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Soil Vulnerability Levels based on Microtremor Data using the HVSR method in the Old City Area of Semarang

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Abstract: Kota Lama Semarang with the Dutch colonial era relics is currently used as a cultural heritage tourist spot. As a cultural heritage tourism place, it is necessarily aware of the potential for earthquake disasters due to active faults and volcanic eruptions, as well as the phenomenon of land subsidence caused by geological conditions of young alluvium. One of the geophysical techniques to determine subsurface structure is microtremor measurement. This study aims to determine vulnerability level based on dominant frequency, amplification, and seismic vulnerability index using HVSR analysis in Kota Lama area. Microtremor data measurement contained 11 points with a data retrieval duration of 30 minutes. The results of microtremor data analysis obtained dominant frequency values of 7.03 - 19.36 Hz, amplification of 0.72 – 3.7, and seismic vulnerability index of 0.074 – 0.95. Based on the parameters, it can be concluded that the Kota Lama Semarang area has a low level of vulnerability.

Keywords: Seismic Vulnerability Index, HVSR, Kota Lama Semarang.

1. Introduction

The Old City of Semarang is one of the former areas of the Dutch colonial era. This area is located in the north of the city of Semarang, close to the coast of the island of Java. Currently, the Old City area of Semarang still has many ancient buildings with typical European ornaments that stand firmly, such as the Jiwasraya Office, Berok Bridge, Tawang Station, Blenduk Church, Semarang Post Office, and others, so that it is used as a cultural heritage tourist spot.

The Old Town area of Semarang is an area with a low level of seismicity due to its location in the north of Java Island, far from the epicenter of the earthquake originating from the southern subduction zone of Java Island (Hidayat, 2013). However, the Kota Lama area of Semarang needs to be aware of an earthquake disaster. The potential for earthquakes in the Kota Lama area of Semarang is caused by the presence of active faults on the island of Java such as the Lasem, Pati, Opak, Kaligarang, and Yogyakarta faults (Sulistiawan et al, 2017). Based on the catalog of the Center for Volcanology and Geological Hazard Mitigation (PVMBG), January 19, 1856 Semarang experienced an earthquake with a magnitude of VI-VII MMI causing damage to buildings. In addition to earthquakes caused by active faults, the Kota Lama area of Semarang also needs to be aware of earthquakes caused by volcanic eruptions in Central Java such as Mount Merapi, Sindoro, Slamet, and Sumbing.

The level of damage caused by an earthquake does not only depend on the magnitude and distance from the epicenter, but also the geological conditions affecting the damage. According to Chieffo & Formisano (2019) geological conditions can affect the level of high shaking on the ground surface even during earthquakes or low-intensity shaking, this is due to significant differences in soil layers that can cause site amplification. Jamroni et al (2017) added the phenomenon of local site effect damage caused by earthquakes caused by impedance contrasts.

Based on the geological map of the Magelang Semarang sheet, the Semarang Old City area is included in the alluvium formation, namely the coastal plain consisting of clay and sand with a thickness of more than 50 m. Sand deposits generally produce delta deposits as water-carrying layers with a thickness of more than 80 m. The plains of Kota Lama Semarang are formed from alluvial deposits that are relatively young so that the subsurface structure is constantly being compacted. This incident is one of the reasons the Old City area of Semarang experienced land subsidence. In addition, subsidence can be caused by excessive exploitation of subsurface natural resources (Parwata et al, 2019), construction loads, soil backfill, and overexploitation of groundwater (Supriyadi et al, 2018). The results of research according to Islam et al (2017) regarding land subsidence, the northern Semarang area experienced an average land subsidence of 8.23 cm/year. The subsidence of the land causes the northern Semarang area, including the Semarang Old City area, to often experience tidal waves and floods.

Calculation of the level of ground motion due to a potentially destructive earthquake requires an evaluation of the location response (Kang et al, 2020). One of the geophysical studies related to subsurface structures, seismic response of an area, and seismic hazard can be determined by measuring microtremor (Tün et al, 2016). Microtremor surveys are considered the most common method for estimating site effects, especially in urban areas (Abudeif et al, 2019) because they are able to determine the location of dominant frequencies and amplification equivalent to ground motion and benefit from passive techniques that do not cause disturbance to residents and surrounding buildings. when measuring microtremor (Toni et al, 2019). Other advantages of measuring microtremor compared to other methods are effective, relatively short time, reliable, precise, and able to obtain consistent measurement results when determining transfer functions such as frequency, resonance, and building vulnerability index (Sungkono et al, 2011). Single station microtremor measurements with three signal components were applied and analyzed using the Nakamura method (HVSR). The comparison of H/V signals is used to determine the dominant period and the value of Kg (Pamuk et al, 2017); Hadianfard et al (2016).

In recent years, researchers have conducted research on the vulnerability of an area using microtremor data with HVSR analysis. Kang et al (2020) calculated a seismic vulnerability index using the HVSR method in Haenam, Korea. Akkaya (2020) uses the seismic vulnerability index to assess building damage in Van, Eastern Turkey. Koesuma et al (2019) analyzed microtremor data for microzonation based on the seismic vulnerability index using the HVSR method in the southern region of Klaten district. Siska et al (2020) conducted a seismic vulnerability mapping to support the spatial planning of the Lhokseumawe city area. Abdelrahman et al (2017) used microtremor data to calculate seismic vulnerability index in new urban areas, Diriyah government, Riyadh, Saudi Arabia.

From the description above, it is necessary to have knowledge regarding the level of vulnerability in the Kota Lama area of Semarang based on the dominant frequency, amplification, and seismic vulnerability index. This is because the Old Town area of Semarang is a cultural heritage tourism area that needs to be considered regarding the layout of the building and also as knowledge related to seismic hazards based on microtremor data analysis.

2. Experimental

2.1. Research sites

The location of data collection was carried out in the Old City of Semarang with alluvium formation geology, namely the coastal plain consisting of clay and sand with a thickness of more than 50 m. Sand deposits generally produce delta deposits as water-carrying layers with a thickness of more than 80 m. Data retrieval was carried out by taking into account the rule guidelines based on SESAME (2004). The 11 points of microtremor data collection are shown in Figure 1.

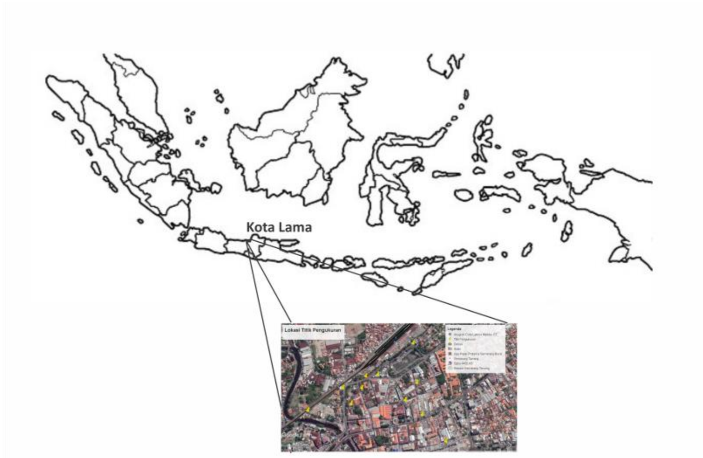

Figure 1. Measurement Point Location

2.2. Microtremor Data Processing

Microtremor is a very small vibration on the ground continuously caused by motor vehicle activities, wind, rain, human activities, and so on (Kanai, 1983). Microtremor is also defined as natural harmonic vibrations in the soil continuously, trapped in the sediment surface layer, undergoing a process of reflection caused by differences in the density of the medium between layers with a constant frequency, due to micro-sized vibrations at the bottom of the earth's surface or other activities. Microtremor waves can be used to determine soil types based on the dominant period of the soil, the smaller the value of the dominant period of the soil, the harder the constituent rocks will be and vice versa, the greater the value of the dominant period of the soil, the softer the constituent rocks (Chemistra et al, 2018). Microtremor surveys can be carried out by analyzing the Horizontal to Vertical Spectral Ratio (HVSR) by Nakamura in 1989.

The beginning of the HVSR method presented by Nogoshi & Iragashi (1971) suggested an interaction between the ratio of horizontal and vertical components by the ellipticity curve of Rayleigh waves. In 1989 Nakamura suggested that the ratio between the horizontal and vertical spectra in the frequency function is closely related to the site transfer function. Nakamura formulated the HVSR equation as in equation 1.

$$HVSR = T_{SITE} = \frac{S_{HS}}{S_{VS}} = \frac{\sqrt{(S_{north-south})^2 + (S_{west-east})^2}}{S_{vertical}} \quad (1)$$

The HVSR method uses three components of seismic disturbance measurement (ambient seismic noise), consisting of long-term microtremor such as natural activities such as wind, ocean waves, etc. with a period of more than 2 seconds), and short-term microtremor (caused by human activities such as traffic, machinery, etc. with periods under 2 seconds) (Yamanaka et al, 1994). The comparison of the H/V component microtremor signal resulted in the dominant frequency and amplification parameters. Dominant frequency and amplification values are indicated by the highest peak in the H/V microtremor ratio (Cox et al, 2020).

The microtremor data recorded using the MAE S3S vibralog seismometer is shown in Figure 2. The duration of each data measurement point is 30 minutes with 11 points. The seismometer is set for the duration of microtremor data recording with a sample rate of 250 Hz. Microtremor data processing was carried out using Geopsy software. First, windowing the microtremor signal with the aim of cutting the signal that is considered noise with the signal processing time window length for the Fourier transformation is set to 25 s. The second is to compare the H/V microtremor signal by setting the sampling frequency to 4.5 – 20 Hz and the Konno-Ohmachi filter used. The next step is to perform HVSR analysis to obtain an H/V curve containing the dominant frequency and amplification. The dominant frequency and amplification parameter values are used to calculate the seismic susceptibility index value of Kg (Wahyudin et al, 2019). The value of the seismic vulnerability index can be obtained as in equation 2.

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

Figure 2. MAE S3S Vibralog Seismometer Tool

3. Results and Discussion

The dominant frequency is the frequency that is often seen where the frequency interprets the types and characteristics of rock layers in the area (Bessi et al, 2018). The dominant frequency is the resonant frequency on the surface of the sediment layer when the amplification reaches its maximum value (Prabowo et al, 2021). Based on the processing, the dominant frequency values in the Old Town area of Semarang range from 7.03 to 19.36 Hz, the dominant frequency distribution value map is shown in Figure 2.

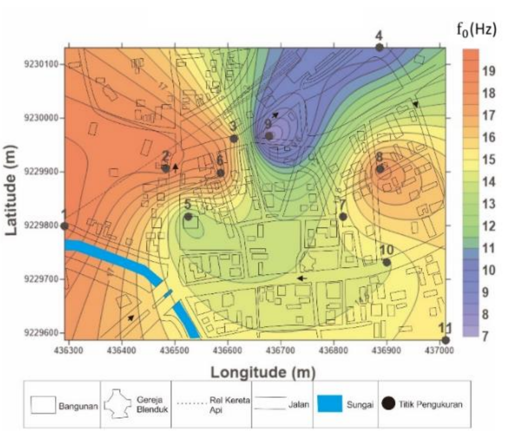

Figure 3. Dominant Frequency Value Distribution Map in Research Locations

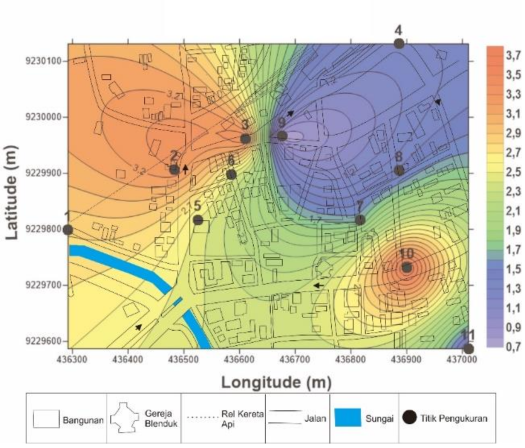

Figure 4. Amplification Value Distribution Map at Research Sites

Based on Figure 3, the area that has the lowest dominant frequency value is at point klm9, which is 7.03772 Hz, shown in blue, while the area that has the highest dominant frequency value is at point klm1, which is 19.3581 Hz, shown in red. A high frequency value indicates that the subsurface structure is a hard rock layer. The distribution of high-value frequency values is around the points klm 6, klm2, klm1 to the west and is also at the point klm8. Furthermore, the low frequency value indicates that the subsurface structure is a soft layer. The distribution of frequency values with low values is at points klm9 and klm4 to the north. Subsurface rock structures that are hard when affected by an earthquake have a lower level of damage compared to subsurface structures composed of soft rock.

Amplification is a wave amplification event that occurs because seismic waves pass through a softer medium. In addition, amplification can occur when a seismic wave passes through a medium that has the same frequency (Tanjung et al. 2019). A high amplification factor value indicates that the area is experiencing wave strengthening which makes it prone to damage due to earthquakes. The amplification value is influenced by rock deformation and weathering (Januarta et al, 2020). Based on the processing, the amplification value in the Old Town area of Semarang ranges from 0.72 to 3.7, shown a map of the distribution of amplification factor values as shown in Figure 4.

Based on Figure 4, the area that has the lowest amplification factor value is located around the klm9 point, which is 0.725215 shown in light blue. The area that has the highest amplification factor value is located around the klm10 point, which is 3.694195 shown in red. Almost the overall value of the amplification factor in the Kota Lama area of Semarang is classified as low to moderate. Areas included in the classification of moderate amplification values are at points klm2, klm3, and klm10. Overall, areas that have low amplification values are located in the north to the east including the klm9, klm8, klm7, and klm11 points located in the south west, experiencing small wave strengthening so that the level of damage to the ground surface during an earthquake is likely to be small. . Furthermore, areas that have greater wave reinforcement tend to have a high level of damage effect on the ground surface compared to others. This area is located in the north to west, namely klm1, klm2, klm3, and south to east, namely klm10 point.

The vulnerability index is a value that describes the vulnerability of the soil surface layer to deformation during an earthquake. The vulnerability index is obtained when the structure or soil surface experiences a shift and strain due to an earthquake (Putri et al, 2017). Based on the calculation, the vulnerability index value in the Old City area of Semarang ranges from 0.074 to 0.95 as shown in Figure 5.

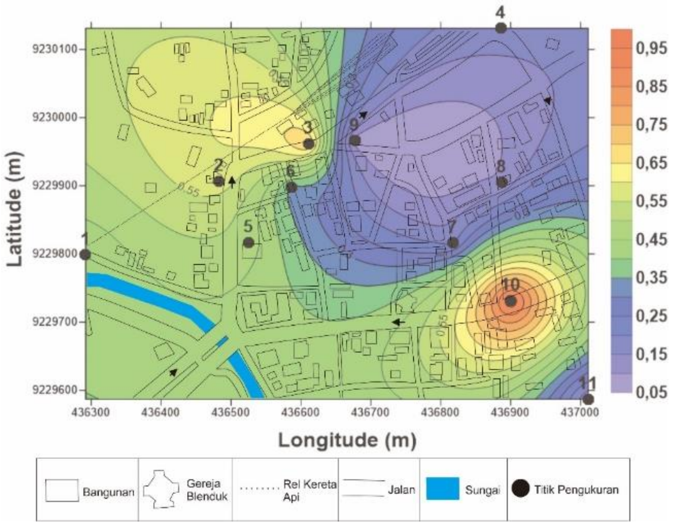

Figure 5. Map of Distribution of Seismic Vulnerability Index Values at Research Sites

Based on Figure 5, the area where the lowest vulnerability index value is located at the klm9 point is 0.074731 shown in light blue. While the area that has the highest vulnerability index value is at the klm10 point, which is 0.948115 shown in red. The area that has the potential to have a higher risk of damage to buildings than other points due to the earthquake is at the klm10 point. Meanwhile, areas that have the potential to have lower building damage than other points due to the earthquake are at points klm9, klm4, klm8, klm7, and kl11. Overall, the Old City area of Semarang has a small vulnerability index value, this indicates that the area when experiencing an earthquake disaster has a low level of surface layer vulnerability.

4. Conclusion

The results of microtremor measurements in the Old City area of Semarang were 11 points with HVSR technique analysis showing the dominant frequency values ranging from 7.03 to 19.36 Hz, amplification 0.72 – 3.7, and seismic susceptibility index (Kg)

0.074 – 0.95 . Overall, it can be concluded that the Kota Lama area of Semarang based on microtemor data has a low level of seismic hazard.

5. Suggestion

Based on the research above, it is necessary to increase the number of measurement points in order to know the seismic conditions in detail and evenly in the Semarang Old Town area.

References

Abdelrahman, K., Fnais, M., Abdelmonem, E., Magram, K., & Bin saadoon, A. (2017). Seismic vulnerability assessment in the new urban area of Diriyah Governorate, Riyadh, Saudi Arabia. *Arabian Journal of Geosciences*, *10*(19). https://doi.org/10.1007/s12517-017-3222-7

Abudeif, A., Fat-Helbary, R., Mohammed, M., El-Khashab, H., & Masoud, M. (2019). Estimation of the Site Effect Using Microtremor Technique at New Akhmim City, Akhmim, Sohag, Egypt. *Russian Geology and Geophysics*, *60*(2), 231–239. https://doi.org/10.15372/RGG2019036

Akkaya, İ. (2020). Availability of seismic vulnerability index (Kg) in the assessment of building damage in Van, Eastern Turkey. *Earthquake Engineering and Engineering Vibration*, *19*(1), 189–204. https://doi.org/10.1007/s11803-020-0556-z

Bessy, A., Sianturi, H., & Bernandus. (2018). Pemetaan Nilai Percepatan Tanah Maksimum dengan Metode Deterministic Seismic Hazard Analysis Di Lokasi Pembangunan Observatorium Nasional Desa Bitobe Kecamatan Amfoang Tengah Kabupaten Kupang. *Jurnal Fisika Sains Dan Aplikasinya*, *3*(1), 49–53.

Chemsitra, P., Utama, W., & Syaeful, A. (2018). Identifikasi Litologi Lapisan Sedimen Pada Daerah Karst Pacitan Menggunakan Metode Mikrotremor HVSR. *Jurnal Teknik ITS*, *7*(1), C77–C80.

Chieffo, N., & Formisano, A. (2019). Geo-Hazard-Based Approach for the Estimation of Seismic Vulnerability and Damage Scenarios of the Old City of Senerchia (Avellino, Italy). *Geosciences*, *9*(2). https://doi.org/10.3390/geosciences9020059

Cox, B., Cheng, T., Vantasell, J., & Manuel, L. (2020). A statistical representation and frequency-domain window-rejection algorithm for single-station HVSR measurements. *Geophysical Journal International*, *221*, 2170–2183. https://doi.org/: 10.1093/gji/ggaa119

Hadianfard, M. A., Rabiee, R., & Sarshad, A. (2016). Assessment of Vulnerability and Dynamic Characteristics of a Historical Building Using Microtremor Measurements. *International Journal of Civil Engineering*, *15*(2), 175–183. https://doi.org/10.1007/s40999-016-0086-2

Hidayat, E. (2013). Identifikasi Sesar Aktif Di Sepanjang Jalur Kali Garang, Semarang. *JSD.Geol.*, *23*(1), 31–37.

Islam, L., Prasetyo, Y., & Sudarsono, B. (2017). Analisis Penurunan Muka Tanah (Land Subsidence) Kota Semarang Menggunakan Citra SENTINEL-1 Berdasarkan

Metode DINSAR pada Perangkat Lunak SNAP. *Jurnal Geodesi Undip*, *6*(2), 29–36.

Jamroni, R., Imran, A., & Azikin, B. (2017). Analysis of Microtremor Data Using Horizontal to Vertical Spectral Ratio (HVSR) Method of Makassar, South Sulawesi. *International Journal of Engineering and Science Applications*, *4*(1), 63–68.

Januarta, G., Yudistira, T., Tohari, A., & Fattah, E. (2020). Mikrozonasi Seismik Wilayah Padalarang, Kabupaten Bandung Barat Menggunakan Metode Horizontal to Vertical Spectral Ratio (HVSR). *Jurnal RISET Geologi Dan Pertambangan*, *30*(2), 143–152. https://doi.org/10.14203/risetgeotam2020.v30.1087

Kanai, K. (1983). *Engineering Seismology*. University of Tokyo Press.

Kang, S. Y., Kim, K.-H., Chiu, J.-M., & Liu, L. (2020). Microtremor HVSR analysis of heterogeneous shallow sedimentary structures at Pohang, South Korea. *Journal of Geophysics and Engineering*, *17*(5), 861–869. https://doi.org/10.1093/jge/gxaa035

Koesuma, S., Hatmo Putera, M. A., & Darsono, D. (2019). A microtremor analysis for microzonation of seismic vulnerability index by using horiziontal to vertical spectral ratio in the southern area of Klaten regency. *Journal of Physics: Conference Series*. https://doi.org/10.1088/1742-6596/1153/1/012023

Nakamura, Y. (1989). A Method for Dynamics Characteristics Estimation of Subsurface using Microtremor on The Ground Surface. *QR of RTRI*, *30*(1), 25–33.

Nogoshi, M., & Igarashi, T. (1971). On the Amplitude Characteristics of Microtremor (Part 2). *Journal of the Seimological Society of Japan*, *24*, 26–40.

Pamuk, E., Özdağ, Ö. C., Tunçel, A., Özyalın, Ş., & Akgün, M. (2018). Local site effects evaluation for Aliağa/İzmir using HVSR (Nakamura technique) and MASW methods. *Natural Hazards*, *90*(2), 887–899. https://doi.org/10.1007/s11069-017-3077-y

Parwata, I., Ogawara, K., Tanaka, T., & Osawa, T. (2019). Land Subsidence Monitoring From ALOS/PALSAR Data By Using D-InSAR Technique In Semarang City, Indonesia. *International Journal of Environment and Geosciences*, *3*(1), 1–9.

Prabowo, U., Sehah, & Ferdiyan, A. (2021). Estimasi ketebalan lapisan sedimen permukaan berdasarkan pengukuran mikrotremor di Pemalang, Jawa Tengah. *Jurnal Teras Fisika*, *4*(1), 187–193. https://doi.org/10.20884/1.jtf.2021.4.1.3436

Putri, A., Purwanto, M., & Widodo, A. (2017). Identifikasi Percepatan Tanah Maksimum (PGA) dan Kerentanan Tanah Menggunakan Metode Mikrotremor I Jalur Sesar Kendeng. *Jurnal Geosaintek*, *3*(2), 107–114.

Siska, D., Fithra, H., Lisa, N., Haerudin, N., & Farid, M. (2020). Seismic Vulnerability Mapping to Support Spatial Plans in Lhokseumawe City Area. *International Journal on Advanced Science Engineering Information Technology*, *10*(1), 269–273.

Sulistiawan, H., Supriyadi, & Yulianti, I. (2017). Seismic Hazard Analysis based on Earthquake Vulnerability and Peak Ground Acceleration using Microseismic Method at Universitas Negeri Semarang. *Journal of Physics: Conference Series*. https://doi.org/10.1088/1742-6596/812/1/012002

Sungkono, & Santoso, B. . (2011). Karakterisasi Kurva Horizontal-to-Vertical Spectra Ratio: Kajian Literatur dan Permodelan. *Jurnal Neutrino*, *4*(1).

Supriyadi, Khumaedi, Sugiyanto, & Hidayatullah, R. . (2018). Identifikasi Ketebalan Lapisan Sedimen dan Struktur Bawah Permukaan di Zona Amblesan Kota Lama Semarang Berdasarkan Data Mikroseismik. *Spektra: Jurnal Fisika Dan Aplikasinya*, *3*(3), 159–166. https://doi.org/doi.org/10.21009/SPEKTRA.033.04

Tanjung, N., Yuniarto, H., & Widyawarman, D. (2019). Analisis Amplifikasi dan Indeks Kerentanan Seismik di Kawasan FMIPA UGM Menggunakan Metode HVSR. *Jurnal Geosaintek*, *5*(2), 60–67. https://doi.org/10.12962/j25023659.v5i2.5726

Toni, M., Yokoi, T., & El Rayess, M. (2019). Site characterization using passive seismic techniques: A case of Suez city, Egypt. *Journal of African Earth Sciences*, *156*, 1–11. https://doi.org/10.1016/j.jafrearsci.2019.05.004

Tün, M., Pekkan, E., Özel, O., & Guney, Y. (2016). An investigation into the bedrock depth in the Eskisehir Quaternary Basin (Turkey) using the microtremor method. *Geophysical Journal International*, *207*(1), 589–607. https://doi.org/10.1093/gji/ggw294

Yamanaka, H., Takemura, M., Ishida, H., & Niwa, M. (1994). Characteristics of Long-Period Microtremors and Their Applicability in Exploration of Deep Sedimentary Layers. *Bulletin of The Seismological Society of America*, *84*(6), 1831–1841.