Earthquake Microzonation Using Microtremor Analysis and Horizontal to Vertical Spectral Ratio Method Study Case at Ampelgading and Tirtoyudo Sub-district, Malang, East Java

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Abstract. The earthquake that occurred on April 10, 2021, with a magnitude of 6, was felt in several areas on the island of Java and Ampelgading and Tirtoyudo sub-districts are the most affected areas. Due to the impact caused by the earthquake, a method is needed to be able to reduce the destructive effects of earthquakes. One way is to conduct a seismic hazard assessment or microzonation using microtremor. Microtremor data was measured in these two sub-districts are able to determine the parameters of soil characteristics based on natural frequency, amplitude, and seismic susceptibility index. Microtremor data analysis used the HVSR method with geopsy software to collect two main parameters, f0 and A0. Then from these parameters can be used to calculate the seismic susceptibility index parameter. The results showed that the natural frequency ranged from 1.28–13.23 Hz, with areas with low natural frequencies being in the central to southern Ampelgading District and the central to northern Tirtoyudo District. The amplitude has a value range of 1.33–10.77, with high amplitude areas located in the middle part of Ampelgading and Tirtoyudo Districts. The seismic susceptibility index has a value range of 0.13–29.91, with areas with a high seismic susceptibility index located in the central part of Ampelgading and Tirtoyudo Districts, including Jogomulyan Village, Kepatihan Village, Sumbertangkil Village located in Tirtoyudo District, as well as Wirotaman Village and Sonowangi Village located in Ampelgading District and were the villages most affected by the earthquake.

Keywords: HVSR · microtremor · microzonation · seismic susceptibility index

1 Introduction

The earthquake that occurred on April 10, 2021, with a magnitude of 6, was felt in several areas on the island of Java, such as Surabaya, Bojonegoro, Yogyakarta, Pasuruan, Blitar, Tulungagung, Wonogiri, and surrounding areas. The most affected regions were Tirtoyudo and Ampelgading sub-districts, Malang district, which suffered severe damage to residents' houses, sub-district infrastructure and caused fatalities. Every earthquake

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activity can cause various kinds of damage caused by factors of magnitude, earthquake depth, earthquake hypocenter distance, vibration duration, soil, and building conditions [1]. Geological conditions play an important role. In several studies it is stated that the level of damage caused by earthquakes is influenced by local soil conditions.

One method to determine local geological conditions is using the HVSR technique introduced by Nakamura et al. with the aim of being able to characterize the soil structure [2]. The soil susceptibility index can be estimated by using the development of this method. The parameters of the HVSR method are needed to determine the subsurface conditions that affect the natural frequency and amplitude aimed at interpreting microzonation with HVSR correctly [3]. The HVSR method is a cheap, effective, and environmentally friendly method. However, there is still much debate on the HVSR concept related to the dominance of shear waves and surface waves on the HVSR curve. This method has been proven and is often used for mapping microzonation [4, 5], estimation of bedrock depth [6], and mapping of faults [4, 7].

Based on the Disaster Risk Index data released in 2020 [8], the Malang Regency area is classified as a high-risk class, but the research conducted, especially in the Ampelgading and Tirtoyudo sub-districts are still not much. Therefore, this research was conducted to conduct a seismic hazard assessment or microzonation in Tirtoyudo and Ampelgading Districts using microtremor analysis with the HVSR method.

2 Basic Theory

2.1 Geological Setting

Malang Regency is in a highland area with coordinates 112° 17′ 10.9″–112° 57′ 0.0′ Longitude and 7° 44′ 55.11″–8° 26′ 35.45″ Latitude. Malang Regency is located between 0–2000 masl. This shows varying conditions, namely sloping conditions to mountainous conditions. This is influenced by the Tengger mountains in the east, Mount Kawi and Kelud in the west and Mount Arjuna and Welirang in the north.

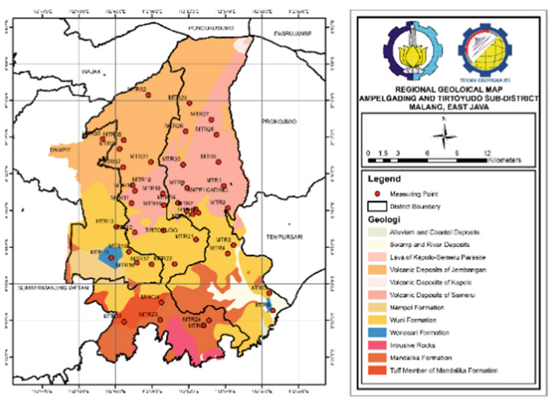

Fig. 1. Microtremor data acquisition point

Figure 1 shows that in the study area there are several formations in order from old to young, namely the Mandalika Formation (Tomm), Intrusive Rocks (Tomi), Tuff member of Mandalika Formation (Tomt), Wuni Formation (Tmw), Nampol Formation (Tmn), Wonosari Formation (Tmwl), Volcanic Deposits of Jembangan (Qvj), Volcanic Deposits of Kepolo (Qvk), Volcanic Deposits of Semeru (Qvs), Lava of Kepolo-Semeru parasite (Qlks), Swamp and river deposits (Qas) and alluvium and coastal deposits (Qal).

2.2 HVSR Method in Microtremor Data Processing

The HVSR method is a method in which the horizontal and vertical spectral parameters are compared as a function of frequency through the Fourier transformation associated with the horizontal S wave propagation trapped at the sedimentary layer boundary with the bedrock (bedrock engineering) [5, 6]. The HVSR method assumes that the ratio of the horizontal and vertical spectra of the surface vibration is a function of displacement. This shows that the dynamic characteristics of the surface layer at the observation point can be understood if the observation of the microtremor seismic waveform is carried out on the horizontal component and the vertical component, determining the structure of the subsurface layer, can be done by correlating the ratio of the Fourier spectrum ratio of the horizontal component of the microtremor signal divided by the vertical component [7, 8].

The HVSR technique itself has been widely used in microzonation assessment and local effect studies because the HVSR method can provide information about the dominant frequency values and amplitude of earthquake waves. The HVSR method can also be applied in estimating the level of susceptibility to earthquake hazards and estimating volcanic activity [8, 9]. The HVSR equation itself can be written as follows:

$$HVSR = T_{site} = \frac{S_{HS}}{S_{VS}} = \sqrt{\frac{\left[(S_{N-S})^2 + (S_{W-E})^2\right]}{S_{Vertical}}} \tag{1}$$

where T_{site} is the HVSR, $S_{(North-south)}$ is the amplitude value of the frequency spectrum of the North-South component, $S_{(West-East)}$ is the amplitude value of the frequency spectrum of the West-East component, and the amplitude value of the vertical component frequency spectrum is $S_{Vertical}$ [9].

The HVSR method's processing produces natural frequency and amplitude values using the Fourier transform concept. The following is the classification of the dominant

Table 1. Classification of amplitude factor values based on the Japan Road Association [12]

ZONE	Amplitude Factor	Description
I	$fa < 3$	Low amplitude
II	$3 \leq fa < 6$	Medium amplitude
III	$6 \leq fa < 9$	High amplitude
IV	$fa \geq 9$	Very high amplitude

Table 2. Soil classification based on dominant frequency values [13]

Soil Classification		Natural frequency (Hz)	Kanai Classification	Description
Type	Class			
IV	I	6.665–20	Tertiary or older rocks. It consists of hard sandy, gravel, etc.	The thickness of the sediment surface is very thin and is dominated by hard rock.
	II	4–10	Alluvial rock with a thickness of 5m. Consists of sandy-gravel, sandy hard clay, loam, etc.	The thickness of the surface sediment is in the medium category of 5–10 m
III	III	2.5–4	Alluvial rock with a thickness of >5 m. consists of sandy-gravel, sandy hard clay, loam etc.	The thickness of the surface sediment falls into the thick category, around 10–30 m
II	IV	<2.5	Alluvial rock formed from delta sedimentation, top soil, mud and others with a depth of 30 m or more	The thickness of the surface sediment is very thick
I				

frequency values according to Kanai and the classification of amplitude according to the Japan Road Association (Table 1 and 2).

2.3 Seismic *Susceptibility Index (Kg)*

Seismic susceptibility index (Kg) is the susceptibility of the soil surface layer to deformation when an earthquake occurs. The value of the soil susceptibility index can also estimate the susceptibility of an area to soil movement obtained based on the correlation between natural frequency (f_o) and amplitude factor (A_0) [9]. The calculation of the susceptibility index can be done by squaring the value of the amplitude factor and dividing the natural frequency value that can be shown in Eq. (2) by [14]:

$$K_g = \frac{A_0^2}{f_0} \quad (2)$$

where Kg is the seismic susceptibility index value, A_0 is the amplitude factor value, and f_0 is the natural soil frequency (Hz).

3 Methdology

This research data acquisition process was carried out from October 23 to October 28, 2021, and took place in two sub-districts, Ampelgading and Tirtoyudo Districts. Primary data collection was carried out as many as 31 data spread across the two districts. The following is the location of the research points shown in the Fig. 1.

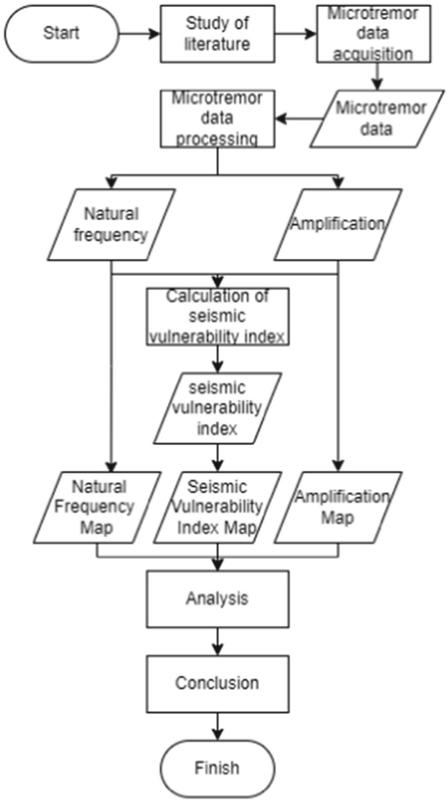

Fig. 2. Microtremor research flow chart using the HVSR method.

The Data processing will be carried out using Geopsy software to produce parameters of the natural frequency of the soil and the amplitude factor. Based on these two parameters, calculations can be made to obtain the soil susceptibility index parameter. More details, can be seen in Fig. 2.

4 Result and Discussion

Based on the results of the HVSR curve processing from 31 measurement points, the values of the microzonation parameters can be obtained including the natural soil frequency value (f_0), the amplitude factor value (A_0), and the parameter of seismic susceptibility index from Ampelgading and Tirtoyudo Districts which can be seen in Table 3.

The natural frequency parameter is one of the parameters in the HVSR curve analysis, which is the frequency of the peak amplitude value on the HVSR curve and is recognized as the frequency value of the rock layers of an area that describes the characteristics of the soil layer [3]. The natural frequency values that have been made can be classified according to the classification by (Kanai, 1983).

Based on Fig. 3, it can be analyzed the distribution of the natural frequency values of the soil and its classification in Ampelgading and Tirtoyudo Subdistricts with natural

Table 3. Natural frequency, Amplitude Factor, and Seismic Susceptibility Index value at each measurement point

Acquisition Point	Natural Frequency	Amplitude Factor	Seismic Susceptibility Index
MTR-1	1.76	2.49	3.52
MTR-2	1.67	2.52	3.81
MTR-3	2.02	2.12	2.22
MTR-4	7.91	3.61	1.65
MTR-5	1.29	4.22	13.87
MTR-6	2.56	4.99	9.72
MTR-7	13.24	1.33	0.13
MTR-8	4.26	5.51	7.13
MTR-9	2.51	4.96	9.80
MTR-10	4.33	9.67	21.59
MTR-11	2.22	5.27	12.54
MTR-12	2.50	4.11	6.75
MTR-13	4.59	10.77	25.28
MTR-14	6.60	7.05	7.52
MTR-15	2.22	5.93	15.82
MTR-16	2.35	5.86	14.62
MTR-17	2.30	6.30	17.26
MTR-18	4.88	12.08	29.91
MTR-19	2.70	5.85	12.64
MTR-20	3.33	5.33	8.53
MTR-21	12.38	2.91	0.69
MTR-22	2.59	6.00	13.94
MTR-23	9.11	1.85	0.37
MTR-24	8.47	1.79	0.38
MTR-25	1.80	2.84	4.48
MTR-26	3.56	4.04	4.60
MTR-27	1.55	2.89	5.38
MTR-28	2.21	5.64	14.35
MTR-29	2.18	3.00	4.13
MTR-30	1.92	4.16	9.01
MTR-31	8.35	2.90	1.01

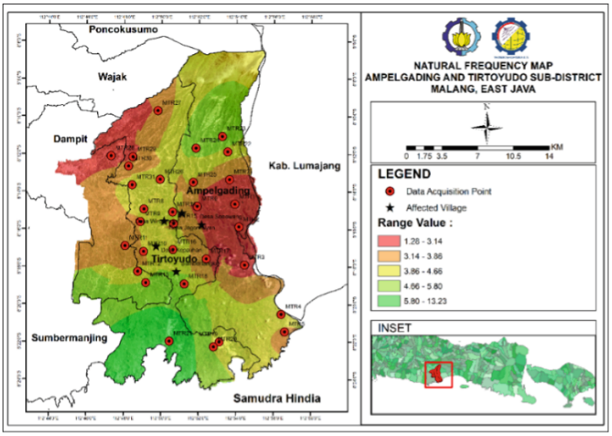

Fig. 3. Microzonation Map Distribution of Natural Frequency Value (f0) in Ampelgading and Tirtoyudo Sub-District

frequency values belonging to the high category spread over the northern area of Ampelgading District, and the southern part of Tirtoyudo District with a range of values after interpolation of 4.66 up to 13.23 Hz, and belongs to type 4 class 1 and type 2. In the range of natural frequency values, it is composed of several geological formations such as the Mandalika formation and the Semeru Volcanic Deposit formation. In the range of natural frequency values which are included in the medium category with a value range of 3.86 Hz to 4.66 Hz located in the southern and northern parts of Ampelgading District and the middle to northern part of Tirtoyudo District, and belongs to type 3 class 3 and type 4 class 2, in the range The natural frequency value is composed of several geological formations such as the Wuni formation, the Mandalika formation, the Semeru Volcanic Sediment formation, and the Jembangan Volcanic Sediment formation. The natural frequency value is included in the low category with a value range of 1.28 Hz to 3.86 Hz which is located in the middle part of Ampelgading District and the central and northern part of Tirtoyudo District and belongs to type 2 type 4 and type 3 type 3, which consists of several formations are, Alluvium, Wuni Formation, Mandalika Formation, Jembangan Volcanic Deposition Formation, and Semeru Volcano Sediment Formation.

The amplitude factor is a seismic microzonation parameter obtained from the analysis of the peaks of the HVSR curve, and according to [9] the amplitude factor is the magnification of the seismic wave strength when passing through a medium that is softer than the initial medium through which it passes or there is an impedance contrast between the sediment and bedrock layers. In Fig. 4. it can be seen if the dominant amplitude factor value in the southern area of Ampelgading District and the middle part of Tirtoyudo District with an amplitude factor range value of 5.66 to 10.77, which can be identified as a high to very high classification, at that point the measurement is arranged by several rock formations such as the Alluvial formation, the Wuni formation, the Mandalika formation, and the tuff members of the Mandalika formation. In the range of amplitude factor values dominated by the medium classification with a value range of 3.84 to 6 located in the central to southern part of Ampelgading District and in the middle and

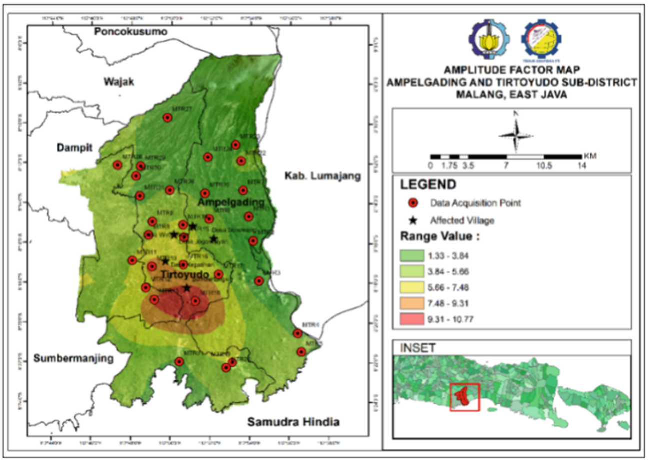

Fig. 4. Microzonation Map Distribution of Amplitude Factor Values (A0) in Ampelgading and Tirtoyudo Sub-Districts.

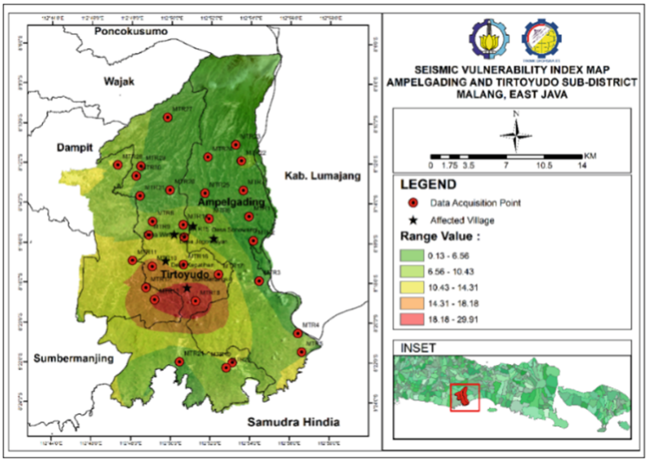

Fig. 5. Microzonation Map Distribution of Seismic Susceptibility Index Values (Kg) in Ampelgading and Tirtoyudo Districts.

southern part of Tirtoyudo District, at the measurement point it is composed of several types of formations such as the Jembangan Volcanic Deposit formation, Semeru Volcanic Deposit formation, Wuni formation, and Mandalika formation. In the range of amplitude factor values, which are dominated by low values, located in the north to the middle of Ampelgading District and the northern and southern parts of Tirtoyudo District with a value range of 1.33 to 3.84, at the measurement point it is composed of several formations such as the Semeru Volcano Deposit formation, Jembangan Volcanic Deposits, and the Wuni Formation.

According to [11, 12] the level of susceptibility or resistance of the subsurface layer caused by deformation when the earthquake phenomenon occurs, is referred to as the seismic susceptibility index (Kg). Based on Fig. 5. The distribution of the seismic susceptibility index which is in the low value range of 0.13 to 10.43 is in the northern and southern parts of the Ampelgading and Tirtoyudo sub-districts, and in this range of values is composed by several formations such as the Semeru Volcano Deposit formation, Jembangan Volcanic Deposit formation, Wuni formation, Mandalika formation. The distribution of the seismic susceptibility index in the moderate range of 10.43 to 14.31 is in the middle part of the Ampelgading and Tirtoyudo sub-districts, in this value range it is composed of several formations such as the Wuni formation, the Mandalika formation, members of the tuff of the Mandalika formation, the Semeru Volcanic Sediment formation. The distribution of the seismic susceptibility index in the high value range of 14.31 to 29.91 located in the middle part of Ampelgading and Tirtoyudo Districts, in this value range composed of several formations such as Alluvium, Wuni formation, and Mandalika formation. The results of the susceptibility index in this study are in accordance with the earthquake-affected area, which is in the middle part of Ampelgading and Tirtoyudo Districts, namely, Sumbertangkil Village, Kepatihan Village, Jogomulyan Village, which is in Tirtoyudo District, as well as Wirotaman Village and Sonowangi Village located in Ampelgading District.

5 Conclusion

Based on the results and analysis that has been carried out, several conclusions can be drawn, firstly, the low value range of the natural frequency is generally found in the central to southern part of Ampelgading District and the middle to northern part of Tirtoyudo District which can be caused by the thickness of the sediment layer. Second, the range of high values of the amplitude factor can be found in the middle part of Ampelgading and Tirtoyudo Subdistricts, and finally, the range of high values of the seismic susceptibility index can be found in the middle part of Ampelgading and Tirtoyudo Subdistricts, including Jogomulyan Village, Kepatihan Village, Sumbertangkil Village which is located in Tirtoyudo District, as well as Wirotaman Village and Sonowangi Village which are in Ampelgading District and are the villages most affected by the earthquake.

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References

1. Ambarsari, D. (2017). Analisis Mikrotremor Dengan Metode HVSR Untuk Mikrozonasi Kabupaten Gunungkidul Yogyakarta (Doctoral Dissertation, Institut Teknologi Sepuluh Nopember). https://repository.its.ac.id/id/eprint/45998
2. Nakamura, Y., 1997. Seismic Susceptibility Indices for Ground and Structures Using Microtremor. World Congr. Railw. Res. Florence Nov.

3. Sungkono, S., Santosa, B.J., (2011). Karakterisasi Kurva Horizontal-To-Vertical Spectral Ratio: Kajian Literatur Dan Permodelan. J. Neutrino. https://doi.org/10.18860/neu.v0i0.1662
4. Juan Pandu Gya Nur Rochman et al 2021 IOP Conf. Ser.: Earth Environ. Sci. 936 012026.
5. Baskoro, W. T., Warnana, D. D., Widodo, A., Rochman, J. P. G. N., & Santosa, B. J. (2019). Preliminary site characteristics for urban seismic hazard in pasuruan fault from microtremor measurements. IOP Conference Series: Earth and Environmental Science, 389(1).
6. A. P. Arwananda, B. Aryaseta, H. Dezulfakar, Y. Fatahillah, and J. P. G. N. Rochman, 'Horizontal-vertical Spectral Ratio Method in Microtremor to Estimate Engineering Bedrock Thickness at Sedati Mud Volcano', IOP Conf. Ser. Earth Environ. Sci., vol. 62, p. 012010, Apr. 2017, doi: https://doi.org/10.1088/1755-1315/62/1/012010.
7. F. Syaifuddin, A. S. Bahri, W. Lestari, and J. Pandu, 'Microtremor study of Gunung Anyar mud volcano, Surabaya, East Java', AIP Conf. Proc., vol. 1730, no. 1, p. 050004, May 2016, doi: https://doi.org/10.1063/1.4947400.
8. Irbi Indeks Risiko Bencana Indonesia BNPB (2020)
9. Nakamura, Y., Sato, T., & Nishinaga, M. (2000, November). Local Site Effect Of Kobe Based On Microtremor Measurement. In Proceeding Of The Sixth International Conference On Seismic Zonation EERI, Palm Springs California
10. Gallipoli, M. R., Mucciarelli, M., Šket-Motnikar, B., Zupanćić, P., Gosar, A., Prevolnik, S., ... & Olumćeva, T. (2010). Empirical Estimates Of Dynamic Parameters On A Large Set Of European Buildings. Bulletin Of Earthquake Engineering, 8(3), 593-607. https://doi.org/10.1007/s10518-009-9133-6
11. Nakamura Y. (1989). A Method for Dynamic Characteristics of Subsurface using Microtremor on the Ground Surface. Quarterly Report of Railway Technical Research Institute, Japan , 30-1, 25-33.
12. Arifin, S. S. (2014). Penentuan Zona Rawan Guncangan Bencana Gempa Bumi Berdasarkan Analisis Nilai Amplifikasi HVSR Mikrotremor dan Analisis Periode Dominan Daerah Liwa dan Sekitarnya. JGE (Jurnal Geofisika Eksplorasi), 2(01), 30–40. https://doi.org/10.23960/jge.v2i01.217
13. Purnomo, S. S. (2019). Analisis Struktur Bawah Permukaan Kota Surakarta Bagian Timur Berdasarkan Nilai Kecepatan Gelombang Geser Dengan Metode Ellipticity Curve. Skripsi
14. Nakamura. (2008). On The H/V Spectrum. the 14th world conference on eathquake engineering , 1–10.
15. Sujanto. (1992). Peta geologi lembar Turen, Jawa: Geological map of the Turen quadrangle, Jawa. Bandung: Pusat Penelitian dan Pengembangan Geologi.