Microtremor survey to investigate seismic vulnerability around the Seulimum Fault, Aceh Besar-Indonesia

Andrean V H Simanjuntak¹²³, Umar Muksin¹³, Febrina Rahmayani³⁴
¹Department of Physics, Syiah Kuala University, Banda Aceh, Indonesia
²Mata Ie Geophysical Station of BMKG Aceh, Aceh Besar, Aceh
³Tsunami and Disaster Mitigation Research Center, Syiah Kuala University, Banda Aceh, Indonesia
⁴Department of Geophysics, Syiah Kuala University, Banda Aceh, Indonesia

E-mail: andreansimanjuntak@gmail.com

Abstract. The Seulimeum Fault has generated inland earthquake with magnitude larger than M 6.5 that destroyed houses in the Lanteuba and Krueng Raya Villages. Earthquakes along the Seulimeum Fault are mostly right lateral strike-slip characterizing the Fault. The understanding of the seismic vulnerability around the highly populated Banda Aceh City and the villages in Aceh Besar is therefore very important since the city, and the villages are very close to the Seulimeum Fault. A microtremor survey has been conducted to investigate seismic vulnerability in the area closed to the Seulimeum Fault. The waveforms of the microtremor have been recorded in Lanteuba and Kreung Raya villages, Aceh Besar at 20 sites for 7 days from August 14, 2017 with the interval of measurement of 1 km. The waveforms recorded for 30 minutes at each site by using one Taurus Seismometer in miniseed format. The data has been analyzing by using Geopsy to obtain the Horizontal-Vertical Spectral Ratio for each site. The seismic vulnerability is considered to be high if the value of the Horizontal-Vertical Spectral Ratio is high. The HVSR values are then interpolated to obtain the seismic vulnerability map. The preliminary result shows high seismic vulnerability in the area around the first site.

1. Introduction

Since 1892, more than 20 destructive inland earthquakes with magnitudes larger than M 6.0 have occurred along the Sumatran Fault including along the secondary faults. The Seulimeum Fault generated large earthquakes in 1964 and 1975 although the localization facilities were limited at that time to obtain an exact earthquake location. People in the Krueng Raya, the Lanteuba, and the Seulimeum regions informed that their regions were among the highly affected areas by the massive earthquake in 1964. Geoscientists have focused their studies on the Seulimeum Fault as the fault has not been activated for a quite long time by large earthquakes. The length of the Seulimeum Fault is expected to be around 120 km and moves 2.5 mm/year with the maximum magnitude of earthquake could reach M 7.5.

The Pidie Jaya earthquake with magnitude of M 6.7 is the latest earthquake which occurred along the secondary fault in the Aceh province. The Pidie Jaya earthquake could affect the activity of the Seulimum Fault because the stress could be transferred to the Seulimeum Fault (the closest fault). Although the area around the Seulimum Fault is very vulnerable, information on the seismic vulnerability index in the region is still very limited. Quantitative and qualitative data on seismic
vulnerability analysis becomes very important as that information could be used for the earthquake risk reduction program.

![Figure 1](image)

**Figure 1.** Historical of earthquake data and focal mechanism in Aceh Province from Global CMT, International Seismological Center (ISC), and GFZ-Potsdam.

Figure 1 explains the seismotectonic condition in the Aceh Province. The epicenters are from local fault activity and have strike-slip or oblique focal mechanism. The strikes of some focal mechanisms follow the straightness of the fault. We can see that the strike direction from NorthWest (NW) to SouthEast (SE) which is in agreement with the strike of the fault. Also, seismic susceptibility for microzonation index can be used as a reference to build safer buildings by infrastructure developer.

Earthquakes and tremors can be distinguished when we view the seismic waveforms. An earthquake waveform has several peaks indicating the arrivals of seismic energy of the earthquake such as P and S arrivals. Natural vibration (ambient vibration) of the earth comes from two main sources, nature and human activity with the frequency below 1 Hz while microtremor is natural ambient noise [1]. Microtremor is a ground vibration with an amplitude displacement between 0.1 to 1 micron with speed range from 0.001 to 0.01 cm/s which could be detected by a seismometer located in the highly amplified region [2]. Among the natural sources of ambient vibrations are sea waves (with a frequency of ~0.2 Hz), the sea and beach waves with a frequency of ~0.5 Hz, the activity in the atmosphere (frequency below 0.1 Hz), and wind and water flow (with the frequency higher than 1 Hz).

Microtremor has been widely used to estimate the risk level and damage index caused by earthquakes and also used to investigate the geological structure of a region [3]. Nakamura [4] analyzed and found that the horizontal and vertical spectrum ratio of microtremor increased at a resonance frequency. Nakamura [4] suggested that the H/V ratio reflects the amplification level of ground motion.

2. Geology and Tectonic Settings

The geological and tectonic setting of the Seulimum Fault region has been well explained and mapped [5] as shown in figure 2. The Sumatran Fault starts to bifurcate around Tangse to create the Seulimum fault striking NNNW-SSE or around 10° north of the Aceh segment.

The lineation of the Seulimum Fault is precisely in the middle of the sediment formation from Plio-Pleistocene era and volcanic rocks from the Seulawah Agam volcano. The lithology of Krueng Raya, an area located in the northernmost of the Seulimum Fault, is dominated by the same volcanic rock which spreading in the Lam Teuba area as shown in figure 2.
Figure 2. Structural, Geology and Tectonic Setting Map of the North Sumatran Basin [5].

The northern part of the Seulimeum Fault was created in the Cretaceous period. The rock in the Kreung Raya region is dominated by the same rocks in the Lam Teuba area which is volcanic rock caused by the Seulawah Volcano eruption [6]. The oldest rocks in this area from the pre-quartener era consist of limestone, slates and phyllites [7].

3. Data and Method

Prior the survey, a literature study has been performed to better design the microtremor measurement and was conducted for 6 days from August 11th, 2017. One set low-frequency Lenard Seismograph, owned by Mata Ie Geophysical Station, was used to record 20 observation points microtremor. The locations of the measurements are shown in Figure 3. We recorded the microtremor in the area with a low level of noise and far from human activities. The duration of measurement is 30 minutes in each point which is considered to be sufficient to record the microwave around the site.

Figure 3. Some point observation with blue triangle near Seulimeum Fault with first point (001).

The microtremor data retrieval was performed by the rules set by the SESAME European research project [8]. The seismic waveforms in a MiniSeed format which were downloaded each hour through data logger and downloaded by connecting the RJ-45 cable to laptop or pc. Data retrieval was based on the measurement point that has been prepared previously using google maps and Garmin.

3.1 Method - Horizontal to Vertical Spectrum Ratio (HVSR)

The HVSR method compares the microtremor spectrum of the horizontal component to the vertical component. Nakamura [4] stated that the spectrum of H/V as a frequency function is closely related to the site transfer function of shear waves.
Nakamura [4] showed that the H/V ratio on the tape that has ambient noise is closely related to the frequency found on the ground, which is one of the amplification factors. In 1989, Nakamura [4] obtained observations indicating that the recording at a station located in hard rock region, the maximum value of the horizontal component spectrum ratio to the vertical close to the value of 1. At the station located in soft rocks, the H/V maximum is greater than 1.

Non-natural wave sources on the surface tend to trigger Rayleigh waves that propagate in the soil layer or soft sediment [9]. Rayleigh waves affect the horizontal and vertical components on the surface, but hardly affect the wave component in bedrock [1]. Nakamura [4] stated that there are two horizontal components measured in the N-S and W-E direction in the observation field. It can be expressed with:

\[
SM(w) = \left[ \left( \frac{HSN(w)^2 + HWE(w)^2}{\sqrt{2}} \right)^{1/2} \right] / VS(w)
\]  

\( HSN(w) \) = North-South horizontal spectrum component of microtremor  
\( HWE(w) \) = East-West horizontal spectrum component of microtremor  
\( VS(w) \) = Vertical spectrum component of microtremor

4. Result and Discussion

We conducted a proper and comprehensive evaluation of each measurement point. Evaluation is conducted by visually investigate the characteristics of the signal after the merging.

Figure 4. (A) The record has not match signal and each component separated in 3 part (B) The record was merged to make all separate signal to be united in one part.

Figure 4 showed we combined several separated waveforms (figure4A)) into 3 components (vertical, north, and east). After merging, the waveforms have identical origin time measurement.

4.1. Frequency/time graphic

We evaluate the frequency of the waveforms with time to see when the time have a maximum and minimum frequency amplitude values. We then perform automatic windowing to obtain the value of H/V and resonance frequency. The function of frequency and time of the Site 001 is shown in figure 5 for the Z component waveform.

From figure 5, we can see that the maximum frequency of the vertical component is the range between 40 and 60 Hz, and a minimum frequency of 0 -1 Hz. High amplitude at a certain time shown in figure 5 indicates that the waveforms contain transient noise from the surrounding environment.
From this evaluation, we could determine the characteristic of recording frequency and distinguish the natural seismic waveform and transient noise.

**Figure 5.** The comparison between frequency over time of the Vertical (Z) component of the waveform recorded at the 001 site.

The maximum frequencies of the N-S and E-W components are the same as that of the Z component between 40 and 60 Hz and a minimum frequency between 0-1 Hz. The frequencies in those ranges were used in the determination the value of H/V while noise was not included in the calculation. To determine the value of H/V, we performed a band-pass filter between 0.01 - 20 Hz, which is the characteristic of the microtremor signal. After that, the STA/LTA procedure was applied to exclude transient noise from the waveforms.

4.2. H/V Ratio

The waveform is windowed in 25 seconds and the HVSR is for each window. Based on the preliminary result, we can see that the predominant frequency value \(f_0\) at the point 001 is 0.093851 Hz with the amplitude of 3.8481. The waveforms have a range of frequency between 0.01 – 20 Hz which is a typical seismic frequency. The result also shows the stable graphical trend from 1 – 20 Hz. The region of the 001 site has low amplification of seismic energy. The type of constituent rocks found are following the alleged preliminary study since the majority is composed of volcanic and tuff rocks. This makes the land in the area quite compact and not easily amplified. The preliminary results also show that recorded data is stable and could be used for the next data analysis (for other points).
The study still does not cover all the points, because it is still in the process of assessment at observation points that have a good record and results. From the preliminary result, we can make a good waveform for reducing the noise, after knowing the frequency characteristic. Next, all values from each point will be mapped by interpolating all the H/V values. The seismic vulnerability index can be derived from the H/V values. All that result is very useful and important to make mitigation near the Seulimeu Fault. The microtremor survey will be continued next year by adding more observation points.

5. Conclusion

The preliminary results show the reliability waveform data we have recorded and could be used for further data analysis. The region around the first point (001) has resonant frequency $f_0$ of 0.093851 Hz with an amplitude of 3.8481. The values obtained by automatic windowing with the filter band pass from 0.01 - 20 Hz on the combined recordings. The recorded waveform has a maximum frequency range between 40 and 60 Hz, and a minimum frequency between 0 - 1 Hz. The value of resonant frequency and H/V spectrum value of the 001 site indicate that the region has an acceptable soil susceptibility and does not experience high amplification effect if an earthquake occurs.

References

[1] Takai dan Tanaka. 1961 On microtremors VIII. Tokyo: Bull. Earthquake Res. Inst 39 97-114
[2] Konno K, dan Omachi T 1998 Ground Motion Characteristics Estimated from Spectral Ratio Between Horizontal and Vertical Components of Microtremor Bull. Seism. Soc. Am 88 228-241
[3] Nakamura Y 2008 On the H/V Spectrum Beijing: The 14th World Conference on Earthquake Engineering NEHRP. 2000. Site Classifications Taken from Table 1615 1.1 Site Class Definitions published in 2000 International Building code International Code Council, Inc. on page 350
[4] Nakamura Y 1989 A Method for Dynamic Characteristics Estimation Od Subsurface Using Microtremor on The Ground Surface Tokyo: Quarterly Reports of the Railway Technical Research Institute 30 25-33
[5] Bennett J D, McC Bridge D, Cameron N R, Djunuddin A, Ghazali S A, Jeffrey D H, Kartawa W, Keats W, Rock N M S, Thomson S J and Whandoyo R 1981 Geologic map of the Banda Aceh Quadrangle (Sumatra-Indonesia)
[6] Barber A J, and Crow M J 2005 Chapter 4: Pre-Tertiary Stratigraphy. In Barber A J, Crow MJ and Milsom J S Sumatra: Geology, Resources and Tectonic Evolution, Geological Society (London, Memoirs) 31 24-53.
[7] Culshaw M, G, Duncan S V and Sutarto N R 1979 Engineering geological mapping of the Banda Aceh alluvial basin, Northern Sumatra, Indonesia. Bulletin of Engineering Geology and the Environment 19 40-47
[8] Bard P Y 2005 SESAME-Team (2005) Guidelines for the implementation of the H/V spectral ratio technique on ambient vibrations: measurements, processing, and interpretations SESAME European research project
[9] Mirzaogl glu M dan Dýkmen U 2003 Application of Microtremors to Seismic Microzoning Procedure Journal Of The Balkan Geophysical Society 6 143 – 156