Seismic microzonation by using microtremor method in Pandan volcano, Bojonegoro, East Java

Samsul Hidayat, Dwa Desa Warnana, Sorja Koosuma and Cari

1 Physics Department of Graduate Program, Sebelas Maret University, Jl. Ir. Sutami 36A Kendingan Jebres Surakarta 57126, INDONESIA

2 Civil Engineering Department, Institut Teknologi Sepuluh Nopember, Jl. Arief Rahman Hakim Sukolilo Surabaya 60111, INDONESIA

E-mail: cak.syam.hidayat@gmail.com

Abstract. Pandan volcano geographically is located in the north of Madiun and Nganjuk district, and south Bojonegoro district. The status of this volcano is longer not active, but it still emerges hot spring in some areas. This research aims to understand the distribution of the natural frequency value, the amplification factor value, and the vulnerability index value by using microtremor horizontal to vertical spectrum ratio (HVSR) method, that is believed to have an important contribution to earthquake disaster mitigation. There are 19 measurement sites where geographically ranges between 7°26'36.60"–7°27'16.49"S and 111°46'31.76"–111°47'11.98"E. The survey used portable seismograph 3-components SL07 SARA single station. For each site of measurement needs 30 minutes of ambient noise recording with a sampling rate of 100 Hz. The data processing was done by HVSR analysis method on Easy HVSR software. The natural frequency ($f_o$) value ranges between 1,1 and 9,95 Hz, and amplification factor ($A_g$) value varies from 2,1 to 7,2. The vulnerability index ($K_g$) value ranging from 0,48 to 25,34. The highest risk index is located in the north part of the research area where have high potential to damage when the earthquake happens.

1. Introduction

Microtremor is one of the passive seismic method which utilizes ambient noise from nature to understand the structure character of the subsurface layer without causing a disturbance on its structure. Nakamura [1] introduce microtremor horizontal to vertical spectral ratio (HVSR) method or called Nakamura technique to determine local site effects on seismic ground motion, expressed by natural frequency ($f_o$) and amplification factor ($A_g$) of sediment. Local site effects play an important role in the earthquake damage distribution and refer to the effect of the local geological surface and subsurface structure characteristics on the seismic ground motion [2]. In terms of seismic risk, the unconsolidated sediment materials could amplify ground motion during an earthquake and this causes building on these grounds to become more vulnerable to earthquake damage than those build above the hard rocks [3]. Nakamura (e.g. [4], [5], [6]) proposed the vulnerability index ($K_g$) to identified weak zone, a potential to damage when the earthquake occur. The magnitude of vulnerability index value is related to ground amplification factor and natural frequency. The vulnerability index is indicated the soil damage level due to ground motions [7].

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Now, the microtremor HVSR method has been widely used for seismic microzonation purposes (e.g. [8], [9], [10]). Seismic microzonation is the process to dividing a zone into smaller zone based on the response local geology to earthquakes [11]. Seismic microzonation is useful for earthquake disaster mitigation (e.g. [12], [13]).

Earthquake events around Pandan volcano during 2016 have increased significantly [14]. Recorded earthquake data from Indonesian agency for Meteorological, Climatological, and Geophysical (Figure 1) shows that there are 73 earthquake events with a magnitude range below 4 Richter scale and the depth ranges is mostly below 30 km (shallow earthquake). Related to the occurrence of the earthquake, Santoso et al [15] explain there are two possibilities, first it was related to thrust fault activation (in the north of Pandan volcano a thrust fault is found), and secondly is related to sub-magmatic activation. There is also possibility that due to active fault movement may trigger upwelling magma.

![Figure 1. earthquake events during 2016 in Pandan volcano (blue circle) and surrounding (modified [16])](image)

To reduce the impact of disaster risk, disaster mitigation efforts should be undertaken. One of the earthquake disaster mitigation efforts can be done by assessing local site effect. Microtremor measurement was conducted in the research area in order to know site characteristics based on natural frequency and amplification factor, and vulnerability index values to predict area has high potential to damage due to ground motions.

2. Location and geological setting

Pandan volcano geographically is located in north of Madiun and Nganjuk district, and south Bojonegoro district. It is approximately 40 km northeast of Madiun town. The status of this volcano is not active, but it still emerges hot spring in some areas. Location of site survey is on the western flank of Pandan volcano, Klino village, Bojonegoro district or geographically ranges between 7°26’36.60” – 7°27’16.49” S and 111°46’31.76” – 111°47’11.98”E (Figure 2). The elevation ranges between 474 m and 578 m.
Based on the geologic map of the Bojonegoro Quadrangle, East Java [17], Pandan volcano is a Quaternary volcano formed on Early Pleistocene. The rock unit of the research area is dominated by the volcanic breccia (Pandan breccia) (Figure 3).

![Figure 2. location map of research area (shown by yellow box)](image)

![Figure 3. geological map Pandan volcano and surrounding (site area shown by red box)](image)

3. Microtremor measurement and processing
The Nakamura technique is very useful tool for subsurface soil structure and site response studies, especially recommended in areas of low and moderate seismicity, owing to the lack of significant earthquake recording [18]. Measurements microtremor data was carried out at 19 sites on the western flank of Pandan volcano. The survey to record the ambient noise was used portable seismograph 3-components SL07 SARA single station, that recorded signal in three perpendicular directions: vertical (Z) and two horizontal (NS and EW). For each site of measurement needs 30 minutes of ambient noise recording with a sampling rate of 100 Hz (dt=0.01 s). The guidelines of the SESAME European
research project [19] was used for the implementation of the Nakamura technique for microtremors. These H/V user guidelines recommend the procedure for observation point selection, field experiment design, data processing, and interpretation of result data [20]. The data processing was done by HVSR analysis method on Easy HVSR software.

In order to obtain the HVSR curve at each site, the collected data was performed processing data in the following steps: each component of the recorded signal was windowed in a time series of 40 sec length non overlapping and for each selected time window the Fast Fourier Transform (FFT) was calculated and smoothed using Konno & Ohmachi logarithmic window function. Recorded data of FFT and spectrums of each component were obtained using frequency-domain analysis. For each selected windows the spectral ratio between the mean square average spectrum of the horizontal component over the spectrum of the vertical component was calculated. Finally, the HVSR curve was generated. The resulting HVSR curve satisfies the criteria defined by SESAME European research project [18]. The criteria for a reliable HVSR curve and clear HVSR peak for reliable measurements are shown in Tabel 1.

Table 1. Criteria for a reliable HVSR curve and clear HVSR peak defined by SESAME European research project.

| Criteria for a reliable HVSR curve                                                                 |
| (all criteria should be fulfilled)                                                                 |
| 1) \( f_o > 10 / I_w \)                                                                            |
| 2) \( n_n (f_o) > 200 \)                                                                            |
| 3) \( \sigma_A (f) < 2 \) for \( 0.5 f_o < f < 2 f_o \) if \( f_o > 0.5 \) Hz or \( \sigma_A (f) < 2 \) for \( 0.5 f_o < f < 2 f_o \) if \( f_o < 0.5 \) Hz |

| Criteria for clear HVSR peak                                                                             |
| (at least 5 out of 6 criteria fulfilled)                                                                 |
| 1) \( \exists f \in [f_o / 4, f_o] \mid A_{H/V} (f) < A_o / 2 \)                                    |
| 2) \( \exists f^+ \in [f_o, 4 f_o] \mid A_{H/V} (f^+) < A_o / 2 \)                                |
| 3) \( A_o > 2 \)                                                                                       |
| 4) \( f_{peak} \{ A_{H/V} (f) \pm \sigma_A (f) \} = f_o \pm 5 \% \)                                |
| 5) \( \sigma_A < \varepsilon (f_o) \)                                                                  |
| 6) \( \sigma_A (f_o) < \Theta (f_o) \)                                                                |

| Frequency range (Hz) | \(< 0.2\) | \(0.2 - 0.5\) | \(0.5 - 1.0\) | \(1.0 - 2.0\) | \(> 2.0\) |
|----------------------|---------|--------------|--------------|--------------|----------|
| \( \varepsilon (f_o) \) (Hz) | 0.25 \( f_o \) | 0.2 \( f_o \) | 0.15 \( f_o \) | 0.10 \( f_o \) | 0.05 \( f_o \) |
| \( \Theta (f_o) \) for \( \sigma_A (f_o) \) | 3.0 | 2.5 | 2.0 | 1.78 | 1.58 |
| \( \log \Theta (f_o) \) for \( \sigma_{log} (f_o) \) | 0.48 | 0.40 | 0.30 | 0.25 | 0.20 |

Reference [21] explained that three criteria for reliable HVSR curve are based on the relation of peak frequency to the window length, a number of significant cycles and standard deviation of the peak amplitude. Six criteria for a clear peak are based on the relation of the peak amplitude to the level of the HVSR curve elsewhere, and standard deviations of the peak frequency and of its amplitude (the amplitude should decrease rapidly on each side). An example of microtremor HVSR data has been
processed on Easy HVSR software and fulfill nine criteria defined by SESAME project shown in Figure 4.

![Figure 4](image)

**Figure 4.** An example HVSR curve fulfill nine criteria defined by SESAME project

4. Result and discussion

The HVSR curve contains information of natural frequency and an amplification factor of a site. Figure 5 shows the distribution of natural frequency, ranging from 1.1 to 9.95 Hz. The formula $f_o = C_s / 4h$, where $C_s$ is shear wave velocity of a surface layer and $h$ is depth of the basement (or thickness of sediment) [5], shows that the natural frequency associated with the thickness of sediment. The greater of natural frequency value indicates smaller of thickness of sediment. Previous studies has proved the validity of this formula (e.g. [21], [22], [23], [24]).

![Figure 5](image)

**Figure 5.** Distribution map of the natural frequency value in research area

The amplification factor (or peak HVSR curve) value in research area shown in Figure 6. It ranges between 2.1 and 7.2, though most areas having 2.01 to 3.5 $A_v$ value. The large amplification factor is related to high impedance contrast between the sedimentary cover and the bedrock [22]. Reference [7] explained that no correlation between natural frequency and amplification factor. The variation of amplification factor value is not strongly effected by the soil depth, but the geological factors are more dominant to the variation of amplification factor value.
Figure 6. distribution map of the amplification factor value in research area

The natural frequency \( (f_0) \) value and the amplification factor \( (A_g) \) value were used as the input of parameters to generate seismic vulnerability index \( (K_g) \) to the formula: \( K_g = A_g^2 / f_0 \) [4]. Reference [4] also explained that vulnerability index useful as an indicator weak points of the ground due to ground motion. The distribution of vulnerability index in research area shown in Figure 7. Its shows \( K_g \) value ranges between 0,48 and 25,34. The highest risk index is located in the north part of the research area where have high potential to damage when the earthquake occurring.

Figure 7. distribution map of the vulnerability index value in research area

5. Conclusion
The microtremor HVSR method has been widely used in seismic micro-zonation studies and site effect studies. Past earthquake information and the geological map of the research area is very valuable information for seismic microzonation at the research area. Microtremor measurements performed on the western flank of Pandan volcano, Bojonegoro district. The data analysis used Nakamura technique (horizontal to vertical spectral ratio method) on Easy HVSR software. The result
data showed that the natural frequency value varies from 1.1 to 9.95 Hz and the amplification factor value ranges between 2.1 and 7.2. The vulnerability index determined based on the natural frequency value and the amplification factor value. In this study, the vulnerability index value ranging from 0.48 to 25.34. The highest $K_g$ value is located in the north part of the research area, as indicate as weak point and potential to damage when the earthquake happens.

References

[1] Nakamura Y 1989 Quarterly Report of Railway Technical Research Institute (RTRI) 30 25
[2] Stanko D, Markusic S, Strelec S, Gazdek M 2017 Soil Dynamics and Earthquake Engineering 92 666
[3] Mohamed A A, Helal A M A, Mohamed A M E, Shokry M M F, Ezzelarab M 2016 NRIAG Journal of Astronomy and Geophysics 5 55
[4] Nakamura Y 1997 World Congress on Railway Research (Italy: Florence) p 1
[5] Nakamura Y 2000 World Congress on Earthquakes Engineering (New Zealand) 2656
[6] Nakamura Y 2008 14th World Congress on Earthquakes Engineering (China: Beijing)
[7] Warnana D D, Soemitro R A A, Utama W 2011 International Journal of Basic & Applied Sciences JBAS-JIENS 11 73
[8] Leyton F, Ruiz S, Sepulveda S A, Contreras J P, Rebolloso S, Astroza M 2013 Engineering Geology 161 26
[9] Herak M 2011 Geofizika 28 21
[10] Akbari M, Ghafoori M, Moghaddas N H, Lashkaripour G R 2011 Annals of Geophysics 227 354
[11] P Nur Ayu Diana Citra Dewi S, Lestari R T, Soemitro R A A, Warnana D D 2016 Procedia Social and Behavioral Sciences 227 354
[12] Mokhberi M 2015 International Journal of Disaster Risk Reduction 13 369
[13] Suita J, P Maria L, Bautista, Nakamura Y 2004 13th World Congress on Earthquakes Engineering (Canada: Vancouver) 905
[14] Hidayat S, Cari, Warnana D D, Koesuma S 2017 Pertemuan Ilmiah XXXI HFI Jateng & DIY (Yogyakarta: STTN Batan)
[15] Santoso D, Wahyudi E J, Alawiyah S, Nugraha A D, Widiyantoro S, Kadir W G A, Supendi P, Wiyono S, Zulkafiriza 2017 IOP Conf. Series: Earth and Environmental Sciences 62 1
[16] http://repogempa.bmkg.go.id/index_peta.php?id=101&session_id=J93zN0LZ
[17] Pringgoprawiro H and Sukido 1992 Geologic Map of the Bojonegoro Quadrangle, East Java (Bandung: Pusat penelitian dan pengembangan geologi)
[18] Kyaw Z L, Pramunijoyo S, Husein S, Fathani T F, Kiyono J 2015 Procedia Earth and Planetary Science 12 31
[19] SESAME 2004 Guidelines for the Implementation of the H/V Spectral Ratio Technique on Ambient Vibrations: Measurement Processing and Interpretation SESAME European research project WP12
[20] Akbari M, Ghafoori M, Moghaddas N H, Lashkaripour G R 2011 Annals of Geophysics 54 424
[21] Gosar A 2009 Acta Geotechnica Slovenica 2 31
[22] Leyton F, Ruiz S, Sepulveda S A, Contreras J P, Rebolloso S, Astroza M 2015 Engineering Geology 161 26
[23] Walling M Y, Mohanty W K, Nath S K, Mitra S, John A 2009 Engineering Geology 106 123
[24] Herak M 2011 Geofizika 28 21