Identification of earthquake hazard areas using microtremor refraction (Remi) in central Sukoharjo district

Agustius Dian Nugroho, Sorja Koesuma*, Budi Legowo
Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret, Jl. Ir. Sutami 36 A Kentingan, Surakarta 57126

*E-mail: sorja@uns.ac.id

Abstract. Study about microtremor method has been done in Sukoharjo regency. This study aims to determine and mapping the earthquake-prone areas as mitigation efforts based on dominant frequency parameters, dominant periods, and amplification factors. Data acquisition is performed at 19 sites with intervals of each location 2 – 3 Km. P.A.S.I Seismograph 16S24-P is used to acquiring the data. The data acquisition is done with a duration of 20 minutes in three times repetitions. Microtremor data processing using the Geopsy software. Based on HVSR curve analysis, obtained the dominant frequency and amplification factor values. From the result of parameter analysis obtained is made of earthquake hazard map by reviewing the soil classification that has become the standard geological parameter of a region. The dominant period in type IV has a degree of vulnerability to earthquakes, as it has a dominant period of more than 0.75. Type IV is located on Parangjoro, Gadingan, Dukuh, and Jetis areas with the dominant period in 2.43 s until 2.63 s. Most of Sukoharjo areas have low amplification in the zone I with amplification between 1.11 and 2.92.

1. Introduction
Sukoharjo selected as location research because located in the basin area between Lawu volcano and Merapi volcano, which activities volcanic from Merapi volcano potentially cause vibration and influence the geology state in Sukoharjo. There is similarity of the type of lithology between Klaten district area and Sukoharjo district area, where generally in this area are composed of quarter sedimentation. Rock layer is composed of the precipitate quarter, where generally have physical condition uncompacted entirely. On the condition when an earthquake happens, it will have an amplification of earthquake magnitude on the structure layer, so it can be the risk for people [1]. This factor is important to consider that Sukoharjo regency is a crowded populated area with a population of 849,303 peoples and a population density of 1.820 persons/Km2 [2].

This mitigation effort can be done through microtremor measurement. Microtremor measurement has done to determine the dynamic characteristics (predominant frequency and amplification factors) [3,4] and the sediment depth of the layer [5,6]. Earthquake amplification maps can be made by reviewing the standard classification of rock types in the area [7]. The amplification factor and the dominant period are useful for analyzing the basic relief response to sediment thickness when an earthquake occurs. Determination of predominant amplification and frequency values based on the HVSR method [8,9]. The HVSR equations for measured vibration on the surface area expressed as follows [10]:

$$HVSR = \frac{s_s (u-s)^2 + s (B-\tau)^2}{S_{VS}}$$

(1)
HVSR = Horizontal to Vertical Spectral Ratio

\[ S_{(U-S)} = \text{Value Amplitude spectrum frequency North-South component} \]

\[ S_{(E-W)} = \text{Value Amplitude spectrum frequency East - West component} \]

\[ S_{VS} = \text{Value Amplitude spectrum frequency Vertical component} \]

2. Experimental Methods

Microtremor measurements were performed to determine the dynamic characteristics (predominant frequency and amplification factor) of the soil layers proposed by Kanai and Tanaka in 1954 and 1961. This survey has been done during October 2017 in Sukoharjo district at 19 points with intervals of 2-3 km each. P.A.S.I Seismograph 16S24-P is used to acquiring the data. The Recording time was done with a duration of 20 minutes with three repetitions. Microtremor data processing using Geopsy and Surfer 11 software. Based on HVSR curve analysis from data processing obtained the dominant frequency value and amplification factor. Contour map of earthquake hazard can be made from these results. Figure 1 shows the survey locations (black triangle).

3. Results and Discussion

The data collected from measurements are numerical data in hexadecimal form with the format (.DAT). The data was converted into the appropriate format with the Geopsy software, by changing it in ASCII format (decimal file) by selecting format (*.saf). The recording file every 60 minutes is used as input to display the microtremor data in 3 directional components. Figure 2 shows these 3 components, which consist of Vertical direction component, NS (North-South) direction component, and EW (East-West) direction component. To obtain the data that meet the criteria of microwave (ambient noise), we filtered the data with low pass 10 Hz filter. The HVSR graphic is done by the windowing process, which is divided the microtremor data into some window of time. The obtained HVSR graph shows the relationship between the H/V value against its frequency, where the X-axis shows the frequency value while the Y-axis shows H/V or the amplification value. Figure 3 shows the HVSR graph in Kriwen site, where the dominant frequency is 4.68 Hz.

The frequency and periode dominant for all site survey are plotted in Figure 4 and Figure 5, respectively. Based on the classification of Kanai [11] in Sukoharjo has type IV of a vulnerability index to the earthquake, because the dominant periode value is more than 0.75. The type IV of earthquake vulnerability index is
located in Parangjoro (2.43s), Gadingan (2.5s), Dukuh (2.56s) and Jetis (2.63s). Most of the survey area are
categorized in Zone I, where has low amplification value [11]. The amplification value is ranged between
1.11 to 2.92, and only one site has high amplification, i.e. Parangjoro site (6.4). Table 1 shows data of
frequency dominan, amplification and periode dominat for all site surveys.

Table 1: Data of frequency dominan, amplification and periode dominat for all site surveys.

| Site     | Frequency Dominant | Amplification | Periode Dominant |
|----------|--------------------|---------------|-----------------|
| Parangjoro | 6.4                | 6.4           | 0.4             |
| Gadingan  | 2.5                | 2.5           | 0.6             |
| Dukuh     | 2.56               | 2.56          | 0.8             |
| Jetis     | 2.63               | 2.63          | 1.0             |

Figure 2. Windowing process

Figure 3. Graph of HVSR in Kriwen-Sukoharjo site

Figure 4. Zonation map of dominant frequency
Figure 5. Zonation map of dominant period

Table 1. Data from 19 locations

| Location | Description           | F0 (Hz) | A0   | T0(s) |
|----------|-----------------------|---------|------|-------|
| LK_1     | Siwal, Baki           | 4.13    | 1.6  | 0.24  |
| LK_2     | Banaran, Grogol       | 4.1     | 2.92 | 0.24  |
| LK_3     | Mancasan, Baki        | 3.35    | 1.73 | 0.29  |
| LK_4     | Kudu, Baki            | 3.95    | 1.4  | 0.25  |
| LK_5     | Madegondo, Grogol     | 5.09    | 1.11 | 0.19  |
| LK_6     | Wonosari, Klaten      | 7.07    | 1.11 | 0.14  |
| LK_7     | Parangjoro, Grogol    | 0.41    | 6.4  | 2.43  |
| LK_8     | Telukan, Sukoharjo    | 9.68    | 1.25 | 0.10  |
| LK_9     | Gadingan, Mojolaban   | 0.4     | 1.2  | 2.5   |
| LK_10    | Wirun, Mojolaban      | 4.77    | 1.38 | 0.20  |
| LK_11    | Bugel, Polokarto      | 5.53    | 1.48 | 0.18  |
| LK_12    | Bulakrejo, Sukoharjo  | 4.52    | 1.27 | 0.22  |
| LK_13    | Dukuh, Sukoharjo      | 0.39    | 1.19 | 2.56  |
| LK_14    | Kriwen, Sukoharjo     | 4.68    | 2.1  | 0.21  |
| LK_15    | Ponowaren, Tawangsari | 4.75    | 2.21 | 0.21  |
| LK_16    | Jetis, Sukoharjo      | 0.38    | 1.26 | 2.63  |
| LK_17    | Toriyo, Bendosari     | 11.34   | 1.28 | 0.08  |
| LK_18    | Kemasan, Polokarto    | 8.58    | 1.28 | 0.11  |
| LK_19    | Begajah, Sukoharjo    | 7.69    | 1.38 | 0.13  |
4. Conclusion
Sukoharjo district has type IV of vulnerability index of the earthquake and most of the site surveys have low amplification, while in Parangjoro site should more pay attention because it has high amplification value.

5. Acknowledgment
Authors would like to express special thanks of gratitude to members of the Laboratory of Geophysics, Sebelas Maret University for acquiring the data and conducting this research in Sukoharjo.

6. References
[1] Muhammad ADI. Studi Mikrotremor untuk Zonasi Bahaya Gempabumi Daerah Surakarta Provinsi Jawa Tengah. Skripsi. Universitas Gadjah Mada. Yogyakarta. 2014.
[2] BPS Kabupaten Sukoharjo. Sukoharjo Dalam Angka 2014. Badan Pusat Statistik Kabupaten Sukoharjo. 2014.
[3] Sari P, Budi L, Sorja K. Penentuan Tingkat Kerawanan Gempa Bumi Menggunakan Metode Refraksi Mikrotremor (ReMi) di Kota Surakarta. Indonesian Journal of Applied Physics. 2017; 7(1): 59–65.
[4] Samsul H, Dwa DW, Sorja K, and Cari. Seismic Microzonation by using Microtremor Method in Pandan Volcano, Bojonegoro, East Java. J. Phys.: Conf. Ser. 2017; 909, 012031. doi:10.1088/1742-6596/909/1/012031
[5] Sorja K, Mohamad R, Andri DN, Sri W, Yoichi F. Preliminary Estimation of Engineering Bedrock Depths from Microtremor Array Measurement in Solo, Central Java, Indonesia. J. Math. Fund. Sci. 2017; 49(3): 306–320.
[6] Sorja K, Sari P, Budi L. Determination of Sediment Thickness by using Microtremor Method in Surakarta City. Jurnal Risalah Fisika. 2017; 2(3):25–28.
[7] Nugroho BW. Spatial Analysis of Surface Aquifer Thickness Based Frequency predominant in Bantul District. Indonesian Journal of Applied Physics. 2015; 5(1): 62–70.
[8] Reza APH, Laily EF, Ria AAS, Trihanyndio RS. Analisa Mikrotremor Dengan Metode HVSR (Horizontal to Vertical Spectral Ratio) untuk Pemetaan Mikrozonasi di Kelurahan Kejawan Putih Tambak Surabaya. Jurnal Teknik POMITS. 2013; 1(1): 1–4
[9] Satria SA, Bagus SM, Marjiyono, Roby S. Penentuan Zona Rawan Guncangan Bencana Gempa Bumi Berdasarkan Analisis Nilai Amplifikasi HVSR Mikrotremor dan Analisis Periode Dominan Daerah Liwa dan Sekitaranya. Jurnal Geofisika Eksplorasi. 2014; 2(1): 30–40.
[10] Nakamura, Yutaka. (2000). Clear Identification of Fundamental Idea of Nakamura's Technique and Its Application. Proceedings of the 12th World Conference on Earthquake Engineering. Vol. 2656. New Zealand: Auckland.
[11] Kanai, Kiyoshi. (1983). Engineering Seismology. University of Tokyo Press.