.

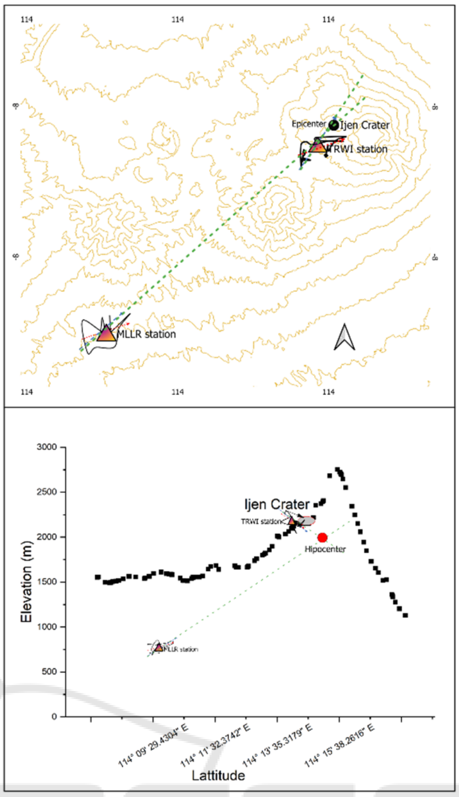

Figure 4: Orientation direction of the epicenter of the volcanic tremor of Ijen volcano (top) and orientation direction of the hypocenter (bottom).

Figure 4 shows the orientation of the epicenter and hypocenter of the Ijen volcano volcanic tremor using the particle motion approach. Figure 5a Particle motion is shown by a black line and the orientation direction of the epicenter is shown by the blue dotted line from the two 3-component data, namely from the MLLR station and TRWI station. The green dotted line indicates that the direction of the orientation of the epicenter of the volcanic tremor is towards the crater of Ijen volcano. Figure 5b shows the orientation of the hypocenter which is also determined based on the particle motion between the amplitude values of the vertical and radial components. In Figure 5b, the direction of the hypocenter orientation of the volcanic tremor of Ijen volcano is obtained, which is under the crater of Mount Ijen or around 400–1000 meters below the Ijen volcano. at this depth it is stated that there is a crack (Ayu & Jufriadi, 2014; Jufriadi, Maryanto, Susilo, Purwanto, & Hendrasto, 2013) and is thought to be a place for fluid to flow towards the surface and to be the source of the volcanic tremors of the Ijen volcano.

4 CONCLUSIONS

The conclusion of this study is that the spectral characteristics of the volcanic tremor of Ijen volcano have two frequency peaks with one dominant frequency peak in the range 1.3-1.5 Hz. Volcanic tremor signals are caused by source effects except for stations far from the peak which are affected by site and path effects. The direction of the orientation of the epicenter of the volcanic tremor of Ijen volcano leads to the Ijen crater lake while the direction of the orientation of the hypocenter leads to a depth of 400-1000 meters below the Ijen crater. Based on the spectral characteristics and direction of the source orientation, the source model is suitable for explaining the source process of the volcanic tremor of the Ijen volcano, namely fluid fill crack.

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