Analysis of seismic signal in order to determine subsurface characteristics

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Abstract. The purpose of this study is to know how to analyze the seismic signals volcanic to determine subsurface characteristics. The method used to analyze seismic signals volcanic is Fast Fourier Transform. Sample signal seismic wave of this study come from Semeru Volcano and Ijen Volcano signal seismic based on seismogram. The first data are given by swarm and www software. Analyze seismic wave in this study proves the existence of a relationship between seismic attributes (frequency, amplitude, time (origin, primer dan secondary) and attenuation) of the characteristics of the earth's surface. This study proved there is the correlation between subsurface characteristics and energy, it shows by attenuation factor value (Q value). The value of factor Q indicates how many waves are absorbed by the medium.

1. Introduction
Seismic waves are energy waves that move through the Earth's layers and are the result of volcanic eruptions, earthquakes, large landslides, magma movements, and large man-made explosions that produce low-frequency acoustic energy. Many anthropogenic and other natural sources create low amplitude waves commonly referred to as ambient vibrations. Seismic wave fields are recorded by hydrophones (in water), seismometers and accelerometers. Seismic signals can be used to determine the characteristics of the earth's surface medium [1,2]. medium characteristics are indicated by physical parameters, such as speed and seismic attenuation. Weakening seismic waves can describe the ability of the medium to reduce waves on the surface of the earth so that the material properties of the earth will be understood [3]. There are several methods used to analyze seismic waves, such as homomorphic deconvolution [4], the wavelet based adaptive tapes method. In this method, we need to find a mother wavelet function to provide a description of the signal being analyzed more informative, efficient and useful [5]. Method of time-frequency mismatch criteria, goodness-of-fit method, and Hawkins reciprocity method. This method has a disadvantage because the dominant frequency of natural noise has not been sampled. So that the frequency data still contains noise. Other methods that can be used to analyze seismic signals are short Time Fourier Transform (STFT) and Continuous Wavelet Transform (CWT) [5]. This method is equally based on Fourier transform, only this method assumes that the spectral component varies slowly so that the signal can be considered stationary in analyzing the time window. Therefore, STFT does not allow the calculation of the dominant frequency, center frequency, or spectral changes in content if the change in time is fast. This study uses the Fast Fourier transform (FFT) method to analyze seismic waves through frequency spectra. Fast Fourier Transform, is an
algorithm for calculating discrete Fourier transforms quickly and efficiently [6,7]. The purpose of this study is to analyze seismic volcanic signals to determine subsurface characteristics. The FFT results will be correlated with the value of wave attenuation (Q value) to increase the accuracy of the results of subsurface characteristics [8].

2. Method
Signal analysis using the principle of fast Fourier transform method is known as spectral analysis. Fast Fourier transform method functions change the time domain into the frequency domain. Therefore, Seismic attributes (frequency, amplitude, time and attenuation) obtained can be used to determine the characteristics of the earth's surface. The sample of the seismic wave is from seismic signals on Semeru Volcano dan Ijen Volcano.

3. Results and discussion
Before analyzing seismic signals. The first step that needs to be done is to cut data. Cutting data is done on the signal to get the signal spectrum on the desired event. The length of data to be cut is for 10 seconds starting shortly before the arrival time of the P wave by looking at the first motion of the signal. Before cutting data, the P wave arrival time ($t_p$) and the S wave arrival time ($t_s$) are determined first. After cutting data, what needs to be done is signal filtering. The bandpass filter is performed to reduce low-frequency noise (e.g. ground roll) and high-frequency noise (e.g. ambient noise). The bandpass filter used has a range of about 0.05 to 30 Hz. Figure 1. shows the process of analyzing seismic signals (case studies of seismic signals on Ijen Volcano) using Swarm [9].

Figure 1. The process of analyzing seismic signals (case studies of seismic signals on Ijen Volcano).
Signal $x(t)$ have Fourier transformation $X(\omega)$, $\omega = 2\pi f$

$$X(\omega) = \int_{-\infty}^{\infty} x(t)e^{-i\omega t} dt$$  \hspace{1cm} (1)

Where $x(t)$ is a wave that is separated into several sines waves and $X(\omega)$ is a Fourier transform of $x(t)$ and $i = \sqrt{-1}$. We obtain

$$X(\omega) = \int_{-\infty}^{\infty} x(t)\cos(\omega t)dt - i \int_{-\infty}^{\infty} x(t)\sin(\omega t)dt$$  \hspace{1cm} (2)

$$= \text{Re}[X(\omega)] - i \text{Im}[X(\omega)]$$

$$= |X(\omega)|e^{i\phi(\omega)}$$  \hspace{1cm} (3)

We have amplitude spectrum equation

$$|X(\omega)| = \sqrt{[\text{Re}[X(\omega)]]^2 + [\text{Im}[X(\omega)]]^2}$$  \hspace{1cm} (4)

The equation can also be expressed as phase spectrum equations

$$\phi(\omega) = \tan^{-1}\left(\frac{-\text{Im}[X(\omega)]}{\text{Re}[X(\omega)]}\right)$$  \hspace{1cm} (5)

While the inverse of Fourier transform is defined

$$x(t) = \int_{-\infty}^{\infty} X(\omega)e^{i\omega t} d\omega$$  \hspace{1cm} (6)

The spectral analysis uses all forms of signals so that if an error occurs, information will be easily avoided compared to the measurement of points in the time domain. Figure 2 shows fast Fourier transform as frequency spectral using wvw SR 900 [10].

![Figure 2](image.png)

**Figure 2.** Analyzing seismic signals using Fast fourier transform to obtain frequency spectral (case studies of seismic signals on Semeru Volcano).

Waves propagating on a medium will experience a signal attenuation caused by the absorption of energy by the medium. This is caused by geometrical spreading, scattering and intrinsic attenuation [11]. Attenuation explains the elastic wave propagation that causes the energy to be lost to heat due to a shift in the grain boundaries and mineral dislocations [12].

The attenuation that occurs can be formulated as

$$A(x) = A_0 e^{-\alpha x}$$  \hspace{1cm} (7)
The attenuation coefficient is indicated by

\[ \alpha = - \frac{1}{A(x)} \frac{dA(x)}{dx} = - \frac{d}{dx} \ln(A(x)) \]  

\( Q \) factor as attenuation is a part of the amount of energy lost in wavelength unity due to the imperfect perfect elasticity of a material. \( Q \) factor is given by

\[ \frac{1}{Q(\omega)} = \frac{\Delta E}{2\pi E} \]  

Where \( E \) is the energy lost and \( E \) is the maximum energy measurement of initial energy and final energy is carried out by spatial or temporal decay. We then have \( E \propto A^2 \) or \( \sqrt{E} = A \).

And so energy can be expressed as

\[ E = - \frac{\Delta EQ(\omega)}{2\pi} \]  

If \( Q \gg 1 \), which physically means that the energy lost is smaller than the initial energy. So we may rewrite the relationship between attenuation and energy as

\[ A = - \frac{\Delta AQ(\omega)}{\pi} \]  

\[ - \frac{\Delta A}{A} = \frac{\pi}{Q} \]  

At temporal decay, if at first \( A = A_0 \), \( A \) will decrease \( \frac{\pi}{Q} \) by 1 round (1T). For \( n \) periods \( (nT = t = \frac{2n\pi}{\omega}) \), then the amplitude in the time function is

\[ A(t) = A_0 \left( 1 - \frac{\pi}{Q} \right)^n \]  

Remembering that \( \pi = \frac{\omega t}{2n} \) and rearranging as series function, we obtain

\[ A(t) = A_0 \exp\left( - \frac{\omega t}{2Q} \right) \]  

For \( \frac{x}{l} \)

Spacial decay we find

\[ A(x) = A_0 \exp\left( - \frac{\omega x}{2vQ} \right) \]  

Amplitude is a function of time and distance, so the attenuation coefficient is

\[ \alpha = \frac{\omega}{2Q} \tan \alpha = \frac{\omega}{2vQ} \]
Q factor for P waves in the earth is systematically greater than S waves. Q values for some rock types are generally Q increases according to material density and speed. The result of formula from this study show that, the effect of attenuation (Q factor) on seismic signals can be seen in the reduced amplitude and widening of the signal. The other result of this study prove that attenuation is a combination of energy reduction and frequency absorption that takes place simultaneously [6]. Frequency absorption process is selective, the medium absorbs the frequency of seismic waves unevenly depending on the characteristics of the earth's surface (porosity, size of the grain, density, fluid saturation, fluid viscosity, and pressure) [13]. Figure 3. is the result from formula on this study. As soon as we input amplitude and Q factor in origin software, the result is characteristic the earth's surface.

4. Conclusion
The Fast Fourier transform method can eventually be used to determine the frequency and amplitude. With the formula Q factor (attenuation) that we have formulated. There appears to be a connection between attenuation, frequency and amplitude as a function of the structure of the earth's surface. Attenuation due strictly to the rock matrix and its associated components saturation, porosity, pore fluid etc.

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