PERJ Vol. 4 No.2 (2022), 71-78

Physics Education Research Journal
ISSN 2685 - 6190 (p)
ISSN 2714 - 7746 (e)
Department of Physics Education
Faculty of Science and Technology
UIN Walisongo Semarang-Indonesia

Soil Classification Using Horizontal to Vertical Spectrum Ratio Methods on Scilab in Sendangmulyo, Semarang

Prima Vitra Varecha*, Andi Fadllan, and Hartono

Department of Physics, Universitas Islam Negeri Walisongo Semarang, Indonesia

ARTICLE INFO

Article history:
Submitted: January 21st, 2022
Revised : May 25th, 2022
Accepted : August 13th, 2022

Keywords:
HVSR; Microtremor; Natural Frequency; Predominant Period; Scilab

ABSTRACT

Microtremor is ambient vibration on the surface ground by natural phenomena, human activities, etc. Microtremor can be used to determine rock characteristics, which can be applied to estimate the susceptibility of an area to earthquakes Microtremor data can be processed using various software such as Geopsy, easyHVSR, and MATLAB. Another alternative software to process microtremor data is Scilab. This research was conducted to classify the soil using HVSR methods on Scilab 6.1.0. in Sendangmulyo, Semarang. Data processing includes generating synthetic signals, coding the HVSR methods on Scilab, synthetic data testing, processing microtremor data, and mapping of natural frequency (f_0) and predominant period (T_0). Coding tests are performed against synthetic signals and can display a pre-set f_0. f_0 from the HVSR spectrum then processed to get the T_0. The f_0 in Sendangmulyo, Semarang ranged from 1.280 Hz – 18.504 Hz, and the T_0 ranged from 0.054 s – 0,781 s. Based on the f_0 and T_0, Sendangmulyo is composed of hard soil, medium soil, soft soil, and very soft soil.

Introduction

Semarang is located in the north of Java, far from the southern subduction zone of Java, but this does not make Semarang unrestrained from earthquakes. Based on PVMBG seismicity catalog data, an earthquake occurred in Semarang on January 19, 1856. The cause of the earthquake is predicted to be the activity of an active fault that divides Semarang City, and it is estimated that the fault is still active or potentially active in the future (Hidayat, 2013). Efforts that can currently be made to deal with earthquake disasters are disaster mitigation efforts by understanding subsurface conditions. To find out the subsurface structure can be used using the microtremor method.

One method for processing microtremor data is the HVSR method. Data processing is usually done using Geopsy or Matlab software. However, since Matlab requires a license and is high-cost, another software alternative that can be used at no cost is Scilab. This study will discuss microtremor data processing using Scilab version 6.1.0, and the result is soil classification in Sendangmulyo, Semarang.

Microtremor

Microtremor is a constant vibration of the earth's surface whose amplitude is very small (Okada, 2003) that comes from natural phenomena or artificial disturbances (Motamed & Ghalandarzadeh, 2004). The microtremor method is a passive geophysical method that does not require an artificial source of vibration during data acquisition. This method is an appropriate tool for estimating the geological effects of surfaces due to seismic vibrations even without any geological information (Nakamura, 2008). Microtremor measurements require a three-

*Correspondence email: primafitra53@gmail.com
doi: 10.21580/perj.2022.4.2.12542

component seismometer that records two horizontal components EW (East-West) and NS (North-South), and one vertical component Z (Up-Down) (Haerudin et al., 2019).

Nakamura explains that on hard soils, the amplitude of vibration in the horizontal direction is equal to the vertical direction, while on soft soils the amplitude of vibration in the horizontal direction is more significant than in the vertical direction (Nakamura, 1989). It happens because vibrations are amplified in the horizontal direction due to the presence of a multi-reflection of the S wave, while vertical vibrations occur due to the multi-reflection of the P wave. Propagation of P waves is generally >1000 m/s, and vibrations of ≤10 Hz are not significantly amplified in surface layers with 10 m thickness.

Fourier Transform

Fourier transform in microtremor data processing is needed to convert seismic waves in the time domain into frequency domains with FFT (Fast Fourier Transform). The FFT process can also be used to determine the magnitude of the frequency and many frequency components of the microtremor. Equation 1 is an equation used to convert a signal from a time domain to a frequency domain. However, the FFT process in Scilab uses the functions already available.

$$X(f)=\int_{-\infty}^{\infty} x(t)e^{-j2\pi ft}dt \quad (1)$$

Information:

$x(t)$ = signal in the time domain

$e^{-2j\pi ft}$ = kernel function

$X(f)$ = function in frequency domain

f = frequency

Horizontal to Vertical Spectral Ratio (HVSR) Methods

The HVSR method is a method that compares horizontal and vertical components of microtremors. The spectral ratio $\frac{H}{V}$ is shown in Equation 2 and can be used to identify the sedimentary layer's resonant frequency and amplification factor (Nakamura, 2000). In addition, the ratio's peak can represent the dynamic characteristics of the sedimentary layer so that the damage caused by geological conditions in an area can be reduced when an earthquake occurs (Nubatonis et al., 2017).

$$HVSR = \frac{\sqrt{(NS^2 + EW^2)/2}}{UD} \quad (2)$$

Natural Frequency (f_0)

Natural frequency (f_0) is the frequency of rock in an area that can describe subsurface characteristics (Pancawati, 2016). The f_0 in Table 1 is used for soil classification.

Table 1

Soil Classification Based on Natural Frequency By Kanai (Arifin Et Al., 2014)

Soil Classification	f_0 (Hz)	Spesification	Description
Type I	6,667 – 20	Tertiary or older rock. It consists of hard sand, gravel, etc	Surface sediment is very thin, dominated by hard rocks
Type II	4,0 – 6,667	Tertiary or older rock. It consists of hard sand, gravel, etc	Surface sediment thickness is medium, about 5 – 10 m
Type III	2,5 – 4,0	Alluvial rock with thickness >5m. consists of sandy gravel, sandy hard clay, loam, etc	Surface sediment is thick, about 10 – 30 m
Type IV	<2,5	Alluvial rock, formed from delta sedimentation, topsoil, mud, etc. ≥30 m in thickness	Surface sediment is very thick

Predominant Period (T_0)

The predominant period (T_0) is the time it takes for vibrations to propagate through a layer of surface sediment. T_0 can be used to determine the soil type or characteristics (Ambarsari, 2017). Kanai divides the soil type based on the T_0 shown in Table 2.

T_0 is calculated using the Equation 3.

$$T_0 = \frac{1}{f_0} \quad (3)$$

Information:

T_0 = predominant period (s)

f_0 = natural frequency (Hz)

Table 2
Soil Classification Based on Predominant Period By Kanai – Omote Nakajima (Ambarsari, 2017)

Soil Classification		T_0 (s)	Specification	Characteristics
Kanai	Omote-Nakajima			
Type I	Type A	0,05 – 0,15	Tertiary or older rocks composed of sandy gravel	Hard
Type II		0,15 – 0,25	Diluvium rock with a thickness of 5 m, consists of sandy gravel, sandy hard clay, loam	Medium
Type III	Type B	0,25 – 0,40	Alluvial rocks that are nearly similar to Type II	Soft
Type IV	Type C	>0,40	Consists of alluvial sediment delta, topsoil, and mud, with a 30 m thickness	Very Soft

Methods

The study was conducted in Sendangmulyo Semarang at 20 points with a 500 m grid shown in Figure 1.

Instrument

The instruments used in this study were:
1. Set Velbox SL06
2. Compass
3. GPS
4. Laptop
5. Google Earth
6. Scilab 6.1.0
7. Microsoft Excel 2019
8. QGIS 3.16

Figure 1
Data Acquisition Points

Procedure

1. Synthetic signal generation on Scilab by adding some microtremor source frequencies. Synthetic signals contain both original signals and noise.
2. FFT process to convert signals from the time domain to the frequency domain.
3. Noise filtering uses a low pass filter, cut-off frequency of 5 Hz.
4. Calculates the $\frac{H}{V}$ ratio. The ratio is then plotted into the HVSR spectrum to determine the natural frequency value (f_0).
5. Coding made from the FFT process, noise filtering, and $\frac{H}{V}$ ratio is then tested on synthetic signals that have been made before. If the results are by what was designed, then coding can be used to process field microtremor data.
6. The field microtremor data is formatted into txt, then data reading and plotting are performed to show the microtremor signal on each component.
7. Microtremor data processing on Scilab with coding that has been created and tested before. The data is processed until it gains an f_0. The f_0 then used to gain the T_0.
8. f_0 and T_0 obtained from data processing and then used for microzonation mapping on QGIS.

Result and Discussions

Coding and Testing Synthetic Data

Coding is compiled on Scilab 6.1.0 to create synthetic signals, FFT processes, noise filtering, and calculate the $\frac{H}{V}$ ratio. The frequency of synthetic signals is adjusted to the conditions of the study area, the source of which vibration comes from human activity, water flow in rivers, and wind. The noise in the area comes from traffic. Referring to SESAME, ambient vibration for short periods and close to the seismometer is considered noise (SESAME, 2004). Synthetic signals are shown in Figure 2.

FFT is then applied to the synthetic signal to convert the signal from the time domain to the frequency domain. The FFT results are shown in Figure 3. The synthetic signal is then made into three components to proceed to the HVSR method, as shown in Figure 4.

At the signal, the amplitude of the horizontal component is made more significant than the amplitude of the vertical component, according to Nakamura's theory.

Figure 2
Synthetic Signals

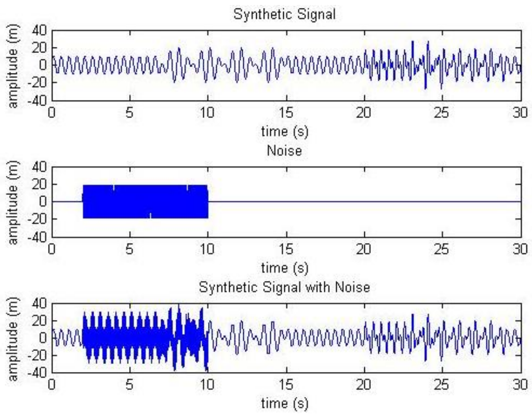


Figure 3
Synthetic Signal FFT Results

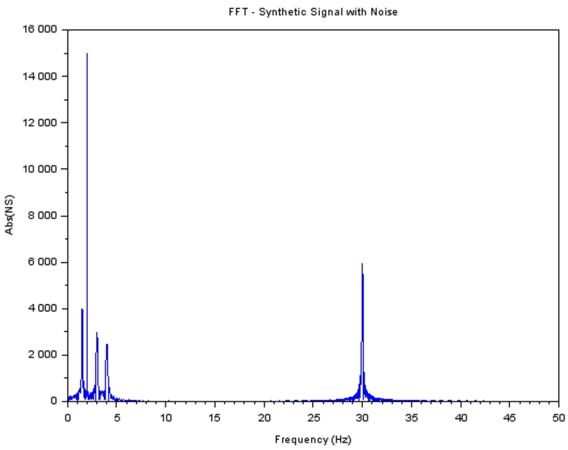
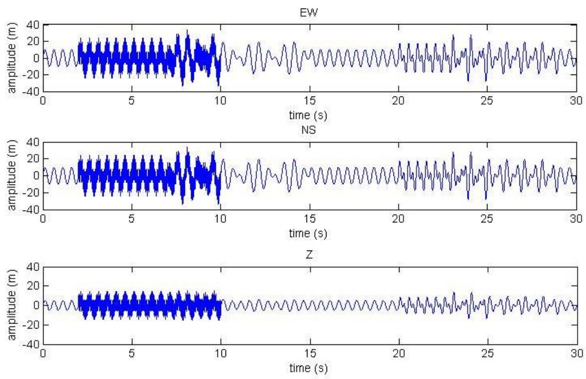


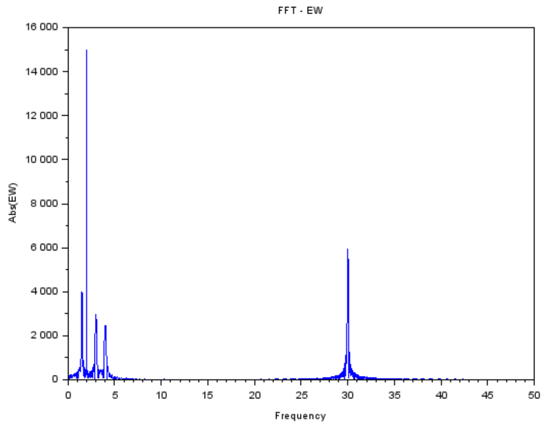
Figure 4
Synthetic Signals on Horizontal Component (EW and NS) and Vertical Component (Z)



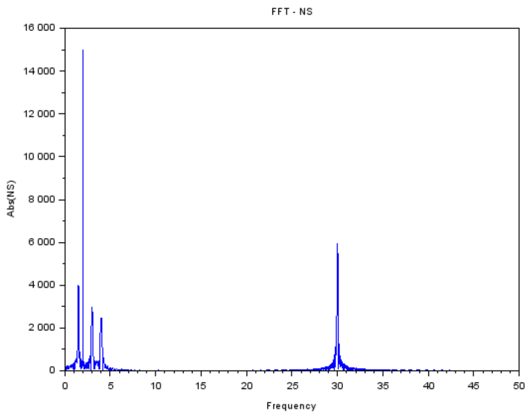
The FFT is then applied to the three components of the synthetic signal to determine the magnitude of the frequency and total frequency contained, as in Figure 5. In addition, the FFT process is also carried out to determine the frequency range that must be cut in the noise filtering process.

In Figure 5 (c), the frequency of 1.5 Hz has a small amplitude. From the picture, it is also known that the frequency of 30 Hz is a noise. The frequency is then cut in the filter process using a low pass filter with a cut-off frequency of 5 Hz.

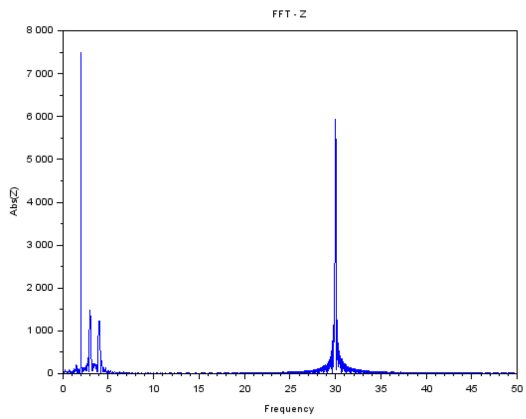
Figure 5
Magnitude and Total Frequency on Synthetic Signal (A) EW Component, (B) NS Component, (C) Z Component



(a)



(b)



(c)

Figure 6 shows that the 30 Hz frequency is cropped and produces a noiseless signal. The exact process is carried out on the components NS and Z. After removing the noise, calculating the $\frac{H}{V}$ ratio and plotting the HVSR spectrum using Equation (2) to determine f_0.

Figure 6

Comparison of EW Components (A) Before Filtering, (B) After Filtering, (C) FFT Results of EW Components After Filtering

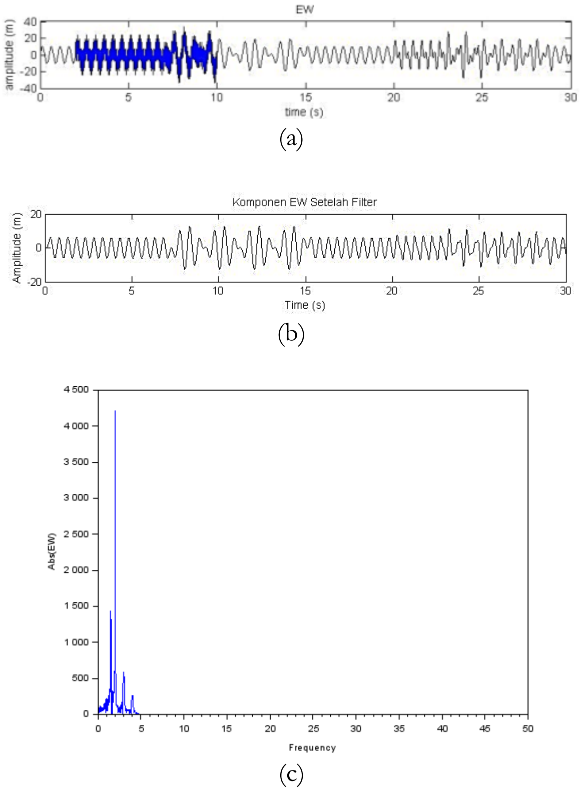
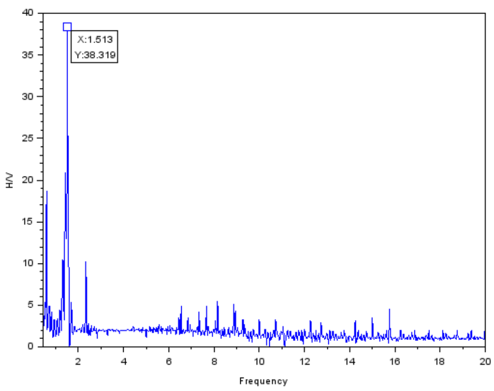


Figure 7

HVSR Spectrum of Synthetic Signal



f_0 is obtained from the highest peak of the HVSR spectrum. Based on Figure 7, it is known that the f_0 of synthetic signals is 1.513 Hz. In theory, f_0 is in the amplified area of the horizontal component but not amplified in the vertical component. Therefore, the vertical component set for a frequency of 1.5 Hz on synthetic signals has minimal amplitude. This means that the synthetic signal is set the f_0 is 1.5 Hz. Since the f_0 of synthetic signal is close to the predetermined value, coding can be used to process field microtremor data.

Field Data Processing

Recorded microtremor data plotted to show graphs in three components. The data is in the time domain, with the X-axis representing time in seconds and the Y-axis representing amplitude in meters. In Figure 8, the horizontal component has a higher amplitude than the vertical component.

Figure 8

Microtremor Data at T7 Recorded In Three Components (A) Horizontal EW, (B) Horizontal NS, (C) Vertical Z

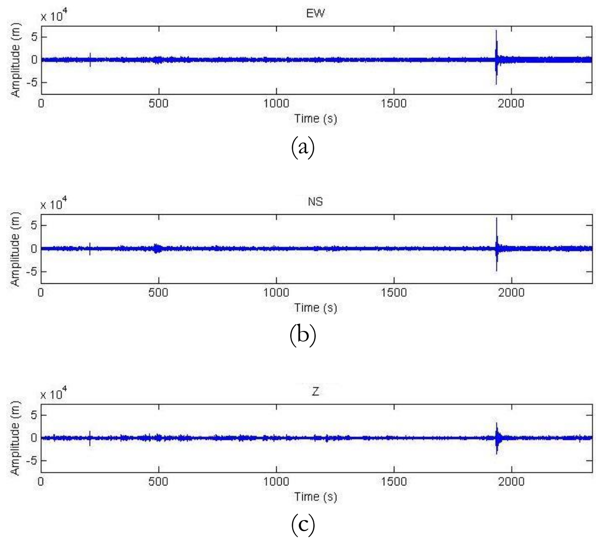
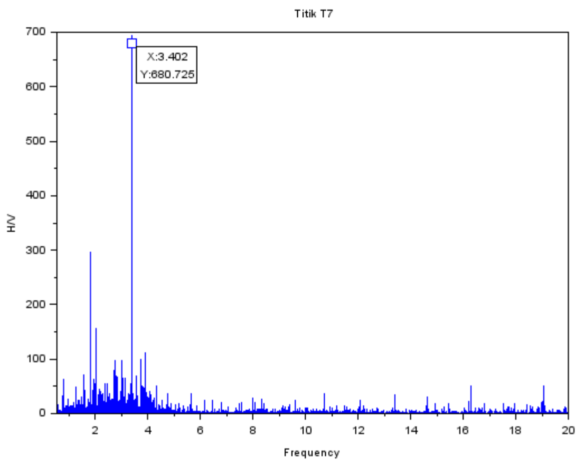


Figure 9

Plotting the HVSR Spectrum and f_0 at T7



FFT is then applied to the microtremor data to facilitate data processing. High frequencies are also cut using low pass filters to leave low frequencies due to those frequencies that indicate the region's susceptibility to earthquakes. The filtered signal is then used to calculate the H/V ratio and plotted to produce the HVSR spectrum as shown in Figure 9.

Natural Frequency

The soil classification of Sendangmulyo Semarang is shown in Table 3. The soil classification is also matched with the geological conditions of Semarang.

Table 3
Soil Classification Based on f_0 *in Sendangmulyo Semarang*

Classification	Points	f_0 (Hz)
Type I	T1	18,504
	T3	16,672
	T8	15,217
	T9	8,890
	T11	18,504
	T13	13,689
	T17	10,724
	T19	18,325
Type II	T2	5,889
	T16	5,940
	T18	5,485
	T20	4,953
Type III	T4	3,085
	T5	3,805
	T7	3,402
	T10	3,867
	T12	2,743
Type IV	T6	2,371
	T14	2,493
	T15	1,28

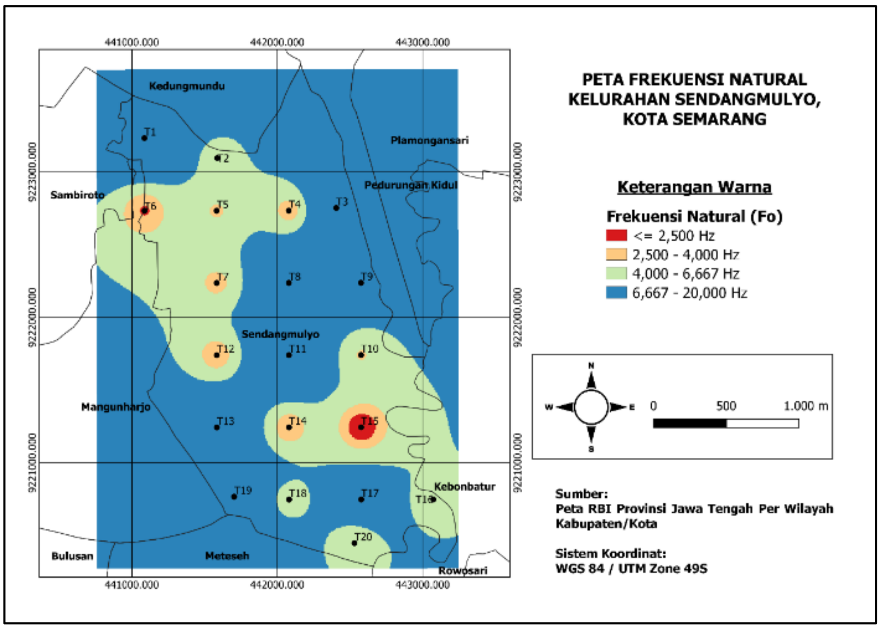
Based on the Kanai classification, Type I soils are thought to have very thin sediment thicknesses composed of hard rocks. While Type II soils have sediment thickness which is included in the intermediate category. Judging from the geological formation of Semarang, the location that has a high f_0 is in the Damar Formation (Qtd), with its constituents being sandstone, conglomerates, and volcanic brections that have complex properties.

Type III and Type IV soils are composed of alluvial rocks formed from delta sedimentation, topsoil, and mud, and it is estimated that the thickness of the sediment is very thick. Therefore, when correlated with the geological conditions of Semarang City, locations that have low f_0 are included in the Alluvium (Qa) formation.

f_0 distribution map in Sendangmulyo is shown in Figure 10. f_0 is related to the level of vulnerability of an area when an earthquake. The greater the value of the f_0 indicates that the soil layer is composed of hard rocks, which will not be significantly damaged when an earthquake. Meanwhile, the lower the value of f_0 indicates that the component rocks consist of soft rocks, and when earthquakes occur, the area tends to be prone to damage.

Evidence of the damage to buildings standing on a soft rock is the severe damage in Mandalawangi District, Banten, after the southern Indian Ocean earthquake of 6.9 SR on August 2, 2019. From the results of a field survey conducted by Stasiun Geofisika Klas I Tangerang after the disaster, it was discovered that the area has soft soil layers with a f_0 value of 0.9263 Hz (Suwardi et al., 2019).

Figure 10
f_0 *Microzonation Map In Sendangmulyo, Semarang*



Predominant Period (T_0)

T_0 is inversely proportional to f_0. Therefore, T_0 can be used to carry out soil classification and determine the soil's character in the research area. From Table 4, it can be seen that Sendangmulyo has the characteristics of hard soil, medium soil, soft soil, and very soft soil.

In an earthquake, vibrations will be muffled on hard soil, and on soft soils, vibrations will be continued. It means earthquakes are relatively more pronounced at points with high T_0 than in areas with low T_0. The area resulting from the T_0classification has similarities with the area resulting from the $f_0$classification. Locations with low T_0 are the same as locations that have high $f_0$with the same soil characteristics, and locations with high T_0 are the same as locations that have low f_0 with the same soil characteristics. It shows that the $T_0$is inversely proportional to the value of the f_0. The distribution of T_0 in Sendangmulyo is shown in Figure 11.

Evidence that buildings on the soft rock will suffer severe damage in Graben, Bantul, where buildings on soft rock suffered severe damage after an earthquake in 2006 (Sunardi et al., 2012). Another study on post-earthquake damage was conducted in Ratu Agung District, Bengkulu, after the 8.6 Mw Indian Ocean earthquake on September 12, 2007. Severe damage occurred because the area was dominated by soft alluvium rock (Suhartini et al., 2019).

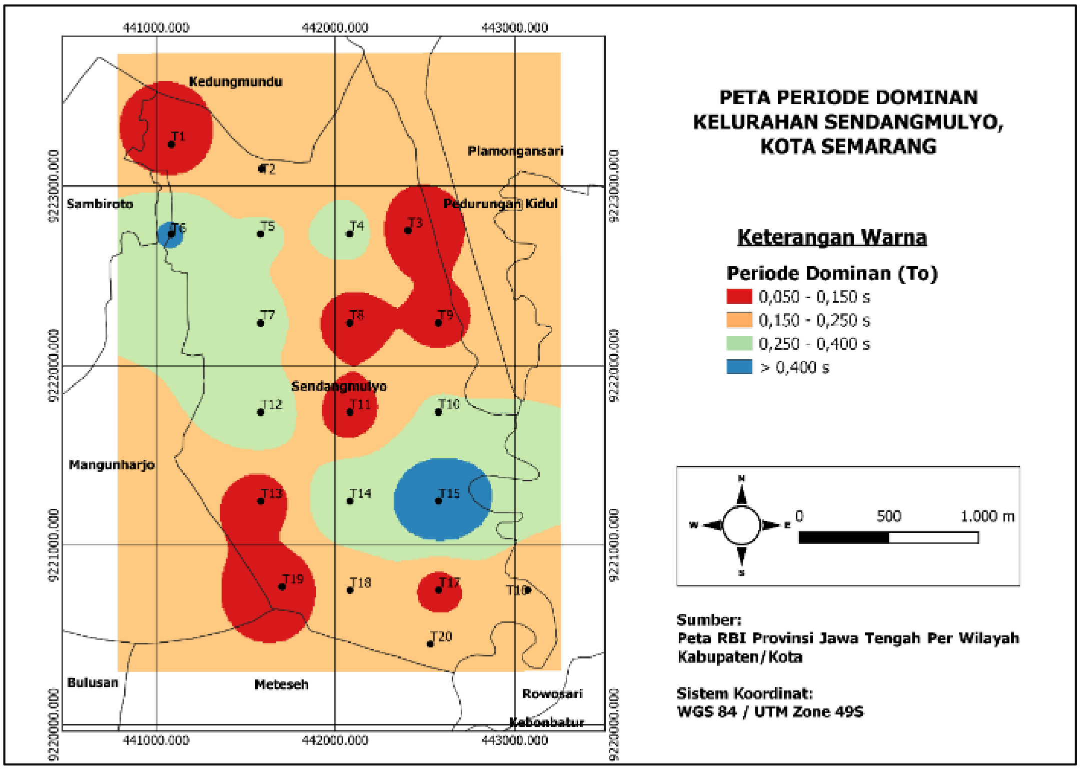
Table 4

Soil Classification based on T_0 in Sendangmulyo, Semarang

Classification	Points	T_0 (s)	Characteristic
Type I	T1	0,054	Hard
	T3	0,060	
	T8	0,066	
	T9	0,112	
	T11	0,054	
	T13	0,073	
	T17	0,093	
	T19	0,055	
Type II	T2	0,170	Medium
	T16	0,168	
	T18	0,182	
	T20	0,202	
Type III	T4	0,324	Soft
	T5	0,263	
	T7	0,294	
	T10	0,259	
	T12	0,365	
Type IV	T6	0,422	Very Soft
	T14	0,401	
	T15	0,781	

Figure 11

T_0 Microzonation Map in Sendangmulyo, Semarang



Conclusions

Based on the results and discussion, it can be concluded that the coding of the HVSR method was made based on Nakamura's theory in Scilab version 6.1.0. In coding tests, it can display predetermined f_0 so that coding can be applied to process microtremor data.

The f_0 in Sendangmulyo ranges from 1.280 Hz to 18.504 Hz, and the T_0 ranges from 0.054 s to 0.781 s. Areas with low f_0 values and high T_0 tend to be prone to earthquake tremors and can suffer heavy damage when shaken by earthquakes. Soil classification is based on f_0 and T_0 classification by Kanai, the soil in Sendangmulyo has hard soil, medium soil, soft soil, and very soft soil.

References

Ambarsari, D. (2017). *Analisis Mikrotremor dengan Metode HVSR untuk Mikrozonasi Kabupaten Gunungkidul Yogyakarta*. Institut Teknologi Sepuluh Nopember.

Arifin, S. S., Mulyatno, B. S., Marjiyono, & Setianegara, R. (2014). Penentuan Zona Rawan Guncangan Bencana Gempa Bumi Berdasarkan Analisis Nilai Amplifikasi HVSR Mikrotremor dan Analisis Periode Dominan Daerah Liwa dan Sekitarnya. *Geofisika Eksplorasi*, *2*(1), 30–40.

Haerudin, N., Alami, F., & Rustadi. (2019). *Mikroseismik, Mikrotremor dan Microearthquake dalam Ilmu Kebumian*. Pusaka Media.

Hidayat, E. (2013). Identifikasi Sesar Aktif Di Sepanjang Jalur Kali Garang, Semarang. *Geologi Dan Sumberdaya Mineral*, *23*(1), 31–37.

Motamed, R., & Ghalandarzadeh, A. (2004). Seismic Microzonation Of Urmia City By Means Of Microtremor Measurements. *13th World Conference on Earthquake Engineering*, *1052*.

Nakamura, Y. (1989). A Method for Dynamic Characteristics Estimation of Subsurface using Microtremor on the Ground Surface. *Quarterly Report of Railway Technical Research Institute*, *30*(1), 25–33.

Nakamura, Y. (2008). On the H/V spectrum. *The 14th World Conference on Earthquake Engineering*. http://117.120.50.114/papers/14wcee/14wcee_hv.pdf

Nakamura, Y. (2000). Clear identification of fundamental idea of Nakamura's technique and its applications. *12th World Conference on Earthquake Engineering*, Paper no. 2656. http://www.sdr.co.jp/papers/n_tech_and_application.pdf

Nubatonis, I., Sianturi, H. L., & Bernandus. (2017). Pemetaan Mikrozonasi Seismik di Desa Lili Kecamatan Fatuleu Kabupaten Kupang. *Fisika Sains Dan Aplikasinya*, *2*(2), 50–57.

Okada, H. (2003). The Microtremor Survey Method. In *The Microtremor Survey Method*. Society of Exploration Geophysicist. https://doi.org/10.1190/1.9781560801740.fm

Pancawati, K. D. (2016). *Identifikasi Kerentanan Dinding Bendungan Dengan Menggunakan Metode Mikroseismik (Studi Kasus Bendungan Jatibarang, Semarang)*. Universitas Negeri Semarang.

Sesame. (2004). *Guidelines For The Implementation Of The H/V Spectral Ratio Technique On Ambient Vibrations*. European Comission-Research General Directorate.

Suhartini, C.E., Mase, L.Z., & Farid, M. (2019). *Mikrozonasi Percepatan Tanah Maksimum Akibat Gempabumi 12 September 2007 di Kecamatan Ratu Agung Kota Bengkulu.* Proceeding Civil Engineering and Built Environment Conference (CEBEC).

Sunardi, B., Daryono, Arifin, J., Susilanto, P., Ngadmanto, D., Nurdiyanto, B., & Sulastri. Kajian Potensi Bahaya Gempabumi Daerah Sumbawa Berdasarkan Efek Tapak Lokal (2012). *Meteorologi dan Geofisika. 13(2)*, 131-137.

Suwardi, Subrata, T., & Purnama. (2019). *Laporan Survey Gempa Samudera Hindia Selatan M 6,9 02 Agustus 2019*. Stasiun Geofisika Klas I Tangerang.