Stratigraphic Determination Based on Shear Wave Velocity for Earthquake Disaster Mitigation in Lebong District

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Abstract *- Bengkulu Province, including North Bengkulu and Lebong, is located in the subduction zone of the Indo-Australian and Eurasian plates, which makes the region prone to earthquakes. This research focuses on earthquake disaster mitigation in the Lemeu area, Uram Jaya District, and Lebong Regency. It identifies areas prone to earthquake shaking based on Vs stratigraphy, Vs30 distribution, and soil site class. The Vs value was measured directly using the Multichannel Analysis of Surface Wave (MASW) method for three passes. Each track has four stations, so there are 12 data collection stations. The station point is the center point of a series of 24 geophones. Each geophone has a recording time of 512 ms and a sampling rate time of 125 μs to obtain 4096 data for each geophone. The measurement data was processed using WINMASW 5.0 professional software to produce a 1D profile. From the stratigraphic Vs, Vs30 is calculated and used to determine the site class, and then a distribution map is made. The results show that this area consists of site classes D, C and B. Medium soil with a value range of 175 ≤ Vs30 ≤ 350, hard soil with a value range of 350 ≤ Vs30 ≤ 750 and soft rock with a value range of 750 ≤ Vs30 ≤ 1500. Of the 12 measurement points, 2 locations have relatively shallow Vs30 values, namely at points 4 and 11. This location has Vs30 values ranging from 221 - 258 m/s, so around this point, there is likely a high potential for building damage in the event of an earthquake.*

Keywords*: Earthquake; MASW; stratigraphy; Lebong Regency*

INTRODUCTION

In general, Lebong Regency consists of rocks formed from volcanic eruptions, some of which have undergone weathering. The influence of Indo-Australian Eurasian subduction, the Sumatra fault and the Ketahun fault causes the Lebong area to be prone to earthquakes. The northern end of Andaman Bay to the southern part of Semangko Bay is part of the mainland of Sumatra island and is divided into two due to the Sumatra Fault (Arisbaya et al., 2015). The fault follows an oblique motion resulting from subduction or convergence between the Indo-Australian and Eurasian plates with a collision direction of 10°N-7°S. At least 19 segments were found, with lengths ranging from 60 km to 200 km (Natawidjaja, 2018). The movement of these plates often causes earthquakes. For communities living along the convergence and transform faults including North Bengkulu and Lebong which are the Ketahun segment of the Sumatran fault, there is a high risk of earthquake hazards. (Ardiansyah, 2017). Earthquakes originating from active fault movements at shallow depths can usually be destructive, as was the case with the Lebong earthquake in 2017.

According to BMKG, the earthquake was about 7.5 km southwest of Muara Aman City (the capital of Lebong), as shown in Figure 1. The epicenter was indicated to be on land. Based on the depth of the hypocenter, the earthquake was a type of shallow tectonic earthquake caused by the activity of the Ketahun segment of the Sumatra fault zone. Based on the focal mechanism, this earthquake has a horizontal fault mechanism with the direction to the right (strike-slip fault). The horizontal fault is located at strike N 138°E, dip 63°, and slip

-169° with intensity scale V MMI (Modified Mercally Intensity) (BMKG, 2011). The focal mechanism studies determining fault plane orientation parameters in the form of strike, dip and rake (Herrmann & Bucksch 2014).

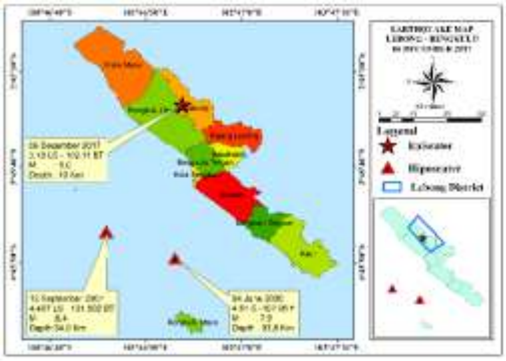


Figure 1. Location Map of the 2017 Lebong Earthquake

The morphology of Lebong consists of partly plain to undulating plains consisting of river alluvial deposits and alluvial deposits resulting from the weathering of young volcanic rocks of the Quaternary age. Another part consists of hills to steep hills composed of young volcanic rocks in the form of lava, breccia, and tuff (Supartoyo et al., 2018).

Earthquakes are disasters that cannot be predicted when, where and how strong they will be. One of the efforts to anticipate the impact of earthquakes is mitigation. Mitigation can be done by knowing the zones that are very vulnerable to zones that are relatively safe against earthquake hazards (Arifudin, 2021). One of them is mapping areas at risk of shaking based on the Vs30 value.

Factors that affect earthquake damage are the magnitude scale and the geological conditions in the region (Agung & Indrajaya 2020). Theoretically, areas at risk of earthquake damage are on relatively soft soils. Therefore, it is essential to analyze the subsurface shear wave velocity (Muzli et al., 2016).

This study aims to identify earthquake-prone areas based on Vs stratigraphy, Vs30 distribution and soil site class. The results of this study are expected to assist the government and the community in efforts to mitigate earthquake disasters, as well as safer spatial planning. Understanding of stratigraphy and soil characteristics can be applied to reduce the risk of earthquake disasters in the research area. The MASW method was chosen because it is one of the seismic methods with high accuracy and resolution on near-surface structures for subsurface stratigraphic modelling (Putri & Hadi 2021).

Shear wave velocity (Vs) is a parameter used to analyze subsurface geology (Nakamura, 2008). In addition, according to (McPherson & Hall 2013) the parameters that can be used in analyzing the level of vulnerability due to earthquakes are the average velocity of shear waves from the surface to a depth of 30 meters.

Several geophysical surveys have utilized the MASW method and are considered quite good at modelling the rock structure at a certain depth in detail. In generating stratigraphy, the obtained rock layer modelling can achieve excellent agreement between the field measurement data and the generated model to obtain the minimum misfit value (Refrizon, Sugianto, & Bernard 2019).

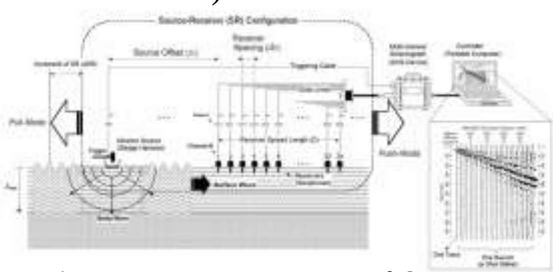


Figure 2. Survey overview of the MASW method (Park, Miller, & Xia 1999)

The MASW method is utilized in geotechnical investigations that rely on the shear wave velocity of rock layers near the surface. In seismic recording, Rayleigh waves are characterized by having a large amplitude and low frequency.

The MASW method survey can be seen in Figure 2, which shows the MASW method data recording process using 24 geophones. This method measures the variation of surface wave velocity as depth increases.

RESEARCH METHODS

Data Acquisition

This research was conducted in the Lemeu area, Uram Jaya District, Lebong Regency. The measurement data of Vs value was obtained by direct measurement using the Multichannel Analysis of Surface Wave (MASW) method. This method has advantages compared to other methods such as relatively low cost, easy data acquisition and processing, and simple equipment size and weight (Hasya, Khaizal, & Irwandi 2021). Data has been collected at 12 measurement points with a distance of 100 meters between points. Each track consists of four stations the midpoint of a series of 24 geophones. The distance between geophones is 2 meters and the distance from the source to the first geophone (offset) is 4 meters. Each geophone has a set recording time of 512 ms and a sampling rate time of 125 µs, so 4.096 pieces of data are obtained for each geophone. In 1 measurement point, 49.152 data were obtained, so for 12 measurement points, 1.179.648 data were obtained.

The active seismic source used in the data collection process is a hammer or sledgehammer hitting an iron plate placed on the ground. Then using a digital seismometer type 16S24 a 24-channel seismic response was recorded. The recording process is done with 3 to 4 repetitions. It aims to get the best recording results. Data collection in the field produces recordings of time domain signals as in Figure 3(a), which are then processed using WINMASW 5.0 professional software.

Data Processing

In WINMASW 5.0 Professional data processing, all recorded data are processed separately (one by one), so the processing results will produce 12 1D profiles. In data processing, the first step is to input data and then perform data selection (filtering). In the process of filtering the data, only the Rayleigh wave with the largest amplitude is used. Noise recorded in the data acquisition process is removed. Next a dispersion curve is made, namely a data plot that connects the phase velocity to the frequency and then picks on the dispersion curve. Picking is done with fundamental mode. Next the inversion process is carried out which will produce shear wave velocity (Vs). The next step is to set the layers in the number of layers menu and run the data to generate 1D profiles and 1D subsurface waves. The model selected has the smallest rms (root mean square) value. The smaller the RMS error value and standard deviation, the better the shear wave profile. After obtaining the 1D profile from the processing results of WINMASW 5.0 professional software, 2D stratigraphic modeling was made. The first step is to enter the Vs value, layer thickness and distance between research points based on the division of the track into the Microsoft Excel program. Furthermore, the excel file is inputted by means of a data grid which will produce a grid output in txt format. The grid file is then used to generate a 2D stratigraphic image in the new contour menu.

Analysis technique

At this stage, data interpretation is carried out by analyzing the entire shear wave velocity profile (Vs) against depth. The results of the dispersion curve inversion are used to estimate the shear wave velocity as a function of depth in a 1D cross-section. Furthermore, the Vs and depth obtained are used to obtain a 2D subsurface structure model. The next data analysis is to use the Vs30 value to determine the class of the soil site based on the SNI 1726 - 2019 classification as shown in Table 2.

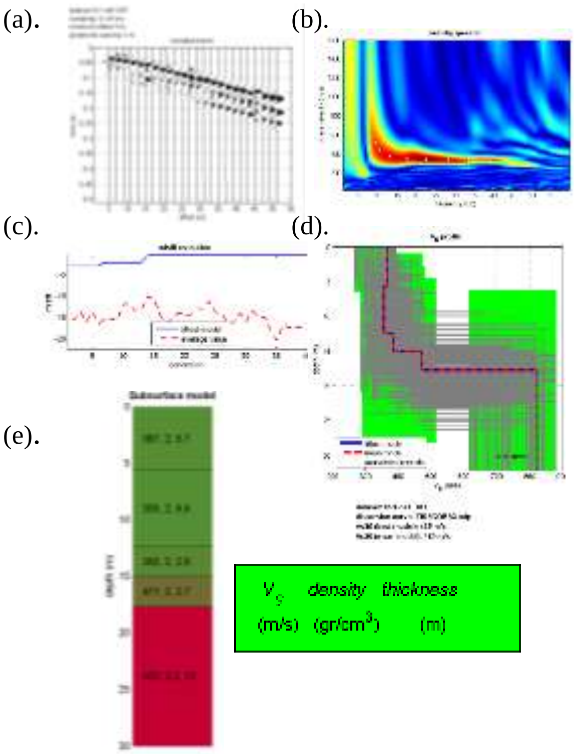


Figure 3. WINMASW 5.0 professional software processing results in the form of signals in the time domain (a), dispersion curves (b), misfit evolution curves (c), Vs profiles (d) and 1D cross-sectional models at each layer (e).

RESULTS AND DISCUSSION

Results

The results of WINMASW 5.0 professional software processing can be observed in Figure 3. The Vs30 value used is the Vs30 value at the mean model obtained from the data picked. In Figure 3(d) the best and mean models have the same value of 485 m/s. This similarity is influenced by the standard deviation value obtained. The coincidence of the lines explains that the value of the standard deviation is equal to zero

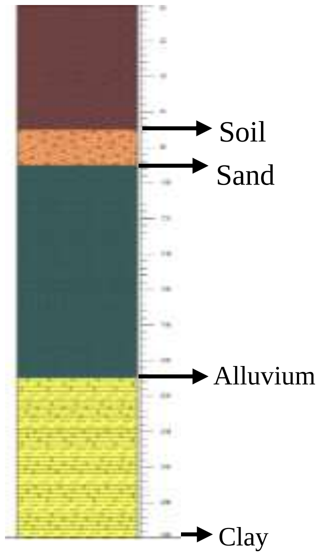


Figure 4. 1D model of subsurface stratigraphy

Each 1D model bar contains information on shear wave velocity (Vs), density and layer thickness. The 1D profile processed by WINMASW 5.0 Professional software only informs the density and Vs values up to a depth of 30 meters from the surface. After interpretation, the Vs values can be grouped based on the site classification table and then mapped for distribution.

The 2D profile can be obtained by interpolating the 1D shear wave velocity values on each track consisting of 4 stratigraphic pieces using surfer software. The required values are Vs, layer thickness and additional variables such as distance between research points.

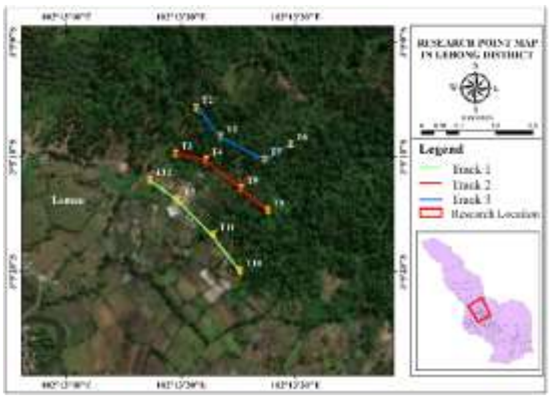
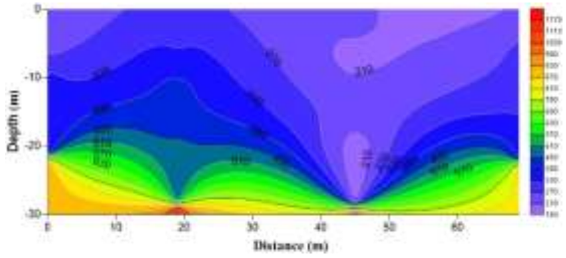
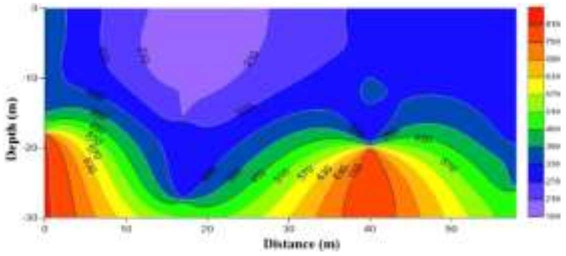


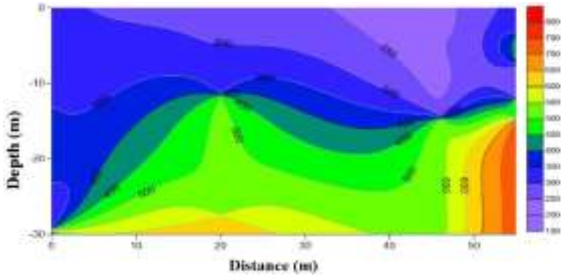
Figure 5. Map of research point distribution



(a). Track 1



(b). Track 2



(c). Track 3

Figure 6. Surfer software processing results produce 2D stratigraphic model Vs values up to 30 meters depth.

In 2D modeling, the 12 measurement points are divided into 3 tracks, as shown in the map of the distribution of research points in Figure 5. Each track consists of 4 measurement points, including track 1 (points 12, 5, 11, 10), track 2 (points 3, 4, 9, 8) and track 3 (points 2, 1, 7, 6). Each distance value is divided by 5 to get a better-looking 2D model result. After obtaining the 2D model, the Vs values were grouped based on the site classification table of SNI 1726 – 2019 (BNPB, 2020) and CEN regarding the classification of rock types and hardness levels.

Table 1. Vs30 values from measurements using the MASW method

MASW Point	X	Y	Vs30m/s
1	102.2231850º	-3.085642º	415
2	102.2225917º	-3.084940º	333
3	102.2220950º	-3.086055º	485
4	102.2228283º	-3086198 º	228
5	102.2221567º	-3.087170º	417
6	102.2248800º	-3.085833º	468
7	102.2242533º	-3.086197º	343
8	102.2243233º	-3.087427º	327
9	102.2236833º	-3.086888º	377
10	102.2236517º	-3.088893º	355
11	102.2230144º	-3.088025º	221
12	102.2214706º	-3.086693º	373

Tabel 2. Site classification refers to SNI 1726 - 2019.

Site class	Soil Profile Name	Vs30 (m/s)
A	Hard Rock	Vs30 > 1500
B	Rock	750 ≤ Vs30 ≤ 1500
C	Very Dense soil and Soft rock	350 ≤ Vs30 ≤ 750
D	Stiff Soil	175 ≤ Vs30 ≤ 350
E	Soft Soil	Vs30 < 175

In addition to analyzing the level of rock stiffness, the Vs values in Table 1 can also be used to determine the type of subsurface constituent material. Figure 4 shows that the constituent materials in the study area consist of soil, sand deposits, alluvium and clay.

In traverse 1 shown in Figure 6a, the first layer is marked with blue contours This layer is indicated as medium soil and is thought to consist of soft clay of varying thickness. The second layer with green to yellow contour colors at depths of more than 20 meters, is classified into hard soil sites which are indicated as clay, gravel, to alluvium materials. The orange contour colour is classified into medium rock sites of wet sand sediment.

In traverse 2 shown in Figure 6a, the blue contour color is classified into medium soil sites consisting of clay to wet sand material. Furthermore, the green and yellow contours are classified into hard soil sites, which are thought to consist of dry sand and gravel at depths ranging from 15 - 18 meters.

This contour layer has varying depths at each measurement point. The last layer is the orange contour as shown is a medium rock composed of gravel and sand deposits at a depth of more than 18 meters.

On track 3 shown in Figure 3c, the first layer with blue contour color is indicated as medium soil at a depth of 0-20 meters which is thought to consist of clay material. The second and third layers, marked with green to orange contour colors, are indicated as hard soil (soft rock) with varying thicknesses. This layer is thought to be clay, gravel to alluvium.

Discussion

The research has shown that the subsurface rock layers of the three tracks have almost the same rock structure but different densities. The first layer of the three passes is soft soil with Vs values of 175 - 350 m/s. This layer is a weathered pyroclastic deposit of clay, sand and gravel deposits. Physically, the soft soil layer lying on the surface is very susceptible to deformation, such as fracture when shaking occurs. The soil layer in the second layer with a Vs value of 350 - 750 m/s is the same as the previous layer, except that the constituent materials differ. The materials that make up this layer consist of clay, sand deposits, gravel to alluvium that has undergone compaction. Of the three passes, the rock layers of this contour (green and yellow) visually appear denser than the first layer and tend to be more complex. In all three passes, there are indications of soft rock (orange contour) with Vs values of 750 - 1500 m/s. This layer tends to be harder than the second layer, but its presence appears less than that of the previous layer. Although the rock structure in this layer is harder than the previous layer, this layer still has the potential for fracturing and weathering.

Research has been conducted by (Sulistiani et al. 2023) with the refraction seismic method in Lebong Regency. In his research, he concluded that the subsurface layer of the research location consists of gravelly clay, alluvium, clay, sand, gravel to saturated clay.

The interpretation results, which have been carried out with reference to SNI 1726 - 2016 (BNPB, 2020) and CEN (CEN, 2004), show that the 12 measurement points belong to three groups of soil sites. The first is medium soil, the second is hard soil and the third is medium rock. After interpretation, it can be concluded that no indication of hard rock exists at the research location, so it is likely to be found at a depth of more than 30 meters.

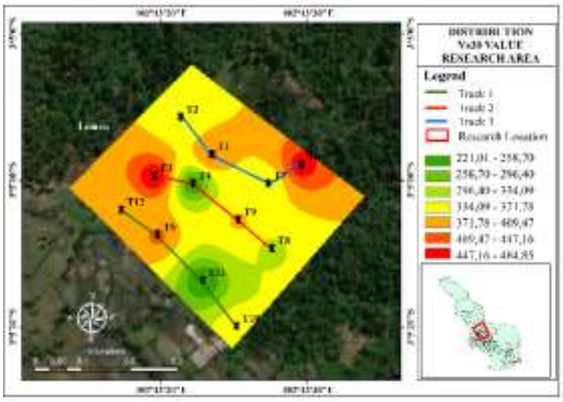


Figure 7. Distribution map of Vs30 values

Based on data analysis, it was found that the soil layer with low Vs value is located in the layer near the surface. This condition can be interpreted as an increased risk of building damage in the event of an earthquake. Conversely, layers with high Vs values have better stability, namely low amplification. Through the Vs distribution, we can identify soil layers with large amplification in the event of an earthquake. The findings of Vs stratigraphy and the distribution of site classes are a guide to identifying areas vulnerable to earthquake shocks and provide a strong basis for more effective mitigation planning recommendations.

Areas with low Vs30 values can be at high risk of shaking. This is because the stiffness of the rock determines the speed of seismic waves traveling through it. A lower Vs30 value means the rock structure is softer and vice versa. Shear waves cannot propagate into the fluid, so the Vs30 value of the rock is low. Earthquake shaking that occurs in the study area with relatively low Vs30 has the potential to cause significant damage. This can lead to landslides if they appear on slopes (Susilanto et al., 2018). In the event of a shock caused by an earthquake or other activity, the areas that experience more significant damage are located at points 4 and 11 of the study site. Because these points have lower Vs30 values than other research point areas.

CONCLUSION

The shear wave velocity (Vs) values in the study area based on the MASW survey are divided into three groups. The first is medium soil, the second is hard soil and the third is medium rock classified as site class D, C and B. From the three research point trajectories, the classification of the soil site class including site class D is indicated to be in the first layer of subsurface rock marked with blue contours. This layer is a layer of soil consisting of soft clay material wet sand and gravel a layer of weathered pyroclastic deposits. The second layer classified as site class C is a soil layer like the first layer except that this layer consists of loam, sand deposits, gravel, and alluvium that has undergone compaction. This layer appears denser and harder than the previous layer. The soil location class B classification is marked with orange contours in the third layer. This track shows the presence of more complex rock material compared to the previous layer, but its presence only appears less. Although this layer tends to be harder, this rock layer still has the potential for fracturing and weathering. It can be concluded that there is no indication of hard rock at this location, and it is thought to be at a depth of more than 30 meters.

The overall hazard level for earthquake damage is at an unsafe level. This is because the structure of the subsurface rock layer at the study site varies and mainly consists of soft soil. The area most prone to earthquake damage is in the soil layer classified as site class D, which has a low Vs30 value of 221 - 258 m/s. On the Vs30 distribution map (Figure 7), this area is located at points 4 and 11 of the study site, so it is recommended that permanent buildings not be built at these locations.

REFERENCES

Agung, R., & Indrajaya, A. (2020). Penentuan nilai percepatan tanah maksimum terhadap mitigasi gempabumi Kabupaten Pidie Jaya, Provinsi Aceh. *Jurnal Geografi: Media Informasi Pengembangan Dan Profesi Kegeografian*, 17(1), 23–26. https://doi.org/10.15294/jg.v17i1.22372

Ardiansyah, S. (2017). Analisis gempabumi merusak Kabupaten Lebong-Bengkulu 6 Desember 2017. *Jurnal Meteorologi Dan Geofisika*, 4(156).

Arifudin, A. (2021). Kecepatan gelombang geser (Vs) dan ketebalan sedimen (H) di Kabupaten Klaten dari data mikrotremor. *Teknisia*, XXVI(1). https://doi.org/10.20885/teknisia.vol26.iss1.art6

Arisbaya, I., Mukti, M. M., Handayani, L., Permana, H., Schnabel, M., & Jaxybulatov, K. (2015). Berdasarkan analisis data geofisika Tabuan Ridge, trace of Sumatran fault in Sunda Strait based on geophysical data analysis. *Jurnal Meteorologi Dan Geofisika*, 33–40.

Badan Standar Nasional. (2020). *Tata cara perencanaan ketahanan gempa untuk* *struktur bangunan gedung dan non gedung*.

BMKG. (2011). Badan Meteorologi Klimatologi dan Geofisika. *Jurnal Meteorologi Dan Geofisika*, 12(2), 2010–2011.

CEN. (2004). Eurocode 8-design of structures for earthquake resistance. Part 1: General rules, seismic actions and rules for buildings. *Jurnal Meteorologi Dan Geofisika*, 3(6), 55–60.

Hasya, C. A., Khaizal, K., & Irwandi, I. (2021). Perbandingan metode multichannel analysis of surface wave dan metode cone penetration test terhadap analisis lapisan tanah. *Journal of The Civil Engineering Student*, 3(1), 14. https://doi.org/10.24815/journalces.v3i1.12265

Herrmann, H., & Bucksch, H. (2014). Focal mechanism. *In Dictionary Geotechnical Engineering/Wörterbuch GeoTechnik* (p. 550). https://doi.org/10.1007/978-3-642-41714-6_62152

McPherson, A., & Hall, L. (2013). Site classification for earthquake hazard and risk assessment in Australia. *Bulletin of the Seismological Society of America*, 103(2 A), 1085–1102. https://doi.org/10.1785/0120120142

Muzli, M., Mahesworo, R. P., Madijono, R., Siswoyo, S., Pramono, S., Dewi, K. R., Budiarta, B., Sativa, O., Sulistyo, B., Swastikarani, R., Oktavia, N., Moehajirin, M., Efendi, N., Wijaya, T. A., Subadyo, B., Mujianto, M., Suwarto, S., & Pramono, S. (2016). Pengukuran Vs30 menggunakan metode MASW untuk wilayah Yogyakarta. *Jurnal Meteorologi Dan Geofisika*, 17(1), 25–32. https://doi.org/10.31172/jmg.v17i1.374

Nakamura, Y. (2008). On the H/V spectrum. *The 14th World Conference on Earthquake Engineering*, 1–10.

Natawidjaja, D. H. (2018). Updating active fault maps and sliprates along the Sumatran fault zone, Indonesia. *IOP Conference Series: Earth and Environmental Science*, 118(1). https://doi.org/10.1088/1755-1315/118/1/012001

Park, C. B., Miller, R. D., & Xia, J. (1999). Multichannel analysis of surface waves. *Geophysics*, 64(3), 800–808. https://doi.org/10.1190/1.1444590

Putri, D., & Hadi, A. I. (2021). Penentuan nilai Vs per kedalaman di Pesisir Pantai Panjang Kota Bengkulu menggunakan metode multichannel analysis of surface wave (MASW). *Jurnal Meteorologi Dan Geofisika*, 0, 270–276.

Refrizon, R., Sugianto, N., & Bernard, A. (2019). Penentuan stratigrafi kecepatan gelombang geser (Vs) di daerah rawan abrasi Kabupaten Bengkulu Utara menggunakan metode multichannel analysis of surface wave (MASW). *Jurnal Meteorologi Klimatologi Dan Geofisika*, 6(2), 15–20. https://doi.org/10.36754/jmkg.v6i2.119

Sulistiani, A., Sinaga, Y. C., Siaman, M., Setiawan, A., Budianto, G., Halauddin, H., Harlianto, B., & Sugianto, N. (2023). Struktur bawah permukaan di daerah geothermal menggunakan seismik refraksi. *Wahana Fisika*, 8(1), 24–35. https://doi.org/10.17509/wafi.v8i1.53778

Supartoyo, Praja, N. K., Praponco, N. T., & Hespiantoro, S. (2018). GM0302_97-104. *Jurnal Meteorologi Dan Geofisika*, 97–104.

Susilanto, P., Ngadmanto, D., Sunardi, B., & Rohadi, S. (2018). Analisis kecepatan gelombang geser (Vs) sebagai upaya mitigasi bencana gempabumi di Kulonprogo, Daerah Istimewa Yogyakarta. *Jurnal Meteorologi Dan Geofisika*, 41–50.