

Distribution of Vs30 in Pondok Kelapa Sub-District, Central Bengkulu, Bengkulu Based on Microtremor Data

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Abstract

Pondok Kelapa is among the sub-districts in Central Bengkulu Regency adjacent to major Sumatran faults, which are the Manna Fault and the Musi Fault, making it vulnerable to earthquakes. Therefore, regional planning and infrastructure development are needed to reduce the impact of earthquakes. This study aims to look at the state of the subsurface layers, the seismic vulnerability index, and the distribution of the average shear wave velocity value at a depth of 30 m (Vs30) and see the soil site class based on the Vs30 value. Field data acquisition used the HVSr methodology, while data analysis used microtremor data. Microtremor data was processed employing Geopsy software to gain H/V curves, which were then inversed using H/Inv software. The results are presented as shear wave velocity value distribution maps. The results showed the A0 (amplification factor value) ranged from 0.73 – 7.41, the dominant frequency (f_0) between 0.74 – 16.84 Hz, and the seismic susceptibility index value (Kg) ranged from 0.11 – 37.12 with the highest seismic susceptibility index value located in the East area of the research location. At the same time, the Vs30 value of the HVSr curve inversion results obtained ranged from 157 – 516 m/s. Site Class in the study area has SC, SD, and SE types, which are dominated by the SD type site class.

Keywords: Bengkulu; HVSr inversion; microtremor; Pondok Kelapa; Vs30.

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Introduction

Pondok Kelapa is a sub-district in Central Bengkulu Regency, Bengkulu Province, with rock formations in alluvium and lake deposits (Gafoer et al., 1992). Rock formations with the lowest seismic wave velocity and bulk density values due to a lack of rock compactness are those that may make more vulnerable to earthquake disasters (Hadi et al., 2021).

Bengkulu Central is located near the Manna Fault and the Musi Fault on the Great Sumatra Fault. The city is also located on

the outskirts of Sumatra Island, with direct access to the Indian Ocean (Natawidjaja, 2018; Al Ansory et al., 2023). The impact of one of the active segments on the Sumatra Fault, especially the Musi segment along the Bukit Barisan, makes Central Bengkulu highly vulnerable to earthquake disasters that trigger building collapses (Hamzah et al., 2020). Infrastructure development should be adapted to local geological conditions to reduce the risk of earthquake casualties and building damage (Nakamura et al., 2000).

One of the first stages of earthquake mitigation efforts to estimate the seismic hazard that could arise is local area micro zonation, which assesses the regional seismic risk. One of the factors used when creating microzoning maps is assessing the potential earthquake hazard (Bignardi et al., 2016). Analysis of ground shaking strength generated from bedrock shaking and amplification of ground motion variables are part of determining the possible earthquake hazard. The estimated value of the ground motion amplification potential involves the identification of local site characteristics, utilizing the average shear wave velocity value as low as 30 m/s to classify local sites (Thamarux et al., 2019; Ghanbari et al., 2018).

The average shear wave velocity at a depth of thirty meters (V_{s30}) and the investigation of the impact of local soil properties on earthquake shaking are crucial components of ground motion prediction (Sunardi et al., 2018). Shows site characteristics, such as soil classification and site amplification, which are essential for building codes and seismic design using borehole geophysical methods (Kim & Hong, 2022). However, these methods are costly and time-consuming. Therefore, microtremor observation using the horizontal-to-vertical spectrum (HVSr) method can present the local dynamic characteristics without drilling (Nakamura, 1989).

Research that distributes V_{s30} has been conducted by Mase et al. (2021). It is using microtremor data and inversion techniques to obtain secondary wave velocity (V_s) values. According to the study results, following the guidelines set by the NEHRP (National Earthquake Hazard Reduction Program) standard, the city of Bengkulu is conquered by site classes SC (Hard, Very Hard, Compacted Soil and Soft Rock) and SD (Medium Soil). Nabhan et al. (2023) used HVSr inversion on the alternative Central Bengkulu – Kepahiang road to

determine soil type as a preventive measure for earthquake hazards, showing that the V_{s30} value was generally high. V_{s30} values remain in the SC to SB (Rock) site classes. Furthermore, Farid et al. (2024) employed the HVSr method to investigate the rate of shoreline change resulting from coastal abrasion in Central Bengkulu Regency. The study generated V_{s30} values within the SC site class heading, ranging from 227 – 1235 m/s.

However, the V_{s30} value generated in the previous study cannot describe the overall subsurface layer conditions in the Central Bengkulu area, especially the Pondok Kelapa sub-district, because the research station points are less spread in the research area. As a result, the author intends to examine the subsurface layers to determine the soil site class based on the V_{s30} , the distribution of the layers' shear wave velocity values, and the seismic vulnerability index.

This research is expected to be helpful for the advancement of science related to V_{s30} . Furthermore, Central Bengkulu Regency's regional development can be built upon the spatial distribution of V_{s30} , particularly in the Pondok Kelapa Sub-district area, where earthquake risk reduction is imperative due to its designation as a regional development area. This may also be taken into account while designing infrastructure that is earthquake-resistant in the beginning.

Pondok Kelapa sub-district is in Central Bengkulu Regency, Bengkulu Province, Indonesia. Based on the geological map (Gafoer et al., 1992), the research point is located in a geological area consisting of various rock formations, depending on the location and geological conditions Figure 1. The geological map shows the area's different rock formations and geological structures, such as the Alluvium formation (Qa) consisting of medium-sized sedimentary rocks, such as pebbles, gravel, sand, silt, mud, and clay. Alluvium

Terraces (Qat2) consist of large sedimentary rocks, such as sand, silt, clay, and gravel. Bintunan (Qtb) consists of fine-sized sedimentary rocks such as conglomerate, tuffaceous claystone, and reef limestone. Swamp Deposits (Qs) consist of large sedimentary stones such as mud, silt, sand, clay, and plant remains. Qa, Qtb, Qs, and Qat rock formations have

different hardness levels, which affect their ability to resist earthquake-induced ground movement. Rock formations with lower hardness levels, such as Qa and Qtb, are more susceptible to ground movement, while rock formations with higher hardness levels, such as Qs and Qat, are more resistant to ground movement (Sugianto et al., 2017).

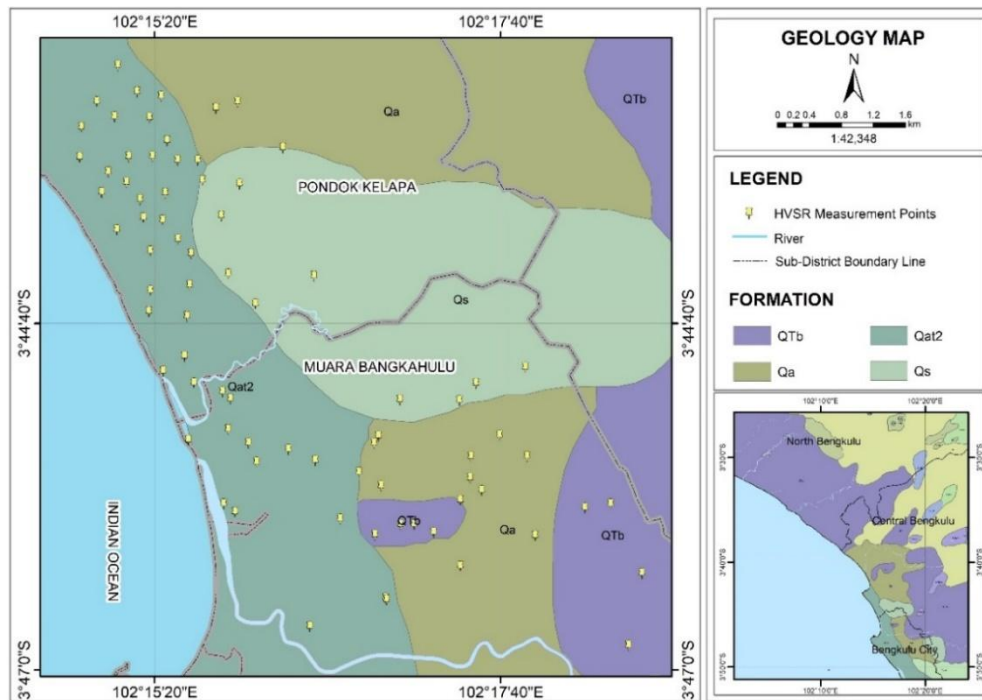


Figure 1. Geological of study area and HVSR measurement point.

Materials and Methods

This research took 78 location points with the microtremor method to estimate the seismic susceptibility value and determine the subsurface layer based on the Vs. Value and the dispersal of Vs30 values in the Bengkulu City expansion area in Pondok Kelapa District, Central Bengkulu. The locations spread towards Muara Bangkahulu Sub-district, Bengkulu City. The recording duration is 960 seconds at each location, while the interval between measurement stations is 200 – 400 m apart. The equipment used is a Portable Short Period Seismometer Gemini 2 Sn-1405 model, laptop, GPS, geological compass, camera, and software such as Geopsy, HV-Inv Beta, and ArcGIS. Figure 2 reveals a

distribution map of the measurement points.

Geopsy software processes the microtremor data recording findings obtained directly from the field (Wathelet et al., 2020). by inputting the signal. Then, the windowing process is carried out to separate microtremor data and transient data. The microtremor data that has been separated is then carried out in the calculation stage of the ratio between the three components (Vertical, North-South, and East-West) to produce the HVSR spectrum (SESAME, 2004). The peak of the HVSR spectrum is based on SESAME criteria (Kang, 2024) to acquire the prevailing f_0 (frequency value) and the A_0 (amplification factor value) and then obtain the H/V curve (Handayani et al., 2021). They are shown in Figure 3.

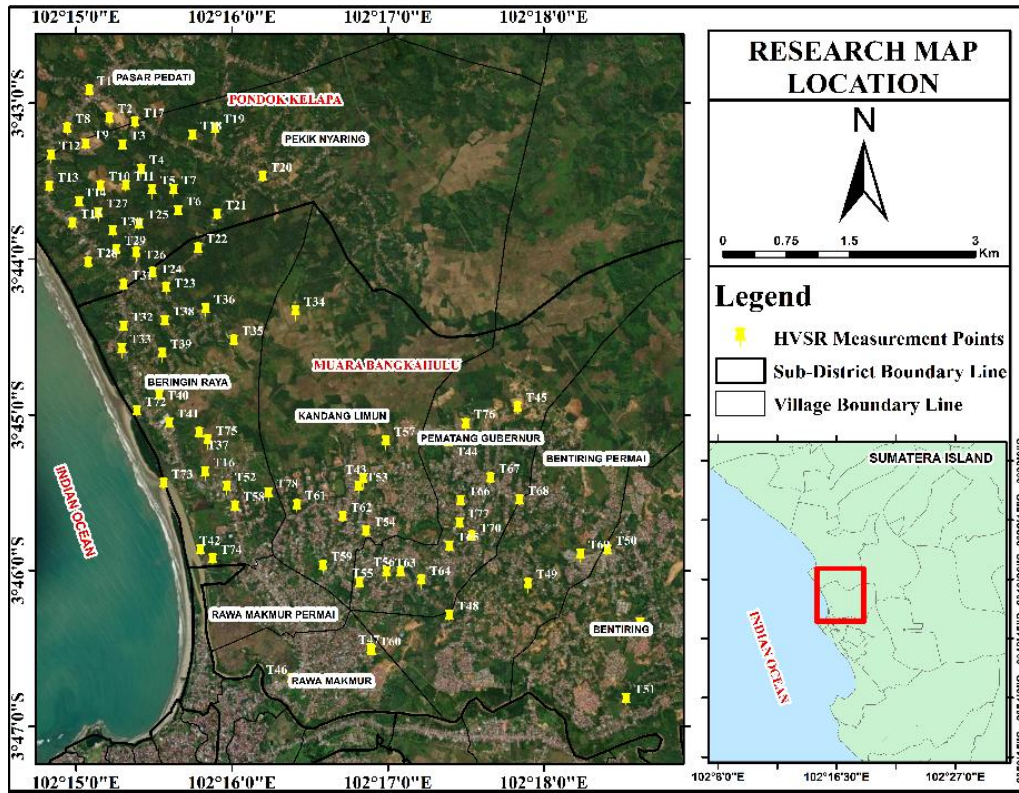


Figure 2. Research location map.

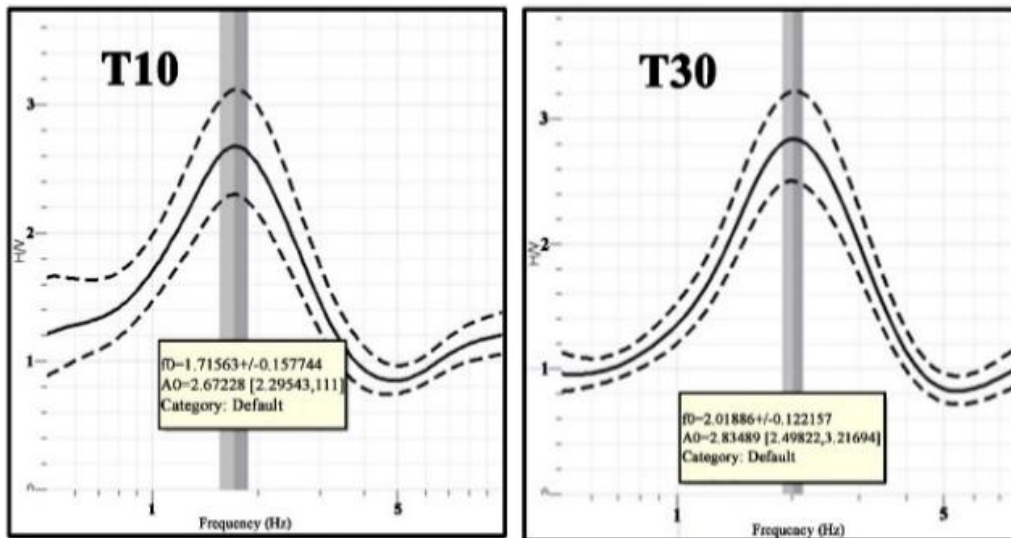


Figure 3. HVSR curve at points T10 and T30.

The seismic susceptibility index (K_g) can be deliberate by considering the central frequency and amplification factor as the determining variables (Yutaka, 1997):

$$K_g = \frac{(A_0)^2}{f_0} \quad (1)$$

where A_0 dan f_0 representing the amplification factor and dominant frequency, respectively. The K_g estimates areas susceptible to cracking and the

potential level of soil deformation due to earthquakes (Nakamura, 1989). Soils with soft sedimentary rock lithologies typically have low K_g values, which suggests that the region is prone to earthquakes. In contrast, areas with high K_g values are usually found in soils composed of solid and stable rock, indicating that the area experiences only minor shaking when an earthquake occurs (Tanjung et al., 2021).

The HVSR inversion procedure minimizes the detached job, which is the difference between the intentional and experimental HVSR, to calculate the shear wave velocity value (Syamsuddin et al., 2022). Shear wave profiles can be employed to describe the geotechnical conditions of soil layers with the HV-Inv Beta software (García-Jerez et al., 2016). HVSR curve inversion using the Forward Modelling (FWD) principle. The subsurface layer is assumed to be a homogenous layer comprising two layered viscoelastic layers. The properties of the layer are density (ρ), thickness (H), associated attenuation factors (Q_p , Q_s), and compressive and shear wave velocity (V_p , V_s) (Wijayanto et al., 2022).

The V_s , which describes the shear features of the soil structure, is one of the essential

metrics that illustrates the dynamics of soil properties (Tawakal et al., 2020). V_{s30} is the average shear wave speed at a depth of 30 meters to see the impact of the local site, especially the sediment layer above the bedrock.

Based on the National Standardization Agency rules, the value of V_{s30} is estimated using the equation (BSN, 2019):

$$V_{s30} = \frac{30}{\sum_{i=1}^n \frac{d_i}{V_{s_i}}} \quad (2)$$

where d_i is the layer thickness at 0 to 30 m depth, The quantity of layers up to a depth of 30 meters (n) determines the speed of the shear waves (V_s). Table 1 reveals the cataloging of soil site classes established on SNI 1726:2019 (BSN, 2019).

Table 1. Classification of site based on V_{s30} data.

Class Site	V_{s30} (m/s)
SA (Hard Rocks)	> 1500
SB (Medium Rocks)	750 – 1500
SC (Hard, Very Hard, Compacted Soil and Soft Rock)	350 – 750
SD (Medium Soil)	175 – 350
SE (Soft Soil)	< 175

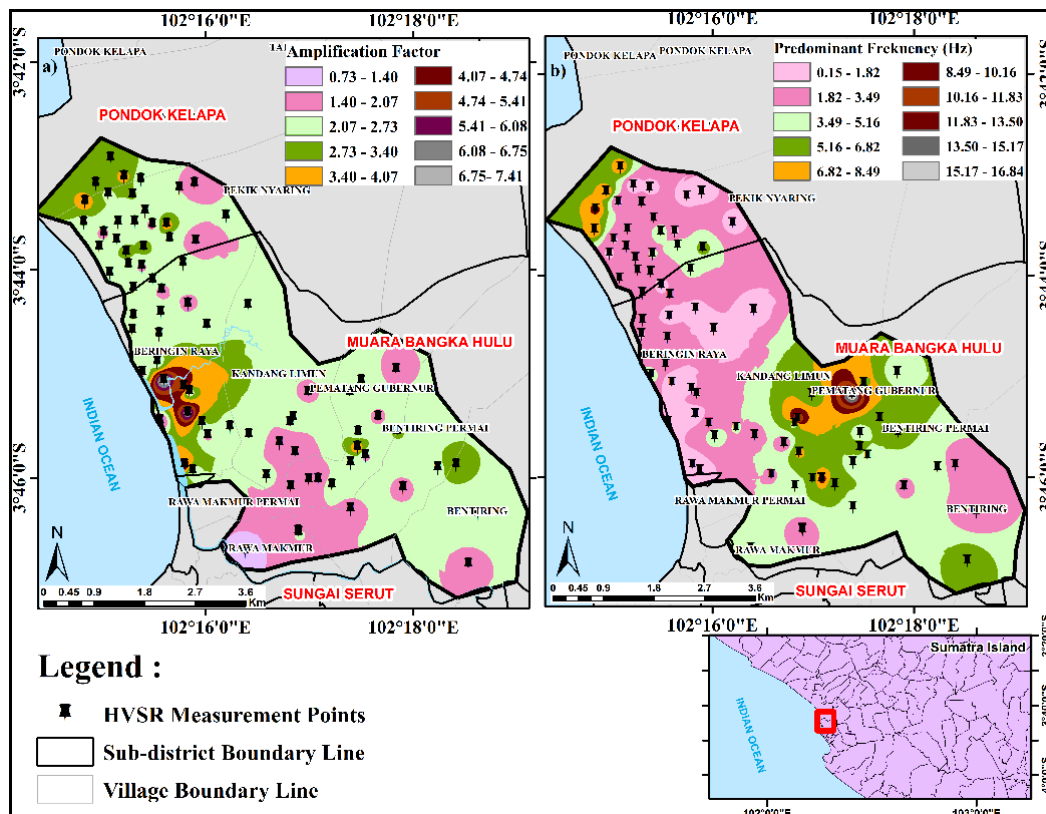


Figure 4. Scatter map of (a) Amplification Factor (b) Dominant Frequency.

Results and Discussion

Based on the field research, the resulting amplification factor values range between 0.73 and 7.41, indicating that most of the amplification factor distribution is low. Amplification values with a low classification of < 3 are almost spread throughout the research site, marked by geological formations Qa (Alluvium), Qs (Swamp Deposits), and QTb (Bintunan), where the characteristics of these formations are relatively soft sedimentary rocks, meaning that the earthquake shaking felt on the ground is relatively more minor than the original shaking in the earth. The amplification value with a medium to high classification of $3 < A < 7$ is shown in some areas of the Qat (Alluvium Terraces) geological formation, which is characterized by relatively large and more complex sedimentary rocks, meaning that the earthquake shaking felt at ground level is greater than the original shaking in the earth (Figure 4a) and the dominant

frequency value is between 0.74 to 16.84 Hz. Based on the classification of the dominant frequency according to Kanai (Ridwan et al., 2021).

In this study, the soil classification by Kanai (Table 2) includes Type I, II, III, and IV soils. Type I and II, with a frequency of < 2.5 Hz, are in the eastern direction, composed of alluvial rocks formed from delta sedimentation, top, soil, and mud exceeding 30 meters. Type III, with a frequency of 2.5 – 4 Hz, is in the west and consists of alluvial rocks > 5 m thick, comprised of alluvial loam, sandy gravel, and sandy hard clay. Type IV type I, a frequency of 6.7 – 20 Hz, is composed of tertiary rocks consisting of Hard sandy and gravel, and Type II, a frequency of 10 – 20 Hz, thickness of 5 m, sandy–gravelly, sandy–hard, clayey, and alluvial rocks located in the Pematang Gubernur and Pasar Pedati areas seen in (Figure 4b).

Table 2. Kanai's classification of soil based on dominant frequency values (Al Ansory et al., 2023).

Classification of Soils Type	Class	Dominant Frequency (Hz)	Kanai Classification	Descriptions
IV	I	6.67 – 20	Tertiary or older rocks. Consists of Hard rock, gravel, sandy, etc.	The thickness of the surface sediments is very thin, dominated by hard rocks.
III	II	4 – 10	Alluvial rocks, with a thickness of 5m. consist of sandy, loam, gravel, sandy hard clay, etc.	Its surface sediment thickness falls into the medium category of 5 – 10 m.
II	III	2.5 – 4	Alluvial rocks, > 5 m thick, consisting of sandy-gravel, sandy hard clay, loam, etc.	The thickness of the surface sediments is in the thick category, about 10 – 30 m.
I	IV	< 2.5	Alluvial rocks, which are formed from sedimentation of delta, top soil, mud, etc. With a depth of ≥ 30 m.	The sediment surface is very thick.

Seismic Vulnerability Index

Based on the formulas and calculations carried out, Seismic vulnerability index values are strongly influenced by maximum amplitude and natural frequency. The seismic vulnerability index will be more significant for larger amplitude and lower natural frequency values. Conversely, lower amplitude values and higher natural

frequency values lead to lower seismic risk index values. The soil structure stability in an area is lower when the seismic vulnerability index is elevated, so the possibility of building damage will increase during an earthquake shock (Maimun et al., 2020).

Based on the data taken at 78 measurement points, the seismic susceptibility index

value in the research area ranges from 0.11 – 37.12 as shown in Figure 5. According to Satria et al. (2020) vulnerability index values are divided into three zones in the study area: the low zone with a Kg value < 3, the medium zone with a Kg value of 3 – 6, and the high zone with a Kg value > 6. The low zone indicates a zone that is safe from land surface movement. The zone is distributed in most of the study area, including Pekik Nyaring, Kandang Limun, Pematang Gubernur, Bentiring Permai, Bentiring, Rawa Makmur Permai, and Rawa Makmur villages. The medium zone indicates a safe zone with relatively small levels of land surface movement. The zone is in a tiny portion of the southern Pasar Pedati area, the northern Beringin Raya

area, and the northern Pekik Nyaring area. In line with moderately high amplification factors, the high zone is concentrated in the southern part of Beringin Raya village, a coastal area.

Soils characterized by soft sedimentary rock lithologies typically exhibit low Kg values, such as the condition of the study area, which has Alluvium, Alluvium Terraces, Bintunan, and Swamp deposit formations. This indicates that the area is susceptible to vibration. On the other hand, soils with strong and stable constituent rocks tend to have high Kg values, indicating that the region experiences only small shocks during vibration.

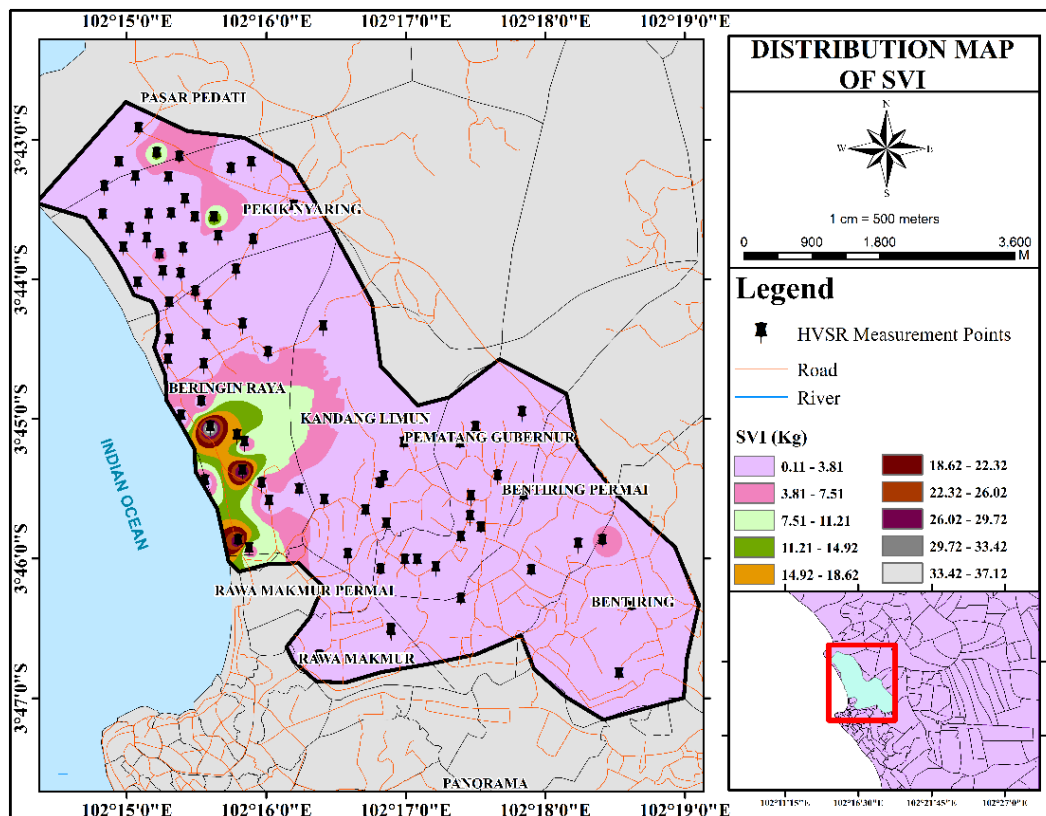


Figure 5. Distribution map of seismic vulnerability index at the research site.

Vs30

Figure 6 shows a spread of Vs30 values, falling between 157 m/s to 516 m/s. Based on the study area's Vs30 readings, most areas are dominated by the SD rock type category triggered in Table 1. Specifically, medium soils have Vs. Values range from

175 to less than 350 m/s; medium soils have a clay texture and minerals that are easy to detach, lift, move, or are prone to land movement. Vs. Values between 350 m/s to 516 m/s are the SC rock type category with hard, thorny soil, compacted soil, and soft rock, which is in Kelurahan Kandang

Limun, Pematang Gubernur, and East Rawamakmur. A tiny portion is included in the SE category that exhibits a range of Vs. Values below 175 m/s, which is soft soil located in a part of Pasar Pedati village, marked with light green. In areas with soft

and medium soil types, seismic waves that propagate will propagate slowly to the ground and buildings above them after being reflected by the medium (Edison et al., 2022).

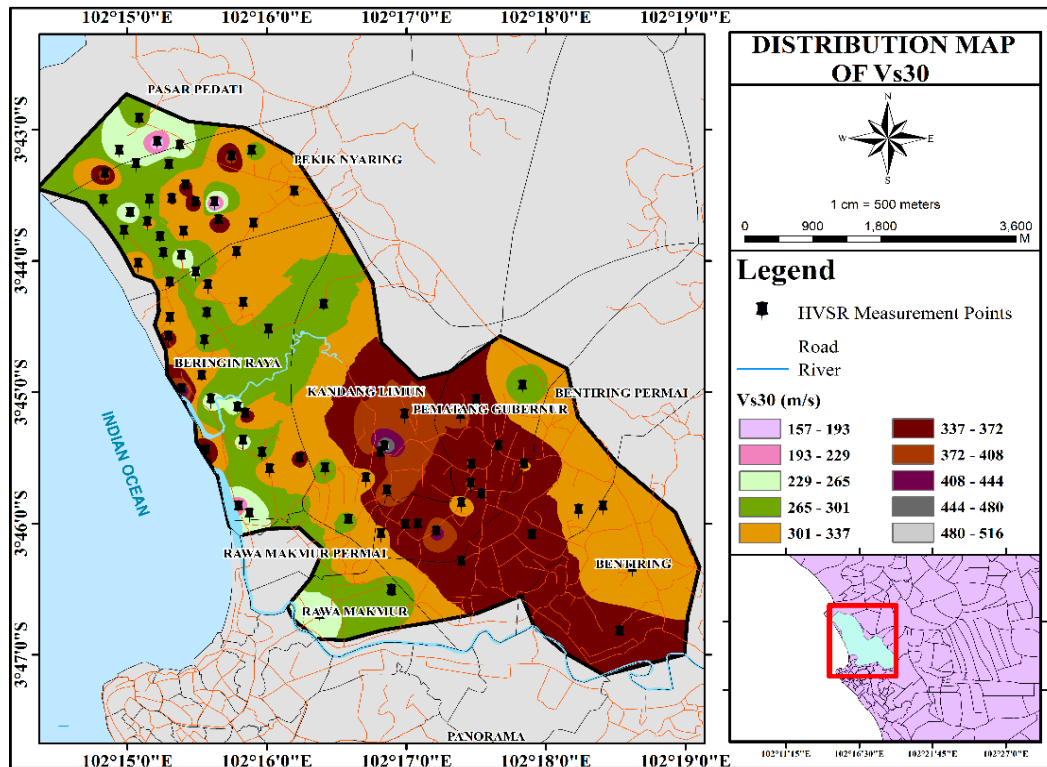


Figure 6. Map of the distribution of Vs30 values at the study site.

A study that employed the same idea was carried out by Nabhan et al. (2023). In the Central Bengkulu-Kepahiang Road section region, the results in the site class SC to SB have a Vs30 value in the 511 – 1422 m/s range. This area tends to have a high value because it is in the andesite-basalt volcanic rock formation, Bal formation, seat formation, and Hulusimpang formation. Furthermore, research in the same area has been conducted by Farid et al. (2024) using the HVSR method and obtaining Vs30 values ranging from 227 – 1235 m/s, which are included in the SC classification (Very Solid Soil and Rigid Soil). This research was only conducted in part of the coastal area and covered only some regions in the sub-district of Pondok Kelapa, Central Bengkulu.

Figure 7 is a 3D profile of the shear wave velocity (Vs) distribution in the northern part of the research region shows Vs values falling between 171 – 593 m/s, with a purple to red gradation. At a depth of 0 – 10 m, the purple to dark blue degradation shows the Vs value is getting more significant with a shear wave velocity of 171 – 276 m/s, which spreads to the north and west. Soil layers with values of 276 – 382 m/s with green color degradation spread to the south and west at 11 – 20m depth. Soil layers with high Vs. Values of 382 – 593 m/s with yellow to red color degradation at a 21 – 30 m/s complexity. Based on the criteria for classifying soil types in Table 1, the Pondok Kelapa area is dominated by type SC, type SD, and a small portion of type SE, which is composed of material types dominated by soft mud, dry sand, and clay. This area has a low Vs value

because it is in an alluvial rock formation composed of gravel, sand, silt, mud, and clay.

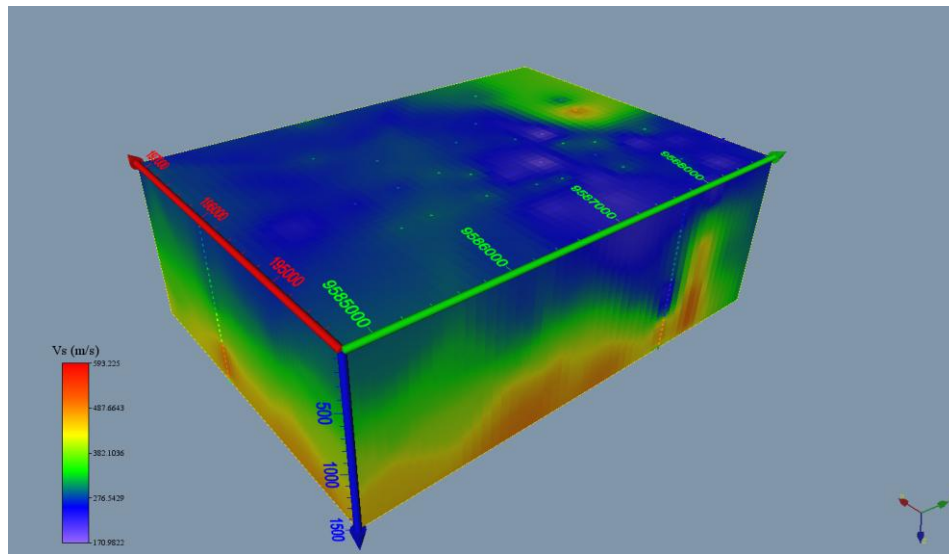


Figure 7. 3D layer profile Vs Pondok Kelapa sub-district.

Based on research findings, the level of risk due to earthquakes in the Pondok Kelapa area and its surroundings is relatively high. This can be used as a reference for building construction. The shaking caused by an earthquake tends to be larger in soft rock than in hard or solid rock. If the shaking gets bigger, potential earthquake damage will be higher. Therefore, it is better to construct buildings in relatively safe areas and make them earthquake-resistant to avoid severe damage.

When viewed from the Vs30 distribution map in Figure 6 areas that are safe for high-rise buildings are areas that have relatively high Vs values with brown to dark brown colour degradation, which are in the North and East Muara Bangka Hulu sub-districts. For areas that have soft soil conditions, the construction of the building must be stronger than the soil conditions that are denser or harder.

Conclusion

Based on research findings, the distribution of A_0 values ranges from 0.73 – 7.41, where the Eastern area has a high amplification factor value compared to other places, and

the f_0 between 0.74 – 16.84 Hz with the highest value in the Western area, and K_g ranged start 0.11 – 37.12, with the highest values in the study site's eastern region. While the Vs30 value obtained ranges from 157 – 516 m/s, indicating that the Pondok Kelapa and Rawa Makmur sub-districts have Site Class SC, SD, and SE, which are dominated by the SD type site class, this illustrates that the area has a significant vulnerability to earthquake hazards so that it requires earthquake-resistant buildings to build buildings.

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Author Contribution

The main author in this article is Olga Triutami, who has overall duties starting from the initial idea, data collection, data processing, analysis and manuscript writing until completion. However, the author

collaborated with the Bengkulu University Geophysics research team, which are Andre Rahmat, Refrizon and M. Farid.

Conflict of Interest

The author declare that the data published in the manuscript has no conflict of interest to any parties.

References

- Al Ansory, A. R., Raihana, H., Farid, M., & Hadi, A. I. (2023). Investigation of Sediment Layer Thickness Estimation at Bengkulu University Hospital Based on A0, f0, and T0 Values. *Jurnal Geoelebes*, 8(1), 1–10. <https://doi.org/10.20956/geoelebes.v8i1.28144>
- Bignardi, S., Mantovani, A., & Abu Zeid, N. (2016). OpenHVSr: Imaging the subsurface 2D/3D elastic properties through multiple HVSr modeling and inversion. *Computers and Geosciences*, 93, 103–113. <https://doi.org/10.1016/j.cageo.2016.05.009>
- BSN. (2019). SNI 1726:2019 Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan Nongedung *Badan Standar Nasional Indonesia*.
- Edison, R., Prakowo, W. A., & Rohadi, S. (2022). Pemetaan Vs30 Dengan Menggunakan Korelasi Zhao Di Pesisir Cilacap. *Jurnal Geosaintek*, 8(1), 181–190. <https://doi.org/10.12962/j25023659.v8i1.12601>
- Farid, M., Hadi, A. I., Refrizon., Suhartoyo, H., Litman., Fadli, D. I., & Putriani, E. (2024). The Combination of Hvsr and Masw Methods with Landsat 8 Imagery to Assess the Changing Shoreline along the Coastal Area of Central Bengkulu. *Trends in Sciences*, 21(5), 1–11. <https://doi.org/10.48048/tis.2024.7544>
- Gafoer, S., Amin, T. C., & Pardede, R. (1992). *Peta Geologi Lembar Bengkulu, Sumatera*. Pusat Survei Geologi. <https://geologi.esdm.go.id/geomap/pages/preview/peta-geologi-lembar-bengkulu-sumatera>
- García-Jerez, A., Piña-Flores, J., Sánchez-Sesma, F. J., Luzón, F., & Pertou, M. (2016). A computer code for forward calculation and inversion of the H/V spectral ratio under the diffuse field assumption. *Computers and Geosciences*, 97, 67–78. <https://doi.org/10.1016/j.cageo.2016.06.016>
- Ghanbari, A., Daghigh, Y., & Hassanvand, F. (2018). Risks of Solely Relying on VS30 in Ground Motion Response Studies. *Civil Engineering Journal*, 4(12), 2937–2945. <https://doi.org/10.28991/cej-03091210>
- Hadi, A. I., Refrizon, R., Halaudhin, H., Lidiawati, L., & Edo, P. (2021). Interpretasi Tingkat Kekerasan Batuan Bawah Permukaan di Daerah Rawan Gempa Bumi Kota Bengkulu. *Indonesian Journal of Applied Physics*, 11(1), 11–24. <https://doi.org/10.13057/ijap.v11i1.46525>
- Hamzah, A., Amri, M. R., Rozita, E., & Yunus, R. (2020). Penilaian Bangunan Sederhanadi Kawasan Rawan Gempabumi (Studi Kasus di Kota Bengkulu dan Kabupaten Bengkulu Tengah). *Jurnal Dialog Penanggulangan Bencana*, 11(1), 13–21. <https://jdpb.bnpb.go.id/index.php/jurnal/article/view/155>
- Handayani, I. P., La Hamimu., Manan, A., & Puspitafuri, C. (2021). Analisis Spektrum HVSr Untuk Pendugaan Potensi Kerusakan Akibat Gempabumi di Daratan Pesisir Kecamatan Wangi-Wangi Selatan Kabupaten Wakatobi. *Jurnal Rekayasa Geofisika Indonesia*, 3(03),

- 123–130.
<https://ojs.uho.ac.id/index.php/jrgi/article/view/23051/14555>
- Kang, S. Y. (2024). Mapping Bedrock Topography and Detecting Blind Faults using the Fundamental Resonance of Microtremor: a case study of the Pohang Basin, southeastern Korea. *Geophysical Journal International*, 238(2), 806–819.
<https://doi.org/10.1093/gji/ggae194>
- Kim, B., & Hong, T.-K. (2022). A National Vs30 Model for South Korea to Combine Nationwide Dense Borehole Measurements With Ambient Seismic Noise Analysis. *Earth and Space Science*, 9(1), e2021EA002066.
<https://doi.org/10.1029/2021EA002066>
- Maimun, A. K., Silvia, U. N., Julia, V., & Ariyanto, P. (2020). Analisis Indeks Kerentanan Seismik, Periode Dominan, Dan Faktor Amplifikasi Menggunakan Metode HVSR di Stage Of Tangerang. *Jurnal Meteorologi Klimatologi Dan Geofisika*, 7(2), 24–30.
<https://jurnal.stmkg.ac.id/index.php/jmkg/article/view/194>
- Mase, L. Z., Sugianto, N., & Refrizon. (2021). Seismic hazard microzonation of Bengkulu City, Indonesia. *Geoenvironmental Disasters*, 8(5), 1–17. <https://doi.org/10.1186/s40677-021-00178-y>
- Nabhan, M. A., Hadi, A. I., Fadli, D. I., Harlianto, B., Refrizon., & Ramdani, R. (2023). Distribusi Vs30 Secara Mikrozonasi Berdasarkan Data Inversi Seismik Pasif di Sepanjang Jalan Provinsi Alternatif Kabupaten Bengkulu Tengah-Kepahiang. *Jurnal Ilmiah Geomatika*, 25(2), 67–76.
<https://www.big.go.id/uploads/content/produk/Geomatika/Vol29.2/1.1206.pdf>
- Nakamura, Y. (1989). A Method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. *Railway Technical Research Institute*, 30(1), 25–33.
https://www.sdr.co.jp/papers/hv_1989.pdf
- Nakamura, Y., Sato, T., & Nishinaga, M. (2000). Local Site Effect of Kobe Based on Microtremor. *Proceedings of the Sixth International Conference on Seismic Zonation (6ISCZ) EERI, November 12-15, 2000/ Palm Springs, California*.
- 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), 012001. <https://doi.org/10.1088/1755-1315/118/1/012001>
- Ridwan, M., Yatini, Y., & Pramono, S. (2021). Mapping of Potential Damages Area in Lombok Island Base on Microtremor Data. *Jurnal Pendidikan Fisika Indonesia*, 17(1), 49–59.
<https://doi.org/10.15294/jpfi.v17i1.27028>
- Satria, A., Resta, I. L., & MZ, N. (2020). Analisis Ketebalan Lapisan Sedimen dan Indeks Kerentanan Sismik Kota Jambi Bagian Timur. *Jurnal Geofisika Eksplorasi*, 6(1), 18–30.
<https://doi.org/10.23960/jge.v6i1.58>
- SESAME. (2004). *Guidelines for the Implementation of the H / V Spectral Ratio Technique on Ambient Vibrations*. December, 1–69.
- Sugianto, N., Farid, M., & Suhendra, S. (2017). Kondisi Geologi Lokal Kota Bengkulu Berdasarkan Ground Shear Strain (GSS). *Spektra: Jurnal Fisika Dan Aplikasinya*, 2(1), 29–36.
<https://doi.org/10.21009/spektra.021.05>
- Sunardi, B., Naimah, S., Haryoko, U., Rohadi, S., Sulatri., & Rasmid. (2018). Vs30 Mapping and Soil Classification in The Southern Part of Kulon Progo Using Rayleigh Wave Ellipticity Inversion. *JGISE: Journal of Geospatial Information Science and*

- Engineering*, 1(2), 58–64.
<https://doi.org/10.22146/jgise.39780>
- Syamsuddin, E., Aswad, S., Assegaf, M. A. H., Rasimeng, S., Sakka, S., Syamsuddin, S., Nasri, M., & Syihab, M. F. (2022). Seismic Site Classification Using the Multichannel Analysis of Surface Waves Method. *Positron*, 12(2), 149–155.
<https://doi.org/10.26418/positron.v12i2.53869>
- Tanjung, N. A. F., Permatasari, I., & Yuniarto, A. H. P. (2021). Mapping of weathered layer thickness and Seismic Vulnerability in Tegal using HVSr method. *Journal of Physics: Conference Series*, 1951(1), 012053.
<https://doi.org/10.1088/1742-6596/1951/1/012053>
- Tawakal, M. I., Haris, A., & Martha, A. A. (2020). Estimating shear wave velocity (Vs30) of East Java, Indonesia, using ambient noise inversion of horizontal to vertical spectral ratio (HVSr). *IOP Conference Series: Earth and Environmental Science*, 538(1), 012012. <https://doi.org/10.1088/1755-1315/538/1/012012>
- Thamarux, P., Matsuoka, M., Poovarodom, N., & Iwahashi, J. (2019). VS30 seismic microzoning based on a geomorphology map: Experimental case study of Chiang mai, Chiang rai, and Lamphun, Thailand. *ISPRS International Journal of Geo-Information*, 8(7), 309.
<https://doi.org/10.3390/ijgi8070309>
- Wathelet, M., Chatelain, J.-L., Cornou, C., Di Giulio, G., Guillier, B., Ohrnberger, M., & Savvaidis, A. (2020). Geopsy: A user-friendly open-source tool set for ambient vibration processing. *Seismological Research Letters*, 91(3), 1878–1889.
<https://doi.org/10.1785/0220190360>
- Wijayanto., Mardiatno, D., Daryono., Nehren, U., Marfai, M. A., & Pramono, S. (2022). Spatial Distribution of Vs30 Based on Masw and Microtremor Inversion in Gunungkidul, Yogyakarta, Indonesia. *International Journal of GEOMATE*, 22(94), 29–38.
<https://doi.org/10.21660/2022.94.2463>
- Yutaka, N. (1997). Seismic Vulnerability Indices for Ground and Structures using Microtremor. *World Congress on Railway Research*, Florence, Nov. 1997.