DYNAMIC RESPONSE OF LOCAL SOIL USING MICROTREMOR ANALYSIS AFTER THE MAY 23, 2025 BENGKULU EARTHQUAKE

Shyaira Marcelina[1], Muchammad Farid[1], Budi Harlianto[1], Bayu Saputra[1], Hana Raihana[1], Lita Putriani[1]

[1] Geophysics Study Program, Faculty of Mathematics and Natural Sciences, the University of Bengkulu, Bengkulu, 38371, Indonesia.

e-mail : mfarid@unib.ac.id

Abstract. The Mw 6.0 earthquake that occurred on May 23, 2025, caused significant damage to the Rafflesia Asri Housing Complex in Bengkulu City. This study aims to examine the dynamic response of the soil and the seismic vulnerability level of the area using the microtremor method and the Horizontal-to-Vertical Spectral Ratio (HVSR) approach. The parameters analyzed include soil dominant frequency (f_0), amplification factor (A_0), seismic vulnerability index (K_g), Peak Ground Acceleration (PGA) estimates, and shear wave velocity (V_s). Measurements were taken at 40 observation points. The analysis results show that f_0 values range from 1.56 to 6.73 Hz, A_0 ranges from 1.97 to 6.46, K_g ranges from 1.15 to 10.38, PGA ranges from 0.15 to 0.32 g, and V_s ranges from 143 to 400 m/s. Zones with low f_0, high A_0 and K_g, and PGA followed by low V_s correlated with more significant building damage. These findings confirm that local soil dynamics play a dominant role in controlling seismic amplification and building damage patterns, underscoring the importance of microtremor-based seismic microzonation analysis for earthquake risk mitigation in Bengkulu City

Keywords: earthquake*; HVSR; microtremor; Seismic Vulnerability Index; shear Wave Velocity*

INTRODUCTION

Due to its location in the active subduction zone in the western portion of Sumatra Island, where the Indo-Australian Plate meets the Eurasian Plate and is impacted by the Sumatra Fault System to the east, the province of Bengkulu is among the areas of Indonesia most susceptible to earthquakes (Mase et al., 2021). The Bengkulu region is regularly vulnerable to moderate to strong earthquakes due to this tectonic process, which increases the risk of damage to residential areas and infrastructure (Choirunnisa et al., 2025).

According to a seismic microzonation study conducted in Bengkulu City, the majority of the region consists of soft soil layers and new alluvial sediment with low shear wave velocity (V_s) values (Kirana et al., 2025). By intensifying seismic waves, these geological and geotechnical elements make buildings more vulnerable to earthquake damage and raise ground vibration sensitivity (Harlianto et al., 2025). The site effect, a phenomenon of increased vibration caused by local soil properties, is crucial in regulating the spatial distribution of damage levels in a region (Rahayu et al., 2022).

Historically, the Bengkulu region has been hit by several major earthquakes that caused severe damage, such as the Bengkulu-Enggano earthquake in 2000 (Mw 7.9) and the Bengkulu-Mentawai earthquake in 2007 (Mw 8.4), as well as a series of aftershocks that had a significant impact on residential areas and public infrastructure (Refrizon et al., 2025). The accumulation of tectonic stress in the Sunda Arc and the high intensity of seismic activity along the Sumatra subduction zone suggest that a significant earthquake is still possible. Therefore, to lessen the effects of earthquakes, risk-reduction studies that consider local geological conditions are crucial (Khalqillah et al., 2025).

Apriana and colleagues in Bengkulu City employed the Horizontal-to-Vertical Spectral Ratio (HVSR) approach in combination with the microtremor method to ascertain soil dynamic features and seismic susceptibility levels (Apriana et al., 2025) in Bengkulu City, the results show that moderate to high amplification factors (A_0) and low dominant frequency values (f_0) are common and frequently linked to soft sediment layers and shallow deposits (Siburian et al., 2024). Relatively few studies, particularly in residential areas, quantitatively and directly relate microtremor parameters to the actual patterns of building damage brought on by particular earthquakes. This restriction shows a lack of work to confirm the link between the degree of building damage seen in the field and the dynamic response of the soil.

DOI : http://dx.doi.org/10.12962/j25023659.v12i3.9490

Received: 25-05-2026 Reviewed: 02-06-2026 Accepted: 10-08-2026 Available Online: 23-08-2026

The earthquake that occurred on May 23, 2025, had a magnitude of Mw 6.0, a hypocenter depth of approximately 84 km, and was felt in the Bengkulu City area and its surroundings. According to an analysis of the source mechanism, the Indo-Australian Plate deformed during subduction beneath the Eurasian Plate via a thrust fault, triggering an intraslab earthquake (Badan Meteorologi, Klimatologi, dan Geofisika, 2025). Hundreds of homes in Bengkulu City and Central Bengkulu Regency were damaged as a result of this incident, with the Rafflesia Asri Housing Complex in Betungan Village, Selebar District, suffering the greatest damage. As seen in Figure 1 (a and b), the identified damage includes cracked walls, structural element damage, and a decline in building quality. The unequal distribution of damage demonstrates how subsurface conditions and the local soil's dynamic response to the building's intensity (Lorenzo-velazquez & Cabas, 2009).

(a) (b)

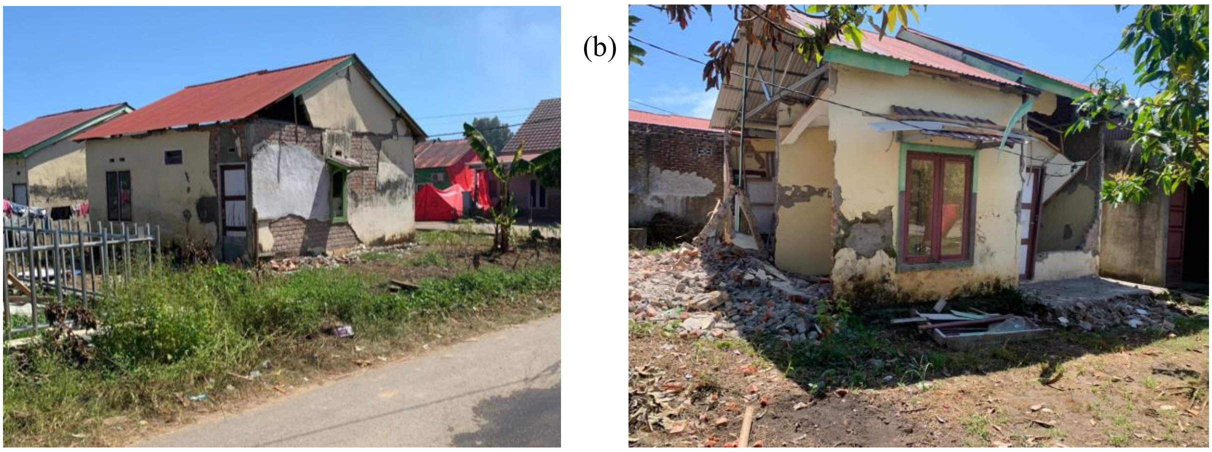

Figure 1. (a) Damage to building walls caused by the May 23, 2025 earthquake in the Rafflesia Asri Housing Complex (b) Damage to structural elements of buildings at the research site.

Given these conditions, the goal of this study is to identify the features of soil dynamic response and investigate their relationship to building damage patterns in the Rafflesia Asri Housing Complex. to determine the shear wave velocity (V_s), seismic vulnerability index (K_g), amplification factor (A_0), dominant frequency parameter (f_0), and peak ground acceleration (PGA). Using the Horizontal-to-Vertical Spectral Ratio (HVSR) approach, the analysis used a microtremor method. These parameters were correlated with the distribution of building damage from the May 23, 2025, earthquake using an integrative approach. This made it possible to assess the impact of local geological conditions on seismic hazard at the micro scale more thoroughly. Unlike previous studies in Bengkulu City, which were generally limited to mapping microtremor parameters, this study directly links f_0, A_0, K_g, PGA, and V_s to the actual damage distribution caused by a specific earthquake event. This method strengthens the scientific foundation for risk mitigation techniques, earthquake-resistant building design, and spatial planning in the Bengkulu coastal region while providing empirical validation of the relationship between soil dynamic response characteristics and structural damage levels.

METHODOLOGY

Geology Regional

Locally interspersed with the Bintunan Formation (Q_{Tb}) and andesite units (T_{pan}), the Rafflesia Asri Housing Complex and its environs are made up of both young alluvial deposits (Q_{at}) and old alluvial deposits (Q_{at2}), which are dominated by loose materials like clay, silt, and fine sand (Figure 2). Alluvial deposits form through sedimentation in river, coastal, and swamp environments (Chapkanski et al., 2022).

DOI : http://dx.doi.org/10.12962/j25023659.v12i3.9490

Received: 25-05-2026 Reviewed: 02-06-2026 Accepted: 10-08-2026 Available Online: 23-08-2026

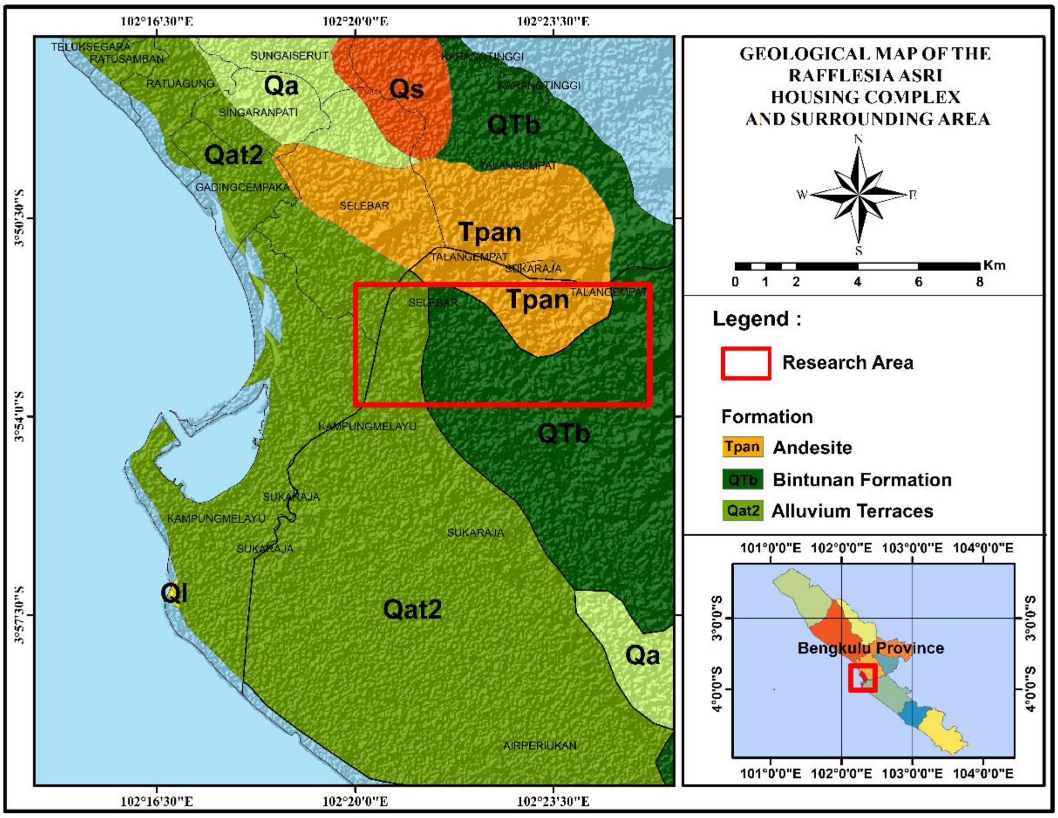

Figure 2. Examine the Geological Map

The presence of thick, soft alluvial layers greatly impacts the dynamic response characteristics of the soil. The impedance contrast between the layers causes the velocity to drop and the amplitude to increase when seismic waves move from stiffer rocks, like T_{pan} or Q_{Tb}, to softer Q_{at2} sediments (Carcione et al., 2017). Furthermore, a heterogeneous, easily deformed seismic response at spatial scales can result from lateral variations in amplification caused by the transition between hard rock and soft sediment.

Acquisition Data

The Rafflesia Asri Housing Complex, located at coordinates 3°52′59″ – 3°53′83″ S and 102°20′48″ – 102°20′80″ E in Betungan Village, Selebar District, Bengkulu Province, was the site of microtremor measurements in June 2025 (Figure 3). This area was designated as the research location because it was affected by an earthquake on May 23, 2025, and is a rapidly developing residential area located in an active tectonic zone, thus having a relatively high potential for seismic vulnerability.

DOI : http://dx.doi.org/10.12962/j25023659.v12i3.9490

Received: 25-05-2026 Reviewed: 02-06-2026 Accepted: 10-08-2026 Available Online: 23-08-2026

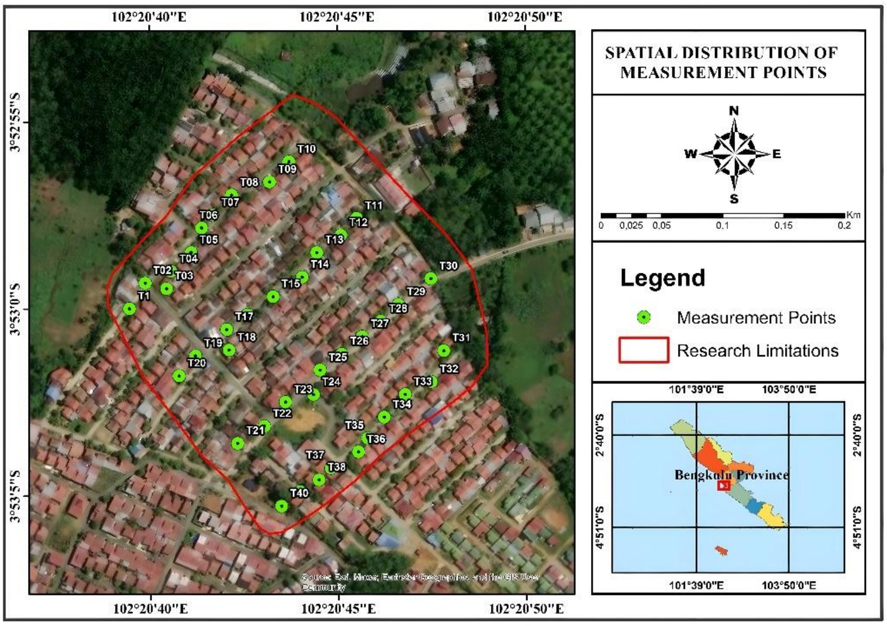

Figure 3. Point of Measurement for Microtremors

Data were gathered at 40 uniformly spaced measurement sites, about 20 meters apart, throughout the study area to show spatial variations in subsurface conditions. A Gemini 2 Sn-1405 short-period portable seismometer was used to measure microtremor. Three ground motion components were recorded: two horizontal (East-West and North-South) and one vertical (Up-Down). To generate steady, consistent, and representative microtremor signals of local soil dynamics, signal recording was carried out for 30 minutes at each observation station at a sampling frequency of 200 Hz in accordance with the guidelines (SESAME, 2004). The data obtained from seismometer recordings are stored as signal recordings in the *SAF format (Fadli et al., 2023) (Figure 4).

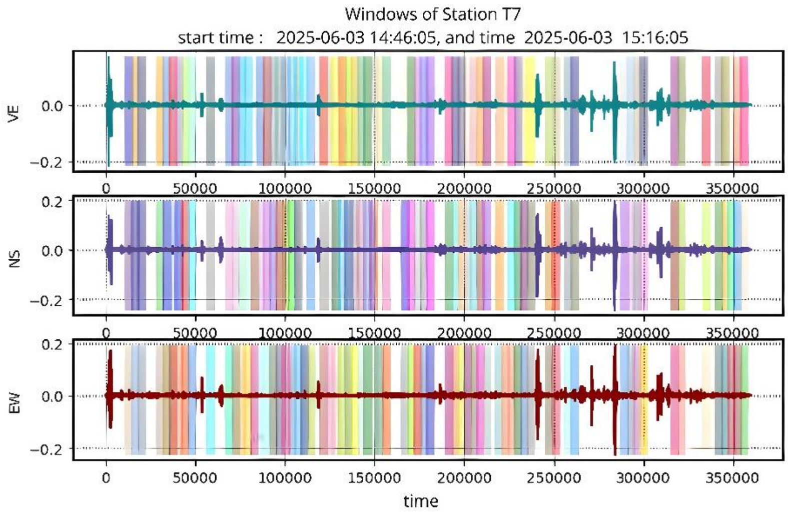

Figure 4. At station T7, the microtremor signal recording and window selection procedure

The microtremor approach is a passive geophysical method that takes advantage of low-amplitude natural ground vibrations caused by both natural and man-made phenomena (Farid & Mase, 2020). Because it is passive, doesn't require artificial vibration sources, and is affordable and useful for urban and regional applications, this approach is frequently used in seismic microzonation research (Gosar, 2017).

The acquired microtremor data were processed using TerraWare-HV software running on Python version 3.7.0 using the Horizontal-to-Vertical Spectral Ratio (HVSR) approach. The HVSR method, a microtremor analysis technique, is used to compare the amplitude spectrum ratio of the horizontal-to-vertical components

DOI : http://dx.doi.org/10.12962/j25023659.v12i3.9490

Received: 25-05-2026 Reviewed: 02-06-2026 Accepted: 10-08-2026 Available Online: 23-08-2026

of ground vibration (Helinnes et al., 2025). The initial processing stage in TerraWare-HV automatically removes transient noise, but the operator can also review and manually adjust the time window to ensure data quality. The Fast Fourier Transform (FFT) method is then used to split the filtered signal into multiple stationary time frames and convert it into the frequency domain.

The Konno-Ohmachi method is then used to smooth the amplitude spectrum of the transformation results (Senkaya, 2025). An HVSR is obtained by combining the spectra of the two horizontal components using the root-mean-square (RMS) approach and then comparing the results with the spectrum of the vertical component (Figure 5). The peak of the HVSR curve represents the dominant frequency of the ground (f_0), and the amplification factor (A_0) is indicated by the peak amplitude.

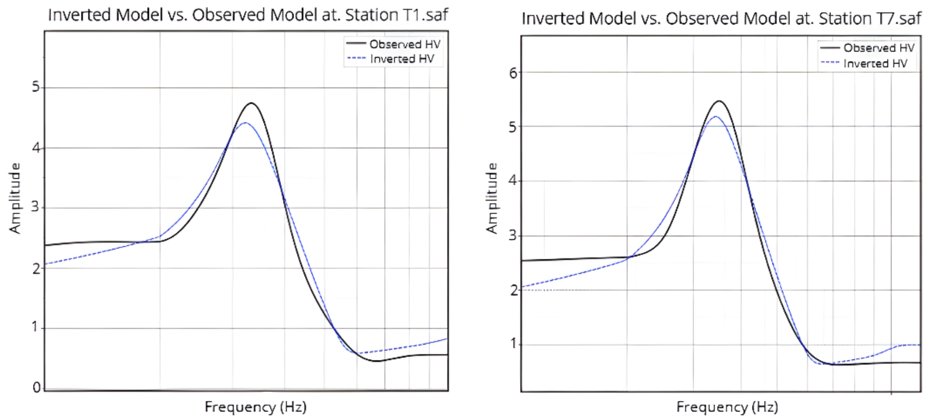

Figure 5. Curve matching of observations and inversions

The seismic vulnerability index (K_g), which measures the sensitivity of soil layers to seismic shocks, is then computed using the acquired parameters f_0 and A_0. According to Nakamura (2008), in equation 1, the seismic vulnerability index is formulated as follows

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

A high K_g value indicates relatively soft soil conditions and a greater potential for damage during an earthquake (Sunardi et al., 2025).

A Peak Ground Acceleration (PGA) estimate, which characterizes the maximum ground acceleration caused by earthquake shaking, was also performed to support the assessment of surface seismic hazard potential (Hadi et al., 2012).

The Kanai (1966) empirical equation, which takes into account the distance from the epicentre, the characteristics of the local soil, and the parameters of the earthquake source, was used to calculate the estimated PGA value. This allowed for an assessment of the impact of soil response on the increase in surface acceleration. Mathematically, PGA is formulated as Equation 2

$$\alpha_g = \frac{5}{\sqrt{T_0}} 10^{0,61M-(1,66+\frac{3,6}{R})\log R+0,167-\frac{1,83}{R}} \quad (2)$$

Where α_g is the ground acceleration at the observation point (gal), T_0 is the dominant period of the ground (s), M is the earthquake magnitude (Mw), and R is the distance from the epicenter to the measurement point (km).

Furthermore, the stiffness and elasticity of subsurface materials are described by the shear wave velocity (V_s) parameter. The V_s value is a crucial metric in this study for classifying site conditions and assessing the local soil response to seismic shocks (Kirana et al., 2025). Using the TerraWare-HV software running on Python 3.7.0, the HVSR inversion operation yields the V_s value. The observed HVSR curve, derived from field-recorded microtremor data, yields the HVSR inversion parameters. HVSR inversion is a process used to

DOI : http://dx.doi.org/10.12962/j25023659.v12i3.9490
Received: 25-05-2026 Reviewed: 02-06-2026 Accepted: 10-08-2026 Available Online: 23-08-2026

analyse observed HVSR data and determine the most appropriate soil model (Jamal et al., 2017). Table 1 displays the many classes into which site circumstances are categorised according to the V_s value.

Table 1. Site classification is determined based on shear wave velocity (V_s), with reference to the standards set out in SNI (Rabbani et al., 2025).

Site Classification	Shear Wave Velocity V_s (m/s)
SA (Hard Rock)	>1500
SB (Rock)	750 – 1500
SC (Very dense soil and soft rock	350 – 750
SD (Stiff Soil)	175 – 350
SE (Soft Soil)	< 175

RESULTS AND DISCUSSION

Table 2. Descriptive Statistics of Microtremor Parameters and Seismic Response Characteristics

Parameters	Minimum	Maximum	Mean	Standard Deviation	Range
f_0	1,56 Hz	6,73 Hz	3,68 Hz	1,15 Hz	5,17 Hz
A_0	1,97	6,46	3,35	1,17	4,49
K_g	1,15	10,38	3,52	2,51	9,23
PGA	0,15 g	0,32 g	0,23 g	0,037 g	0,17 g
V_s (m/s)	143 m/s	400 m/s	278 m/s	91,6 m/s	257 m/s

Table 2 presents descriptive statistics for the parameters of the microtremor analysis, including the dominant frequency (f_0), the amplification factor (A_0), the seismic vulnerability index (K_g), the peak ground acceleration (PGA), and the shear wave velocity (V_s) for 40 observation points. The statistics presented include the minimum, maximum, mean values, as well as the standard deviation and range, which are used to describe the general characteristics and degree of variation of each parameter at the study site. In general, the variations observed in the values indicate heterogeneity in subsurface conditions that may influence the dynamic response of the soil to seismic shaking. To better understand these characteristics, each parameter was analyzed separately, beginning with the dominant frequency (f_0).

The dominant frequency (f_0) is a fundamental parameter in analysing soil dynamic response, as it reflects the natural frequency of the surface sediment layer during seismic wave propagation (Amirudin et al., 2023). A low f_0 value generally indicates the presence of relatively thick soft sediments. In contrast, a high f_0 value is associated with stiffer materials or shallow bedrock, which are generally less sensitive to seismic activity (Ansory et al., 2024).

Rafflesia Asri Housing Complex's dominant frequency distribution map (Figure 6) displays notable spatial variation in f_0 values, which range from 1.56 to 6.73 Hz. The research areas centre and eastern regions are primarily home to low f_0 values (1.56–3.29 Hz), suggesting the presence of soft, relatively thick sediment that may resonate at low frequencies. This condition is even more risky if the building vibrations match the ground vibrations, because the building can vibrate more strongly and be more easily damaged (Handayania et al., 2025). Most of the study area is dominated by moderate f_0 values (3.29–5.01 Hz), which indicate moderate soil stiffness, while high f_0 values (5.01–6.73 Hz) are scattered locally in the north and south, indicating a predominance of stiffer soils or relatively thin sediments. Even though alluvial deposits predominate in the area, this variation shows that subsurface conditions are heterogeneous.

DOI : http://dx.doi.org/10.12962/j25023659.v12i3.9490

Received: 25-05-2026 Reviewed: 02-06-2026 Accepted: 10-08-2026 Available Online: 23-08-2026

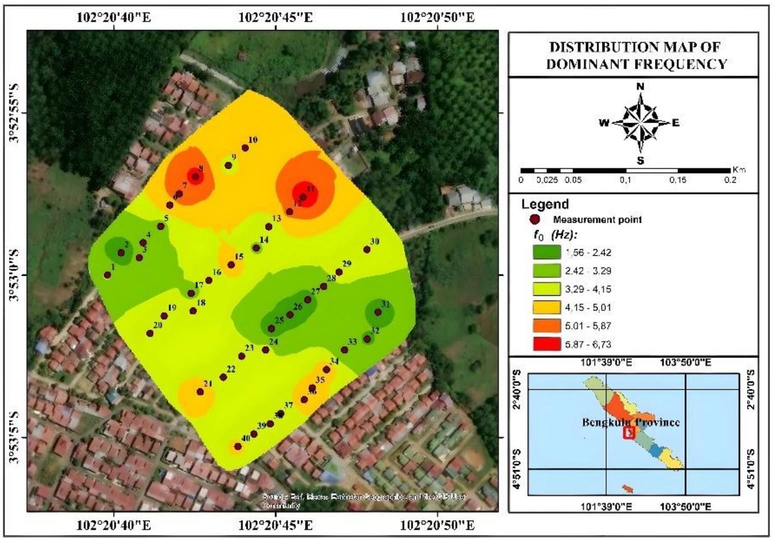

Figure 6. Map of Dominant Frequency Value Distribution

Amplification (A_0) is a soil reaction parameter that reflects the degree of seismic wave amplitude amplification caused by geological conditions and the dynamic properties of subsurface layers (Fahrezi et al., 2025). Since a high A_0 value is linked to an increase in wave amplitude brought on by a decrease in seismic wave velocity, it denotes a higher risk of earthquakes (Hadi et al., 2025)

Figure 7 illustrates the range of amplification factors (A_0) in the study area, which varies from 1.97 to 6.46, indicating variations in the capacity of surface soil layers to enhance seismic wave amplitudes. The central and southern regions of the research area are dominated by areas with low to moderate A_0 values (1.97–4.22), suggesting moderate amplification. On the other hand, local observations in the north and northwest show high to extremely high A_0 values (4.97–6.46), which the substantial impedance differential between bedrock and soft sediments will greatly amplify (Hossain et al., 2025). Numerous seismic microzonation studies in the Bengkulu region have also documented a strong site effect, which is reflected in this phenomenon (Siagian et al., 2025).

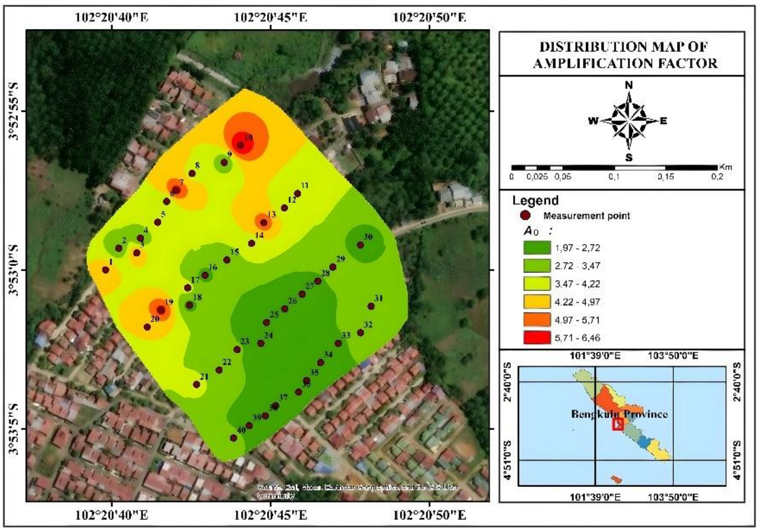

Figure 7. Amplification Value Distribution Map

The susceptibility of soil layers to deformation during an earthquake is quantitatively described by the seismic vulnerability index (K_g) (Amirudin et al., 2023). The K_g a combination of Amplification controls value (A_0) and Dominant Frequency (f_0), where high A_0 and low f_0 tend to produce large K_g values, while low A_0 and higher f_0 produce small K_g values (Setyowati et al., 2024).

DOI : http://dx.doi.org/10.12962/j25023659.v12i3.9490

Received: 25-05-2026 Reviewed: 02-06-2026 Accepted: 10-08-2026 Available Online: 23-08-2026

The distribution map of K_g in Rafflesia Asri Housing Complex (Figure 8) ranges from 1.15 to 10.38. Areas with low to moderate K_g values (1.15–5.77) dominate the central to southern parts and reflect relatively low to moderate seismic vulnerability. On the other hand, the northwest, north, and east of the research area contain the majority of the zones with high to extremely high K_g values (7.31–10.38). Areas with low f_0 and high A_0, which denote soft sediments with high amplification potential, consistently correlate with this pattern. These results are consistent with earlier studies conducted in Bengkulu, which discovered that high K_g values are a crucial sign of regions that have a high risk of earthquake damage (Mentari et al., 2023).

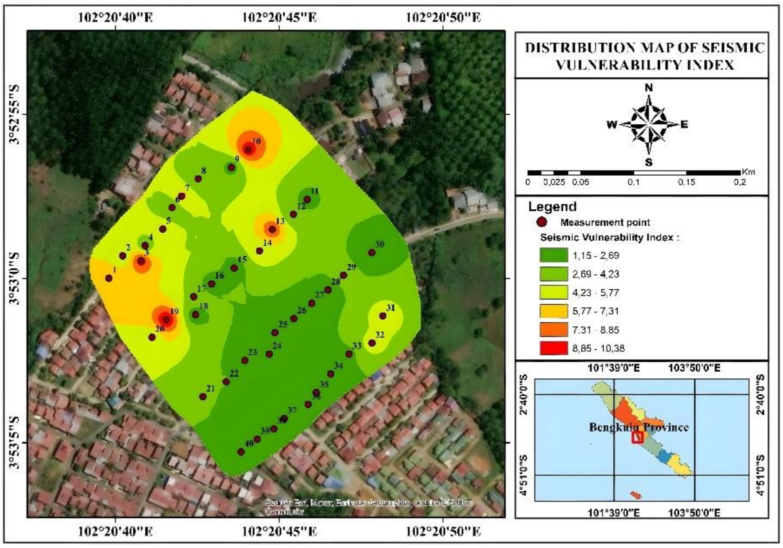

Figure 8. Map of Seismic Vulnerability Index Distribution

The interpretation of seismic hazard levels in the research area is further supported by the Peak Ground Acceleration (PGA) analysis shown in Figure 9. The Rafflesia Asri Housing Complex has PGA values ranging from 0.15 g to 0.32 g, with most areas having medium values (0.20–0.26 g). Zones with high to extremely high PGA (0.26–0.32 g) were found locally, especially in the study areas' northern and northeastern regions. High PGA values indicate strong shaking, which can raise the risk of damage, especially for structures that don't meet earthquake codes. The estimates' validity is reinforced by the fact that the PGA values acquired fall within the medium-to-high acceleration zones as per PUSGEN (2017) earthquake hazard mapping.

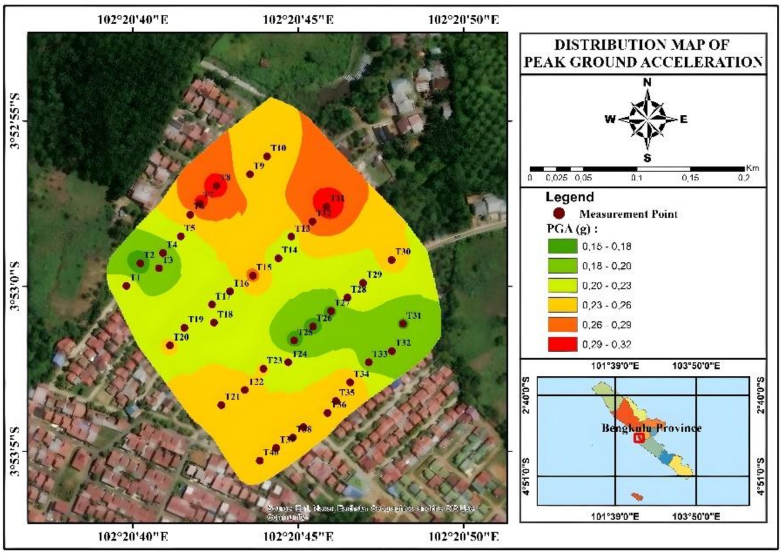

Figure 9. Map of PGA Value Distribution

DOI : http://dx.doi.org/10.12962/j25023659.v12i3.9490

Received: 25-05-2026 Reviewed: 02-06-2026 Accepted: 10-08-2026 Available Online: 23-08-2026

The analysis of shear wave velocity (V_s) is further refined as a proxy for the subsurface layer's stiffness based on the parameter results (f_0, A_0, K_g, and PGA). Variations in the V_s range at each observation point reflect the lateral and vertical distribution of constituent materials and indicate the dynamic response characteristics and local geological conditions. Controlling soil behavior during earthquakes is largely dependent on V_s, an elastic parameter that is sensitive to lithology, compaction level, and sediment mechanical properties.

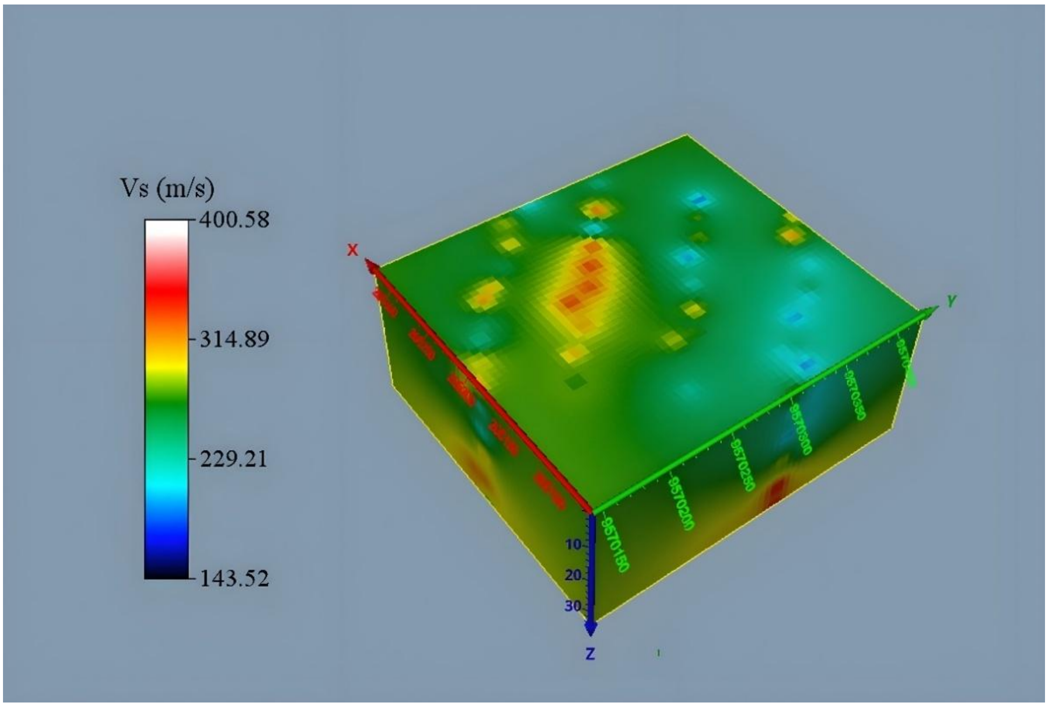

Figure 10. 3D modelling of underground distribution in Rafflesia Asri Housing Complex

Figure 10 shows a 3D visualisation of the V_s distribution in the subsurface volume at the Rafflesia Asri Housing Complex. In the research area, the shear wave velocity (V_s) values vary from 143 m/s to 400 m/s. Zones with low V_s values (143 m/s–229 m/s), indicated by blue to cyan colours, indicate the presence of soft sediments or loose soil in the shallow layers. The predominance of soil materials with moderate to relatively rigid stiffness, on the other hand, is indicated by zones with medium to high V_s values (229–400 m/s), which are represented by green to red colors. Both the dominance of SC- to SE-site classes in the SNI classification, which are typically linked to relatively high seismic wave amplification potential, and lithological conditions, such as alluvial deposits made of clay, silt, sand, and gravel, are reflected in these variations in V_s values, as shown in Table 3.

Table 3. Research site lithology (Anggi et al., 2025)

Research Point	Soil Class	V_s (m/s)	Material Type	Research Point	Soil Class	V_s (m/s)	Material Type
Point 1	SD	175 – 350	Sand	Point 2	SE	< 175	Clay
	SE	< 175	Clay		SD	175 – 350	Silt
	SD	175 – 350	Silt		SE	< 175	Clay
	SC	350 – 750	Gravel		SD	175 – 350	Sand
Point 3	SD	175 – 350	Silt	Point 4	SD	175 – 350	Sand
	SE	< 175	Clay		SE	< 175	Silt
	SD	175 – 350	Sand		SD	175 – 350	Clay
	SC	350 – 750	Gravel		SC	350 – 750	Gravel
Point 5	SD	175 – 350	Silt	Point 6	SD	175 – 350	Silt
	SE	< 175	Clay		SD	175 – 350	Sand

DOI : http://dx.doi.org/10.12962/j25023659.v12i3.9490
Received: 25-05-2026 Reviewed: 02-06-2026 Accepted: 10-08-2026 Available Online: 23-08-2026

Research Point	Soil Class	V_s (m/s)	Material Type	Research Point	Soil Class	V_s (m/s)	Material Type
	SD	175 – 350	Sand		SE	< 175	Clay
	SC	350 – 750	Gravel		SD	175 – 350	Silt
					SC	350 – 750	Gravel
Point 7	SD	175 – 350	Sand	Point 8	SD	175 – 350	Silt
	SE	< 175	Clay		SE	< 175	Clay
	SC	350 – 750	Gravel		SD	175 – 350	Sand
					SC	350 – 750	Gravel
Point 9	SC	350 – 750	Gravel	Point 10	SD	175 – 350	Sand
	SE	< 175	Silt		SE	< 175	Clay
	SC	350 – 750	Gravel		SD	175 – 350	Sand
	SE	< 175	Silt		SC	350 – 750	Gravel
	SC	350 – 750	Gravel				
Point 11	SE	< 175	Clay	Point 12	SD	175 – 350	Sand
	SD	175 – 350	Silt		SD	175 – 350	Silt
	SD	175 – 350	Sand		SD	175 – 350	Sand
	SC	350 – 750	Gravel		SC	350 – 750	Gravel
Point 13	SD	175 – 350	Sand	Point 14	SE	< 175	Clay
	SE	< 175	Clay		SD	175 – 350	Silt
	SD	175 – 350	Silt		SD	175 – 350	Sand
	SC	350 – 750	Gravel				
Point 15	SD	175 – 350	Silt	Point 16	SD	175 – 350	Sand
	SD	175 – 350	Sand		SD	175 – 350	Silt
	SC	350 – 750	Gravel		SD	175 – 350	Sand
					SC	350 – 750	Gravel
Point 17	SD	175 – 350	Sand	Point 18	SD	175 – 350	Sand
	SE	< 175	Clay		SD	175 – 350	Silt
	SD	175 – 350	Silt		SC	350 – 750	Gravel
	SC	350 – 750	Gravel				
Point 19	SD	175 – 350	Sand	Point 20	SD	175 – 350	Silt
	SE	< 175	Clay		SE	< 175	Clay
	SD	175 – 350	Silt		SC	350 – 750	Gravel
	SC	350 – 750	Gravel				
Point 21	SD	175 – 350	Sand	Point 22	SC	350 – 750	Gravel
	SC	350 – 750	Gravel		SE	< 175	Clay
	SE	< 175	Clay		SD	175 – 350	Sand
	SD	175 – 350	Sand		SE	< 175	Clay
	SC	350 – 750	Gravel		SC	350 – 750	Gravel
Point 23	SD	175 – 350	Sand	Point 24	SC	350 – 750	Gravel
	SE	< 175	Clay		SD	175 – 350	Sand
	SC	350 – 750	Gravel		SD	175 – 350	Silt
					SC	350 – 750	Gravel
Point 25	SC	350 – 750	Gravel	Point 26	SC	350 – 750	Gravel
	SD	175 – 350	Silt		SE	< 175	Clay
	SD	175 – 350	Sand		SD	175 – 350	Sand
	SC	350 – 750	Gravel		SC	350 – 750	Gravel
Point 27	SC	350 – 750	Gravel	Point 28	SE	< 175	Clay
	SE	< 175	Clay		SD	175 – 350	Silt
	SD	175 – 350	Sand		SE	< 175	Clay
	SC	350 – 750	Gravel		SC	350 – 750	Gravel
Point 29	SC	350 – 750	Gravel	Point 30	SD	175 – 350	Silt
	SD	175 – 350	Sand		SD	175 – 350	Sand
	SD	175 – 350	Silt		SC	350 – 750	Gravel
	SC	350 – 750	Gravel				
Point 31	SD	175 – 350	Silt	Point 32	SD	175 – 350	Sand
	SE	< 175	Clay		SE	< 175	Clay

DOI : http://dx.doi.org/10.12962/j25023659.v12i3.9490

Received: 25-05-2026 Reviewed: 02-06-2026 Accepted: 10-08-2026 Available Online: 23-08-2026

Research Point	Soil Class	V_s (m/s)	Material Type	Research Point	Soil Class	V_s (m/s)	Material Type
	SD	175 – 350	Sand		SD	175 – 350	Silt
	SC	350 – 750	Gravel		SC	350 – 750	Gravel
Point 33	SD	175 – 350	Sand	Point 34	SD	175 – 350	Silt
	SD	175 – 350	Silt		SD	175 – 350	Sand
	SC	350 – 750	Gravel		SC	350 – 750	Gravel
Point 35	SC	350 – 750	Gravel	Point 36	SC	350 – 750	Gravel
	SE	< 175	Silt		SD	175 – 350	Silt
	SC	350 – 750	Gravel		SE	< 175	Clay
	SD	175 – 350	Sand		SC	350 – 750	Gravel
Point 37	SD	175 – 350	Sand	Point 38	SD	175 – 350	Silt
	SE	< 175	Clay		SD	175 – 350	Sand
	SD	175 – 350	Silt		SC	350 – 750	Gravel
	SC	350 – 750	Gravel		SD	175 – 350	Sand
Point 39	SD	175 – 350	Silt	Point 40	SD	175 – 350	Sand
	SC	350 – 750	Gravel		SE	< 175	Clay
	SE	< 175	Clay		SD	175 – 350	Silt
	SC	350 – 750	Gravel		SC	350 – 750	Gravel

These results are consistent with the study by Refrizon et al. (2025), which found that the Bengkulu City region, composed primarily of young alluvial deposits, has a relatively low V_S value and is vulnerable to seismic wave amplification due to impedance contrast between the bedrock and sediment layers. Siburian et al. (2024), also reported similar findings, demonstrating that zones with low V_S in central and northern Bengkulu have higher seismic vulnerability and HVSR amplification values.

With the dominance of SC to SE site classes, the seismic vulnerability index (K_g) varies considerably. High K_g values are generally found in zones with relatively low V_S, indicating the presence of softer, less rigid soil. According to Carcione et al. (2017) in these circumstances, impedance contrasts between sediment layers cause seismic waves to slow down and undergo amplitude amplification, increasing the dynamic response of the soil. On the other hand, because more rigid soil can lessen seismic wave amplification, the K_g value is typically lower in areas with higher V_S (Farid et al., 2024).

This condition shows that some zones in the research area have relatively high seismic vulnerability to earthquake shocks, even though the area is generally categorized as moderate sediment. The distribution of PGA shows a similar pattern: lower V_S values are typically associated with higher PGA values. This supports the findings of Hadi et al. (2025), who found a direct correlation between higher maximum ground acceleration and a higher risk of building damage for soft site classes (SD–SE).

Table 4. Classification of Potential Building Damage Based on Seismic Vulnerability Index (K_g) and PGA

Damage class	K_g Value	PGA (g)	Measurement Point	Description
Low	< 4	0.15	T4, T6, T8, T9, T11, T12, T15, T16, T18, T21, T22, T23, T24, T25, T26, T27, T28, T29, T30, T33, T34, T35, T36, T37, T38, T39, T40	Geological conditions are relatively stable, with low seismic vulnerability and limited amplification effects. In the event of an earthquake, buildings are expected to sustain only minor damage.
Moderate	4-7	0.20	T1, T2, T5, T7, T14, T17, T20, T31, T32	Moderate seismic vulnerability, with buildings potentially experiencing cracks and moderate non-structural damage during strong earthquakes.
High	>7	>0.26	T3, T10, T13, T19	High seismic vulnerability indicates an increased risk of damage to buildings due to ground amplification and high ground accelerations during earthquakes.

DOI : http://dx.doi.org/10.12962/j25023659.v12i3.9490

Received: 25-05-2026 Reviewed: 02-06-2026 Accepted: 10-08-2026 Available Online: 23-08-2026

Based on the classification presented in Table 4, points T3, T10, T13, and T19 are identified as having the highest potential for earthquake-induced damage. These locations are characterized by high K_g and PGA values and correspond to areas where the most severe building damage was observed following the 23 May 2025 Bengkulu earthquake, as shown in Figure 1.

Overall, the relationship between the parameters f_0, A_0, K_g, PGA, and V_s shows that the zones with the highest seismic hazard potential in the Rafflesia Asri Housing Complex are concentrated in the northwest, north, and east of the study area. These zones are characterised by low dominant frequencies, high amplification factors, high seismic vulnerability indices, relatively high maximum ground accelerations, and low V_s values. Low V_s zones, high K_g values, and high PGA values are spatially correlated, suggesting that local amplification plays a major role in damage distribution. These results show that at the local level, variations in distance from the earthquake source have less of an impact on damage levels than differences in soil response characteristics. Thus, the findings of this study further support the significance of seismic microzonation based on microtremors as a scientific foundation for Bengkulu City's spatial planning, earthquake-resistant building design, and disaster mitigation strategy development.

CONCLUSION

According to the study's findings, the Rafflesia Asri Housing Complex in Bengkulu City's seismic hazard levels and building damage patterns are greatly influenced by the soil's dynamic response. Microtremor analysis using the HVSR method produced a dominant frequency (f_0) value of 1.56–6.73 Hz, amplification factors (A_0) of 1.97–6.46, seismic vulnerability index (K_g) of 1.15–10.38, and maximum ground acceleration (PGA) of 0.15–0.32 g. Analysis of shear wave velocity (V_s) showed a range of 143–400 m/s with a predominance of hard or very dense (SC) to soft (SE) soil classes.

Low f_0, high A_0 and K_g, and relatively large PGA are linked to zones with low V_s values (<200 m/s), indicating the possibility of substantial seismic amplification. On the other hand, because of increased soil stiffness, zones with higher V_s values exhibit a smaller seismic response. The study areas northwest, north, and east contain the highest seismic hazard zones, which correspond to the extent of building damage caused by the May 23, 2025, earthquake. The significance of microtremor-based seismic microzonation as a foundation for earthquake-resistant building design and disaster relief in Bengkulu City is highlighted by these findings.

Acknowledgement

The author would like to sincerely thank Bengkulu University's Geophysics Study Program for providing the facilities, academic support, and encouraging scientific environment that made this research possible.

REFERENCE

Amirudin, Madrinovella, I., & Sofian. (2023). *Seismic Vulnerability Analysis Using the Horizontal to Vertical Spectral Ratio (HVSR) Method on the West Palu Bay Coastline*. *08*(02), 23–34. https://doi.org/10.25299/jgeet.2023.8.02-2.13879

Anggi, A. P., Refrizon, R., Harlianto, B., Apriyanti, N., Saputri, W., Febriansyah, G. O., Al-ansory, A. R., Raihana, H., & Daniel, A. (2025). *Analysis of Earthquake Risk Estimation for Sustainable Development Using Microtremor Data Based on* $\boldsymbol{Vs30}$ *Distribution : Comparative Study of DFA and Geopsy in Central Bengkulu , Indonesia*. *17*(2), 214–228.

Ansory, A. R. Al, Raihana, H., Farid, M., & Hadi, A. I. (2024). *Investigation of Sediment Layer Thickness Estimation at Bengkulu University Hospital Based on Microtremor Data*. *8*(1), 1–10. https://doi.org/10.20956/geocelebes.v8i1.28144

Apriana, A., Azhari, M. F., Yuliza, E., & Refrizon. (2025). *Identification Of Subsurface Structures Of Accretion Area Using HVSR Method: A Case Study Of Bengkulu*. *11*(2), 111–126. https://doi.org/10.22373/ekw.v11i2.30270

Badan Meteorologi, Klimatologi, dan G. (2025). *Ulasan Guncangan Tanah Akibat Gempa Bumi Bengkulu*.

Carcione, J. M., Picotti, S., Francese, R., Giorgi, M., & Pettenati, F. (2017). Effect of soil and bedrock anelasticity on the

DOI : http://dx.doi.org/10.12962/j25023659.v12i3.9490

Received: 25-05-2026 Reviewed: 02-06-2026 Accepted: 10-08-2026 Available Online: 23-08-2026

S-wave amplification function. *Geophysical Journal International*, *208*(1), 424–431. https://doi.org/10.1093/gji/ggw402

Chapkanski, S., Doaré, M. Le, Brocard, G., Steuer, A., Siemon, B., Lavigne, F., Ismail, N., Meilianda, E., Virmoux, C., Darusman, D., & Goiran, J. (2022). Distribution of landforms and buried sedimentary deposits during the growth of the Aceh River delta (Sumatra , Indonesia). *Journal of Maps*, 1–15. https://doi.org/10.1080/17445647.2022.2139203

Choirunnisa, K., Fahmi, M. N., & Realita, A. (2025). *Seismisitas Pulau Sumatera dan Wilayah Sekitarnya Akibat Aktivitas Seismo-Tektonik Zona Subduksi dann Patahan*. *14*, 253–267.

Fadli, D. I., Hadi, A. I., Allifya, Z., Anggriani, S., Ramdani, R., Idris, B. S., & Refrizon. (2023). *Identifikasi Daerah Rawan Longsor Secara Mikrozonasi Di Jalan Alternatif Provinsi Menggunakan Metode Simple Additive Weighting (SAW)*. *13*(1), 37–52.

Fahrezi, Z., Misliniyati, R., Amri, K., Mase, L. Z., & Hardiansyah. (2025). *Model Respons Seismik Tanah di Kecamatan Selebar Akibat Perambatan Gelombang Gempa Satu Dimensi*. *30*(2), 234–245. https://doi.org/10.14710/mkts.v30i2.64462

Farid, M., Hadi, A. I., Refrizon, Suhartoyo, H., 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*. *21*(5), 1–11.

Farid, M., & Mase, L. Z. (2020). Implementation Of Seismic Hazard Mitigation based on Ground Shear Strain Indicator For Spatial Plan Of Bengkulu City, Indonesia. *International Journal of GEOMATE, 18(69),199 - 207*, *18*(69). https://doi.org/10.21660/2020.69.24759

Gosar, A. (2017). *Study on the applicability of the microtremor HVSR method to support seismic microzonation in the town of Idrija (W Slovenia)*. 925–937.

Hadi, A. I., Farid, M., & Fauzi, Y. (2012). *Pemetaan Percepatan Getaran Tanah Maksimum dan Kerentanan Seismik Akibat Gempa Bumi untuk Mendukung Rencana Tata Ruang dan Wilayah (RTRW) Kota Bengkulu*. *1*(September), 81–86.

Hadi, A. I., Farid, M., Mase, L. Z. R., Aditya, K. B., Fadli, D. I., & Sumanjaya, E. (2025). Seismic microzonation of kepahiang regency , Indonesia using the HVSR method : enhancing Urban resilience to mitigate earthquake vulnerability. *Indian Geotechnical Journal*, *1*. https://doi.org/10.1007/s40098-025-01299-z

Handayania, N. R., Mase, Lindung Zalbuin Nugroho, S. H., Supriani, F., Misliniyatie, R., & Amri, K. (2025). *Evaluation of Building Performance Against Large Subduction Earthquakes Incorporating Ground Response and Structural Dynamics Analysis*. *29*(6). https://doi.org/10.4186/ej.2025.29.6.59

Harlianto, B., Fadli, D. I., Sumanjaya, E., Hadi, A. I., Maulidiyah, A., Suwarsono, & Purwanto, E. H. (2025). Seismic Vulnerability Along the Kaur-South OKU Highway in Bengkulu, Indonesia: Planning for More Resilient and Safer Cities. *Indian Geotechnical Journal*, *55*(5), 3042–3057. https://doi.org/10.1007/s40098-024-01101-6

Helinnes, P., Hadi, A. I., Farid, M., Setyowati, Y., Hardiansyah, D., Gumanty, U., Raihana, H., Ansory, A. R. Al, & Muammar, Z. (2025). *Application of Satellite Imagery and HVSR Method for Coastal Analysis in*. *14*(3), 413–424. https://doi.org/10.14710/buloma.v14i3.68258

Hossain, A. S. M. F., Saeidi, A., Salsabili, M., Nastev, M., Suescun, J. R., & Bayati, Z. (2025). *A Review of Parameters and Methods for Seismic Site Response*.

Jamal, R. J., Lantu, Aswad, S., & Sulaiman, C. (2017). *Mikrozonasi Kawasan Rawan Bencana Gempabumi Dengan Studi Peak Ground Acceleration Menggunakan Metode Boore Atkinson dan Data Mikrotremor di Daerah Kupang*. *1*(1), 5–12.

Kanai, K. (1966). *A Short On The Seismological Features Of The Niigata Earthquake*.

Khalqillah, A., Muksin, U., Simanjutak, A. V. H., Jihad, A., & Banyunegoro, V. H. (2025). *Engineering , Environment , and Technology Seismic Hazard Estimation for Sumatra and Kalimantan Region Using Event-Based Probabilistic Seismic Hazard Analysis (EB-PSHA)*. *10*(3), 329–337. https://doi.org/10.25299/jgeet.2025.10.3.21936

Kirana, V. D., Mase, L. Z., Supriani, F., Misliniyati, R., & Amri, K. (2025). *Microzonation of soil resistance using shear wave velocity (V s) for earthquake disaster mitigation in Singaran Pati District , Bengkulu City*. *30*(2), 73–83. https://doi.org/10.20885/teknisia.vol30.iss2.art2

Lorenzo-velazquez, C., & Cabas, A. (2009). *Spatial variability of site effects and its correlation with site response in Japan*. 2480–2485.

DOI : http://dx.doi.org/10.12962/j25023659.v12i3.9490

Received: 25-05-2026 Reviewed: 02-06-2026 Accepted: 10-08-2026 Available Online: 23-08-2026

Mase, L. Z., Bahri, S., & Saputra, A. (2021). *A comparative study of geophysical measurements to characterise the local site condition of Bengkulu City , Indonesia*. *22*(June), 1–13.

Mentari, N. F., Susanti, D. B., & Andi. (2023). *Analisis Indeks Kerentanan Seismik di Desa Kalongan , Kecamatan Ungaran Timur , Kabupaten Semarang Menggunakan Metode HVSR*. *1*(2), 6–11.

Nakamura, Y. (2008). *ON THE H / V SPECTRUM*.

PUSGEN. (2017). *PETA SUMBER DAN BAHAYA GEMPA INDONESIA TAHUN 2017*.

Rabbani, M. R., Hadi, A. I., Harlianto, B., Farid, M., Raihana, H., & Anggi, A. P. (2025). *HVSR Microtremor Analysis to Assess Subsurface Fault Characteristics and Geothermal Potential in Kepahiang*. *9*(2), 157–170. https://doi.org/10.70561/geocelebes.v9i2.43347

Rahayu, T., Nasution, Z., Roesyanto, & Karnawati, D. (2022). Regional zonation based on seismic vulnerability using local site effect analysis and potential damage to the city of Medan (North Sumatra , Indonesia) due to earthquake. *Geoenvironmental Disasters*. https://doi.org/10.1186/s40677-022-00227-0

Refrizon, R., Fadli, D. I., Sumanjaya, E., Maulidiyah, A., Hardianza, M., & Hardiansyah, D. (2025). Seismic microzonation in Bengkulu City, Indonesia: insights for resilient planning after 2000 Mw 7.9 and 2007 Mw 8.4 earthquakes. *Bulletin of Earthquake Engineering*, *23*, 3085–3107. https://doi.org/10.1007/s10518-025-02168-z

Senkaya, M. (2025). Feasibility of Utilizing Continuous Records from Weak And Strong-Motion Recorder Channels of Permanent Stations for Horizontal To Vertical Spectral Ratio (HVSR) Analysis During Calm-Day Conditions. *Pure and Applied Geophysics*, *182*(2), 537–555. https://doi.org/10.1007/s00024-025-03669-3

SESAME. (2004). Guidelines for The Implementation of The H/V Spectral Ratio Technique on Ambient Vibrations-Measurement, Processing And Interpretation, SESAME European research project. *SESAME: Site Effects Assessment Using Ambient Excitations*, *December*, 1–62.

Setyowati, Y., Farid, M., Hadi, A. I., Helinnes, P., Hardiansyah, D., Gumanty, U., Raihana, H., Ansory, A. R. Al, & Syah, M. T. (2024). *Subsurface Sediment Layer Analysis at the Dendam Tak Sudah Lake Flyover Construction Site in Bengkulu City Using the HV-Inv Method*. *16*(2), 187–197.

Siagian, S., Refrizon, & Hadi, A. I. (2025). *Mapping of Natural Frequency, Amplification, Seismic Vulnerability, and Vs30 Velocity in Selebar District, Bengkulu City*. *15*(1), 20–29.

Siburian, B., Marzuki, M., & Lubis, A. (2024). Local site effects and seismic microzonation around Suban Area, Curup Rejang Lebong, Bengkulu deduced by ambient noise measurements. *Geoenvironmental Disasters*, *11*. https://doi.org/10.1186/s40677-024-00268-7

Sunardi, B., Sismanto, Hartantyo, E., & Nukman, M. (2025). *Seismic Vulnerability in Yogyakarta Basin Based on HVSR Frequency Domain Window Rejection Algorithm*. *20*(4), 813–823.

DOI : http://dx.doi.org/10.12962/j25023659.v12i3.9490

Received: 25-05-2026 Reviewed: 02-06-2026 Accepted: 10-08-2026 Available Online: 23-08-2026